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Bone–patellar tendon–bone autograft could be recommended as a superior graft to hamstring autograft for ACL reconstruction in patients with generalized joint laxity: 2- and 5-year follow-up study

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Abstract

Purpose The present study aimed to compare 2- and 5-year outcomes of ACL reconstruction between patients with and without generalized joint laxity and to perform comparative evaluation between two types of grafts used for ACL reconstruction in patients with generalized joint laxity.

Methods Two hundred and thirty-seven patients who underwent ACL reconstruction from 2001 to 2008 were included. Patients were classified into two groups according to the presence or the absence of generalized joint laxity, and further subdivided into two subgroups based on the type of graft used: bone–patellar tendon–bone (BPTB) or hamstring. Generalized joint laxity was assessed with the Beighton and Horan criteria using a point scoring system. Stability reflected by the Lachman test, pivot-shift test, and anterior translation measured with KT-2000, and functional outcomes reflected by Lysholm knee score, and International Knee Documentation Committee (IKDC) subjective score were investigated. IKDC objective grade and radiographic grade were also assessed. Clinical assessments were conducted preoperatively and at 2 and 5 years after operation.

Results Two-year follow-up results showed that patients with generalized joint laxity receiving hamstring grafts had poorer outcomes than those without generalized joint laxity. Five-year follow-up results showed that patients with generalized joint laxity experienced poorer outcomes than patients without generalized joint laxity, irrespective of the type of graft. Comparison of grafts used showed that, in patients with generalized joint laxity, BPTB graft provided significantly better stability and functional outcomes than hamstring graft at both 2- and 5-year follow-ups. Comparisons between serial outcomes measured at 2 and 5 years demonstrated that stability and functional outcomes deteriorated over time in patients with generalized joint laxity.

Conclusions Less satisfactory stability and functional outcomes were noted in patients with generalized joint laxity, compared to patients without generalized joint laxity. Comparisons of stability and functional outcomes after ACL reconstruction in patients with generalized joint laxity between two different grafts demonstrated that BPTB graft achieves better results than hamstring graft.

Level of evidence III, a retrospective cohort study.

Keywords Anterior cruciate ligament reconstruction · Graft · Bone–patellar tendon–bone · Hamstring · Risk factor · Generalized joint laxity

Introduction

In spite of risk factors causing recurrent instability, inherent physiologic characteristics of patients tend to be overlooked in anterior cruciate ligament (ACL) reconstruction [15, 16, 18]. Generalized joint laxity is regarded as one of such risk factors. The association between generalized joint laxity and ACL injury has been documented [22, 31]. In regards to ACL reconstruction, only a few studies have demonstrated

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that generalized joint laxity has adverse effects on postoperative outcomes [16, 19].

Graft selection is also an important issue in ACL reconstruction. Despite several studies on graft selection for ACL reconstruction [8, 33], an optimal graft still remains controversial. In addition, studies on graft selection in ACL reconstruction for patients with generalized joint laxity are scarce. Generalized joint laxity was noted as being related to late recurrent instability after ACL reconstruction [14]. However, a previous study [16] addressing graft selection for patients with generalized joint laxity only reported short-term follow-up results of about 2 years after operation. Therefore, the present study, involving more study subjects and longer term outcomes, compared to this previous study [16], was conducted to obtain more reliable results. The purpose of this study was to compare 2- and 5-year outcomes of ACL reconstruction between patients with and without generalized joint laxity and to perform comparative evaluation between two types of grafts used for ACL reconstruction in patients with generalized joint laxity. It was hypothesized that patients with generalized joint laxity would have worse outcomes than patients without generalized joint laxity and that 2- and 5-year follow-up results would indicate an appropriate graft for ACL reconstruction in patients with generalized joint laxity.

Materials and methods

Medical records of 675 consecutive patients who underwent unilateral ACL reconstruction from 2001 to 2008 were retrospectively reviewed. Inclusion criteria were: (1) age of more than 18 years; (2) primary single-bundle ACL reconstruction; (3) isolated ACL injury without a concomitant ligament injury; (4) normal alignment of the lower extremities; and (5) a minimum follow-up duration of 2 years. Exclusion criteria were (1) concomitant subtotal or total meniscectomy; (2) chondral lesion of more than Outerbridge grade II at arthroscopy [24]; (3) previous surgery at the affected knee; and (4) previous injury to the contralateral knee. After application of the above inclusion and exclusion criteria, a total of 237 patients were included. All of these patients were followed up at 2 years; 189 patients were followed up at 5 years.

Included patients were classified according to the presence or the absence of generalized joint laxity. Generalized joint laxity was assessed with the Beighton and Horan criteria using a point scoring system (Table 1) [1]. In the present study, to exclude the effect of trauma on range of motion of the affected knee, the affected knee was excluded from the score. The scores were totaled, and generalized joint laxity was defined as a score of ≥ 4 points (with a score of 8 being highest). Since the affected knee was excluded from the score and the highest score possible was 8, 29 patients who met the inclusion and exclusion criteria above, but given a score of 3 points were not included for study for clearer demarcation between the presence and the absence of generalized joint laxity. According to the above-mentioned criteria, included patients were classified into a group of patients without generalized joint laxity (≤ 2 points) or a group of patients with generalized joint laxity (≥ 4 points). Then, these patients were further subdivided according to the type of graft used: bone–patellar tendon–bone (BPTB) autograft or hamstring (semitendinosus–gracilis) autograft. During the study period, a guideline for selection of graft materials was provided as follows [17]: To avoid graft length mismatch, a BPTB graft was selected if the length of the patellar tendon was less than 4 cm on magnetic resonance imaging. If the length of the patellar tendon was more than 4 cm, hamstring graft was selected. Graft selection was not randomized; however, all surgeries were performed by the senior author.

According to the criteria listed above, all patients were classified into four groups: group NB, consisting of patients without generalized joint laxity treated with BPTB graft; group NH, consisting of patients without generalized joint laxity treated with hamstring graft; group LB consisting of patients with generalized joint laxity treated with BPTB graft; and group LH, consisting of patients with generalized joint laxity treated with hamstring graft. Group NB consisted of 122 patients, group NH consisted of 53 patients, group LB consisted of 41 patients, and group LH consisted of 21 patients. These patients were followed for 2 years. There were no significant differences in patient demographic data between the four groups (Tables 6 and 7 in Appendix). The four groups also did not differ significantly in regards to preoperative Lachman test and pivot-shift test results, mean side-to-side difference (SSD) in anterior translation, mean

Table 1 Beighton and Horan criteria for generalized joint laxity

Passive dorsiflexion of both fifth fingers beyond 90°
Passive opposition of both thumbs to volar aspects of ipsilateral forearms
Hyperextension of both elbows beyond 10°
Hyperextension of both knees beyond 10°
Forward flexion of the trunk with the knees fully extended and palms resting on the floor
The patient received a score per individual joint applicable to him or her among the above items. Generalized joint laxity was defined as a total score of ≥ 4 points

Lysholm knee score, mean IKDC subjective score, or IKDC objective grades (Table 6 in Appendix). The intraclass correlation coefficient (ICC) of preoperative SSDs in anterior translation measured with a KT-2000 arthrometer was 0.917 (95% confidence interval 0.892–0.936, $p < 0.001$). **Ninety-seven** patients in group NB, 41 patients in group NH, 33 patients in group LB, and 18 patients in group LH were followed up for 5 years.

Surgical technique

The same surgical technique and postoperative rehabilitation protocol were used for all patients included in the study. The BPTB graft comprised a tendon width of 10 mm and bone blocks of 10 mm in width and 20 mm in length. The thickness of the quadruple semitendinosus and gracilis tendon graft was 7–9 mm. The graft was pretensioned to 88 N for 20 min. A femoral socket was made at the 10:00–10:30 position on the right knee or at the 1:30–2:00 position on the left knee with a transtibial technique. The BPTB graft was secured within the femoral socket and tibial tunnel with bioabsorbable interference screws. For quadruple hamstring graft, suspensory fixation with the EndoButton was performed in the femoral socket. The graft was secured with buckle staples (Smith & Nephew, Memphis, Tennessee) to the tibial cortex distally. Bioabsorbable interference screws were additionally inserted in the femoral socket and tibial tunnel.

Clinical assessments

Clinical examinations were conducted preoperatively and at 2 and 5 years postoperatively. All physical examinations were performed by blinded trained orthopaedic fellows. Knee stability was evaluated using the Lachman test and pivot-shift test. The results of the Lachman test were graded using a scale of 0 (< 3 mm), 1 (≥ 3 and < 5 mm), 2 (≥ 5 and < 10 mm), or 3 (≥ 10 mm), and the results of the pivot-shift test were graded using a scale of 0 (equal), 1 (glide), 2 (clunk), or 3 (gross). Anterior stability was evaluated with the KT-2000 arthrometer (MEDmetric, San Diego, California) in 30° of knee flexion applying a force of 134 N. Regarding the Lachman test and anterior stability measured with the KT-2000 arthrometer, the value of the affected knee was compared with that of the normal contralateral knee for SSD. Two different examiners measured anterior stability with the KT-2000 arthrometer to improve reliability. The average of two measured values was used and recorded to one decimal place. Preoperative and postoperative functional evaluations were made using the Lysholm knee scoring scale [21] and the International Knee Documentation Committee (IKDC) subjective score and examination form [11]. Mean Lysholm knee scoring scale and mean IKDC subjective scores were also recorded to one decimal place. For radiologic evaluation, all patients underwent anteroposterior, lateral, and posteroanterior weight-bearing radiographs at 35°–45° of flexion and Merchant views taken preoperatively and postoperatively. The IKDC radiographic assessment scale [11] was employed for radiological grading.

Comparisons of follow-up outcomes among the four groups were made at 2- and 5-year follow-up. The proportions of patients who suffered graft rupture and contralateral ACL rupture during follow-up were also examined. Patients who sustained rupture of a reconstructed ACL graft or contralateral ACL during follow-up were excluded at the next upcoming assessment period. To examine changes in outcomes over time, comparisons of serial outcomes measured at 2- and 5-year follow-up within each group were conducted. According to the classification of the previous study [3], categorical variables were divided into dichotomous grades of normal and abnormal, and then compared. This study was conducted upon gaining approval from the Institutional Review Board of Severance Hospital, Yonsei University College of Medicine (IRB number 4-2017-0303).

Statistical analysis

To compare the four study groups, analysis of variance (ANOVA) or the Kruskal–Wallis test for continuous variables and the Chi-square test or Fisher exact test for categorical variables were performed. To make pairwise comparisons between groups, post-hoc testing with use of the Bonferroni correction was employed. Serial outcomes within each group were compared using the paired *t* test or Wilcoxon signed-rank test for continuous variables and the McNemar's test for dichotomous categorical variables. Interobserver reliability was evaluated with use of the ICC set at a 95% confidence interval. Statistical analysis was performed using SPSS software (version 23.0; IBM, Armonk, New York), and a p value < 0.05 was considered significant. Statistical power was calculated with the use of G*Power, version 3.1 [6].

Results

Comparison of the four study groups at 2-year follow-up revealed significant differences in stability, including the Lachman test, pivot-shift test, and mean SSD in anterior translation; functional outcomes, including Lysholm knee score and IKDC subjective score; and the proportions of cases by IKDC objective grade (Table 2). The results of post-hoc testing were as follows. In terms of stability, group LH had worse results on the Lachman test than group NB, and group LH had a worse mean SSD in anterior translation than group NB, group NH, and group LB (Table 3). In

Table 2 Comparison of postoperative outcomes among the four study groups at 2 years after operation

Variable	Group NB (n = 122)	Group NH (n = 53)	Group LB (n = 41)	Group LH (n = 21)	p value
Lachman test[a]					0.003
0	104 (85.2%)	44 (83.0%)	27 (65.9%)	11 (52.4%)	
I	16 (13.1%)	8 (15.1%)	11 (26.8%)	7 (33.3%)	
II	2 (1.6%)	1 (1.9%)	3 (7.3%)	3 (14.3%)	
III	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
Pivot-shift test[a]					0.027
0	106 (86.9%)	47 (88.7%)	30 (73.2%)	13 (61.9%)	
I	14 (11.5%)	5 (9.4%)	8 (19.5%)	6 (28.6%)	
II	2 (1.6%)	1 (1.9%)	3 (7.3%)	2 (9.5%)	
III	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
SSD in anterior translation[b,c]	2.1 ± 1.0	2.3 ± 0.9	2.7 ± 1.4	3.5 ± 1.4	< 0.001
< 3 mm	106 (86.9%)	46 (86.8%)	28 (68.3%)	10 (47.6%)	< 0.001
≥ 3 & < 5 mm	14 (11.5%)	6 (11.3%)	10 (24.4%)	8 (38.1%)	
≥ 5 & < 10 mm	2 (1.6%)	1 (1.9%)	3 (7.3%)	3 (14.3%)	
≥ 10 mm	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
Lysholm knee score[b]	91.1 ± 4.2	91.6 ± 5.6	88.8 ± 4.9	84.1 ± 3.6	< 0.001
IKDC subjective score[b]	89.5 ± 7.3	90.1 ± 4.5	86.3 ± 8.8	81.1 ± 3.5	< 0.001
IKDC objective grade[a]					0.008
A	96 (78.7%)	42 (79.2%)	26 (63.4%)	9 (42.9%)	
B	23 (18.9%)	9 (17.0%)	11 (26.8%)	9 (42.9%)	
C	3 (2.5%)	2 (3.8%)	4 (9.8%)	3 (14.3%)	
D	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
IKDC radiographic grade[b]					n.s
A	117 (95.9%)	51 (96.2%)	38 (92.7%)	20 (95.2%)	
B	5 (4.1%)	2 (3.8%)	3 (7.3%)	1 (4.8%)	
C	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
D	0 (0%)	0 (0%)	0 (0%)	0 (0%)	

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

[a]The values are given as n (%)

[b]The values are given as a mean ± standard deviation

[c]As measured with a KT-2000 arthrometer at 30° of knee flexion with a force of 134 N

Table 3 Post-hoc test of postoperative variables measured at 2 years after operation among the four study groups with use of Bonferroni correction

Variable	Group NB vs NH	Group NB vs LB	Group NB vs LH	Group NH vs LB	Group NH vs LH	Group LB vs LH
Lachman test	n.s	n.s	0.006	n.s	n.s	n.s
Pivot-shift test	n.s	n.s	n.s	n.s	n.s	n.s
SSD in anterior translation[a]	n.s	n.s	< 0.001	n.s	< 0.001	0.043
Lysholm knee score[a]	n.s	n.s	< 0.001	n.s	< 0.001	0.004
IKDC subjective score[a]	n.s	n.s	< 0.001	n.s	< 0.001	0.013
IKDC objective grade	n.s	n.s	0.009	n.s	0.042	n.s

The values are given as adjusted p values with use of Bonferroni correction

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

terms of functional outcomes, both Lysholm knee and IKDC subjective scores were significantly poorer in group LH than in groups NB, NH, and LB (Table 3). In terms of IKDC objective grade, group LH had worse results than groups

NB and NH (Table 3). IKDC radiographic grade did not differ significantly (Table 2). The ICC of the SSD in anterior translation was 0.960 (95% confidence interval 0.944–0.971, $p<0.001$). During 2 years after operation, the proportions of patients who sustained graft and contralateral ACL ruptures among the four groups did not show significant differences (Table 8 in Appendix).

Comparison of the four study groups at 5-year follow-up also revealed significant differences in stability, functional outcomes, and the proportions of cases by IKDC objective grade (Table 4). The results of post-hoc testing were as follows. In terms of stability on the Lachman test, group LB had worse results than group NB, and group LH had worse results than groups NB and NH. On the pivot-shift test, group NB had better results than groups LB and LH. Mean SSD in anterior translation were significantly greater in groups LB and LH than in groups NB and NH, and the mean value in group LH was also greater than that in group LB (Table 5). In terms of functional outcomes, both Lysholm knee and IKDC subjective scores were significantly poorer in group LB, compared to groups NB and NH, and in group LH, compared to groups NB, NH, and LB (Table 5). IKDC radiographic grades did not differ significantly (Table 4). The ICC of the SSD in anterior translation at 5-year follow-up was 0.965 (95% confidence interval 0.941–0.977, $p<0.001$). The statistical power for SSD in anterior translation at 5 years was 0.99. Comparison of the proportions of patients who suffered graft ruptures among the four groups showed significant differences at 5 years after operation (group NB = 1.0%; NH = 2.3%; LB = 7.9%; LH = 9.5%, $p=0.042$) (Table 9 in Appendix). However, post-hoc test did not uphold the significant differences (Table 10 in Appendix). The

Table 4 Comparison of postoperative outcomes among the four study groups at 5 years after operation

Variable	Group NB ($n=97$)	Group NH ($n=41$)	Group LB ($n=33$)	Group LH ($n=18$)	p value
Lachman test[a]					0.001
0	79 (81.4%)	33 (80.5%)	18 (54.5%)	7 (35.3%)	
I	15 (15.5%)	6 (14.6%)	11 (33.3%)	8 (47.1%)	
II	3 (3.1%)	2 (4.9%)	3 (9.1%)	3 (17.6%)	
III	0 (0%)	0 (0%)	1 (3.0%)	0 (0%)	
Pivot-shift test[a]					0.001
0	83 (85.6%)	35 (85.4%)	19 (57.6%)	9 (50.0%)	
I	12 (12.4%)	5 (12.2%)	10 (30.3%)	7 (38.9%)	
II	2 (2.1%)	1 (2.4%)	4 (12.1%)	2 (11.1%)	
III	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
SSD in anterior translation[b,c]	2.2 ± 1.2	2.3 ± 0.9	3.2 ± 1.8	4.4 ± 1.8	< 0.001
< 3 mm	80 (82.5%)	35 (85.4%)	17 (51.5%)	8 (44.4%)	< 0.001
≥ 3 & < 5 mm	15 (15.5%)	4 (9.8%)	12 (36.4%)	7 (38.9%)	
≥ 5 & < 10 mm	2 (2.1%)	2 (4.9%)	3 (9.1%)	3 (16.7%)	
≥ 10 mm	0 (0%)	0 (0%)	1 (3.0%)	0 (0%)	
Lysholm knee score[b]	91.4 ± 3.6	91.1 ± 4.4	86.6 ± 6.1	81.2 ± 4.2	< 0.001
IKDC subjective score[b]	88.6 ± 6.8	89.2 ± 4.5	82.4 ± 10.3	79.2 ± 4.7	< 0.001
IKDC objective grade[a]					0.023
A	64 (66.0%)	29 (70.7%)	15 (45.5%)	6 (33.3%)	
B	28 (28.9%)	9 (22.0%)	12 (36.4%)	9 (50.0%)	
C	5 (5.2%)	3 (7.3%)	5 (15.2%)	3 (16.7%)	
D	0 (0%)	0 (0%)	1 (3.0%)	0 (0%)	
IKDC radiographic grade[a]					n.s
A	79 (81.4%)	32 (78.0%)	24 (72.7%)	12 (66.7%)	
B	18 (18.6%)	9 (22.0%)	8 (24.2%)	5 (27.8%)	
C	0 (0%)	0 (0%)	1 (3.0%)	1 (5.6%)	
D	0 (0%)	0 (0%)	0 (0%)	0 (0%)	

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

[a]The values are given as n (%)

[b]The values are given as a mean ± standard deviation

[c]As measured with a KT-2000 arthrometer at 30° of knee flexion with a force of 134 N

Table 5 Post-hoc test of postoperative variables measured at 5 years after operation between four groups with use of Bonferroni correction

Variable	Group NB vs NH	Group NB vs LB	Group NB vs LH	Group NH vs LB	Group NH vs LH	Group LB vs LH
Lachman test	n.s	0.034	0.004	n.s	0.040	n.s
Pivot-shift test	n.s	0.013	0.016	n.s	n.s	n.s
SSD in anterior translation	n.s	0.001	< 0.001	0.008	< 0.001	0.034
Lysholm knee score	n.s	< 0.001	< 0.001	0.007	< 0.001	0.005
IKDC subjective score	n.s	< 0.001	< 0.001	0.007	< 0.001	0.005
IKDC objective grade	n.s	n.s	n.s	n.s	n.s	n.s

The values are given as adjusted *p* values with use of Bonferroni correction

SSD side-to-side difference, *IKDC* International Knee Documentation Committee, *BPTB*

proportions of patients who sustained contralateral ACL rupture did not differ significantly (Table 9 in Appendix).

Comparisons of serial outcomes within each group were conducted. In groups NB and NH, there was no significant difference with respect to all variables (Tables 11 and 12 in Appendix). In groups LB and LH, SSD in anterior translation, Lysholm knee score, and IKDC subjective score at 2 and 5 years differed significantly (Tables 13 and 14 in Appendix).

Discussion

The most important finding of the present study was as follows: 2-year follow-up results showed that patients with generalized joint laxity receiving hamstring grafts had poorer outcomes than those without generalized joint laxity, and 5-year follow-up results reflected poorer outcomes in patients with generalized joint laxity than those without generalized joint laxity regardless of graft type; Comparison of grafts used showed that, in patients with generalized joint laxity, BPTB grafts provided significantly better stability and functional outcomes than hamstring grafts at both 2- and 5-year follow-ups.

A lack of stabilizing structures surrounding the knee in patients with generalized joint laxity is considered to lead to poor outcomes of ACL reconstruction. Generalized joint laxity reflects the inherent extensibility of joints in relation with the composition and orientation of connective tissues [20]. The absence of structural stabilization by sufficiently taut tendons, ligaments, and a joint capsule was noted to be related to a high likelihood of ACL injury [31]. These lax secondary restraints could affect the stability of a reconstructed graft and cause poor outcomes. Knee hyperextension also could have a direct adverse effect on the reconstructed ACL graft, even if not all patients with generalized joint laxity have knee hyperextension. According to a previous study [26] on the relationship between outcomes of ACL reconstruction and knee hyperextension, severe, consistent stress was found to be imposed on the graft for stabilization of the knee in hyperextension. Repeated roof impingement of reconstructed ACL grafts by hyperextension could also put more stress on the graft [12, 28].

Regarding the comparative results of the differences in outcomes between the two types of grafts used, patients treated with BPTB graft had significantly less anterior instability and better functional outcomes than patients treated with hamstring grafts among patients with generalized joint laxity. A previous study [16] comparing 2-year outcomes between BPTB and hamstring grafts in small number of patients with generalized joint laxity also demonstrated that BPTB grafts offered greater stability and better Lysholm scores, similar to the results of the present study: in the aforementioned study [16], the mean SSDs in anterior tibial translation were 2.7 ± 1.9 mm in the BPTB graft group and 3.5 ± 1.7 mm in the hamstring graft group. Mean Lysholm scores were 91 ± 7 points in the BPTB graft group and 85 ± 10 points in the hamstring graft group. Generalized joint laxity, which is more frequently present in females, has also been mentioned as a cause of inferior outcomes in female patients treated with hamstring graft [7, 23]. Gobbi et al. reported that female patients had average SSD of 1.04 mm for patellar tendon grafts and 1.7 mm for hamstring grafts upon instrumented laxity testing [7]. Noojin et al. also noted that a higher number of female patients (31% = 11 of 39) than male patients (8% = 2 of 26) were graded as having a 1 + Lachman result at follow-up examination, although the male and female patients were comparable at the time of the initial evaluation, upon ACL reconstruction using a hamstring graft. Clinical failure rates for hamstring grafts were reported at 23% (9 of 39) for the female patients and 4% (1 of 26) for the male patients, a difference that was statistically significant [23]. Due to a lack of basic research, the exact pathophysiologic mechanisms affecting differences in outcomes between grafts have yet to be elucidated. Nevertheless, according to the results of the present study and previous studies [7, 16, 23], generalized joint laxity appears to have a greater negative influence on hamstring grafts than BPTB grafts. A hamstring graft is a soft-tissue graft consisting of only tendon, whereas a BPTB graft consists of bone and a short tendon portion, relative to a hamstring graft. Tendon portions of autograft tissue have the properties of inherent extensibility and less of an ability to produce sufficient cross links necessary for a structurally sound ACL graft [10]. Thus, in regards to generalized joint laxity, a hamstring graft consisting of only tendon could be affected more by these extensible properties of autograft tissue. In addition, tendon-to-bone healing in a hamstring graft has been found to be longer than the direct bone to bone healing in a BPTB graft [13]. Delayed graft healing of a hamstring graft under less stability caused by insufficient secondary stabilization could lead to poorer outcomes than a BPTB graft [16]. In terms of the relationship between graft thickness and stability, the previous studies [25, 30] noted that as the thickness of a graft decreases, the rate of rupture increases and that grafts for ACL reconstruction with a smaller cross-sectional area may be weaker. Thus, a less thick hamstring graft could be more affected by the unstable condition resulting from generalized joint laxity. In the present study, the results of comparison of postoperative stability showed that there was significant difference in not only anterior stability, but also rotatory stability on the pivot-shift test among the four study groups. It has been proposed that the anterolateral ligament assists the ACL as a stabilizer against anterior tibial translation and internal rotation [4, 5, 32]. Combined extraarticular stabilization, including anterolateral ligament reconstruction with intraarticular ACL reconstruction, could be considered to complement weakness of stability and ACL graft rupture in generalized joint laxity patients with ACL injury. Another in-depth study is needed to reveal the effectiveness of combined intraarticular and extraarticular stabilization on outcomes in patients with generalized joint laxity.

According to the results of comparisons of serial outcomes within each group, stability and functional scores measured at 5 years were worse than those measured at 2 years irrespective of the type of graft in patients with generalized joint laxity. Other studies [27, 29] noted no significant changing trend in functional outcomes after 2 years from operation similar to the results observed in patients without generalized joint laxity in the present study. However, the present study showed that, in patients with generalized joint laxity, outcomes of ACL reconstruction continued to deteriorate as time passed after 2 years from operation. Although it was not clear how long postoperative outcomes deteriorated, the negative effects mentioned above could be considered to worsen the stability and functional outcomes of ACL reconstruction in patients with generalized joint laxity.

Regarding graft rupture and contralateral ACL rupture, the proportion of graft ruptures in patients with generalized joint laxity was higher than that in patients without generalized joint laxity, although pairwise comparison did not show statistical significance. Characteristics of generalized joint laxity caused by the inherent extensibility of connective tissue seemed to be associated with more consistent stress and repeated trauma on the graft and graft rupture.

The results of the present study demonstrated that generalized joint laxity could be a risk factor for unsatisfactory outcomes of ACL reconstruction and that BPTB autograft could be recommended as a superior graft to hamstring autograft for ACL reconstruction in patients with generalized joint laxity. In treating ACL injury in patients with generalized joint laxity, these findings should be considered in a series of processes from surgery to rehabilitation, and it is also important to get patients who undergo operation to understand that generalized joint laxity is a risk factor influencing outcomes.

Careful attention to interpreting the functional outcomes of this study is warranted. Although differences between groups reached statistical significance, some of the differences between each group were not substantial and less than a minimal clinically important difference (IKDC subjective score [9] = 6.3) and a minimal detectable change (Lysholm knee score [2] = 8.9). There are more several limitations that warrant review before definite conclusions can be reached. First, we reviewed data retrospectively. Second, selection of the graft was not randomized. To reach a more reliable conclusion, a prospective randomized study is needed. Third, because accurate measurement was difficult due to the effect of trauma on range of motion, the affected knee was excluded from the score for assessment of generalized joint laxity. Consequently, an eight-point scoring system was used unlike the original nine-point scoring system [1]. If the extent of joint mobility in the affected knee could be accurately assessed and included in the score, results could be affected. Fourth, patients who suffered graft rupture and contralateral ACL rupture in the middle of follow-up were excluded from the subjects at the next upcoming assessment period. Inclusion of these patients could influence the results of the study. However, because these excluded patients were a minority and there was no statistical difference in the proportion of ruptures between the groups, exclusion of these patients might not lead to a great difference in the results of the comparisons.

Conclusions

In the present 2–5-year follow-up study, less satisfactory outcomes regarding stability and functional scores were recorded in patients with generalized joint laxity, compared to patients without generalized joint laxity. Comparisons of stability and functional outcomes after ACL reconstruction in patients with generalized joint laxity demonstrated that BPTB graft showed better results than hamstring graft. Generalized joint laxity could be a risk factor for unsatisfactory outcomes of ACL reconstruction, and BPTB autograft could be recommended as a superior graft to hamstring autograft for ACL reconstruction in patients with generalized joint laxity.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was conducted following the approval of Institutional Review Board of Severance Hospital, Yonsei University College of Medicine (IRB number 4-2017-0303).

Informed consent This retrospective study received exemption from informed consent by the Institutional Review Board of Severance Hospital.

Appendix

See Tables 6, 7, 8, 9, 10, 11, 12, 13 and 14.

Table 6 Demographic data and preoperative variables of patients who were followed up for 2 years

Variable	Group NB (*n* = 122)	Group NH (*n* = 53)	Group LB (*n* = 41)	Group LH (*n* = 21)	*p* value
Age (years)[a]	29.9 ± 10.6	31.1 ± 10.2	29.4 ± 10.5	28.5 ± 8.0	n.s
Sex[b]					n.s
Male	97 (79.5%)	42 (79.2%)	29 (70.7%)	15 (71.4%)	
Female	25 (20.5%)	11 (20.8%)	12 (29.3%)	6 (28.6%)	
Side[b]					n.s
Right	66 (54.1%)	25 (47.2%)	23 (56.1%)	12 (57.1%)	
Left	56 (45.9%)	28 (52.8%)	18 (43.9%)	9 (42.9%)	
Duration from injury to operation (months)[a]	8.6 ± 8.7	8.9 ± 13.2	8.3 ± 9.5	9.0 ± 14.2	n.s
Additional diagnosis[b]					n.s
Yes	75 (61.5%)	30 (56.6%)	24 (58.5%)	13 (61.9%)	
No	47 (38.5%)	23 (43.4%)	17 (41.5%)	8 (38.1%)	
Lachman test[b]					n.s
I	6 (4.9%)	2 (3.8%)	2 (4.9%)	1 (4.8%)	
II	95 (77.9%)	42 (79.2%)	31 (75.6%)	17 (81.0%)	
III	21 (17.2%)	9 (17.0%)	8 (19.5%)	3 (14.3%)	
Pivot-shift test[b]					n.s
I	9 (7.4%)	2 (3.8%)	3 (7.3%)	1 (4.8%)	
II	97 (79.5%)	44 (83.0%)	31 (75.6%)	18 (85.7%)	
III	16 (13.1%)	7 (13.2%)	7 (17.1%)	2 (9.5%)	
SSD in anterior translation[a,c]	7.7 ± 2.1	7.9 ± 2.0	7.9 ± 2.0	7.6 ± 2.1	n.s
≥ 3 & < 5 mm	9 (7.4%)	3 (5.7%)	3 (7.3%)	1 (4.8%)	n.s
≥ 5 & < 10 mm	90 (73.8%)	40 (75.5%)	29 (70.7%)	16 (76.2%)	
≥ 10 mm	23 (18.9%)	10 (18.9%)	9 (22.0%)	4 (19.1%)	
Lysholm knee score[a]	71.0 ± 10.7	70.2 ± 8.5	72.3 ± 8.6	71.2 ± 5.2	n.s
IKDC subjective score[a]	55.7 ± 9.7	55.1 ± 8.3	55.5 ± 7.7	56.1 ± 8.7	n.s
IKDC objective grade[b]					n.s
B	2 (1.6%)	1 (1.9%)	1 (2.4%)	1 (4.8%)	
C	85 (69.7%)	40 (75.5%)	30 (73.2%)	15 (71.4%)	
D	35 (28.7%)	12 (22.6%)	10 (24.4%)	5 (23.8%)	

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

[a]The values are given as a mean ± standard deviation

[b]The values are given as *n* (%)

[c]As measured with a KT-2000 arthrometer at 30° of knee flexion with a force of 134 N

Table 7 Distribution of total scores according to Beighton and Horan criteria in each group

Variable	Group NB ($n=122$)	Group NH ($n=53$)	Group LB ($n=41$)	Group LH ($n=21$)
Total Beighton score				
0	91	38		
1	8	5		
2	23	10		
4			12	7
5			10	5
6			7	4
7			5	2
8			7	3

Table 8 Comparison of the proportions of graft and contralateral ACL ruptures among the four study groups at 2 years from operation

Variable	Group NB ($n=122$)	Group NH ($n=53$)	Group LB ($n=43$)	Group LH ($n=23$)	p value
Graft rupture					n.s
Yes	0 (0%)	0 (0%)	1 (2.3%)	1 (4.3%)	
No	122 (100%)	53 (100%)	42 (97.7%)	22 (95.7%)	
Contralateral ACL rupture					n.s
Yes	0 (0%)	0 (0%)	1 (2.3%)	1 (4.3%)	
No	122 (100%)	53 (100%)	42 (97.7%)	22 (95.7%)	

The values are given as *n* (%)

Table 9 Comparison of the proportions of graft and contralateral ACL ruptures among the four study groups at 5 years from operation

Variable	Group NB ($n=99$)	Group NH ($n=43$)	Group LB ($n=38$)	Group LH ($n=21$)	p value
Graft rupture					0.042
Yes	1 (1.0%)	1 (2.3%)	3 (7.9%)	2 (9.5%)	
No	98 (99.0%)	42 (97.7%)	35 (92.1%)	19 (90.5%)	
Contralateral ACL rupture					n.s
Yes	1 (1.0%)	1 (2.3%)	2 (5.3%)	1 (4.8%)	
No	98 (99.0%)	42 (97.7%)	36 (94.7%)	20 (95.2%)	

The values are given as *n* (%)

Table 10 Post-hoc test of the proportions of graft ruptures at 5 years from operation among the four study groups with use of Bonferroni correction

Variable	Group NB vs NH	Group NB vs LB	Group NB vs LH	Group NH vs LB	Group NH vs LH	Group LB vs LH
Graft rupture	n.s	n.s	n.s	n.s	n.s	n.s

The values are given as adjusted *p* values with use of Bonferroni correction

Table 11 Comparison of outcomes at 2 and 5 years after operation in group NB consisting of patients with normal joint laxity treated with BPTB graft ($n=97$)

Variable	2 years	5 years	p value
Lachman test[a]			n.s
0 or I	95 (97.9%)	94 (96.9%)	
II or III	2 (2.1%)	3 (3.1%)	
Pivot-shift test[a]			n.s
0 or I	96 (99.0%)	95 (97.9%)	
II or III	1 (1.0%)	2 (2.1%)	
SSD in anterior translation[b,c]	2.1 ± 1.1	2.2 ± 1.2	n.s
Lysholm knee score[b]	91.1 ± 4.2	91.4 ± 3.6	n.s
IKDC subjective score[b]	88.5 ± 7.8	88.6 ± 6.8	n.s
IKDC objective grade[a]			n.s
A or B	94 (96.9%)	92 (94.8%)	
C or D	3 (3.1%)	5 (5.2%)	

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

[a]The values are given as n (%)

[b]The values are given as a mean ± standard deviation

[c]As measured with a KT-2000 arthrometer at 30° of knee flexion with a force of 134 N

Table 12 Comparison between outcomes at 2 and 5 years after operation in group NH consisting of patients with normal joint laxity treated with hamstring graft ($n=41$)

Variable	2 years	5 years	p value
Lachman test[a]			n.s
0 or I	41 (100%)	39 (95.1%)	
II or III	0 (0%)	2 (4.9%)	
Pivot-shift test[a]			n.s
0 or I	40 (97.6%)	40 (97.6%)	
II or III	1 (2.4%)	1 (2.4%)	
SSD in anterior translation[b,c]	2.2 ± 0.8	2.3 ± 0.9	n.s
Lysholm knee score[b]	91.6 ± 5.7	91.1 ± 4.4	n.s
IKDC subjective score[b]	90.0 ± 4.8	89.2 ± 4.5	n.s
IKDC objective grade[a]			n.s
A or B	40 (97.6%)	38 (92.7%)	
C or D	1 (2.4%)	3 (7.3%)	

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

[a]The values are given as n (%)

[b]The values are given as a mean ± standard deviation

[c]As measured with a KT-2000 arthrometer at 30° of knee flexion with a force of 134 N

Table 13 Comparison between outcomes at 2 and 5 years after operation in group LB consisting of patients with generalized joint laxity treated with BPTB graft ($n=33$)

Variable	2 years	5 years	p value
Lachman test[a]			n.s
0 or I	30 (90.9%)	29 (87.9%)	
II or III	3 (9.1%)	4 (12.1%)	
Pivot-shift test[a]			n.s
0 or I	30 (90.9%)	29 (87.9%)	
II or III	3 (9.1%)	4 (12.1%)	
SSD in anterior translation[b,c]	2.8 ± 1.4	3.2 ± 1.8	0.006
Lysholm knee score[b]	89.3 ± 4.8	86.5 ± 6.1	0.005
IKDC subjective score[b]	85.2 ± 9.1	82.4 ± 10.3	0.025
IKDC objective grade[a]			n.s
A or B	29 (87.9%)	27 (81.8%)	
C or D	4 (12.1%)	6 (18.2%)	

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

[a]The values are given as n (%)

[b]The values are given as a mean ± standard deviation

[c]As measured with a KT-2000 arthrometer at 30° of knee flexion with a force of 134 N

Table 14 Comparison between outcomes at 2 and 5 years after operation in group LH consisting of patients with generalized joint laxity treated with hamstring graft ($n=18$)

Variable	2 years	5 years	p value
Lachman test[a]			n.s
0 or I	16 (88.9%)	15 (83.3%)	
II or III	2 (11.1%)	3 (16.7%)	
Pivot-shift test[a]			n.s
0 or I	17 (94.4%)	16 (88.9%)	
II or III	1 (5.6%)	2 (11.1%)	
SSD in anterior translation[b,c]	3.5 ± 1.3	4.4 ± 1.8	0.001
Lysholm knee score[b]	84.3 ± 3.8	81.2 ± 4.2	< 0.001
IKDC subjective score[b]	81.5 ± 3.3	79.2 ± 4.7	0.006
IKDC objective grade[a]			n.s
A or B	16 (88.9%)	15 (83.3%)	
C or D	2 (11.1%)	3 (16.7%)	

SSD side-to-side difference, *IKDC* International Knee Documentation Committee

[a]The values are given as n (%)

[b]The values are given as a mean ± standard deviation

[c]As measured with a KT-2000 arthrometer at 30° of knee flexion with a force of 134 N

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