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Influence of hamstring tendon and bone-patellar tendon-bone autografts on worsened patient reported outcome measurements in revision anterior cruciate ligament reconstruction: Comparing outcomes between primary and revision reconstructions

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A B S T R A C T

Background: This study aimed to compare the clinical outcomes and patient reported outcome measurement scales (PROMs) between hamstring tendon (HT) or bone-patellar tendon-bone (BTB) grafts in each primary and revision anterior cruciate ligament (ACL) reconstruction. Additionally, the clinical outcomes and PROMs between primary and revision surgeries were compared.
Methods: A total of 150 patients (109 primary and 41 revision ACL reconstructions) were enrolled and followed up for an average of 3.9 years (2 years minimum). Knee injury and osteoarthritis outcome scores (KOOS) were examined as PROMs. Side-to-side differences of anterior knee laxity were assessed using KT-1000 and were recorded at the final follow-up. After categorizing patients into HT and BTB reconstruction groups, regression analysis was performed to determine the relationship between revision surgery and changes in KOOS.
Results: In patients who underwent primary surgery, there was no significant difference in side-to-side differences of anterior laxity and KOOS between HT and BTB grafts. In those who underwent revision surgery, BTB grafts had a higher KOOS for activities of daily living (ADL) than HT grafts ($p = 0.032$). Comparing primary and revision surgeries, postoperative side-to-side differences of anterior laxity in the revision group were significantly larger than those in the primary group ($p = 0.001$). The KOOS for sports after overall revision reconstruction was significantly lower than that after primary reconstruction ($p = 0.026$). Comparing the KOOS after dividing all patients into HT and BTB reconstruction groups, in the HT reconstruction group, postoperative KOOS results were not different in any subscale from BTB grafts. In contrast, the KOOS for sports ($p = 0.008$) and QOL ($p = 0.039$) were significantly lower in revision surgery than in primary surgery. Furthermore, regression analysis including multiple confounders in the HT reconstruction group showed revision surgery using HT graft was correlated with worsened KOOS for symptoms ($p = 0.012$) and sports ($p = 0.010$). Revision surgery using BTB graft was not correlated with decreased KOOS.
Conclusions: There were no differences between the clinical outcome and KOOS in primary and revision surgery, except for ADL scores following revision ACL reconstruction using BTB graft. Side-to-side difference of anterior laxity and KOOS for sports following revision ACL reconstruction were inferior to those following primary ACL reconstruction.
Furthermore, revision ACL reconstruction using HT grafts were correlated with low scores in KOOS for symptoms and sports, while there was no difference of anterior laxity between BTB and HT grafts in revision surgery.

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1. Introduction

Anterior cruciate ligament (ACL) reconstruction for ACL injuries is a standardized treatment for athletes or highly active patients. Primary ACL reconstruction is generally regarded as a safe and effective procedure with high rates of return to sport and reduced occurrence of posttraumatic osteoarthritis.[1,2] However, it remains challenging for athletes to return to their pre-injury sports level after revision ACL reconstruction, and only a small percentage of patients achieve this level.[3] The clinical outcomes of revision surgery were inferior to those of primary surgery, and several risk factors have been found to be associated with poor outcomes.[4,5]

Considering methods to improve the outcomes of revision surgery, it is necessary to create a tunnel in the anatomical ACL insertion.[6,7] However, widened tunnel aperture[8] and restricted graft choice[4] are often unfavorable effects. Among these unfavorable effects, the graft choice for revision surgery is of great concern to surgeons because primary ACL reconstruction limits the grafts available for revision surgery. Previously, allograft reconstruction attracted attention as an available graft for revision ACL reconstruction because repeated reconstruction reduces autograft options for these individuals. However, the Multi-Center ACL Revision Study (MARS) and other reports revealed poor clinical outcomes after ACL reconstruction with allografts.[9] Autografts are used prior to allografts for revision ACL reconstruction because of their superior outcomes, but little evidence supports the benefits of the hamstring tendon (HT) of the semitendinosus/gracilis or bone-patellar tendon-bone (BTB) grafts over other commonly used autografts.[2] Although evidence shows the restoration of good stability following revision ACL reconstruction on objective evaluation, patient satisfaction, measured by patient reported outcome measurement scales (PROMs), was not fully evaluated in most previous studies.

The aims of this study were to 1) compare the clinical outcomes and knee injury and osteoarthritis outcome scores (KOOS) between HT and BTB grafts in primary reconstruction, 2) compare the clinical outcomes and KOOS between HT and BTB grafts in revision reconstruction, and 3) compare the clinical outcomes and KOOS between primary and revision surgeries. We hypothesized that PROMs after revision surgery would be at the same level as those after primary surgery, and that revision ACL reconstruction using a BTB graft would improve patient satisfaction in comparison with a HT graft.

2. Materials and methods

2.1. Subjects

Patients who underwent primary ACL reconstruction from January 2007 to December 2009, and patients who underwent revision ACL reconstruction from May 2007 to October 2016 were included in the study. Inclusion criteria for the primary ACL reconstruction was knee instability related to ACL injury. Inclusion criteria for the revision ACL reconstruction was knee instability related to ACL re-injuries with trauma, or surgical technical errors including malpositioned primary ACL reconstruction. Exclusion criteria were as follows: (1) age below 14 years or skeletally immature patients with open physis of the femur or tibia on magnetic resonance imaging (MRI),[10] (2) bilateral ACL injuries, (3) multiple knee ligament injuries, (4) prior revision ACL surgery, (5) severe cartilage injury greater than International Cartilage Repair Society (ICRS) grade 3, (6) knee osteoarthritis based on Kellgren-Lawrence grade 2 or higher, (7) combined knee surgery with high tibial osteotomy or medial patellofemoral ligament reconstruction, (8) fracture of the lower extremity, (9) patients with incomplete questionnaires, or (10) less than 2 years follow-up. Background data, including age, sex, height, and weight at the time of surgery, were retrospectively collected from the patients' medical records.

The study was performed in agreement with the 1964 Helsinki Declaration and later amendments or comparable ethical standards. Approval was obtained from the ethics committee of the Hirosaki University Graduate School of Medicine. Written informed consent was obtained from all participants.

2.2. Surgical procedures

For primary and revision ACL reconstructions, the senior author performed or directly supervised the reconstruction of the ACL without notch plasty for all patients. Associated injuries of the medial and lateral menisci were repaired or partially resected before ACL reconstruction. Treatment for concomitant cartilage injury was not performed at the time of reconstruction. Primary surgery patients were randomized into the HT or BTB group using Microsoft Excel, where random numbers were generated and assigned to patients to ensure that the treatment groups had similar sample sizes, as previously reported.[1] An autograft was selected for the revision surgery based on the failure of the graft used for the primary surgery.

2.3. Double-bundle ACL reconstruction with HT

Double bundle ACL reconstruction with HT was performed using the *trans*-portal technique. The semitendinosus tendon was harvested with a tendon stripper. If the harvested graft was shorter than 23 cm, or the looped tendon was thinner than 5 mm in diameter, part of the gracilis tendon was also harvested, looped, and added to the anteromedial (AM) graft. A suture plate (B. Braun Aesculap AG, Germany) was attached to the proximal end of each graft and the length of the suture loop was adjusted to the femoral tunnel length measured during reconstruction. The distal end of each graft was connected with a No. 2 Ethibond (Ethicon Inc., US) using the baseball glove suturing technique. The AM and posterolateral (PL) grafts were 6.2 ± 0.6 (range: 5.5-8.0) mm and 5.9 ± 0.6 (range: 4.5-7.5) mm in diameter, respectively. The AM and PL tunnels were created to be the same size as the graft diameters. The femoral tunnels for both the AM and PL grafts were created posterior to the resident's ridge and in the center of the direct insertion site of the native AM bundle and PL bundle by a common transtibial or transportal technique.[6,7,11] The tibial tunnels for the AM and PL grafts were created posterior to the anterior ridge (Parsons' knob).[12] After creating the two tibial and two femoral tunnels with the diameter corresponding to the measured diameter of the prepared graft, the PL graft, followed by the AM graft, were introduced through the tibial tunnel into the femoral tunnel. Finally, the manual maximum force was applied as an initial tension to fix the PL and AM grafts, and both grafts were fixed with a suture minidisc (B. Braun Aesculap AG, Germany) at a knee flexion position of 15–20°.

2.4. Rectangular tunnel ACL reconstruction with BTB

Rectangular tunnel ACL reconstruction with BTB graft was performed by the basic transtibial or transportal technique described by Shino et al.[13] A 10-mm wide BTB graft was harvested from the central portion of the patellar tendon, with approximately 15-mm long bone plugs at both ends. The patellar bone plug was prepared for placement into the femoral tunnel and was shaped to a 6-mm thickness. The femoral tunnel was prepared by inserting the anteromedial guide wire posteriorly to the resident's ridge through the transportal technique. The posterolateral guide wire was inserted parallel to the anteromedial guide wire, and both wires were over-drilled with a 5.5 mm cannulated reamer, dilated with a 10 × 6 mm dilator to a depth of about 25 mm. The proximal tibial rectangular tunnel was created and smoothed using an outside-in dilator. With two leading sutures, the graft was passed through the tibial tunnel to the femoral tunnel, then the proximal bone plug was fixed with an Endobutton CL BTB (Smith & Nephew Endoscopy). The manual maximum force was applied as an initial tension to fix the BTB graft, and the distal bone plug was fixed with metal or absorbable interference screws at a knee flexion position of 15 to 20°.

2.5. Revision ACL reconstruction

All revision surgeries were conducted as a one-stage reconstruction surgery. No patient required the two-stage surgery for bone defects related to tunnel enlargement. Grafts for revision ACL reconstruction were selected based on the graft used for the primary reconstruction. Primarily, ipsilateral BTB grafts were used for the patients following primary ACL reconstruction with HT grafts. However, contralateral HT grafts were chosen for patients who did not want ipsilateral BTB grafts because of fear of anterior knee pain. Also, ipsilateral HT graft was selected in patients following primary ACL reconstruction with a BTB graft or artificial ligaments. In the revision ACL reconstruction with BTB grafts, the degree of the tunnel aperture enlargement or fusion of the bone plugs were evaluated by 3D-computed tomography (CT) images. If femoral tunnel was not anatomical in the primary surgery based on 3D-CT and arthroscopy, the femoral rectangular tunnel was created at the appropriate anatomical site related to the resident's ridge in a manner similar to that in primary ACL reconstruction (Fig. 1). When the primary tunnel was created at this anatomical position during primary surgery, guided pin insertion and over drilling were performed by adjusting the tunnel direction not to overlap the prior tunnel based on the preoperative planning using 3D-CT images. The proximal bone plug was fixed with an Endobutton CL BTB (Smith & Nephew Endoscopy) or interference screw. The manual maximum force was applied as an initial tension to fix the BTB graft, and the distal bone plug was fixed with metal or absorbable interference screws at a knee flexion position of 15 to 20°. In the revision ACL reconstruction with HT grafts (Fig. 2), the two femoral tunnels were created in a similar manner with primary ACL reconstruction base on the harvested graft size, and fixed with a suture plate (B. Braun Aesculap AG, Germany). In cases where the primary tunnel was created at a non-anatomical position during primary surgery based on 3D-CT and arthroscopy, the femoral tunnel was created at the appropriate anatomical site related to the resident's ridge in a manner similar to that in primary ACL reconstruction. In cases where the primary tunnel was created at an anatomical position during primary surgery, based on the residual bone defect, guided pin insertion and over drilling were performed by adjusting the tunnel direction so as not to overlap the prior tunnel based on the preoperative planning using 3D-CT images. After graft passing, the femoral side was fixed with an Endobutton CL (Smith & Nephew Endoscopy). The manual maximum force was then applied as an initial tension to fix the PL and AM grafts, and both grafts were fixed with a suture minidisc (B. Braun Aesculap AG, Germany) at a knee flexion position of 15 to 20°.

2.6. Postoperative rehabilitation

Regardless of meniscus treatment, patients began crutch-assisted, partial-body weight bearing ambulation and range of motion and isometric muscle-strengthening exercises the day after surgery. Full weight bearing and closed kinetic chain exercises were allowed between 7 and 14 days postoperatively, while running, open kinetic chain exercises, and jump-landing training were allowed after 3 months. Sport-specific training was allowed after 5–6 months and return to sports was permitted after 6–9 months. Patients in both the HT and BTB groups performed the same postoperative rehabilitation.[1]

2.7. Clinical assessment

For postoperative laxity, side-to-side differences of anterior laxity (mm) were evaluated using KT-1000 (MEDmetric)

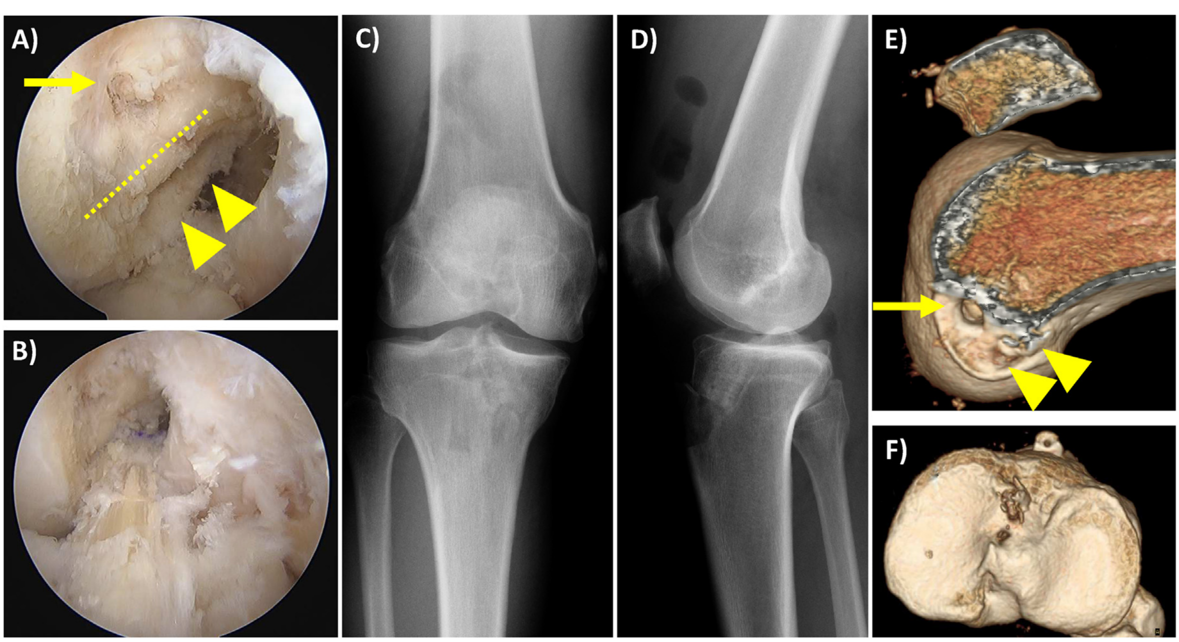

Fig. 1. Revision double-bundle ACL reconstruction using hamstring tendon graft after bone-patellar tendon-bone graft rupture. A) Arthroscopic findings of the primary surgery screw hole (Arrow) and femoral tunnel of revision surgery (arrowhead) created behind the Resident's ridge (dotted line). B) Arthroscopic findings of revision ACL reconstruction. C, D) Postoperative anteroposterior and lateral radiographs. E, F) Femoral tunnel and tibial tunnel positions in postoperative 3-dimensional computed tomography.

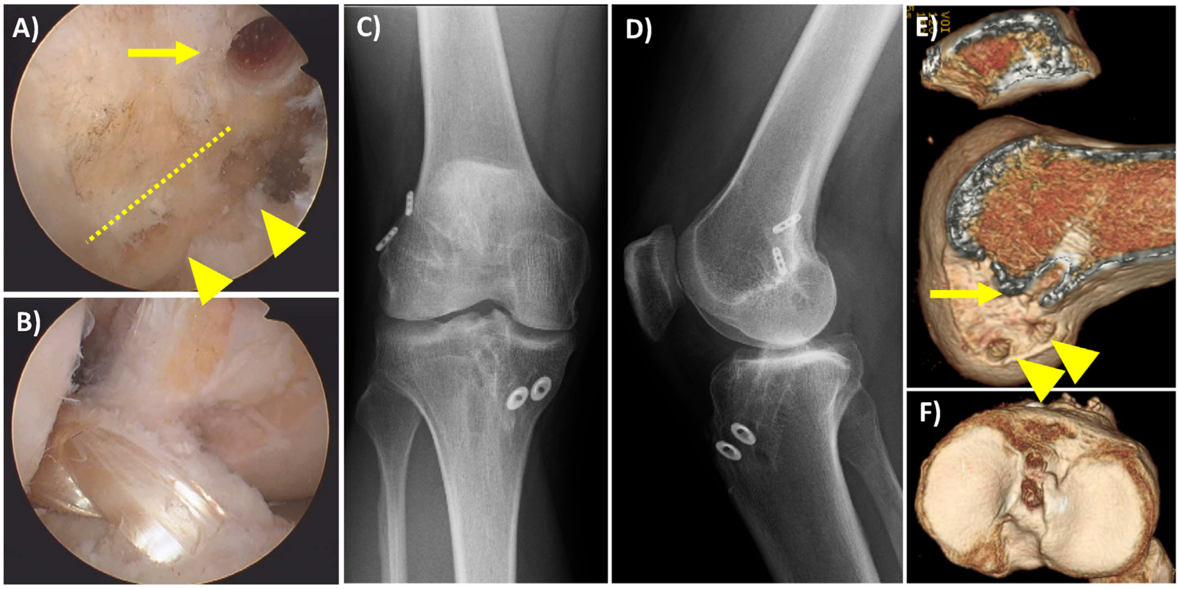

Fig. 2. Revision ACL reconstruction using a rectangular bone-patellar tendon-bone graft after hamstring tendon graft rupture. A) Arthroscopic findings of the primary surgery interference screw hole (Arrow) and femoral tunnel of revision surgery (arrowhead) created behind the Resident's ridge (dotted line). B) Arthroscopic findings of revision ACL reconstruction. C, D) Postoperative anteroposterior and lateral radiographs. E, F) Femoral tunnel and tibial tunnel positions in postoperative 3-dimensional computed tomography.

measurements, and a pivot shift test was graded based on the International Knee Documentation Committee (IKDC) objective score. Preoperative and postoperative activities were quantified using the Tegner activity scales, from 0 to 9 points. PROMs related to knee symptoms were evaluated using the Knee injury and Osteoarthritis Outcome Scale scores (KOOS), which consist of 42 knee-related items, with each item scored from 0 to 4.[14] There were 5 subscales, with 7 items in the symptoms subscale, 9 items in the pain subscale, 17 items in the activities of daily living (ADL) subscale, 5 items in the sports subscale, and 4 items in the quality of life (QOL) subscale. The summed scores of each subscale were converted to 100 points, where a score of 100 was considered as the best condition. KOOS results were evaluated on the injured knee without consideration of the contralateral knee. Muscle strength was assessed by measuring the knee extension or flexion torque using an isokinetic dynamometer (Cybex6000; Lumex, Inc) by physical therapists as previously described.[1] Isokinetic peak torque during concentric knee extension and flexion was measured at an angular velocity of 60 deg/s, and normalized peak torque of the reconstructed knee was calculated by dividing by the measurement value of the non-injured contralateral knee.

2.8. Statistical analyses

Continuous demographic variables are shown as mean ± standard deviation. Chi-square test for categorical variables and Mann–Whitney *U* test for continuous variables were performed to compare demographic data between the primary and revision groups. After dividing the overall patients into HT graft and BTB graft groups, the Mann–Whitney *U* test was performed to compare the KOOS subscales between primary surgery and revision surgery in each HT graft and BTB graft group. Furthermore, linear regression analysis was performed to determine the influence of revision surgery compared with primary surgery on KOOS. In the regression models, KOOS in both the HT graft and BTB graft groups was set as the dependent variable, respectively. Independent variables included age at the time of surgery, sex, body mass index (BMI), postoperative side-to-side difference of anterior laxity, postoperative pivot shift grade, knee extension and flexion strength, and revision surgery versus primary surgery. Data input and analyses were performed using SPSS version 25.0J (SPSS Inc., Chicago, IL, USA). A P value < 0.05 was considered statistically significant.

3. Results

A total of 194 patients underwent primary ACL reconstruction from January 2007 to December 2009, and 93 patients underwent revision ACL reconstruction from May 2007 to October 2016. After a minimum of 2 years of follow-up, according to the exclusion criteria, a total of 109 patients who had primary ACL reconstruction and 41 patients who had revision ACL reconstruction were enrolled for statistical analyses. In revision surgery, 23 of the 41 patients (56.0%) underwent primary ACL reconstruction in other hospitals, and then visited our institution for revision surgery.

3.1. Comparison of the clinical outcomes and KOOS between HT and BTB grafts in primary reconstruction

In the primary reconstruction group, HT graft was used for 57 patients and BTB graft for 52 patients. The average follow-up period was 3.9 years (Table 1). The side-to-side difference of anterior laxity in HT and BTB grafts were 0.35 ± 0.8 mm and 0.11 ± 0.7 mm, respectively ($p = 0.145$). Also, no patient exhibited a pivot shift grade of 2 or 3 in either group at final follow-up. Post-operative KOOS for HT graft in Pain, Symptoms, ADL, Sports, and QOL were 92.9, 90.9, 98.4, 91.8, and 83.1 respectively. Post-operative KOOS for BTB grafts were 93.4, 89.2, 98.7, 91.6, and 80.8 in Pain, Symptoms, ADL, Sports, and QOL, respectively. There was no significant difference in KOOS outcome between HT and BTB grafts in the primary reconstruction.

3.2. Comparison of the clinical outcomes and KOOS between HT and BTB grafts in revision reconstruction

In the revision surgery group, for patients who underwent primary ACL reconstruction with HT grafts, 17 ipsilateral BTB grafts were used, and for the four patients who did not want ipsilateral

Table 1
Demographic data of patients undergoing primary and revision anterior cruciate ligament reconstructions.

Demographic data	Primary	Revision
Number, n	109	41
Females n, (%)	60 (55.0)	26 (63.4)
Age at surgery (y.o.)	27.8 ± 13.1	26.1 ± 11.5
BMI (kg/m^2)	22.8 ± 3.3	23.3 ± 3.0
Graft for primary surgery (HT: BTB: AL) n	57 : 52: 0	21 : 18: 2
Graft for revision surgery (HT: BTB: AL) n	–	24 : 17: 0
Meniscus injury n, (%)	76 (69.7)	22 (53.7)
Medial meniscus injury, n (%)	45 (41.3%)	19 (46.3%)
Repair, n (%)	31 (68.9%)	15 (78.9%)
Partial meniscectomy, n (%)	6 (13.3%)	3 (15.8%)
Untreated, n (%)	8 (17.8%)	1 (5.3%)
Lateral meniscus injury, n (%)	56 (51.4%)	13 (31.7%)
Repair, n (%)	13 (23.2%)	7 (53.8%)
Partial meniscectomy, n (%)	18 (32.1%)	1 (7.7%)
Untreated, n (%)	25 (44.6%)	5 (38.5%)

Values are means ± standard deviation of the demographic data. Values in () indicate percentage in each group. Percentage of repair, partial meniscectomy, or untreated for medial and lateral meniscus injuries were calculated. Differences between primary and revision groups were compared by Mann-Whitney *U* test or chi-square test. A p value < 0.05 was considered statistically significant (*). HT: hamstring tendon graft; BTB: Bone-patellar tendon-bone graft; AL: Artificial ligament; BMI: body mass index.

Table 2
Comparison of postoperative status after revision surgery using hamstring tendon and bone-patellar tendon-bone autografts.

Clinical evaluation	Revision surery		
	HT	BTB	p-value
Side-to-side differences of anterior laxity (mm)	0.7 ± 1.0	0.9 ± 1.0	0.448
Tegner activity scales	5.6 ± 1.3	5.1 ± 2.1	1.000
Knee extension strength	0.9 ± 0.3	0.9 ± 0.2	0.859
Knee flexion strength	0.9 ± 0.2	1.0 ± 0.2	0.165

Values are means ± standard deviation of objective data after revision surgery. Differences between PRI and REV groups were compared by Mann-Whitney *U* test. A p value < 0.05 was considered statistically significant (*). HT: hamstring tendon graft; BTB: Bone-patellar tendon-bone graft.

BTB graft due to the anterior knee pain, contralateral HT grafts were used. For the remaining revision surgery patients who had undergone primary reconstruction using 18 BTB graft and two artificial ligaments, ipsilateral HT grafts were used. (Table 1). Duration from primary surgery to revision surgery was 96.9 ± 103.1 (6.3–372.0) months. There was no postoperative side-to-side difference of anterior laxity between HT and BTB grafts (p = 0.448) (Table 2), and no patient exhibited a pivot shift grade of 2 or 3 in either group. Regarding KOOS results, ADL for BTB graft was 99.0 ± 2.9, and significantly higher than 96.0 ± 6.0 of HT graft (p = 0.032), while there were no significant differences between KOOS Pain, Symptoms, Sports, and QOL when comparing between HT and BTB grafts in the revision surgery. Furthermore, there were no significant differences between Tegner activity score and postoperative muscular recoveries (Table 2).

3.3. Comparison of the clinical outcomes and KOOS between primary and revision surgeries

There were no significant differences in age, sex, or BMI between the primary and revision groups (Table 1). Postoperative side-to-side difference of anterior laxity was higher in the revision group than in the primary group (Table 3). Peak knee extension torque in the involved knee was 118.9 ± 43.1 Nm in the primary group and 120.1 ± 34.9 Nm in the revision group. Furthermore, peak flexion torque of knee extension in the involved knee was

Table 3
Comparison of objective scales and patient reported outcome measurement scales in primary and revision anterior cruciate ligament reconstructions.

Objective scales and KOOS		Primary	Revision	p-value
Post-operative Side-to-side differences of anterir laxity (mm)				
		0.2 ± 0.8	0.8 ± 1.0	0.001
Post-operative pivot shift test (%)				
	0	101 (91.7)	30 (73.2)	<0.001
	1	3 (2.9)	11 (26.8)	
	2	0 (0)	0	
	3	0 (0)	0	
Tegner activity scales				
	Pre op.	6.5 ± 1.6	6.4 ± 1.8	0.966
	Post op.	5.1 ± 2.2	5.4 ± 1.6	0.536
KOOS				
	Pain	93.1 ± 9.4	91.6 ± 10.2	0.297
	Symptom	90.1 ± 11.3	88.5 ± 11.7	0.364
	ADL	98.6 ± 3.4	97.2 ± 5.1	0.272
	Sports/recreation	91.7 ± 11.3	85.1 ± 16.8	0.026
	QOL	82.0 ± 17.3	76.7 ± 20.2	0.161
Relative strength against uninjured side				
	Knee extension	0.8 ± 0.2	0.9 ± 0.3	0.197
	Knee flexion	1.0 ± 0.2	1.0 ± 0.2	0.551

Values are means ± standard deviation of the demographic data. Values in () indicate percentage in each group. Differences between primary and revision groups were compared by Mann-Whitney *U* test or chi-square test. A p value < 0.05 was considered statistically significant (*). KOOS: Knee Injury and Osteoarthritis Outcome Score; ADL: activities of daily livings; and QOL: quality of life.

68.5 ± 25.6 Nm in the primary group and 64.8 ± 28.2 Nm in the revision group. Comparing KOOS between primary and revision surgery in all patients, sports results were significantly lower in the revision surgery than in the primary surgery ($p = 0.026$) group.

Furthermore, overall patients were divided into the HT and BTB graft groups to investigate the correlation between KOOS of primary and revision surgeries in each graft usage. In the HT graft group, KOOS Sports ($P = 0.008$) and QOL ($P = 0.039$) were significantly lower in revision surgery than in primary surgery (Fig. 3A). In contrast, postoperative KOOS results were not different in any subscale when BTB grafts were used for the revision surgery (Fig. 3B). Regression analysis showed related factors for decreased KOOS (Table 4). In the HT graft group, revision surgery using HT graft was correlated with lower KOOS Symptoms (p = 0.012) and Sports (p = 0.010), while side-to-side difference of anterior laxty was not associated with all KOOS subscales. Also, higher BMI was correlated with low scores for KOOS ADL ($P = 0.003$), Sports ($P = 0.001$), and QOL ($P = 0.003$). In the BTB graft group, revision surgery with BTB graft was not correlated with low scores for KOOS subscales, while low values of knee extension strength was correlated with low KOOS QOL.

4. Discussion

This study compared the clinical outcomes of primary and revision ACL reconstructions with HT or BTB grafts. Although the clinical outcomes of primary ACL reconstruction are excellent with modern procedures and techniques, a high frequency of graft rupture remains problematic; as many as 8% of patients undergoing ACL reconstruction will undergo a subsequent revision procedure.[15] Improving procedures and techniques along with appropriate graft choices are urgent issues for surgeons to consider. Our results may be helpful to guide graft choice in primary and revision ALC reconstructions.

This study revealed that, while there were no differences between the clinical outcome and KOOS in primary surgery, only ADL scores of BTB graft were higher than those of HT graft in revision surgery. Comparing between primary and revison surgery, both side-to-side differences of anterior laxity and KOOS for Sports

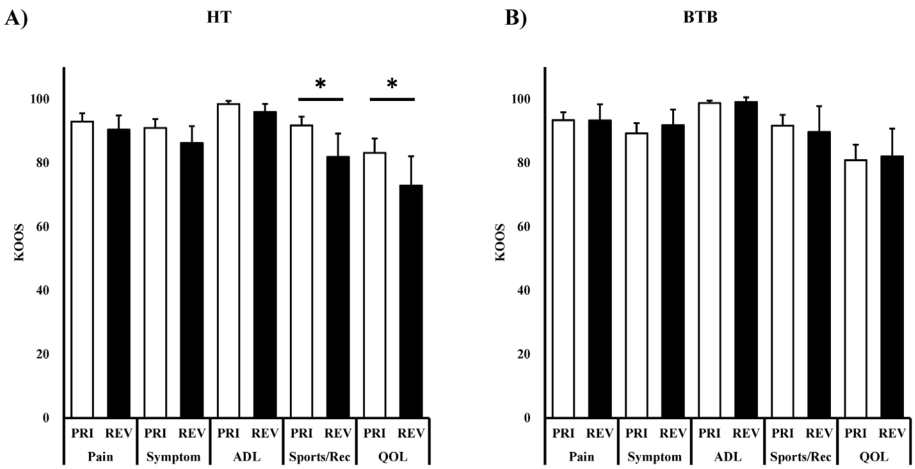

Fig. 3. Comparison of the knee injury and osteoarthritis outcome scores according to the graft selection. KOOS between primary (white bar) and revision (black bar) groups were compared by Mann-Whitney *U* test in bone-patellar tendon-bone graft and double bundle hamstring tendon reconstructions, respectively. Error bar indicates 95% confidence interval. A *P*-value <0.05 was considered statistically significant (*).

Table 4
Factors affecting KOOS subscales in hamstring tendon reconstruction and bone-patellar tendon-bone reconstructions.

KOOS subscales	Pain		Symptom		ADL		Sports/Recreation		QOL	
	B	p-value	B	p-value	B	p-value	B	p-value	B	p-value
HT										
Females	−2.62	0.441	−0.23	0.122	−0.26	0.073	−0.20	0.147	−0.18	0.172
Age at surgery	−0.12	0.281	−0.18	0.209	−0.16	0.242	−0.15	0.281	−0.21	0.115
BMI	−0.64	0.216	−0.14	0.368	**−0.47**	**0.003**	**−0.33**	**0.025**	**−0.44**	**0.003**
Postoperative side to side difference	−1.53	0.356	−0.12	0.408	−0.02	0.909	−0.01	0.930	−0.18	0.161
Postoperative pivot shift grade	0.54	0.902	0.17	0.262	0.12	0.416	−0.05	0.700	0.20	0.148
Knee extension strength	−2.06	0.751	0.17	0.215	−0.21	0.114	−0.08	0.549	−0.22	0.092
Knee flexion strength	−5.64	0.591	−0.02	0.870	0.11	0.409	0.05	0.665	−0.05	0.676
Revision against primary ACLR	−2.46	0.407	**−0.35**	**0.012**	−0.14	0.284	**−0.33**	**0.010**	−0.21	0.078
BTB										
Females	−2.71	0.255	**−0.30**	**0.024**	−0.16	0.255	−0.19	0.180	−0.17	0.209
Age at surgery	0.04	0.714	0.01	0.949	**−0.30**	**0.048**	−0.09	0.545	−0.11	0.452
BMI	−0.19	0.623	−0.04	0.750	−0.17	0.224	−0.14	0.331	−0.01	0.969
Postoperative side to side difference	−0.62	0.700	−0.08	0.613	−0.04	0.833	0.08	0.623	−0.17	0.294
Postoperative pivot shift grade	−0.15	0.978	0.02	0.871	0.02	0.886	−0.05	0.727	−0.04	0.796
Knee extension strength	12.03	0.070	0.25	0.091	0.12	0.454	0.25	0.116	**0.37**	**0.019**
Knee flexion strength	10.41	0.146	**0.33**	**0.019**	0.06	0.682	0.01	0.991	0.09	0.555
Revision against primary ACLR	−1.38	0.639	−0.01	0.924	−0.09	0.586	−0.23	0.176	−0.03	0.873

Dependent variables consisted of each Knee Injury and Osteoarthritis Outcome Score (KOOS) subscale (pain, symptoms, activities of daily living [ADL], sports, and quality of life [QOL]) after HT and BTB reconstruction, and independent variables were age at the time of surgery, sex, body mass index (BMI), postoperative side to side difference of anterior laxity, postoperative pivot shift grade, knee extension strength, flexion strength, and revision surgery against primary surgery in each technique. HT: hamstring tendon graft; BTB: Bone-patellar tendon-bone graft.

following revision ACL reconstruction were inferior to those following primary ACL reconstruction. Furthermore, revision ACL reconstruction using HT grafts were correlated with low scores in KOOS Symptoms and Sports, while there was no difference in anterior laxity between BTB and HT grafts in revision surgery. Revision ACL reconstruction with BTB grafts was not associated with low KOOS subscale scores.

4.1. Comparison of the clinical outcomes and KOOS between HT and BTB grafts in primary reconstruction

This study showed that there were no significant differences in clinical outcomes and KOOS between HT and BTB grafts. Similarly, several reports observed no difference between HT and BTB grafts in the clinical outcomes of primary ACL reconstruction using both subjective and objective scales.[1,16] One reason is related to the technical features of both procedures. Double bundle reconstruction using HT grafts has an advantage of restoring both the AM and PL bundle, which may improve knee kinematics, especially with rotatory loads. In contrast, while BTB graft is classified as a single graft reconstruction, rectangular tunnels make it possible to restore the anatomical structure of the AM and PL bundles, besides the advantage of bone-to-bone healing.[17] Shino et al. reported an anatomic rectangular-tunnel SB reconstruction technique with a patellar tendon graft that increases bone-to-bone contact area and mimics the arrangement of the native ACL.[13] Their colleagues suggested in a cadaveric study that this procedure restored near-normal knee biomechanics compared with round-tunnel ACL reconstruction.[18] In primary surgeries, the anatomical relationships between grafts and tunnels might be maintained, and the lack of bone defects related to previous tunnels and their enlargements might be beneficial to these results.

4.2. Comparison of outcomes between HT and BTB grafts in revision ACL reconstruction

In this study, there were no significant differences in clinical outcomes and KOOS subscales, besides KOOS for ADL. However, the KOOS ADL subscale was better in the BTB revision reconstruction group than in the HT group. It is difficult to determine the detailed mechanism of difference for the varying KOOS ADL scores between grafts used in revision surgery. One reason might be related to the presence of the bone plug in BTB grafts. Tunnel enlargement is a significant challenge in revision surgery, even if the size is not particularly large. Widening of the tunnel aperture can lead to loosening of graft fixation points. It is possible that the bony union of a BTB graft may reduce this problem. Moreover, Tomihara et al. reported that a two-stage surgery was not required in revision surgery with a BTB autograft after double bundle ACL reconstruction with an HT graft, and excellent clinical outcomes were obtained. This may be because the bone block of the BTB autograft secured the graft fixation in the bone tunnel during revision surgery.[19] These points might contribute to the functional difference in KOOS ADL scores between HT and BTB grafts in revision surgery.

4.3. Comparison of the clinical outcomes and KOOS between primary and revision surgeries

Comparing primary and revision surgeries, side-to-side differences were larger in revision surgeries than in primary surgeries. While a systematic review showed no difference in postoperative stability between primary and revision ACL reconstructions,[4] previous reports support our result that the patients who underwent revision ACL reconstruction had a higher anterior knee laxity than those with primary reconstruction.[20] Furthermore, postoperative KOOS for Sports after revision ACL reconstruction were lower than those following primary surgery. These results are supported by previous reports that revision ACL reconstruction is inferior to primary ACL reconstruction regarding postoperative instability, return to sports, and patient satisfaction.[5]

Furthermore, in this study, regression analysis with multiple confounders showed that low scores in KOOS Symptoms and Sports were related to revision surgery with HT graft compared to primary surgery with HT graft. These results indicate that the HT graft might be inferior to the BTB graft in revision ACL reconstruction. However, Ahn et al. suggested that revision ACL reconstruction could improve clinical and stability results, and the success of the operation did not depend on the choice of the graft material.[21] Other reports showed a return to sports ratio in soccer players of up to 63% after revision ACL reconstruction.[22] However, there are few reports comparing return to sports ratios between BTB and HT grafts in revision surgeries. Meta-analysis showed that revision ACL reconstruction using BTB autografts demonstrated higher overall return to sports rates when compared with HT autografts in primary surgery.[23] Given the current evidence, further observation and comparison of return to sports between BTB and HT grafts is necessary.

In other aspects, this study showed that PROMs were important in evaluating postoperative outcome, because the evaluation of multiple aspects could reveal differences between primary and revision surgery, or between HT and BTB grafts used in revision surgery. A systematic review on re-revision cases showed that, while graft re-rupture rate was below 5% over a 5-year period from revision ACL reconstruction, the overall failure rate increased when considering an objective clinical failure.[24] Mayr et al. reported that failure rate with symptoms, including continuous swelling or pain, increased to an average of 25% after revision surgery.[25] According to these results, PROMs could identify potential subjective failures, including pain, symptoms, or functionality, which indicates the importance of PROMs in evaluating postoperative patients who have undergone revision ACL reconstruction.

5. Limitations

There are several limitations in this study. First, we evaluated only KOOS as the PROMs. Although there are many scores such as the Short Form Survey 36, Euro QOL, and the Knee Society 2011 rating scale, we selected KOOS according to the recommendations of prior research.[26] Second, we could not conduct imaging analysis, including radiograph or MRI. The information regarding concomitant injury, degenerative change, and progression of osteoarthritis is very important when investigating patient satisfaction. Also, future long-term observational study is needed to detect osteoarthritic changes in imaging examinations after revision ACL reconstruction with the various autografts. Third, there was a risk for selection bias related to the duration of patient inclusion. Because the number of revision surgeries was very small compared to the primary surgery, inclusion duration was set at a longer point to balance the number for proper statistical analysis.

6. Conclusions

Although there were no significant differences in the KOOS subscales between HT and BTB grafts in primary surgery, the KOOS for ADL in BTB grafts was higher than that of HT grafts in revision surgery. The KOOS and side-to-side difference in anterior laxity following revision ACL reconstruction were inferior to those following primary ACL reconstruction. Among them, revision ACL reconstruction using HT grafts were correlated with low scores in KOOS Symptoms and Sports, while there was no difference in anterior laxity between BTB and HT grafts in revision surgery.

Ethics approval and consent to participate

The study was performed in agreement with the 1964 Helsinki Declaration and later amendments or comparable ethical standards. Approval was obtained from the ethics committee of the Hirosaki University Graduate School of Medicine. Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Availability of data and material

The study protocol, statistical analysis, and data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Declaration of competing interest

The authors declare that they have no competing interests.

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List of Abbreviations

ACL: anterior cruciate ligament
HT hamstring tendon
BTB bone-patellar tendon-bone
PROM patient reported outcome measurement
KOOS Knee injury osteoarthritis outcome score
MARS Multi-Center ACL Revision Study
ICRS International Cartilage Repair Society
AM anteromedial
PL: posterolateral
ADL activities of daily living
QOL: quality of life
BMI body mass index
SB-PT SB reconstruction using PT grafts
RTSB-PT rectangular-tunnel SB reconstruction technique with a PT graft
QT quadriceps tendon

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