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Proprioception analysis of patients with anterior cruciate ligament reconstruction

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ABSTRACT

Objectives: This study evaluates the effect of tibial stump mechanoreceptor preservation on proprioception, muscle strength, recovery and functional outcomes after arthroscopic anterior cruciate ligament surgery (ACLS).

Methods: Patients undergoing ACLS between January-July 2019 were evaluated by a single surgeon. The HUMAC NORM 2 device measured patients' proprioceptive sensation and muscle strength before and after surgery; KOOS and Oxford scales were used to score patients' functional results. The patients were divided into two groups: those who underwent stump-preserving surgery (SP group) and those who underwent conventional surgery (C group).

Results: Our study evaluated 27 patients, 11 in the SP and 16 in the C groups. The two groups had no statistical difference in muscle strength, proprioception, and functional scores in the first and third postoperative months. In the sixth-month evaluation, significantly better functional scores were found in the C group. Further, the athletic function was better in patients with good proprioception recovery, regardless of the group comparison.

Conclusions: Preserving the stump and mechanoreceptors on the tibial face was not determined to provide additional benefit to the patients in the first six months after surgery. Returning to sports was faster and functional scores were better in patients with good proprioception recovery.

Keywords: Anterior cruciate ligament tear, arthroscopic anterior cruciate ligament surgery, tibial remnant

The number of people engaged in recreational activities is increasing day by day. Anterior cruciate ligament (ACL) injury is most commonly seen during athletic activity after the injury to the menisci. The ACL is an essential structure in knee kinematics, and ACL injuries significantly impair pivot movements [1].

Arthroscopic anterior cruciate ligament surgery (ACLS) is one of the most common surgical procedures performed by orthopedic surgeons. Various surgical techniques (single, double bundle, transtibial, all-inside, etc.) have been devised to achieve improved mechanical stability, and studies of ideal reconstruction are ongoing. Recent studies focus on proprioception preservation, graft recovery, and mechanical

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stabilization [2, 3]. Animal studies have demonstrated that preserving mechanoreceptors [4] in the femoral and tibial stump region positively affects graft healing [5]. However, these studies have yet to offer definitive evidence that the stump preservation technique is superior to the standard (conventional) technique.

Stump-preserving ACL reconstruction may positively affect functional outcomes by contributing to proprioceptive recovery. Our study aims to investigate the effect of stump preservation during ACL surgery on postoperative muscle strength and proprioception recovery.

METHODS

Patients

Our study was planned as a prospective observational study, approved by the institutional review board, and performed according to the ethical standards outlined in the Declaration of Helsinki. All patients provided written informed consent before participating in the study. Twenty-seven patients who underwent ACLS between January and July 2019 and had a minimum 6-month clinical follow-up were included in the study; The same surgeon operated on all patients. The following were the criteria for inclusion in the study:

(a) Isolated ACL rupture according to clinical and radiologic findings with no additional knee lesion requiring surgical treatment,

(b) Closed physis lines,

(c) High demand and activity level, and

(d) Stage 0 or 1 knees, according to Kellgren and Lawrence (K-L) osteoarthritis radiologic staging.

The patients were separated into stump-preserving and conventional groups (Table 1). If the patients had a stump long enough to reach the lateral wall of the femur, stump-preserving surgery was performed. If the stump length was insufficient, conventional surgery was performed. The patient's muscle strength and proprioception were evaluated using the HUMAC NORM II® isokinetic dynamometer (CSMi, Stoughton, MA) described by Bayramoglu *et al*. [6]. KOOS and Oxford knee scores were used to evaluate recovery and functional outcomes [7, 8].

Surgical Technique

A single surgeon performed the surgeries on the patients included in the study. The patients' instability tests were repeated under anesthesia (Pivot shift, Lachman). Standard AM (anteromedial), AL (anterolateral), and central portals were used. In all cases, the arthroscopic examination was performed before graft harvesting. The patients were evaluated for medial, lateral meniscus or chondral damage, and isolated ACL rupture was confirmed. Patients with stumps that could extend to the lateral wall were treated with a stump-preserving surgical approach utilizing arthroscopic scissors and a shaver; in these cases, the ACL stump was released without using radiofrequency ablation to prevent possible damage to the neuronal elements in the stump (Fig. 1A). The central portal was added as the viewing portal. The suture carrier was taken out by grasping the proximal end of the stump with the Lasso loop (Fig. 1B), and a high-strength suture in the form of a loop was passed through the stump and left in the knee. One of the free feet was taken from the loop, a lasso loop technique was formed, and the stump was hanged (Fig. 1C). Both free feet were moved to the same portal. The femoral tunnel was prepared anatomically (Fig. 1D). Then, the stump was pulled anteriorly with the help of the in-

Table 1. Demographic data of study groups

	Stump-preserving surgery group (n = 11)	Conventional surgical group (n = 16)
Gender, n (%)		
Female	2 (18.2)	2 (12.5)
Male	9 (81.8)	14 (87.5)
Age (years)	28.0 ± 8.3	28.1 ± 8.6
Time elapsed until the operation (days)	363.6 ± 637.4	358.7 ± 870.8

Data are shown as mean ± standard deviation or number (percent)

serted lasso suture. A tibial drill guide was placed so that it came out of the centre of the tibial footprint. A tibial tunnel of appropriate width and length was created. The free ends of the suture on the stump were removed from the tibial tunnel and passed through the femoral EndoButton® sling of the hamstring graft used (Fig. 1E). The free ends of the stump were prepared to stay out of the tibial tunnel. While the prepared graft was pulled towards the femoral tunnel with the help of the EndoButton® system, the threads on the stump pulled the proximal end of the stump from the hanger of the EndoButton® towards the femoral tunnel. As the free ends coming out of the tibial tunnel were pulled over the EndoButton® loop, the covering of the stump was increased, and its tension was ensured. This preserved the stump and prevented it from getting stuck in the intercondylar notch.

Measurement of Proprioception Sense and Isokinetic Muscle Strength

One of the reproduction tests evaluating the perception of joint position, the passive-active method, was used in the sitting position. Proprioception was measured using the HUMAC NORM II® isokinetic dynamometer (Fig. 2). Headphones and a blindfold ensured the patients' visual and auditory senses did not affect proprioception. The isokinetic dynamometer was set to 2°/sec angular velocity in continuous passive motion mode. The target angle was set to 30°. When the device reached the target angle in flexion, it stopped and gave an audible warning for 10 seconds. The patient was asked to remember where the movement stopped, and the device was reset to the starting position. The device was operated with a constant angular velocity between 0 and 90 degrees, and the patient was asked to stop the device with the remote control when he/she felt that it had reached the target angle. The difference (MAH) between the target angle and the angle at which the patient stopped the device was recorded. The process was repeated three times with 20-second breaks. The mean measurement was calculated and defined as the sense of position [6]. The mean MAH value is inversely proportional to the proprioceptive sensitivity. Angular velocities of 60°/sec and 180°/sec were used for isokinetic muscle strength measurement. The test was started in full flexion. The submaximal strength trial tests were followed by five maximum power repetitions at 60°/sec and 15 maxi-

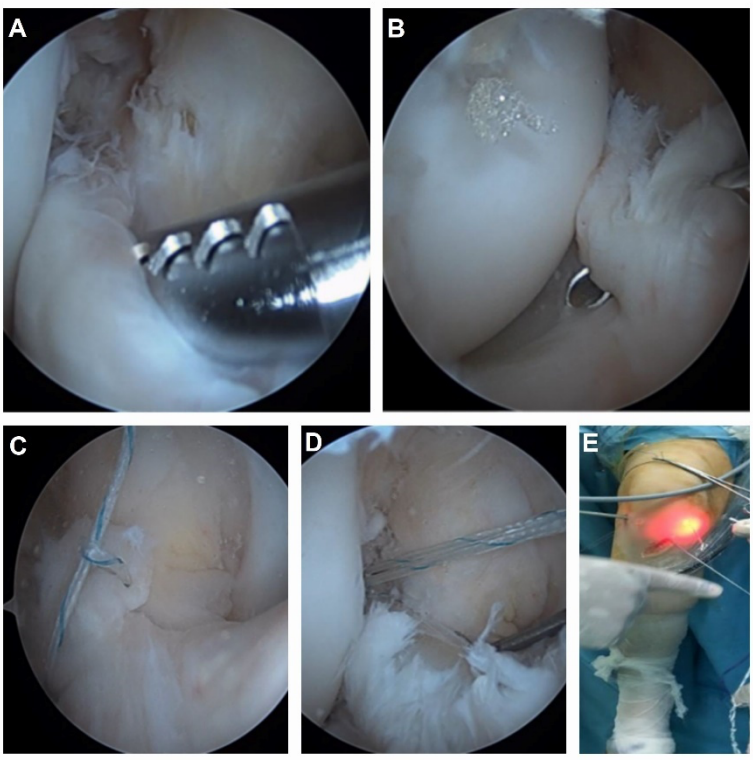

Fig. 1. (A) Release of the anterior cruciate ligament stump, (B) Suturing with a lasso suture, (C) Suturing the anterior cruciate ligament proximal stump, (D and E) Stump string threaded through endobutton sling.

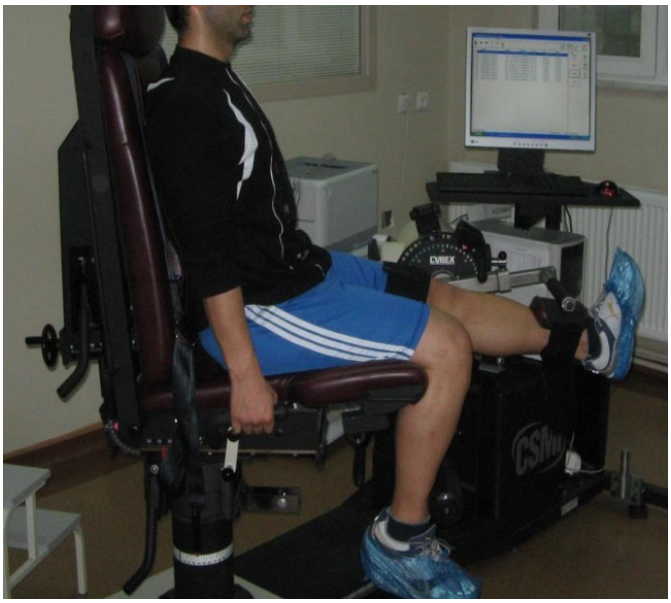

Fig. 2. Measurement of muscle strength and proprioception with the HUMAC NORM II® isokinetic dynamometer.

mum strength repetitions at 180°/sec, with 30-second breaks during speed changes. Quadriceps and hamstring peak torque values (Nm) were recorded for both speed measurements. After physical tests, functional results were evaluated with KOOS and Oxford knee scores.

Postoperative Rehabilitation Protocol

The same rehabilitation protocol was applied to all patients. Postoperative knee orthosis was not used. The patients were mobilized with full weight-bearing on the first postoperative day. Range of joint motion, isometric muscle and closed kinetic chain exercises were started on the second postoperative day. Light jogging was started in the second month, and open kinetic chain exercises were applied after the third month. Jumping, landing, bending and cutting exercises were started in the fourth month, and sprinting and other competitive exercises were started after the sixth month.

Statistical Analysis

In the preoperative period, patients' age, gender, injured side, the time elapsed until surgery, proprioception, muscle strength measurements, and Oxford knee and KOOS scores were recorded. In the postoperative first, third, and sixth months of KOOS, Oxford muscle strength and proprioception measurements were recorded. Whether the data were suitable for normal distribution was determined using the Shapiro-Wilk test. Mann-Whitney U test was used to compare the groups, and Wilcoxon sing rang test was used to compare preoperative and postoperative first, third-, and sixth-months results. Pearson correlation analysis evaluated the relationship between proprioception values and functional scores. $P < 0.05$ was accepted as statistically significant in all analyses. Data were analyzed using the SPSS version 20.0 program.

RESULTS

In the cases of stump-preserving surgery, the surgeon determined the degree of synovial coverage according to the amount of extension to the lateral wall; 87% coverage was obtained. There was no significant difference between preoperative flexion and extension muscle strengths and no significant difference in preoperative functional scores (Table 2). In the first month, functional scores decreased, and proprioceptive values increased, depending on possible pain levels, but the difference between the two groups was insignificant (Table 3). In the third and sixth months, KOOS scores were higher in pain ($p = 0.048$) and sports parameters ($p = 0.009$) in the conventional group (Table 4). In the sixth month, there was no sig-

Table 2. Comparison of study groups before surgery

	Stump-preserving surgery group	Conventional surgical group	p value[Ω]
KOOStotal⁎ (point)	51.8 (18)	58.6 (19)	0.365
Symptoms	61.3 (19.7)	62.5 (19.8)	0.883
Pain	55.3 (16.1)	63.5 (16)	0.273
Function, daily living	59.9 (22.8)	68.5 (21.1)	0.324
Function, sports and recreational activities	23.2 (20.1)	37.5 (32)	0.201
Quality of life	26.1 (18.7)	24.2 (14.7)	0.769
Oxford knee score (point)	26.0 (10.1)	30.5 (10.9)	0.297
Proprioception (degree)	6.78° (4.5)	4.95° (4)	0.281
Flexor muscle strength (Newton.meter)	107.4 (45.3)	97.1 (34.8)	0.510
Extensor muscle strength (Newton.meter)	181.2 (52.6)	143.0 (61.6)	0.106

Data are shown as median (interquartile range). ⁎KOOStotal =Knee Injury and Osteoarthritis Outcome Score-total, ranges from 0 to 100; with higher scores indicating better results.
[Ω]Mann-Whitney U test

nificant difference in flexion and extension muscle strength values; further, patients in the SP group did not regain the muscle strength of the preoperative period, though patients in the C group did. Proprioception values were better in the SP group. Although there was a significant statistical difference at the 3rd month (p = 0.010), no significant statistical difference was observed at the 6th month. When evaluated independently of the grouping, there was a significant correlation between proprioception and sports activities. Patients with low proprioception deficiency showed significantly better scores for sports activities. (r = -0.452, p = 0.018,).

DISCUSSION

Our study observed that patients who underwent ACL stump resection returned to sports activities more quickly. There was no significant relationship between stump resection and proprioception deficit at the 6th month, but we think that in reducing the number of receptors in the sensory nerve endings, stump resection positively affects pain scores, thus increasing the athletic activity scores. Better athletic scores were seen in patients with less proprioceptive deficit. We concluded that proprioception is an essential factor affecting the success of ACL reconstruction.

Although mechanical stability is achieved after reconstruction, the sense of joint position may be lost, causing poor functional results [9, 10]. After reconstruction, lost position sense and proprioception may cause degenerative changes in cartilage structures; grafts that exceed normal strength and introduce necessary tension [11] are required for a satisfactory outcome and proprioceptive sensation restoration [12]. The density of mechanoreceptors found in stump tissue may help provide this restoration [4, 13]. For mechanoreceptors to function in the remaining stump, the stump must be integrated into the graft at the appropriate tension. Although sufficient tension was provided in the stump in the six months of the study, active nerve stimulation could not be generated due to the possible incomplete neural regeneration.

Recovery of proprioceptive sense in professional athletes is essential to re-adapt to sports, recovering former prowess and preventing re-ruptures. In athletes, motor function is stimulated much faster by processing proprioceptive, visual, and auditory senses than normal individuals. Athletes who cannot achieve rapid re-adaptation may become prone to re-rupture or secondary injuries due to abnormal knee kinematics [14]. Though athletes develop keen proprioception due to intense exercise [15, 16], they experience a profound loss of proprioception when returning to sports after reconstruction [17, 18].

Table 3. Functional score, proprioception (degrees), flexion and extension muscle strength values (Newton/meter) at 1st -3rd and 6th month

	Stump-preserving surgery group	Conventional surgical group	*p* value**
KOOS* (point)			
1st month	46.4 (32.1)	59.2 (29.5)	0.730
3rd month	78.6 (26.3)	70.6 (20.5)	0.415
6th month	78.6 (28.3)	85.1 (13.3)	0.277
Oxford score (point)			
1st month	28.0 (16)	27 (15)	0.805
3rd month	40 (11)	41.5 (13)	0.941
6th month	40 (11)	42.5 (7.5)	0.294
Proprioception (º)			
1st month	4.33° (4.67)	6.83° (7.83)	0.458
3rd month	1.66° (3)	3.5° (4.3)	**0.010**
6th month	1° (2.3)	3.7° (4)	0.195
Flexion strenght (Newton.meter)			
1st month	39 (51)	51 (43.5)	0.711
3rd month	80 (26)	87.5 (50)	0.621
6th month	89 (37)	117 (62)	0.256
Extension strength (Newton.meter)			
1st month	65 (67)	53 (67)	0.729
3rd month	99 (50)	108 (61)	0.805
6th month	141 (99)	150 (107.5)	0.388

Data are shown as median (interquartile range). *KOOS =Knee Injury and Osteoarthritis Outcome Score, ranges from 0 to 100; with higher scores indicating better results.

**Mann-Whitney U test

Table 4. Statistical difference between the two groups of KOOS subunits at 3-6 months

	Stump-preserving surgery group	Conventional surgical group	*p* value$^{\Omega}$
KOOStotal⁎ (point)	74.3 (18.2)	83.2 (10.8)	**0.013**
Symptoms	69.9 (21.2)	82 (10.2)	**0.036**
Pain	75.8 (17.6)	86.6 (11)	**0.048**
Function, daily living	82.2 (16)	90.2 (10)	0.146
Function, sports and recreational activities	61.4 (29.3)	71.6 (19.1)	**0.009**
Quality of life	65.8 (23.6)	63.5 (22.5)	0.141

Data are shown as median (interquartile range) ⁎KOOStotal = Knee Injury and Osteoarthritis Outcome Score-total, ranges from 0 to 100; with higher scores indicating better results.

$^{\Omega}$Mann-Whitney U test

A proprioception deficit of 5 degrees or more adversely affects clinical outcomes [18]. Our study observed that patients with low proprioceptive deficits returned to sports activities earlier. However, there is no significant benefit of stump preservation in the first six months, and multicenter long-term results with higher patient numbers are needed to arrive at a definite conclusion.

Another measure of the success of surgical treatment is the level of muscle strength recovery. Decreased afferent nerve receptors reduce proprioception and inhibit muscle. It is thought that the loss of mechanoreceptors in the ACL impairs the ligament-muscle reflex between the ACL and the quadriceps and prevents high-threshold motor activation during voluntary quadriceps contraction [19]. However, whether more flexor or extensor muscle strength is lost is still being determined. In knees reconstructed with hamstring autograft, decreased flexion strength before and after surgery [20] and decreased quadriceps strength in reconstructions with patellar tendon seem more evident [21]. It has been generally observed that hamstring reconstructions cause weaker muscle strength and may affect knee stability in the long term [22]. Damage to the hamstring muscles during graft removal may cause more significant muscle strength loss. Hamstring autograft was used in all patients in our study, and no statistically significant difference was found between the two groups regarding knee flexor and extensor strengths over six months. The inability to reach preoperative muscle strength in the stump-preserving surgery group is due to worse pain parameters and muscle inhibition results.

Return to functional life is closely related to patient satisfaction. Despite reports of good patient outcomes in many comprehensive studies of ACL reconstruction, surgery and rehabilitation in the last 20 years, 28% of patients are still dissatisfied with the surgery regarding knee function [10]. In the literature, poor outcomes have been associated with developing flexion contracture, continued laxity and pivot shift, effusion, and wound tenderness [20]. However, proprioception defect instability may diminish function and decrease satisfaction with the surgical treatment [23]. No significant difference was observed in studies evaluating IKDC (International Knee Documentation Committee Qestionnaire) and Lysholm scores and functional status in stump-preserved and non-preserved patient groups [24]. However, in the secondary arthroscopy performed on the same patients, it was observed that the synovial coverage in the stump-preserved group was significantly higher than those in the unprotected group [24]. Similar results were seen in patients with partial tears and those undergoing selective ligament strengthening.

No significant difference was found in IKDC, Lysholm and KOOS scores evaluated at 6 and 12 months [25]. The changes in pivot shift and anterior laxity were compared in the same patient group, and there was no significant difference between the two groups [25]. In a study in which subgroups were evaluated according to the stump coverage rate in stump-preserving reconstructions with bone-tendon-bone, no significant difference was observed between the groups in IKDC and Lysholm scores [26]. However, there are results in the literature claiming the opposite. In the study of Naylor *et al*. [27], better ACL-Quality of Life (ACL-QOL) and IKDC scores were found in the stump-preserved group compared to the non-preserved group. Nonetheless, it should be remembered that patient satisfaction is an objective evaluation [28-30]. Our study found a significant difference in the third and sixth month KOOS pain, complaints, and sports parameters, which supports the literature. This difference in the early postoperative period may be due to more intra-articular debridement in the standard surgery group and excision of the receptors carrying pain sensation in the Hoffa. In addition, we think that removing the free nerve endings on the stump with debridement may contribute positively to early rehabilitation by preventing pain in the standard surgical group. The early reduction of neural impulses from these receptors ensures earlier functional recovery. However, long-term studies are needed to reveal the pros and cons for the patient definitively.

Limitations

The most important limitation of our study was the short duration of patient follow-up. Further, more than a few patients may be needed to draw firm conclusions. The HUMAC NORM II® isokinetic dynamometer enabled us to obtain targeted data from the patients. We did not use an arthrometer because we aimed to evaluate muscle strength and proprioception rather than stability.

CONCLUSION

Our study found no difference between proprioception during the 6-month follow-up period after stump-preserving surgery and conventional surgery. When all patients were evaluated independent of the surgical groupings, those with less proprioceptive sensory deficit returned to sports activities earlier and arrived at their previous performance levels more efficiently.

Authors' Contribution

Study Conception: NE, HÇ, SA; Study Design: HÇ, SA; Supervision: NE, HÇ, AY; Funding: N/A; Materials: N/A; Data Collection and/or Processing: SA, HÇ, MY; Statistical Analysis and/or Data Interpretation: TOB, AY, NE; Literature Review: NE, KT, MY; Manuscript Preparation: NE, HÇ, KT and Critical Review: TOB, AY, MY.

Conflict of interest

The authors disclosed no conflict of interest during the preparation or publication of this manuscript.

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