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The relationship between thigh and leg circumferences and proprioceptive sense: Results of postoperative anterior cruciate ligament reconstruction

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Abstract

Proprioceptive sense is damaged in anterior cruciate ligament (ACL) injuries and restoring joint stabilization is very important. The aim of the present study is to evaluate the relationship between the post-operative thigh and leg circumferences and proprioceptive sense on both operated and non-operated sides in patients who have undergone Semitendinosus/Gracilis ST/G (Hamstring Autograft) anterior cruciate ligament reconstruction (ACLR). 20 sedentary male patients aged 18-35 years who had undergone ST/G ACLR at least 6 months ago were included in the study. Leg and thigh circumferences and proprioceptive sense measurements were performed on the operated (OP) and non-operative (NONOP) sides of the patients. Leg and thigh circumferences were recorded in cm with a flexible meter. Proprioceptive sense measurements were determined at 45, 60 and 75 angles for extension (Ex) and 105, 120, 135 angles for flexion (Flx). When the findings of the patients were evaluated statistically between the operated and non-operated sides, no significant difference was found in the leg (p=0.070), thigh (p=0.403) circumferences and proprioception (Ex 45o p=0.547, Ex 60o p=0.124, Ex 75o p=0.956) (Flx 105o p=0.663, Flx 120o p=0.837, Flx 135o p=0.546). No general significance was found in the correlation analyses evaluated on both the operated and non-operated sides. There was a significant positive correlation between thigh circumference and Flx120º in terms of proprioception only on the non-operated side (p<0.05 r=0.639). As a result of the study, similar thigh and leg circumference and proprioceptive sense results of the OP and NONOP sides after the post-operative 6th month ST/G ACLR showed that the ST/G ACLR method reached the same level with the NONOP side in the 6th month with the same rehabilitation program. This shows that the ST/G ACLR method is a viable method in terms of thigh and leg circumferences as well as proprioceptive sense.

Keywords: ACL reconstruction, proprioception sense, anterior cruciate ligament

Introduction

Anterior cruciate ligament (ACL) is a structure that provides the stability of the knee and prevents the forward movement of the tibia relative to the femur [1]. ACL injuries occur as a result of the deterioration of the tibiofemoral joint stability provided by the static and dynamic stability mechanisms of the knee, and these deteriorations usually occur during sports activities that require high performance or sudden physical activity [2]. The main purpose of ACL reconstruction (ACLR), which is applied to patients after injury, is to stabilize the knee so that there is no limitation of movement in the joint [3,4]. ACL has two complementary functions, proprioceptive and mechanical, and after injury, the biomechanics and kinematics of the knee joint are impaired following postural stability damage due to muscle weakness, instability, decreased balance and proprioception in the knee [5,6].

Proprioception is defined as the position perception of the joint and extremity provided by the neural inputs created with the help of the receptors present in the joints and the tissues surrounding them [7]. Proprioceptive sense has an important place in terms

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of joint stabilization and its maintenance [8]. In previous years, experts focused on how to obtain a mechanically stronger ligament of the ACLR after ACL injuries [5]. However, today it has long been thought that different types of grafts used during ACLR after ACL injuries may impair knee proprioception, which may lead to abnormal movement patterns that are a mechanism for further injuries and long-term secondary problems [9]. Studies have revealed important data showing proprioceptive differences between healthy and ACL knees, and frequently between knees that have undergone ACLR and knees that have undergone revision [10]. Serious reductions in proprioception have also been reported in some studies on proprioception in knees with ACL tears [11, 12]. It has been found that decreased proprioception is an important factor in increasing joint damage [13].

There occurs a decrease in the dynamic activity of the muscles surrounding the knee joint and providing its movement as a result of proprioceptive deficits [14-16]. Studies conducted clearly show a loss of strength in the thigh muscles of patients after ACLR [17-20]. It is a known fact that this loss of strength in thigh muscles after ACL injuries is caused by atrophy in the muscles and neural communication disorders in the knee after the injury [21]. In addition, other researchers have shown that the width of thigh circumference, the mass and fibers of the muscles that make up the thigh region are higher and that the force created in the muscle is higher and this affects the maximum strength, which supports the findings of other studies conducted [22]. This situation has revealed the idea that there may be correlations between the differences in muscle volumes or masses and the proprioceptive sense, depending on the negative effects on proprioceptive sense and changes in muscle strength as a result of deformities in the knee joint after ACLR.

When all this information is evaluated, the present study aims to evaluate the relationship between post-operative thigh and leg circumferences and proprioceptive sense in patients who have undergone Semitendinosus/Gracilis (ST/G) Hamstring Autograft ACLR and to compare them with the healthy leg. The study hypothesizes that there will be significant correlations between proprioceptive sense and thigh and leg circumferences after ACLR. It was also hypothesized that the 6th month results after ST/G ACLR would be similar between the OP and NONOP sides.

Material and Methods

Experimental Design and Participants

The study was evaluated as a retrospective cohort of 20 sedentary men who underwent the traditional ACLR (ST/G) technique. The number of subjects to be included in the study was determined by Gpower analysis. It was calculated that 13 subjects would be sufficient. However, it was planned to complete the study with at least 20 subjects in order for the data to yield more reliable results. All patients to participate in the study were informed about the study and their voluntary consent was obtained.

Ethics committee approval of the study was obtained by Samsun University Faculty of Medicine (SÜKAEK-2022/12/20). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. The retrospective cohort part of the study included only post-operative 6th month thigh and leg circumference measurements and proprioceptive sense measurements. All patients were referred to the same rehabilitation specialist and postoperative follow-up (6 months) was done. Inclusion criteria for this study were: (a) 18-35 years old, (b) have had Semitendinosus/Gracilis (Hamstring Autograft) anterior cruciate ligament reconstruction (ACLR), and c) have no other neuromuscular or musculoskeletal injury or a history of contralateral knee surgery or injury. In addition, patients who did not comply with the rehabilitation program, did not complete the postoperative laboratory visit, or were exposed to various complications during their follow-up were excluded from the study. All of the measurements were made at these time intervals considering the circadian cycle (12:00-16:00). All of the measurements were completed by the researchers on the same day (Table 1).

Table 1. Descriptive data of the subjects (n=20)

	Mean	S.D	Min	Max.
Age (year)	29.33	7.29	19.0	44.0
Height (cm)	177.13	6.90	169.0	190.0
Weight (kg)	89.20	12.83	75.0	125.0
BMI (kg/m^2)	28.35	2.78	22.88	34.63
Follow Up (month)				
	R	**L**		
Operated knee (n/%)	9/60	6/40		
Dominant Side (n/%)	11/73.33	4/26.67		

*p<0.05; S.D standard deviation; Min, minimum; Max. maximum; BMI body mass index; R right; L left

Procedures

Proprioceptive Sense

The proprioceptive senses of the subjects were evaluated with the sense of joint position. Joint position sense was measured as the previously taught ability to actively find joint position (AFJP) [23]. AFJP scores of the subjects were tested with the Cybex NORM isokinetic dynamometer. In terms of proprioceptive senses of the subjects, for extension, the knee was brought slowly from 90° flexion to extension and stopped at 75°, 60° and 45° flexion angles, respectively, for 10 seconds and these angles were taught to the patient. The knee was then flexed to 90° again and the subjects were asked to find these angles they were taught. The subjects tried to find the angles by actively moving their knees from this starting position to the 75°, 60° and 45° flexion angles they had learned before. The resulting findings were recorded as EX75°, EX60°, EX45° proprioceptive sensory parameters. For flexion, the subjects were brought slowly from 90° flexion to flexion in the sitting position, while they were stopped at 105°, 120° and 135° flexion angles, respectively, for 10 seconds and these angles were taught to the patient. The knee was then flexed to 90° again and the subjects were asked to find these angles they were taught. The subjects tried to find these angles by actively moving their knees from this starting position to the 105°, 120°

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and 135° flexion angles they had learned before. The resulting findings were recorded as FLX105°, FLX120° and FLX135° proprioceptive sensory parameters. The difference between the angles found by the subjects and the real absolute values was recorded. Three repetitions were performed for each leg at all angles, and the means were calculated and compared.

Thigh and Leg Circumference

Thigh circumference measurement: While the subject is sitting in 90° flexion of the knee, the inguinal region and the proximal patella are marked (10-15 cm above) to the midpoint, the subject is made to stand and the measurement is made from the marked point when the feet are 10 cm apart and the body weight is evenly distributed on both feet.

Leg circumference measurement: Measurements were taken from the widest part of the gastrocnemius while the subject was standing with the feet approximately 20 cm apart. All measurements were recorded in cm.

Statistical Analysis

SPSS 21. Package program was used in the statistical analysis of the study. The results were presented as mean and standard deviation. Shapiro-Wilk test was used for normality test and Levene's test was used for homogeneity assumptions. Paired sample test or Wilcoxon rank tests were used to compare the paired groups (healthy knee - ACLR knee and pre-op and post-op IKDC, Tegner and Lyhsolm). One-Way ANOVA was used to compare the proprioceptive senses of the operated and non-operated sides. In addition, in the comparing of paired groups, effect sizes were found according to Cohen's d effect size (M2 − M1)⁄SDpooled). According to this formula, a d value of <0.2 was defined as weak effect size while a d value of 0.5 was defined as moderate and a d value of >0.8 was defined as strong effect size. The results were considered significant at p<0,05, at within a confidence interval of 95%.

Results

When the thigh and leg circumferences of the operated and non-operated sides were evaluated, no significant difference was found between leg circumference (p=.70, 95% CI= -1.26 - .055) and thigh circumference (p=.403, 95% CI=-1.16 -.50) values (Table 2).

Table 2. Comparison of thigh and leg circumferences of operated and non-operated sides

	OP	NONOP	t	P	E.S	95% CI	
	Mean.±S.D	Mean.±S.D				LB	UB
Leg circumference (cm)	40.53±4.50	41.13±3.66	-1.964	.070	0.14	-1.26	.055
Thigh circumference (cm)	57.33±3.02	57.66±3.06	-.863	.403	0.11	-1.16	.50

*p<0.05; S.D standard deviation; Min, minimum; Max. maximum; BMI body mass index; OP operated; NONOP non-operated; ; CI confidence interval; LB lower bound; UB upper bound; E.S cohen's d effect size

When the operated and non-operated side extension proprioception scores were compared, no statistically significant difference was found between 75º (p= .547, 95% CI= -.1.65 – 2.98), 60º (p= .124, 95% CI= -.40 – 2.98) and 45 º (p= .956, 95% CI= -.1.64 – 1.72) values (Table 3).

Table 3. Comparison of operated and non-operated side extension proprioception scores

	OP	NONOP	t	P	E.S	95% CI	
	Mean.±S.D	Mean.±S.D				LB	UB
75º	3.82±.4.34	3.15±.1.90	.617	.547	0.20	-1.65	2.98
60º	5.11±.4.16	3.82±2.98	1.636	.124	0.36	-.40	2.98
45º	3.40±.2.38	3.35±2.37	.056	.956	0.02	-1.64	1.72
F	.856	.432					
P	.290	.750					

*p<0.05; S.D standard deviation; Min, minimum; Max. maximum; BMI body mass index; OP operated; NONOP non-operated; ; CI confidence interval; LB lower bound; UB upper bound; E.S cohen's d effect size

When operated and non-operated side flexion proprioception scores were compared, no significant difference was found between 75º (p=.663, 95% CI= -.1.80 –1.18), 60 º (p=.837, 95% CI=-2.05 –2.50) and 45 º (p=.546, 95% CI= -.1.64 –2.98) values (Table 4).

Table 4. Comparison of operated and non-operated side flexion proprioception scores

	OP	NONOP	t	P	E.S	95% CI	
	Mean.±S.D	Mean.±S.D				LB	UB
105º	2.40±.1.36	2.71±.2.07	-.445	.663	0.18	-1.80	1.18
120º	3.22±.2.80	3.00±2.26	.210	.837	0.09	-2.05	2.50
135º	3.63±.2.50	2.96±2.74	.619	.546	0.26	-1.64	2.98
F	1.101	.066					
P	.342	.936					

*p<0.05; S.D standard deviation; Min, minimum; Max. maximum; BMI body mass index; OP operated; NONOP non-operated; CI confidence interval; LB lower bound; UB upper bound; E.S cohen's d effect size

Table 5 examines the proprioception scores measured on the operated side thigh and leg circumference. When the results found were evaluated, although general positive and negative correlations were found between thigh and leg circumference and proprioception scores, it was found that these correlations were not statistically significant (p>0.05).

Table 5. The correlation between operated side thigh and leg circumference and proprioception scores

	FLX105º	FLX120º	FLX135º	EX75º	EX60º	EX45º
Thigh circumference (cm)	-.254	-.388	-.295	.123	-.018	-.086
Leg circumference (cm)	.501	-.165	.178	-.043	-.103	-.333

The correlation between proprioception scores measured in the circumference of the non-operated thigh and leg was examined with the Pearson correlation test. When the results were evaluated, a positive correlation was observed only between thigh circumference and Flx120º ($p<0.01$, r=.639) (Table 6).

Table 6. The correlation between the non-operated side thigh and leg circumference and proprioception scores

	FLX105º	FLX120º	FLX135º	EX75º	EX60º	EX45º
Thigh circumference (cm)	.277	.639*	-.062	-.432	-.181	.008
Leg circumference (cm)	.099	.069	-.167	.027	-.061	-.094

Discussion

Our 6th month post-operative results did not show a significance between operated and non-operated sides in patients who had undergone ST/G ACLR operation. These results showed that thigh circumference, leg circumference and proprioceptive sense on operated side approached the healthy side in an average of 6 months, indicating a good rehabilitation process after ACLR and regeneration of ACL receptors. No significance was found in general in the correlation analyses evaluated in both the operated and non-operated sides. A significant difference was found between thigh circumference and Flx120º proprioception angle only on the non-operated side.

Proprioception affects neuromuscular performance; it is necessary for the perception of body movement and control of the movement, for the formation of balance, coordination and joint stabilization [24-26]. Decrease in proprioception after ACLR is explained by the emergence of some of the mechanoreceptors, Ruffini-type endings, and Pacinian bodies located in the skin and joints at the end of the surgical operation [5]. It is often preferred because it maintains the extensor mechanism in hamstring grafts, prevents atrophy of the quadriceps muscle, and provides less pain and less movement restriction after the operation [27,28]. In contrast, researchers showed different findings regarding proprioception occurring in patients with ACL injuries and post-ACLR. A study conducted on 20 recreational athletes showed that the insufficient sensory feedback taken from pre-ACLR and post-6th month operated side mechanoreceptors changed the movement biomechanics and caused loss of proprioception [29]. The fact that patellar tendon method, which is another type of graft, requires extensive surgery, the pain experienced during the transition to rehabilitation and also delayed recovery are among the disadvantages of the method [30].

In a study in which patellar tendon graft was applied, researchers found a proprioceptive sensory deficit between the ACLR side and the healthy side 3 months after ACLR, but reported that the proprioceptive sensory deficit was closed in the 6th month findings. This shows that the 6-month rehabilitation and recovery period is a sufficient period of time for the recovery of ACL receptors [31]. In a study they conducted with 20 patients after ACLR with patellar tendon graft method, they reported a decrease in proprioceptive sense and proprioceptive damage decreased in the third month after ACLR. They explained that although the losses in full flexion and full extension were corrected in the 6th month, the losses in the moderate angles could be recovered in 3.7 years [31]. Our current study showed that the ST/G hamstring autograft method produced similar results in the 6th month after ACLR in operative and non-operated side extension and flexion findings.

The results found in the literature and our current study showed that proprioceptive sensory findings at 6 months after ACLR revealed different findings in different graft methods. However, the results of the studies show that the proprioceptive sense does not show similar findings with the healthy side after ACLR in individuals with high levels of physical activity, while the opposite is true in sedentary groups.

Researchers have shown significant loss of strength and atrophy in patients after ACLR [32-34]. Flexor muscle strength deficiency is seen in patients with hamstring grafting, while extensor muscle strength insufficiency is observed in patients with patellar tendon graft [35]. Insufficient functioning of the proprioceptive system may result in inadequate neuromuscular control, inability to perform protective muscle activities, and deterioration of joint stabilization [15].

As a result of proprioceptive deficits, there occurs a decrease in the dynamic activity of the muscles surrounding the knee joint [14-16]. Researchers have shown muscle strength deficiencies in the knee extensor and flexor muscles in both patients with a history of ACL injury and those who have undergone ACLR [34,36,37]. Some studies have stated that the increase in lean leg muscle volume and mass affects the strength in calf and thigh circumference measurement and researchers have interpreted this situation as the increase in calf and thigh circumference, muscle mass and muscle fibers will increase muscle strength [22,38]. In this study, which we conducted by assuming that the change in muscle strength will affect the circumference of the thigh and leg, our hypothesis that there may be a relationship between proprioceptive sense and the circumference of the legs has not been supported by the present findings. All the results found show to be the main limitation of our study as the inability to evaluate the healthy control group of athletes and sedentary patients who underwent ACLR with a different graft method.

The fact that we did not have the results of athletes and sedentary healthy subjects with different grafting methods in our study caused us not to be able to clearly explain the relationship between operated and non-operated sides in terms of all parameters. In addition, the absence of a relationship between thigh and leg circumferences and proprioceptive sense in both the operated and non-operated sides revealed the idea that the patients were sedentary. Repeating the study with the athletic population in future studies is important in order to evaluate the correlations that may arise depending on the physical activity status. Since the present study includes only patients who underwent ACLR with hamstring graft method, it is thought that the evaluation of the healthy control group of athletes and sedentary patients who are applied different ACLR grafting methods will give clearer results in future studies.

The main limitation of the study was that the subjects were referred to the same rehabilitation specialist after ST/G ACLR, but rehabilitation details were not obtained. In addition, there were no healthy controls in the study. Conducting further research by eliminating these limitations will enable us to see the results more clearly.

As a result of the study, similar thigh and leg circumference and proprioceptive sense results of the OP and NONOP sides after the post operative 6th month ST/G ACLR showed that the ST/G ACLR method reached the same level with the NONOP side in the 6th month with the same rehabilitation program. This shows that the ST/G ACLR method is a viable method in terms of thigh and leg circumferences as well as proprioceptive sense. After the main limitation of the research is eliminated, further research will make the results clearer. In addition, researches to be carried out not only with the ST/G ACLR method but also with all other grafting methods will show which method will yield clearer results.

Conflict of interests
The authors declare that there is no conflict of interest in the study.

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Ethical approval
Ethics committee approval of the study was obtained by Samsun University Faculty of Medicine (SÜKAEK-2022/12/20).

References

1. Olsen OE, Myklebust G, Engebretsen L, et al. Relationship between floor type and risk of ACL injury in team handball. Scand J Med Sci Sports. 2003;13:299-04.
2. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: a 21-year population-based study. Am. J. Sports Med. 2016;44:1502-7.
3. Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long term incidence of gonarthrosis. Sports Med. 1999;27:143-56.
4. Nordenvall R, Bahmanyar S, Adami J, et al. Cruciate ligament reconstruction and risk of knee osteoarthritis: the association between cruciate ligament injury and post-traumatic osteoarthritis. a population based nationwide study in Sweden, 1987–2009. PloS One. 2014;9:e104681.
5. Dhillon MS, Bali K, Prabhakar S. Proprioception in anterior cruciate ligament deficient knees and its relevance in anterior cruciate ligament reconstruction. Indian J Orthop. 2011;45:294-300.
6. Barenius B, Ponzer S, Shalabi A, et al. Increased risk of osteoarthritis after anterior cruciate ligament reconstruction: a 14-year follow-up study of a randomized controlled trial. Am J Sports Med. 2014;42:1049-57.
7. Garsden LR, Bullock-Saxton JE. Joint reposition sense in subjects with unilateral osteoarthritis of the knee. Clin Rehabil. 1999;13:148-55.
8. Erkmen N, Suveren S, Göktepe AS, et al. The comparison of balance performance of the athletes who are in different branches. Spormetre. 2007;5:115-22.
9. Relph N, Herrington L, Tyson S. The effects of ACL injury on knee proprioception: a meta-analysis. Physiotherapy. 2014;100:187-95.
10. Pap G, Machner A, Nebelung W, et al. Detailed analysis of proprioception in normal and ACL-deficient knees. J Bone Surg. 1999;81:764-8.
11. Fischer-Rasmussen T, Jensen PE. Proprioceptive sensitivity and performance in anterior cruciate ligament-deficient knee joints. Scand J Med Sci Sports. 2000;10:85-9.
12. Roberts D, Fridén T, Zätterström R, et al. Proprioception in people with anterior cruciate ligament-deficient knees: comparison of symptomatic and asymptomatic patients. JOSPT. 1999;29:587-94.
13. Noyes FR, Mooar PA, Matthews DS, et al. The symptomatic anterior cruciate-deficient knee. Part I: the long-term functional disability in athletically active individuals. JBJS. 1983;65:154-62.
14. Fonseca ST, Ocarino JM, Silva PL, et al. Proprioception in individuals with ACL-deficient knee and good muscular and functional performance. Res Sports Med. 2005;13:47-61.
15. Good L, Roos H, Gottlieb DJ, et al. Joint position sense is not changed after acute disruption of the anterior cruciate ligament. Acta Orthop Scand. 1999;70:194-8.
16. Reider B, Arcand MA, Diehl LH, et al. Proprioception of the knee before and after anterior cruciate ligament reconstruction. Arthroscopy: J Arthrosc Relat Surg. 2003;19:2-12.
17. Thomeé R, Kaplan Y, Kvist J, et al. Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction. Knee Surg. Sports Traumatol Arthrosc. 2011;19:1798-05.
18. Schmitt LC, Paterno MV, Ford KR, et al. Strength asymmetry and landing mechanics at return to sport after ACL reconstruction. MSSE. 2015;47:1426.
19. Anderson JL, Lamb SE, Barker KL, et al. Changes in muscle torque following anterior cruciate ligament reconstruction: a comparison between hamstrings and patella tendon graft procedures on 45 patients. Acta Orthop Scand. 2002;73:546-52.
20. Kehribar L, Coşkun HS, Yılmaz AK, et al. Examination of Isokinetic Knee Strength and Hamstring/Quadriceps Ratios in Individuals with Anterior Cruciate Ligament Injury: ACL Injured Knee Versus Non-Injured Knee. IKSST. 2022;14:158-62
21. Krishnan C, Williams GN. Factors explaining chronic knee extensor strength deficits after ACL reconstruction. J Orthop Res. 2011;29:633-40.
22. Grant S, Hynes V, Whittaker A, et al. Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. J Sports Sci. 1996;14:301-09.
23. Lephart SM, Fu FH. The role of proprioception in the treatment of sports injuries. Sports Exerc Inj. 1995;1:96-102.
24. Mourcou Q, Fleury A, Diot B, et al. Mobile phone-based joint angle measurement for functional assessment and rehabilitation of proprioception. BioMed Res Int. 2015.
25. Fouladi R, Rajabi R, Naseri N, et al. Menstrual cycle and knee joint position sense in healthy female athletes. Knee Surg. Sports Traumatol Arthrosc. 2012;20:1647-52.
26. Ribeiro F, Venâncio J, Quintas P, et al. The effect of fatigue on knee position sense is not dependent upon the muscle group fatigued. Muscle & Nerve. 2011;44:217-20.

27. Kong CG, In Y, Kim GH, et al. Cross pins versus endobutton femoral fixation in hamstring anterior cruciate ligament reconstruction: minimum 4-year follow-up. Knee Surg Relat Res. 2012;24:34-9.

28. Spindler KP, Warren TA, Callison Jr JC, et al. Clinical outcome at a minimum of five years after reconstruction of the anterior cruciate ligament. JBJS. 2005;87:1673-9.

29. Krafft FC, Stetter BJ, Stein T, et al. How does functionality proceed in ACL reconstructed subjects? Proceeding of functional performance from pre-to six months post-ACL reconstruction. PloS one. 2017;12:e0178430.

30. Binnet MS, Demirtaş M. Arthroscoptc ACL reconstruction with patelfar tendon. Acta Orthop Traum Turc. 1990;24:369-75.

31. Fremerey RW, Lobenhoffer P, Zeichen J, et al. Proprioception after rehabilitation and reconstruction in knees with deficiency of the anterior cruciate ligament: a prospective, longitudinal study. J. Bone Surg. 2000;82:801-06.

32. Lorentzon R, Elmqvist LG, Sjostrom M, et al. Thigh musculature in relation to chronic anterior cruciate ligament tear: muscle size, morphology, and mechanical output before reconstruction. Am J Sports Med. 1989;17:423-29.

33. Arangio GA, Chen C, Kalady M, et al. Thigh muscle size and strength after anterior cruciate ligament reconstruction and rehabilitation. J Orthop Sports Phys Ther. 1997;26:238-43.

34. Hiemstra LA, Webber S, MacDonald PB, et al. Knee strength deficits after hamstring tendon and patellar tendon anterior cruciate ligament reconstruction. Med Sci Sports Exerc. 2000;32:1472-9.

35. Petersen W, Taheri P, Forkel P, et al. Return to play following ACL reconstruction: a systematic review about strength deficits. Arch Orthop Trauma Surg. 2014;134:1417-28.

36. Mattacola CG, Perrin DH, Gansneder BM, et al. Strength, functional outcome, and postural stability after anterior cruciate ligament reconstruction. J Athl Train. 2002;37:262-9

37. Keays SL, Bullock-Saxton J, Keays AC. Strength and function before and after anterior cruciate ligament reconstruction. Clin Orthop Relat Res. 2000;373:174-83.

38. De Ste Croix MBA, Armstrong N, Chia MYH, et al. Changes in short-term power output in 10-to 12-year-olds. J Sports Sci. 2001;19:141-8.