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Second-Look Arthroscopic Evaluation and Clinical Outcomes of Anatomic Anterior Cruciate Ligament Reconstruction with Autograft and Hybrid Graft: A Retrospective Study

Authors' Contribution:
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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
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Background: Graft choice is very controversial. This study compared the second-look evaluation and clinical outcomes of anatomic ACL-R using a thin autograft versus a thick hybrid graft.

Material/Methods: Sixty-eight patients who had received ACL-R with hamstring autograft or autograft-allograft hybrid graft accepted second-look arthroscopy were grouped (autograft: n=31, age: 32.8±8.9, Male/Female: 16/15, and hybrid graft: n=37, age: 33.9±8.4, Male/Female: 27/10). Patients were evaluated with the functional score and KT-1000 test before reconstruction. The re-examination and second-look evaluation were performed at 2-year follow-up. Results were compared and further comparisons were made for grafts size >8.5 mm.

Results: The hybrid group showed thicker graft size and bigger graft occupancy (9.0±0.5 mm *vs.* 8.5±0.7 mm, P=.003; 80.1±7.0% *vs.* 69.9±6.9%, P<.001). KT-1000 test, subjective evaluation, and activity level scores increased significantly between pre- and post-reconstruction for both groups (P<.001). There was no significant difference of the second-look evaluation (Graft continuity, Tension and Synovial coverage) between groups. However, from those 2 groups, only grafts size >8.5 mm were selected and compared (autograft, n=16; hybrid, n=29). Graft tension and Synovial coverage showed a significant difference (P=.036 and P=.029). The Lysholm, IKDC, and KT-1000 test were significantly superior for the autograft than the hybrid graft (P=.036, P=.004, and P=.003, respectively).

Conclusions: A pure autograft is superior to a hybrid graft with same diameter in ACL-R because the augmenting allografts may be null and void. Therefore, a homogenous graft is recommended.

MeSH Keywords: **Allografts • Anterior Cruciate Ligament Reconstruction • Autografts • Second-Look Surgery**

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Background

The anterior cruciate ligament (ACL) plays an important role in knee joint stability and competitive sports performance [1]. Sports injuries occur mainly on joints, contusion, and the parts of lower limbs, especially the ACL. Mall et al. reported that more than 100 000 patients receive ACL reconstruction (ACL-R) each year in the United States [2]. To substitute the ACL and complete the surgery, there are many graft choices for reconstruction, such as autologous grafts, allografts, and synthetic grafts. An autograft is associated with earlier incorporation and tendon-bone healing, as well as reduced immunological rejection after transplantation. Additionally, there is no risk of disease transmission [3]. However, a hybrid graft is created by mixing autograft and allograft together to cultivate a thick graft because the thin autograft would not achieve sufficient diameter. Consequently, the surgeon has to augment and weave 1 or 2 allografts into the autograft.

Graft choice is quite controversial, and the tendon-bone healing of different grafts after ACL-R is of great concern because knee stability requires an ideal process of graft remodeling [4–6]. Patellar tendon grafts have been considered as the criterion standard for ACL-R but is criticized for its harvest-site morbidity [7–10], while hamstring tendon autografts have shown better results and less donor-site morbidity [11–13].

Anatomic ACL-R should be individualized to restore the insertion site to at least 60% to 80% of the cross-sectional area [14]. A hybrid graft tends to have a thicker diameter than most autografts, which is important for achieving these ratios. Although numerous studies have compared the clinical outcomes between autografts and allografts, it is still unclear which is better [7,15,16]. Few studies have evaluated hamstring tendon autografts and autograft-allograft hybrid grafts or explored whether augmented allografts were effective [4,17,18], and there has been little research on second-look arthroscopic evaluation and clinical comparison of graft choice [19,20].

Thus, this study sought to use second-look arthroscopy to evaluate the results of single-bundle anatomic ACL-R between patients who received either an autograft or a hybrid graft. In addition, we compared those patients with graft size >8.5 mm [21,22] between the 2 groups, including second-look arthroscopic evaluation and clinical outcomes comparison.

Material and Methods

Participants

This retrospective study (Level of Evidence 3) was conducted with the approval of the Ethics Committee of our institution (approval number H2012-001-1). A total of 68 patients (autograft: n=31 and hybrid graft: n=37) who had received single-bundle anatomic ACL-R using hamstring autograft or autograft-allograft hybrid graft were included in this second-look arthroscopic evaluation and clinical outcomes assessment from January 2014 to August 2017. The inclusion criteria were: (1) unilateral ACL rupture with anatomic ACL-R, (2) hamstring autograft or autograft-allograft hybrid graft only, and (3) the femoral and tibial fixation devices utilized were suspending fixation and compression screw fixation. The exclusion criteria were: (1) ACL tear combined with multiple-ligament tear, (2) contralateral knee ligament rupture or bilateral ACL-R, and (3) ACL tear combined with fracture or avulsion fracture. All patients included were operated on by senior surgeons who had at least 10 years of experience in arthroscopic reconstruction.

Study procedures

Data on the 68 patients were collected from resident's admission notes and operation records and were analyzed before surgery and at follow-up, including demographic characteristics and graft size, originated from the. At follow-up, patients were evaluated using Lysholm Score, Tegner Activity Level, International Knee Documentation Committee (IKDC) Knee Evaluation Form, and KT-1000 test, and we compared these with the pre-operative records. During the second-look arthroscopy, graft continuity, tension, and synovial coverage were evaluated by the same surgeon who originally performed the anatomic ACL-R. The 68 patients were divided into 2 groups based on whether only a hamstring autograft was used or an autograft-allograft hybrid graft was created to acquire sufficient diameter (autograft: n=31 and hybrid graft: n=37). The clinical results were compared between these 2 groups. Then, the data of patients with a graft size > 8.5 mm were selected from each group for further analysis.

The ACL-R surgical technique

The standard anatomic ACL-R was performed by transportal technique. Before reconstruction, a meniscus tear was treated with a partial meniscectomy or FasT-Fix suture. The remnant ACL fibers were debrided to identify the anatomic footprint and confirm the drilling points. A tendon stripper was used to harvest the hamstring graft (semitendinosus and gracilis) through a 2.5-cm oblique incision. The soft tissue was cleaned and folded into 4-stranded autogeneic hamstring tendons. The length and diameter of the graft were measured by the graft sizer. According to the pre-reconstruction measurement of the tendon, allografts were added for augmentation if it could not restore the insertion site to at least 60% of the cross-sectional area, or if the augmentation could result in better graft occupancy. However, if the patient refused to accept the allograft, augmentation would not be performed. The

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allograft was harvested from tibialis anterior tendons that received an irradiation dose of 2.5 Mrad before being distributed to our institution. For autografts and hybrid grafts, the diameter of the homogenous part and allograft was measured, then the 2 free ends were braided with No. 2 Ethibond Excel Polyethylene non-absorbable sutures.

The tibia tunnel drilling point was located with a guide apparatus, then was established using a bone drill of the same diameter. After that, the femoral tunnel was created through the anteromedial-portal approach from inside to outside. The bone drill of the same size sheathed the guide pin, which was located at the center of the femoral footprint. After broadening the tunnels, the graft was pulled into these tunnels. Using suspending fixation, the femoral side was first fixed with an EndoButton (Smith & Nephew Endoscopy, Andover, MA). A Bio-Composite interference screw (Arthrex, Naples, FL) was used for compressed fixation on the tibial side. Concurrent with the manual maximum tension on the graft, a maximum posterior force was loaded on the tibia. It was important to minimize graft laxity in the early stages after the operation.

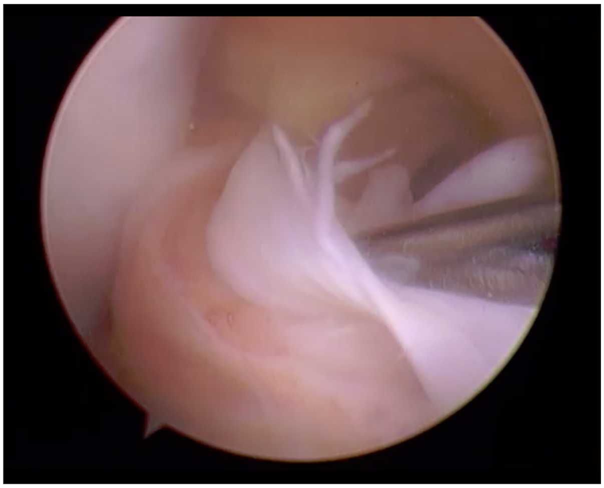

Figure 1. Second-look arthroscopic evaluation of graft tension: lax.

Clinical evaluation

The knee joint was clinically evaluated before reconstruction and at follow-up. The Lysholm Score, Tegner Activity Level, and International Knee Documentation Committee (IKDC) Knee Evaluation Form were used for functional evaluation. The KT-1000 test was used to measure the side-to-side difference in anterior translation.

Second-look arthroscopic evaluation

The arthroscopic examination was carried out before femoral fixation device removal at the last follow-up. On second-look arthroscopic surgery, the graft was observed at various angles of flexion by using a routine technique with the lateral parapatellar portal. The graft continuity was evaluated with general observation and classified into 3 grades (good, fair, and damaged). A graft showing a re-tear was considered damaged and the patient received a revision surgery. The graft tension evaluation was assisted by an arthroscopic probe at 3 different positions: adjacent to the femoral insertion, midsection of graft, and adjacent to the tibial insertion. The surgeon subjectively marked it as taut (normal), mildly lax, or lax using the probe (Figure 1). The synovial coverage was broadly divided into 4 grades: >75% if the synovium seemed well covered throughout the visible tendon; 50-75% if the synovium exceeded half of the visible tendon; 25–50% if the synovium was less than half; and <25% if the graft was exposed and barely covered the synovium (Figure 2). The osteoarthritic changes were classified according to Kellgren-Lawrence grade.

Statistical analysis

Data were analyzed using SPSS software for Windows (version 21.0; Chicago, IL). Independent-samples *t* tests, chi-squared tests, and Mann-Whitney U tests were used to compare the baseline characteristics of the 2 groups. Data with normal distribution and homogeneity of variance were compared using an

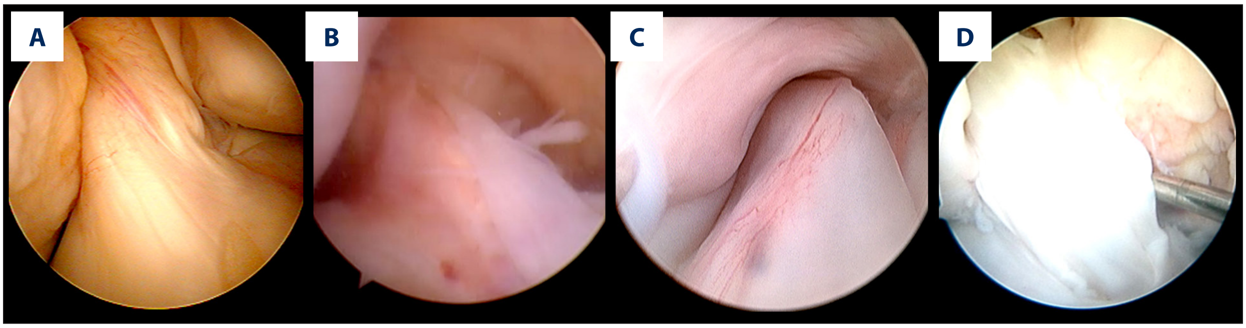

Figure 2. The synovial coverage was broadly divided into 4 grades: (**A**) >75% meant the synovium seemed well covered throughout the visible tendon; (**B**) 50–75% meant the synovium exceeded half of the visible tendon; (**C**) 25–50% meant less than half; and (**D**) <25% meant the graft was exposed and barely covered.

Table 1. Demographic characteristics and intraoperative data.

	Autograft		Hybrid		P value
		95% CI		95% CI	
Age, Mean ±SD, yr[a]	32.8±8.9	29.6–36.1	33.9±8.4	31.1–36.7	.609
Sex, Male/Female, n[b]	16/15		27/10		.069
BMI, Mean ±SD, kg/m^2[a]	26.4±3.4	25.1–27.6	25.7±3.1	24.6–26.7	.383
Graft size, Mean ±SD, mm[c]	8.5±0.7	8.3–8.8	9.0±0.5	8.8–9.2	.003*
Graft occupancy in tibial,%[a]	69.9±6.9	67.4–72.5	80.1±7.0	77.8–82.4	<.001*
Follow-up, Mean ±SD, mo[a]	28.4±2.1	27.6–29.2	28.3±2.8	27.4–29.2	.884

BMI – body mass index; 95%CI – 95% confidence intervals. *Graft occupancy in tibial* means the occupancy of restoring tibial insertion site in the cross-sectional area. [a] Independent-samples *t* test; [b] Chi-squared test; [c] Mann-Whitney test; * statistically significant.

Table 2. The comparison of graft diameter and graft occupancy in tibia between autograft and autograft in hybrid.

	Homogenous autograft		Autograft in hybrid		P value
		95% CI		95% CI	
Graft diameter, Mean ±SD, mm[b]	8.5±0.7	8.3–8.8	8.3±0.7	8.1–8.6	.231
Graft occupancy in tibial, %[a]	69.9±6.9	67.4–72.5	63.1±5.8	61.2–65.0	<.001*

Graft occupancy in tibia means the occupancy of restoring tibial insertion site in the cross-sectional area. [a] Independent-samples *t* test; [b] Mann-Whitney test; * statistically significant.

independent-samples *t* test or Mann-Whitney U test, and dichotomous variables were compared using a chi-squared test. The Mann-Whitney U test was used to compare graft size between the autograft and hybrid graft, or autograft in hybrid through the multiple comparisons, and the paired *t* test was used for the comparison between autograft and the autograft in hybrid grafts. The graft occupancy was measured from the contralateral knee by magnetic resonance imaging (MRI) before surgery [23]. Then, the independent-samples *t* test and the paired *t* test were used for a similar comparison of the graft occupancy in the tibia of different graft types. The second-look arthroscopic evaluation indicator, including graft continuity, tension, and synovial coverage, were analyzed by chi-squared test: likelihood ratio or chi-squared: Pearson test, because, in principle, the minimum expected count might vary. If patients with graft size >8.5 mm were selected, the chi-squared test: Fisher's exact test was used for graft continuity and tension, synovial coverage. The osteoarthritic changes between autograft and hybrid were compared using the Mann-Whitney U test. The pre-reconstruction versus follow-up scores of the KT-1000 test, subjective evaluation, and activity level were compared with the Wilcoxon signed ranks test; comparisons between the 2 groups were evaluated with the Mann-Whitney test. The significance level was set at P<.05.

Results

Demographic analysis

Sixty-eight patients who underwent second-look arthroscopy were included in this study, and the demographic data are listed in Table 1. There were 16 males and 15 females in the autograft group, and 27 males and 10 females in the hybrid graft group. There was no significant difference in the sex distribution among the groups (P=.069). The mean age was 32.8±8.9 years in the autograft group and 33.9±8.4 years in the hybrid group (P=.609). The mean body mass index of the 2 groups was 26.4±3.4 kg/m^2 and 25.7±3.1 kg/m^2 (P=.383), respectively. The follow-up times of the 2 groups, as well as the second-look arthroscopy, were 28.4±2.1 months (autograft) and 28.3±2.8 months (hybrid) (P=.884). However, we compared the graft sizes between the 2 groups and found that the autograft was thinner than the hybrid graft (8.5±0.7 mm *vs.* 9.0±0.5 mm, P=.003), indicating that because most hamstring tendon grafts were not thick enough, an allograft was added to create a thick hybrid graft, which can increase the occupancy of restoring tibial insertion site in the cross-sectional area (69.9±6.9% *vs.* 80.1±7.0%, P<.001) (Table 1).

The comparison of graft size and graft occupancy in tibia between the autograft and autograft in hybrid was also performed (8.5±0.7 *vs.* 8.3±0.7, respectively). However, only graft occupancy

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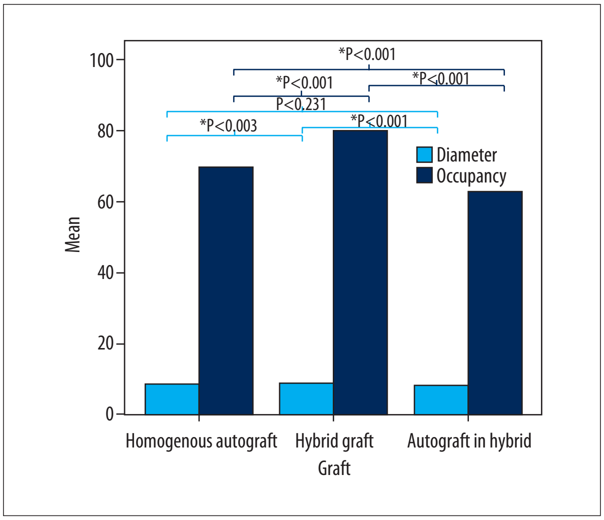

Figure 3. The significant difference in graft diameter and graft occupancy in tibia between different groups. Diameter: Homogenous autograft *vs.* Hybrid graft (P=.003), Homogenous autograft *vs.* Autograft in hybrid (P=.231), Hybrid graft *vs.* Autograft in hybrid (P<.001); Occupancy: Homogenous autograft *vs.* Hybrid graft (P<.001), Homogenous autograft *vs.* Autograft in hybrid (P<.001), Hybrid graft *vs.* Autograft in hybrid (P<.001).

in tibia showed a significant difference (P<.001) (Table 2). The multiple comparisons among groups are shown in Figure 3.

Second-look arthroscopic evaluations analysis

In the arthroscopic evaluations, all 68 patients were operated on by the same surgeon who did the ACL-R. As expected, there was no significant difference in the condition of graft continuity (P=.872), tension (P=.770), or synovial coverage (P=.930) between autografts and hybrids (Table 3). However, there was 1 patient (3.2%) in the autograft group with a retear graft and 2 patients (5.4%) in the hybrid group who had grafts classified as *damaged*. Thus, during the second-look arthroscopy, these 3 patients (4.4%) received an ACL revision.

However, the results showed a significant change when the graft size >8.5mm were selected. For subsequent analyses, 16 patients (51.6%) were included from the autograft group and 29 patients (78.4%) were included from the hybrid group. The graft tension and synovial coverage showed a significant difference between the 2 groups (P=.036 and P=.029, respectively). The graft continuity still showed no significant difference (P=.456) (Table 4). According to the Kellgren-Lawrence grade (K-L grade), even though both groups showed osteoarthritic progression (9.7% in autograft *vs.* 10.8% in the hybrid), there was no significant difference in condition of osteoarthritic changes between autograft and hybrid groups before and after reconstruction (P=.941 and P=.853, respectively) (Table 5).

Clinical evaluations analysis

Clinical evaluations according to the KT-1000 test, subjective evaluation (Lysholm score and IKDC), and activity level scores (Tegner score) showed good to excellent on follow-up examination. For all patients, significant differences were observed between the pre- and post-reconstruction scores for all of these measures (P<.001). However, the pre- and post-reconstruction difference of KT-1000 test, Lysholm score, Tegner score, and

Table 3. Second-look arthroscopic evaluation.

	Grade	Autograft (n=31)	Hybrid (n=37)	P value
Graft continuity[a]	Good	24	27	.872
	Fair	6	8	
	Damaged	1	2	
Tension[b]	Taut	9	9	.770
	Mildly lax	18	21	
	Lax	4	7	
Synovial coverage[b]	75%~	11	12	.930
	50~75%	9	9	
	25~50%	5	7	
	~25%	6	9	

[a] Chi-squared test: Likelihood Ratio; [b] Chi-squared: Pearson test; * statistically significant. There was no significant difference in condition of graft continuity, tension, or synovial coverage between autograft and hybrid groups.

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Table 4. Second-look arthroscopic evaluation of Graft size >8.5 mm.

	Grade	Autograft (n=31)	Hybrid (n=37)	P value
Graft continuity[a]	Good	14	22	.456
	Fair	2	7	
	Damaged	0	0	
Tension[a]	Taut	8	4	.036*
	Mildly lax	7	20	
	Lax	1	5	
Synovial coverage[a]	75%~	9	8	.029*
	50~75%	6	7	
	25~50%	1	6	
	~25%	0	8	

[a] Chi-squared test: Fisher's exact test; * statistically significant.

Table 5. Osteoarthritic changes between autograft and hybrid.

	K-L Grade										No. of OA Progressions
	Pre-re					Post-re					
	0	1	2	3	4	0	1	2	3	4	
Autograft (n=31)	27	4	0	0	0	24	6	1	0	0	3 (9.7%)
Hybrid (n=37)	32	5	0	0	0	28	7	2	0	0	4 (10.8%)
P value[a]			.941					.853			

K-L grade – Kellgren-Lawrence grade; Pre-re – pre-reconstruction; Post-re – post-reconstruction. [a] Mann-Whitney U test. There was no significant difference in condition of osteoarthritic changes between autograft and hybrid groups.

IKDC score between the autograft group and hybrid groups was not statistically significant (Table 6).

In addition, only data of 16 autograft patients (51.6%) and 29 hybrid patients (78.4%) whose graft size was larger than 8.5 mm were analyzed. The Lysholm score was 93.7±2.9 (95% CI, 92.2–95.2) in the autograft group and 91.5±3.1 (95% CI, 90.4–92.7) in the hybrid group (P=.036). Likewise, the IKDC in the autograft group was 90.3±3.7 (95% CI, 88.4–92.3), which was significantly higher than that in the hybrid group (86.5±3.9, 95% CI, 85.0–87.9) (P=.004). However, the Tegner activity level score was 5.6±0.9 (95% CI, 5.3–6.0) in the hybrid group, which was non-significantly lower than the 5.9±0.8 (95% CI, 5.5-6.3) in the autograft group (P=.453). Finally, the KT-1000 test score for the autograft group was 1.2±0.3 (95% CI, 1.0–1.4), which was significantly lower than the score of 1.7±0.6 (95% CI, 1.4–1.9) in the hybrid graft group (P=.003) (Table 7).

Discussion

This study conveys 3 noteworthy messages. Firstly, even though the hybrid grafts were significantly thicker than the autografts, which means that the hybrid group achieved a better occupancy for anatomic ACL-R, according to the second-look arthroscopic evaluation and clinical evaluation, there was no statistical difference in the comparison of graft continuity, tension, synovial coverage, osteoarthritic changes, Lysholm score, Tegner score, IKDC score, and KT-1000 test between the 2 groups. In other words, because there was no significant difference in graft size between the autograft and autograft in hybrid groups, we concluded that the evaluation and clinical outcome was not increased with the increase of graft occupancy by augmented allograft. Secondly, when only the graft sizes >8.5 mm were selected for the tension, the synovial coverage, Lysholm score, IKDC score, and KT-1000 test were significantly superior in the autograft group. There was osteoarthritic progression but no significant difference in the condition of osteoarthritic changes.

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Table 6. KT-1000 test, subjective evaluation, and activity level scores before and after surgery.

	Lysholm			Tegner			IKDC			KT-1000		
	Mean ±SD (95% CI)		P[b]	Mean ±SD (95% CI)		P[b]	Mean ±SD (95% CI)		P[b]	Mean ±SD (95% CI)		P[b]
	Pre-re	Post-re		Pre-re	Post-re		Pre-re	Post-re		Pre-re	Post-re	
Autograft (n=31)	63.2±13.8 (58.1–68.3)	88.3±6.5 (85.9–90.7)	<.001*	1.4±0.8 (1.1–1.7)	5.1±1.2 (4.6–5.5)	<.001*	46.0±9.2 (42.6–49.3)	84.7±6.7 (82.2–87.1)	<.001*	9.2±1.7 (8.6–9.8)	1.6±0.5 (1.4–1.8)	<.001*
Hybrid (n=37)	63.1±17.3 (57.3–68.9)	89.2±5.4 (87.4–91.0)	<.001*	1.6±0.9 (1.3–1.9)	5.2±1.2 (4.8–5.6)	<.001*	47.2±8.3 (44.4–50.0)	85.9±4.8 (84.3–87.5)	<.001*	9.3±2.2 (8.5–10.0)	1.8±0.6 (1.6–2.0)	<.001*
P value[a]	.318	.664		.275	.621		.327	.388		.853	.897	

Pre-re – pre-reconstruction; Post-re – post-reconstruction; IKDC – International Knee Documentation Committee knee evaluation form; CI – confidence interval. [a] Mann-Whitney U test; [b] Wilcoxon Signed Ranks test; * statistically significant.

Table 7. Comparison of KT-1000 Test, subjective evaluation, and activity level scores after surgery for graft sizes above 8.5 mm.

Graft size >8.5 mm	Lysholm			Tegner			IKDC			KT-1000		
	Mean ±SD (95% CI)		P[b]	Mean ±SD (95% CI)		P[b]	Mean ±SD (95% CI)		P[b]	Mean ±SD (95% CI)		P[b]
	Pre-re	Post-re		Pre-re	Post-re		Pre-re	Post-re		Pre-re	Post-re	
Autograft (n=16)	72.5±3.7 (70.5-74.5)	93.7±2.9 (92.2-95.2)	<.001*	1.9±0.6 (1.6-2.2)	5.9±0.8 (5.5-6.3)	<.001*	52.4±8.0 (48.1-56.6)	90.3±3.7 (88.4-92.3)	<.001*	8.2±1.2 (7.5-8.8)	1.2±0.3 (1.0-1.4)	<.001*
Hybrid (n=29)	70.3±11.6 (65.9-74.7)	91.5±3.1 (90.4-92.7)	<.001*	1.7±0.8 (1.4-2.0)	5.6±0.9 (5.3-6.0)	<.001*	49.6±6.3 (47.2-52.0)	86.5±3.9 (85.0-87.9)	<.001*	8.5±1.8 (7.8-9.2)	1.7±0.6 (1.4-1.9)	<.001*
P value[a]	.686	.036*		.177	.453		.367	.004*		.644	.003*	

Pre-re – Pre-reconstruction; Post-re – Post-reconstruction; IKDC – International Knee Documentation Committee knee evaluation form; CI – confidence interval. a Mann-Whitney U test; b Wilcoxon Signed Ranks test; * statistically significant.

Only the graft continuity and Tegner score showed no significant difference between the 2 groups. Thirdly, although there were no functional and instability differences in the autograft group and hybrid group at above 2-year follow-up, a higher rate of partial re-tear (9.7% in autograft *vs.* 16.2% in hybrid) was still found in the hybrid group. The characteristic aspect of this study is that all patients included had received an anatomic ACL-R and second-look arthroscopic surgery from the same surgeon with high seniority in our institution; therefore, the associated human confounding factors that can affect outcome were controlled. These findings suggest that anatomic ACL-R needs to restore the insertion site to at least 60% to 80% of the cross-sectional area, but using an augmented allograft to increase the diameter and restore occupancy might not be effective in the post-operative function and stabilization. In other words, the purity of the graft might play a more critical role in vascularization and the tendon-bone biological healing process.

Numerous studies have proved that the tendon-bone healing and remodeling in collagen fiber are essential to maintain the biological properties and mechanical properties of the graft [24–26]. Ligamentization of the graft can be subdivided into 4 stages: necrosis, revascularization, cellular repopulation, and collagen remodeling [27,28]. This process is the basis of proprioception recovery and returning to activity, and the tendon-bone biological healing process and incorporation in the bone tunnel are the critical factors for knee stability and security [24]. The hybrid graft aims to create a favorable-sized graft that is similar to the native size and achieves the desired rate of cross-sectional area in accordance with the definition of anatomic ACL-R [29]. Alvarez-Pinzon et al. proposed that autograft tendons provide an ideal graft to stabilize the knee; nevertheless, hybridization was necessary for the desired graft size and post-operative stability, especially if difficulties in harvesting adequate autograft tissue or iatrogenic injury to the hamstring tendons occurred [30].

However, in the allograft-autograft hybrid, the speed of cell death within the graft, blood flow to the graft, and revascularization of the tendon graft might not be synchronized. Terauchi et al. used magnetic resonance angiography to evaluate the maturation stage of the autograft, and reported that revascularization occurred in the femoral and tibial bone tunnels 2 months postoperatively. It was not until 6 months after the operation that the blood flow subsequently decreased [31].

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Ge et al. reported that the autograft tendons exhibited superior remodeling compared to allograft tendons in the bone tunnel; however, no statistically significant differences were observed in tendon-bone healing between them postoperatively [32]. Therefore, the healing process of the 2 different types of grafts in the hybrid would not be tightly synchronized. In our study, regardless of the second-look arthroscopic evaluation or clinical outcome comparison, we hypothesized that the hybrid group might be superior to the autograft group because the hybrid graft can achieve the desired cross-sectional area. By contrast, there was no significant difference between autografts and hybrids. More broadly, we compared those grafts size >8.5 mm between the 2 groups who had no significant difference in graft diameter and graft occupancy in tibia. The evaluation criteria of the autograft group were superior to the hybrid group. In other words, the augmented allografts were suboptimal for improving function and stability and might increase graft failure. Burrus et al. reported that autograft hamstring ACL grafts had a lower failure rate than allograft-autograft hybrid hamstring grafts [17]. Li et al. designed a prospective randomized controlled trial comparing autografts, γ-irradiated allografts, and hybrid grafts [18]. The objective and subjective clinical outcomes were similar to our results, in that all had satisfactory results without significant differences between graft types. However, significant differences were observed between graft types using the KT-1000 test. The measurements were 2.1±1.6 mm and 2.0±1.5 mm in the autograft and hybrid graft groups, respectively, compared with 3.5±1.2 mm in the γ-irradiated allograft group (P=.025), demonstrating that the γ-irradiated allograft provided poorer results. Our results of KT-1000 test were 1.2±0.3 mm and 1.7±0.6 in the autograft and hybrid graft size >8.5 mm (P=.003), which further suggests that autograft purity might play a greater role in the post-operative tendon-bone biological healing process.

Second-look arthroscopy is a very good way to evaluate the tendon-bone healing process, including the synovilization and synovium blood supply [33]. During second-look arthroscopic evaluation of grafts sized >8.5 mm, the graft continuity still showed no significant difference (P=.456), probably because the graft continuity was closer to the surgeon's perception by observation. Another factor could be that the autograft and allograft parts vary much less from each other at post-operative follow-up [34,35]. Theoretically, the graft laxity tension could be reflected by KT-1000 test values. Toritsuka et al. reported a correlation between graft tension and clinical laxity. The different laxity positions showed a significant side-to-side difference [36]. In our study, the tension evaluation showed a significant difference in graft size >8.5 mm between the 2 groups (P=.036), which agrees with the result of the KT-1000 test.

Noh et al. reported that the more synovialized the graft was, the better the clinical outcome [33]. Lee et al. reported that if the cases with synovial membrane formation exceeded more than 50%, the IKDC evaluation usually shows a relatively better result [19]. By comparison, Yoon et al. reported the synovial coverage following ACL-R using hamstring tendon autograft was superior to tibialis tendon allograft by using second-look arthroscopy [37]. Furthermore, our study also drew a similar conclusion that there was a significant difference of synovial coverage of graft size >8.5 mm between autograft and hybrid groups (P=.029), which may because the healing process of the graft was more rapid in autografts than in allografts. Guo et al. reported that dehydration, deproteinization, and irradiation might be why the clinical outcomes of allografts were inferior to those of autografts [38]. Although there was no significant difference in the post-operative period, Toritsuka et al. [36] and Jin et al. [39] both concluded that longer post-operative follow-up periods were associated with less partial tearing and better synovial coverage. Murray et al. reported that the vascularity and cell density did not increase to the maximum until the 20th week after the injury [40]. This means that longer injury-to-operation intervals are associated with poorer synovialization. Because the injury-to-operation interval, follow-up period, and clinical results were unlisted in our study, the issue might require further study.

Even though there was no significant difference in the condition of osteoarthritic changes between autografts and hybrids in our study (pre-operative P=.941 and post-operative P=.853) (Table 4), the progress of osteoarthritis in the hybrid group (10.8%) showed a higher rate than in the autograft group (9.7%). However, the allograft group was a little bit older than the autograft group, but without statistical significance. The progress of osteoarthritis determined by the osteoarthritic changes may have an association with age.

By comparing the clinical evaluation of thin autografts and thick hybrid grafts, our study found that the hybrid graft provided no improvement in clinical measures compared with the small autografts. It is likely that autografts were preferentially chosen to decrease the chance of a growth disturbance [41]. Considerable controversy exists regarding the appropriate graft choice for patients undergoing ACL-R, and allografts pretreated with high-dose irradiation should be avoided [42]. Only the Tegner scores had no statistically significant differences in any between-group comparisons. That is likely because the Tegner evaluation assesses the patient's activity level, and most patients in our institution performed no strenuous or high-intensity exercises. Moreover, patients underwent a more conservative rehabilitation treatment process. Even though the patients were allowed to participate in further controlled sports activities or contact sports by their surgeons, post-operative psychogenic conditions still prevented them from confidently moving the operated knee joint. Thus, the Tegner scores of both groups increased significantly, but most patients had not regained their desired activity level.

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A question that has been raised is whether a thin autograft or a thick hybrid graft is superior. Specifically, it needs to be ascertained whether the graft purity or graft diameter or graft occupancy should be considered first when performing anatomic ACL-R. In our study, we found that when only the patients with a graft size >8.5 mm who had a satisfactory graft occupancy were selected, the second-look arthroscopic evaluation and clinical outcomes were significantly superior in the autograft group compared with the hybrid group (Table 6). This suggests that the purity of the autograft plays a more important role than the graft size or occupancy by augmenting allografts. The actual diameter of the hybrid graft postoperatively might not be thicker than the homogenous graft. McRae et al. conducted a randomized controlled trial to evaluate whether ACL-R using a hamstring tendon autograft results in a better patient quality of life if the graft is harvested from the leg contralateral to the ACL rupture compared with the ipsilateral leg. They concluded that there did not appear to be any measurable drawback or benefit to using a hamstring graft from the unaffected limb [43]. Therefore, homogenous grafts were used for anatomic ACL-R, and they restored the insertion site to at least 60% to 80% of the cross-sectional area. If the graft diameter harvested from the ipsilateral knee is not thick enough, the graft can be obtained from the hamstring tendon of the contralateral knee instead of using an allograft.

Limitations

There are several limitations in this study. First, the assessment by second-look arthroscopy was inherently subjective since no definitive measurements can be made. Because of ethical reasons, the maturation of the surface of the grafts could not be made for an *in vitro* study. In addition, we could not evaluate the remodeling process of the graft itself. Second, because some patients refused to undergo the second-look arthroscopy, not all the patients who received anatomic ACL-R were included. Third, this retrospective study lacked randomization, which might cause biased results. Fourth, longer-term follow-up is essential to explore the prognosis. Further research to evaluate the tendon-bone biological healing process with the objective quantitative standard may be needed.

Conclusions

The graft diameter and graft occupancy are important factors that may influence the likelihood of success of anatomic ACL-R, and the graft diameter is also a key method of restoring the insertion site to at least 60% to 80% of the cross-sectional area. However, the evaluation and clinical outcome do not increase with increasing the graft occupancy by augmented allografts. A pure homogenous graft provides superior results on second-look arthroscopic evaluation and the clinical outcomes evaluation to a hybrid graft of the same diameter. Patients undergoing anatomic ACL-R should ideally receive an autograft, even if this requires harvesting the hamstring tendon from the contralateral knee.

Conflicts of interest

None.

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