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Research Article

The effects of remnant-preserving anterior cruciate ligament reconstruction on proprioception: A prospective comparative study

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ABSTRACT

Objective: The aim of this study was to investigate the effects of anterior cruciate ligament reconstruction performed by preserving remnant tissue on proprioception and to assess the effects it has on isokinetic quadriceps and hamstring muscle strength, as well as on range of motion and functional scores.

Methods: A prospective study was conducted with 44 patients who underwent either anterior cruciate ligament reconstruction with remnant preservation (study group, n = 22) or with remnant excision (control group, n = 22) with the use of a 4-strand hamstring allograft. The mean follow-up time was 20.2 ± 1.4 months after surgery. Using an isokinetic dynamometer, proprioception was evaluated with passive joint position perception at 150, 450, and 600, and quadriceps femoris, and hamstring muscle strength were evaluated at speeds of 900, 1800, and 2400 per second. Range of motion was measured using a goniometer. Functional outcomes were assessed using International Knee Documentation Committee subjective knee evaluation score and Lysholm knee scoring questionnaires.

Results: It was only at 15° of knee flexion that there was a statistically significant difference in proprioception; the median of the difference in the amount of deviation from the target angle between the healthy knee and the operated side was 1.7 (range, 0.7-20.7) in those with remnant preserved, and 2.7 (range, 1-26) in those with remnant excised ($P = .016$). At 2400/s speed, the mean quadriceps femoris strength was 77.2 ± 24.3 Nm in those with remnant preserved and 67.6 ± 24.2 Nm in those with remnant excised. ($P = .048$) There was no difference between the 2 groups in terms of range of motion, International Knee Documentation Committee, and Lysholm knee scoring. ($P > .05$)

Conclusion: The present study has demonstrated that better proprioception and higher quadriceps femoris muscle strength can be obtained by remnant-preserving anatomical single-bundle anterior cruciate ligament reconstruction using a hamstring autograft.

Level of Evidence: Level II, Therapeutic study.

Introduction

Although anterior cruciate ligament reconstruction (ACL-R) is a general procedure, reduced functional recovery, poor results in the long-term follow-up, and re-injury rates are substantial despite various surgical techniques and graft options improving over time.[1,2] Even provided with optimum mechanical stability, it is hypothesized that decreased proprioception may be one of the reasons responsible for poor functional recovery.[3,4] In order to reduce the loss of proprioception, the technique of preserving the remnant tissue of the anterior cruciate ligament (ACL) during ACL-R, whose presence of mechanoreceptors has been evidenced by previous histopathological studies, has been defined and become widespread.[5,6]

A plethora of studies have investigated the effect of this increasingly widespread technique on many parameters such as graft revascularization and ligamentization, anterior stability, tibial tunnel enlargement, and clinical functional results.[7-10] However, there is only a limited number of clinical studies examining its effect on proprioception in particular. Besides, mixed results have been reported in these studies. For instance, Lee et al[11] carried out a study that divided 48 patients into 2 groups with a follow-up period consisting of at least 24 months; they reported that better proprioception and functional results were obtained with ACL-R performed by preserving remnant tissue and that postoperative patient satisfaction could be higher with this method. Liu et al.[12] in another retrospective study, separated 46 patients into 2 groups according to the amount of remnant tissue preservation and argued that proprioception sense during the postoperative 3rd and 6th month and activity level in the postoperative 12th month were higher in the patient group with more remnant tissue preserved.[12] Although there are studies proving the positive effect of the remnant-preserving technique on proprioception in general, Hong et al[13] alleged that the remnant-preserving technique had similar proprioceptive results with the standard technique in their prospective study in which they followed 80 patients for at least 2 years postoperatively.[13]

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Therefore, the present study aims to (i) investigate the effect of ACL-R performed by preserving remnant tissue on proprioception, (ii) examine whether there is any difference between the 2 groups in terms of isokinetic quadriceps and hamstring muscle strength as well as range of motion (ROM), International Knee Documentation Committee (IKDC), and Lysholm knee scores (LNS). Our hypothesis is that better proprioception will be obtained in the remnant tissue preserved group.

HIGHLIGHTS

- Decreased proprioception may be one of the reasons responsible for poor functional recovery following anterior cruciate ligament reconstruction. This study aimed to investigate the effect of ACL-R performed by preserving remnant tissue on proprioception, and whether there is any difference between the 2 groups in terms of functional outcomes.
- Results showed that when the deviation of the same patients' intact and operated knee was considered, a significantly less difference in those whose remnant was preserved at 15° flexion was seen compared to those whose remnant was excised. Additionally, the mean quadriceps femoris strength was significantly higher in remnant-preserved patients however, there were no differences in functional scores.
- The results from this study indicate that better proprioception and higher quadriceps femoris muscle strength may be obtained with remnant-preserving anatomical single-bundle anterior cruciate ligament reconstruction using a hamstring autograft.

Materials and Methods

This is a prospective study which compares patients, whose remnant tissue was either preserved or excised during ACL-R, proprioception, isokinetic quadriceps-hamstring performance ROM, IKDC, and LNS. This study is derived from a thesis study. The study was deemed ethically appropriate by Ethics Committee of Health Science University (SBÜ) Ankara Numune Training and Research Hospital (Approval No: 1575/2017, Date: November 8, 2017). Verbal informed consent was obtained from the patients who agreed to take part in the study.

Patients

A total of 81 patients underwent ACL reconstruction surgery from December 2017 to April 2019. There were 3 inclusion criteria for this study: (i) being between the ages of 18 and 50, (ii) being operated within a maximum of 2 months after trauma, (iii) having a similar range of motion as the intact side before the operation. Thus, 14 patients were excluded from the study because they did not meet the inclusion criteria. Patients who have limb malalignment, neurological disease (such as cerebrovascular incident, multiple sclerosis, polio, cerebral palsy), vascular pathology (such as deep vein thrombosis, arterial occlusion, aneurysm), multiple ligament damage (additional posterior cruciate ligament (PCL), medial collateral, lateral collateral ligament injury), meniscus, and cartilage damage requiring

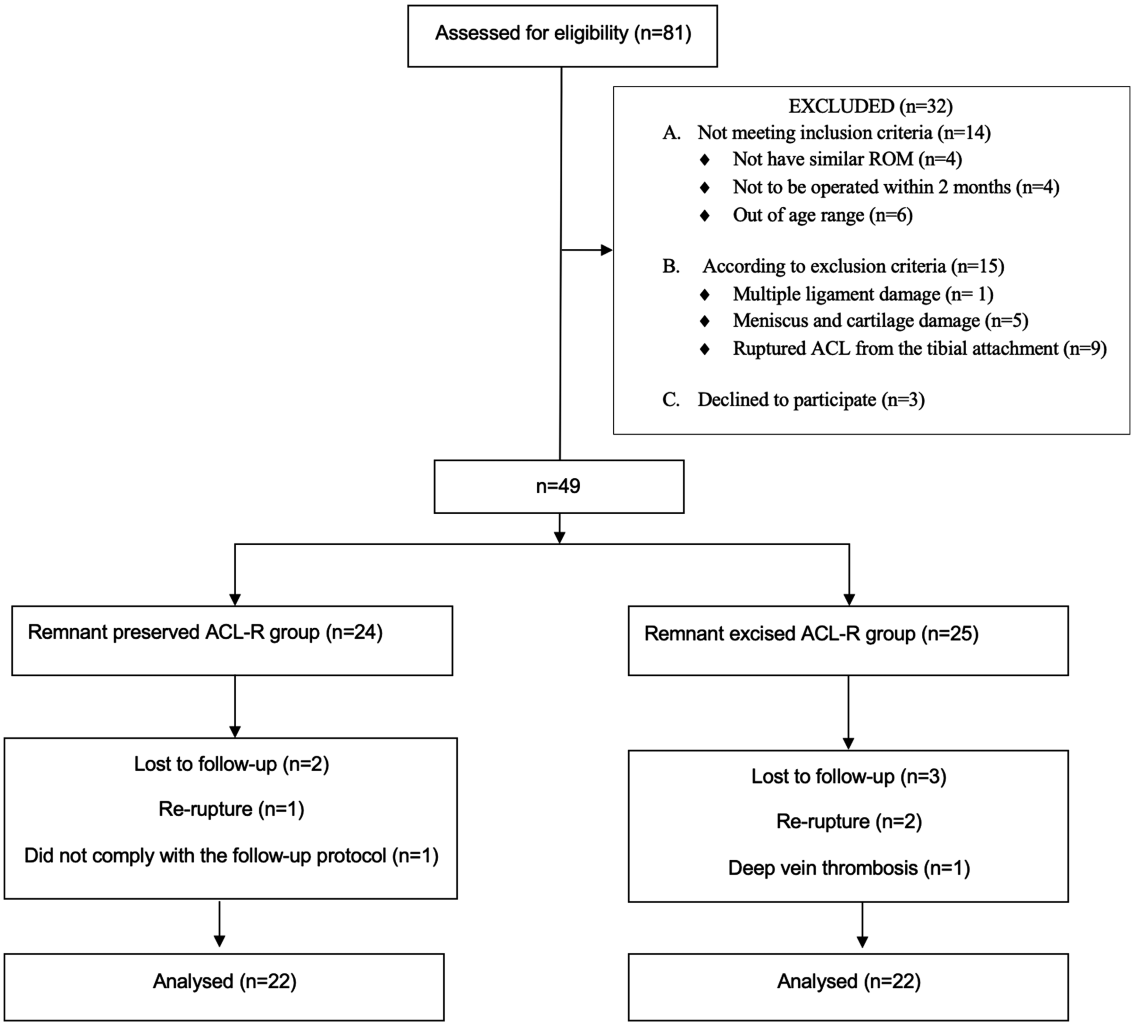


Figure 1. CONSORT flowchart of this trial.

treatment and ruptured ACL from the tibial attachment site were excluded from the study. Therefore, 15 patients were excluded from the study according to the exclusion criteria. Three patients who did not want to participate in the study were further excluded. In addition, in the follow-up process, patients who developed major complications (such as re-injury and deep vein thrombus) in the early or late period were also excluded. Considering these conditions, 44 patients were included in the study. The grouping illustration is given in the Consort flow diagram (Figure 1).

All patients received physical therapy for 3 weeks before the surgery. Then, operations were performed at the earliest appropriate date (within 2 months at most after the injury). Participants were assigned to the groups without randomization, and while 22 (50%) patients' remnants were preserved, 22 (50%) patients' remnants were excised.

Surgical procedure and postoperative rehabilitation

After administration of prophylactic antibiotics and spinal anesthesia, Lachman, anterior drawer, and pivot shift were tested under supine position. Surgery was initiated with standard diagnostic arthroscopy accompanied by a tourniquet. It was observed in all patients that the ACL had a complete rupture from the femoral attachment site. Then hamstring autograft was taken and folded onto itself to make it quadrupled. If the tibial remnant was going to be excised, it would be completely removed (Figure 2), and if not, it would be preserved as much as possible (Figure 3). With the quadrupled hamstring autograft, the anatomical single bundle ACL-R was applied by opening the bone tunnels in the natural footprint center as previously described.[14,15] During this procedure, the operator concentrated on minimizing the injury of the remnant. Femoral graft fixation was performed with the endobutton system (Endobutton CL Ultra; Smith & Nephew) at maximum flexion, and tibial graft fixation was performed with a bioresorbable interference screw (Biosure PK; Smith & Nephew) and U staple (Smith & Nephew) at 20°-30° of flexion. It was observed that Lachman, anterior drawer, and pivot shift tests became negative under anesthesia after the surgery. All surgical procedures and examinations were performed by a single surgeon experienced in ACL-R.

Physical therapy for ROM, muscle control, pain, and edema management was applied during hospitalization. Active flexion and passive extension exercises were performed with the help of an angle-adjusting knee brace that could be released up to 90° for 4 weeks. Mobilization was allowed during the first 4 weeks with double crutches by locking the knee brace in full extension. Then, the patients were allowed to walk with a single crutch, and they left using the crutch 6 weeks later. In the following period, standard physical therapy protocols were applied to all patients by the same physiotherapy team.[16] Open and closed chain strengthening exercises and proprioception and endurance exercise programs were performed. Once the patients completed the first step, then they were allowed to move on to the next step. Suggestions and home exercises were offered to the patients who received physical therapy for at least 12 weeks and completed their protocols. All the patients were evaluated by a team consisting of both orthopedics and physical therapist every 6 weeks. During the 18th month of the postoperative controls, patients' proprioception, isokinetic muscle strength, ROM, IKDC, and LNS were examined and recorded.



Figure 2. Intraoperative view of remnant-excised anterior cruciate ligament reconstruction. Red arrow: Hamstring autograft.

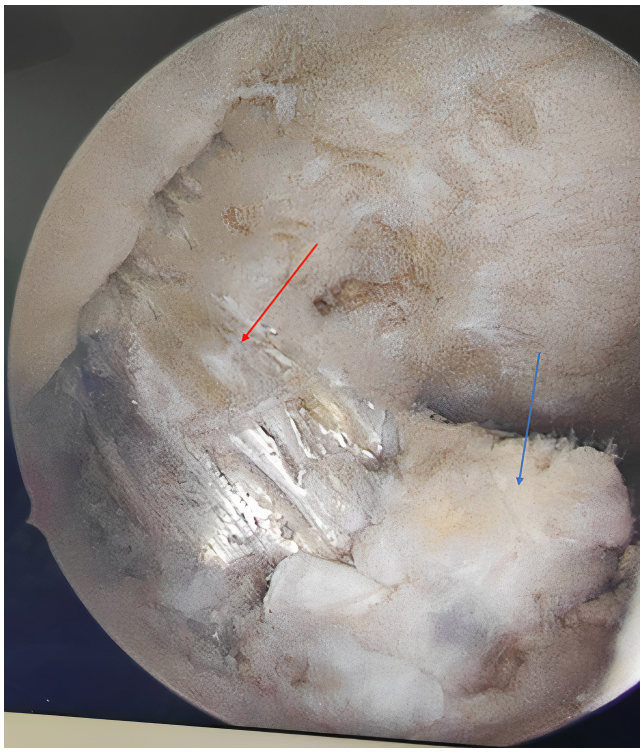


Figure 3. Intraoperative view of remnant-preserving anterior cruciate ligament reconstruction. Red arrow: Hamstring autograft, Blue arrow: Tibial remnant tissue.

Proprioception evaluation

Proprioception was assessed by joint position perception using an isokinetic dynamometer (Biodex Corp., Shirley, NY, USA) for both knees. Participants were seated vertically on the device seat with their hips and knees at 90°; thigh, body, and pelvis were fixed to the seat by means of straps. The force arm and patient position were adjusted so that the rotation axis could be just lateral to the lateral femoral condyle. The distal edge of the pad covering the leg was fixed tightly on the leg just above the lateral malleolus. During the tests, participants were blindfolded to disable visual cues. Headphones were not plugged in as communication with the operator was required (Figure 4). The dynamometer, whose movement speed was set to 2°/s, passively moved each participant's knee to the predetermined reference positions of 15°-45° and 60°. Each participant was allowed to stay at the reference angle for 10 seconds. After neutralization, the knee was passively moved again, and the participants were



Figure 4. Patient positioning in the isokinetic dynamometer during the proprioception and muscle strength measurements.

asked to press the button in their hands when they felt it reached the target point. The difference in degree between the participant's sensation and the positions determined as a reference point was measured as an error score. The measurements were repeated 3 times for each reference angle and the error scores were averaged. The mean proprioceptive error was recorded as an absolute value regardless of whether this value was positive or negative. A 3-minute resting period was allowed between different reference angles.

Isokinetic muscle strength evaluation

Software-supported isokinetic test and exercise system (Biodex System 3 Pro) were used for isokinetic muscle strength measurement. Participants were positioned similarly to the proprioception assessment. The device was adjusted to the speeds of 90°-180°-240°/s respectively, and quadriceps femoris (QF) and hamstring peak torque were measured for both sides at each speed. The measurements were repeated 3 times for each reference speed, and the scores were averaged.

Range of motion evaluation

Bilateral knee ROM was measured with the contralateral hip and knee joints in full extension and without pelvic movement. Measurements were run 3 times based on the landmarks recommended by the American Academy of Orthopedic Surgeons with a universal goniometer with an arm of 26 cm, and their averages were recorded.[17]

Subjective scores evaluation

The IKDC subjective knee evaluation score and LNS were evaluated in the 18 months postoperatively.[18,19] Validated versions of these scores into our native language were available in the literature and used accordingly.[20,21]

Statistical analysis

Statistical analysis was performed using Statistical Package for the Social Sciences software (version 23, IBM). The compliance of the variables to normal distribution was examined by visual (histogram and probability charts) and analytical methods (Shapiro–Wilk test). Descriptive analyses were provided by using mean and standard deviations for normally distributed variables and median and range for non-normally distributed variables (using frequency tables for ordinal variables). Group comparisons of variables with normal distribution were made using Student's *t* test, and group comparisons of non-normally distributed variables were made using Mann–Whitney U and Wilcoxon sign tests. The situations where the *P* value was below .05 were interpreted as statistically significant. The power of the study was found using the G power 3.1.9.7 program. The sample size was determined as 44 to determine the difference between any variable with an 80% confidence interval and a 5% margin of error.

Results

Patient demographics

Among the 44 patients included in the study, 36 (81.8%) were male and 8 (18.2%) were female. The mean follow-up period was 20.2 ± 1.4 months. The detailed distribution of the patients' demographic data is presented in Table 1.

Proprioception outcome

When proprioception was examined only for the operated sides, and no significant difference was observed between the amount of deviation from the target angle in knees with remnant preserved and excised ($P > .05$) (Table 2). However, when the difference between the deviation of the same patients' intact and operated knee was considered, it was found that there was a significantly less difference in those whose remnant was preserved at 15° flexion compared to those whose remnant was excised ($P = .016$) (Table 3).

Isokinetic muscle strength outcome

In terms of QF and hamstring peak torque values, no significant difference was found between the remnant preserved and excised groups

Table 1. Distribution of demographic data

		Remnant preserved (n: 22)	Remnant excised (n: 22)	*P*
Gender	Male	18 (40.9%)	18 (40.9%)	>.05
	Female	4(9.1%)	4(9.1%)	
Age (years)		29 (range: 24-42)	29 (Range: 18-48)	.805
BMI (kg/m²)		26.48 ± 2.5 SD	28.28 ± 2.9 SD	.216
Effected side	Dominant	15 (34.1)	12 (27.3%)	.069
	Nondominant	7 (15.9%)	10 (22.7%)	
Trauma etiology	Sports injury	19 (43.2%)	16 (36.4%)	1.571
	Non-sports injury	3 (6.8%)	6 (13.6%)	
Trauma Mechanism	Contact	6 (13.6%)	4 (9.1%)	.863
	Non-contact	16 (3.4%)	18 (40.9%)	
Time to surgery (day)		46.59 ± 4.19 SD	48.73 ± 4.28 SD	>.05

BMI, body mass index; n, sample size, SD, standard deviation.

Table 2. Comparison of proprioception of operated knees

	Joint position	Remnant	N	Min.	Max.	Median	Interquartile range	*P*
Absolute difference from target joint position (degree)	15° flexion	Preserved	22	1	28.3	2.5	4.6	.223
		Excised	22	0.3	45.7	1.85	2.5	
	45° flexion	Preserved	22	1	27.7	5.85	4.5	.906
		Excised	22	1.3	31	5	5.2	
	60° flexion	Preserved	22	1.3	24.7	6	5.6	.346
		Excised	22	1.7	21.3	5.35	6.1	

Max, maximum; Min, minimum; n, sample size; *P*, statistical significance value.

Table 3. Comparison of the difference in deviation between the intact and operated knees of the same patient for those with remnant preserved and excised groups

	Joint Position	Remnant	n	Min.	Max.	Median	Interquartile range	*P*
Absolute difference between operated and intact side deviation (°)	15° flexion	Preserved	22	0.7	20.7	1.7	1.6	.016
		Excised	22	1	26	2.7	5.6	
	45° flexion	Preserved	22	1.7	8.7	3.65	3.3	.079
		Excised	22	1	6.3	2.85	2.6	
	60° flexion	Preserved	22	1.7	17.3	5.2	5.1	.179
		Excised	22	1.7	9.3	3.8	2.9	

Max, maximum; Min, minimum, n, sample size; *P*, statistical significance value.

Table 4. Comparison of operated side QF and hamstring muscle strengths for remnant preserved and excised groups

Operated side peak torque (Nm)	Speed	Remnant	n	Mean	SD	Min.	Max.	*P*
QF	90°/s	Preserved	22	113.8	42.9	54.3	191.7	.503
		Excised	22	102.8	39.7	26.9	177.3	
	180°/s	Preserved	22	88.1	31.7	46.6	143.8	.162
		Excised	22	77.2	31.4	30.1	142	
	240°/s	Preserved	22	77.2	24.3	36.9	132.5	.048
		Excised	22	67.6	24.2	35.7	132.5	
Hamstring	90°/s	Preserved	22	61.2	25.5	29.1	107.9	.145
		Excised	22	50.7	21.7	22.7	108.4	
	180°/s	Preserved	22	49.8	12.5	2.2	70.6	.070
		Excised	22	43.6	9.5	26.9	63.5	
	240°/sec	Preserved	22	50.1	14.7	17	77.9	.290
		Excised	22	46.4	9.7	36.6	77.9	

Max, maximum; Min, minimum, n, sample size; Nm, Newton-meter; *P*, statistical significance value; QF, quadriceps femoris.

at 90°/s and 180°/s speeds ($P > .05$); QF peak torque was higher in the remnant preserved group at only 240°/s. ($P = .048$) (Table 4).

Range of motion outcome

There was no difference between the groups in which remnant was preserved or excised in terms of flexion and extension degrees ($P = 0.920$, $P = .620$, respectively) (Table 5).

Subjective scores outcome

The median of the IKDC knee evaluation score was 89.7 in those with remnant preserved and 89.1 in those with remnant excised, and there was no relationship between remnant preservation and IKDC knee score ($P = .541$). The LNS was found poor in 3 (6.8%) patients, fair in 11 (25%), good in 20 (45.5%), and excellent in 10 (22.7%) patients. Moreover, there was no significant difference between those with remnant preserved or excised ($P = .532$) (Table 6).

Discussion

In the literature, there is an array of studies investigating the effect of remnant-preserving ACL-R on proprioception. However, in these studies, only the operated sides of different patients were compared.[13,22,23] In our study, proprioception evaluation was carried out not only between the operated sides but also considering the difference between the operated and intact side of the same patient in order to minimize individual sensorimotor differences. The highlight of our study similar to our hypothesis was that the patients who had remnant preserved ACL-R had higher sense of proprioception ($P = .016$). Furthermore, QF muscle strength was also found higher in the remnant preserved group ($P = .048$). There was no significant difference between 2 groups regarding ROM, IKDC, and LNS ($P > .05$).

Table 5. ROM evaluation

ROM	Remnant	n	Mean	SD	Min.	Max.	*P*
Operated side knee flexion angle (degree)	Preserved	22	116.2	8.8	94.1	130.5	.920
	Excised	22	117.3	7.1	110	134	
Operated side knee extension angle (degree)	Preserved	22	2.1	2.3	−3	9	.620
	Excised	22	1.8	2.3	−3.4	8.7	

Max, maximum; Min, minimum, n, sample size; *P*, statistical significance value; ROM, range of motion; SD, standard deviation.

Table 6. Evaluation of clinical subjective functional scores

	Remnant	N	Min.	Max.	Median	Interquartile range	*P*
IKDC knee evaluation score	Preserved	22	71.3	98.9	89.7	6.9	.541
	Excised	22	58.6	97.7	89.1	18.7	
LNS	Preserved	22	69	100	87	20	.532
	Excised	22	52	99	89	20	

IKDC, International Knee Documentation Committee; LNS, Lysholm knee scoring; Min, minimum; Max, maximum; n, sample size; *P*, statistical significance value.

Remnant-preserving ACL-R recently has received attention by focusing on the existence of mechanoreceptors in the ACL remnant that contributes to the proprioceptive function of the ACL. Lee et al[24] found similar neural cells in normal ACL tissue and remnant tissue in the quantitative test in their immunohistochemical studies on rats. They alleged that these results indirectly showed that remnant protective ACL-R could better protect proprioception and might be a source for reinnervation in allografts.[24] Histochemical studies paved the way for clinical studies. Chen et al[25] divided 30 patients with ACL-R into 2 groups as those with remnant preserved or excised and evaluated proprioception during 3-6 and 12-month follow-ups with joint position perception. Accordingly, they noted that better proprioception was obtained in the group with remnant preserved at 0°-30° and 45° knee flexion.[25] Likewise, Andonovski et al[26] found that 6 months after ACL-R, the sense of proprioception evaluated by any degrees between 0° and 90° was higher in the remnant preserved group. As a result, it is a predictable outcome that the remnant, which has been shown to maintain mechanoreceptors, will have a positive effect on proprioception.[26] Nevertheless, it should also be taken into consideration that the clinical reflection may not be the same in every patient. A study carried out by Hong et al[13], in which a follow-up period spanned more than 2 years showed that the remnant preserved ACL-R and standard ACL-R both had similar proprioception at 15° of flexion. The 2 main parameters for this phenomenon are the factors related to the remnant and patients that cannot be standardized. Georgoulis et al[27] examined remnants during ruptured ACL-R from 3 months to 3.5 years after the injury and discovered 2 different types of specimens: One with a remnant adapted to PCL and one with a free mushroom-like remnant.[27] As a result of histopathological examination, more mechanoreceptors were observed in the remnants readapted to PCL, while less mechanoreceptors were observed in the mushroom-like remnants. This study shows that different types of remnants have diverse effects on proprioception. Liu Y et al[12] divided 46 patients who underwent ACL-R into 2 groups in which more than 1/3 of the remnant tissue and less than 1/3 were preserved and evaluated proprioception with joint position perception. They stated that in the group, in which more than 1/3 of the remnant tissue was preserved, proprioception was better at 15° of knee flexion in the postoperative 3rd and 6th months. Cabuk et al[28] investigated the number and type of mechanoreceptors in the remnant by employing 48 patients and examining, 20 knees of 10 cadavers and they reported that delay in the time from the injury to the surgery would cause a decrease in the number of mechanoreceptors.[28] In conclusion, the amount and distribution of mechanoreceptors on the remnant are affected by several parameters including type, volume, and the time transpired after injury. Therefore, the sense of proprioception may

be different in each case. In addition to the differences of remnant, variety in each individual's sensory perception may also affect the evaluation of proprioception. Thus, we suggest that proprioception should be evaluated based on not only the difference between the operated sides of different patients but also the difference between the operated and intact sides of the same patient.

In addition, in our study, 3 different angles of 15°, 45°, and 60° were evaluated in order to minimize the random correlations, and proprioception was found to be significantly higher in those whose remnant tissue was preserved only at 15° similar to Lee BI et al[22] and Adachi N et al[23]. Likewise, in the study of Yiu et al.[12] the difference between the 2 groups was maximum 15°. The underlying factor may be the adaptation of different mechanoreceptors to the different angles. Golgi tendon organ and Ruffini body, which make up the majority of mechanoreceptors in remnant, adapt slowly and are mostly involved in the perception of static joint position.[29] In addition, the remnant is exposed to more tensile force at the beginning of the movement, and more input reaches the central nervous system.[30]

Residual muscular deficit after ACL-R may cause disruptions in knee biomechanics, knee pain, increased risk of osteoarthritis, and re-injuries.[31] Even if optimal mechanical stability is provided, depending on several factors such as muscle atrophy, graft type, donor site recovery, age, gender, and postoperative rehabilitation, postoperative QF and hamstring forces might generally be below 90% within the first 6 months.[32-35] Muscle strength is strongly associated with return to functional activity. Thus, the remnant effect is also investigated for faster and advanced muscular recovery.[36] In their study, Naraoka et al[37] found that Hamstring index was similar in remnant preserved and excised groups while the QF index was found to be lower in the remnant preserved group by measuring only at a speed of 60°/s.[37] They put forward that the reason behind this finding might be the higher average age of the remnant preserved group. Muneta et al.'s study investigating the effect of remnant volume on many parameters revealed that QF and hamstring indices at a speed of 60°/s were similar in all the groups in which the remnant was strongly, moderately, and poorly protected.[38] Although QF and hamstring force were relatively higher at all speeds in remnant preserved ones, QF peak torque value was found to be significantly higher only at 240°/s ($P=.048$). Jerosch and Prymka[39] reported that postural balance could be achieved with the activation of the muscles around the joint in response to the joint position perception. The ability of mechanoreceptors in the remnant, especially the Golgi-like receptors to adapt to different amounts depending on the speed and amount of movement, to create afferent messages, and to activate the central regulatory system that affects muscle strength may explain this situation. Mechanoreceptors also provide afferent arc to report postural changes of the knee with proprioceptive function. This arc affects the motor activity of the muscles around the knee, and a phenomenon called ACL reflex occurs. The ACL reflex is very important in normal knee function, QF muscle activation, and joint position perception.[40] Because of the protected mechanoreceptors, this arc, which is realized through the central nervous system, will bring along increased muscle activity.[41] Although the measurements were made 3 times and averaged, the patients' compliance with different angular velocities, and therefore the possibility of varying amounts of muscle contraction may also be the reason for the significant or insignificant associations in these nonspecific angular values. After all, such decreased proprioception can adversely affect the dynamic stability of the knee, strength, and balance as stated Cho et al.[42] because, a knee with better proprioception is expected to better adapt to physical therapy modalities and muscle strengthening.

The ROM limitation can be seen at varying rates after ACL-R. Although this condition is generally thought to be secondary to preoperative ROM limitation and early surgical treatment, cyclops lesion may be the underlying cause, especially in patients with terminal extension limitation.[2,43] It was previously thought that remnant was associated with ROM limitation by causing cyclops lesion, but recent meta-analyses revealed that remnant did not increase the risk of cyclops lesion.[44,45] Webster et al[45] divided 658 patients into 3 groups in which remnant was excised, less than 50% of the remnant tissue was preserved, and more than 50% of the remnant tissue was preserved, and they found no difference between the groups in terms of extension and flexion deficit.[45] Likewise, Wang et al[46] divided 204 patients, who were treated with ACL-R, into 3 groups in which they completely excised the remnant, preserved only the remnant root, and preserved the entire remnant. The findings indicated no significant difference between the groups in terms of ROM values measured in the postoperative 24th month.[46] In our study, similar to the literature, no difference was found between the ROM of remnant preserved and excised groups. As a result, although the remnant tissue is an extra soft tissue in the knee joint, it is an expected result that it does not cause a limitation in the range of motion unless it causes a symptomatic cyclops lesion.

In our study, no correlation was found between remnant preservation and IKDC knee score and LNS ($P=.541$, $P=.532$, respectively). Similarly, Hong et al[13] did not observe a significant difference in IKDC and LKS between remnant preserved and excised ACL-R in their comparative prospective study carried out with 70 patients. Iwaasa et al[47] claimed that remnant tissue preservation had no effect on the LNS, Tegner activity scale, and IKDC subjective score in their study in which they divided 105 patients treated with ACL-R into 3 groups.[47] We argue that remnant has a positive effect on graft revascularization, ligamentization, and regeneration. Therefore, we foresee that graft healing will bring along functional recovery, but it may take a while for this effect to reflect on clinical functional tests.

This study has several limitations. The first one of them is the inability to standardize the remnant volume and type in the remnant preserved group. The type and volume of remnant can affect the mechanoreceptor number, distribution, and activation. Second, participants are not randomly distributed into the groups, especially in terms of demographic characteristics. In particular, the number of mechanoreceptors is affected by age. It should be kept in mind that this may affect the results. Third, the activity levels of the participants included in the study were not taken into consideration.

While an anatomical single-bundle ACL-R was performed with the hamstring autograft, a higher sense of proprioception and QF strength was obtained by preserving the remnant. In so doing, knee joint movement and sensory function can be better. Thanks to a more proprioceptive remnant-preserving technique, gait abnormalities, recurrent injuries, and early osteoarthritis can be prevented.

Ethics Committee Approval: This study was approved by Ethics Committee of Health Science University (SBÜ) Ankara Numune Training and Research Hospital (Approval No: 1575/2017, Date: November 8, 2017).

Informed Consent: Verbal informed consent was obtained from the patients who agreed to take part in the study.

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