

Research

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Isokinetic Muscle Strength in Recreational Athletes with Partial ACL Lesions Treated with Surgical Reconstruction

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ABSTRACT

Background: Surgery that spares the intact portion of the ACL seems to be more favorable. This surgical technique has a positive effect on joint stability, joint position sense and functional scores in patients with partial ACL lesions.

Aim: This study aimed to assess isokinetic muscle strength following surgical reconstruction of partial ACL lesions.

Materials and Methods: The study included 13 recreational athletes with partial ACL lesions that underwent surgical reconstruction. In all ACL reconstructions the remnant ACL was preserved and reinforced with hamstring autografting. The primary outcome parameter was isokinetic muscle strength of the knee muscles. The secondary outcome parameters were Single Leg Stance Test (SLST) score and the Cincinnati knee-rating score. The clinical outcomes were compared between the treated knees and non-treated (contralateral) knees.

Results: There wasn't a significant difference in peak isokinetic torque of the knee flexors at 60° s⁻¹ and 180° s⁻¹ between the treated and non-treated knees ($p>0.05$); however, there was a significant difference in peak isokinetic torque of the knee extensors at 60° s⁻¹ and 180° s⁻¹ between the knees ($p=0.03$). The mean SLST score for the treated and non-treated knees was 3.90±1.29 and 3.62±1.47, respectively; the difference was not significant ($p=0.44$).

Conclusion: The present findings show that the surgical technique described had a positive effect on isokinetic muscle strength of the knee flexors and joint postural stability during the early post surgery period.

KEYWORDS: Anterior cruciate ligament; Reconstruction; Remnant; Muscle strength.

INTRODUCTION

Partial lesions of the Anterior Cruciate Ligament (ACL) that involve complete tearing of 1 of the 2 bundles—anteromedial (AM) and posterolateral (PL)—or an increase in vascularity of the ACL fibers (as in intrasubstance ruptures) can cause significant knee instability, especially in young patients with high functional demands.¹ The reported rate of ACL partial tears ranges from 10% to 35%.² The treatment of partial ACL lesions is usually conservative; however, surgical treatment may be required in cases of persistent symptomatic instability, especially in young patients with high functional demands.³

Although different surgical techniques are described in the literature, that which spares the intact portion of the ACL is viewed more positively. In this surgical technique the remnant ACL is preserved and reinforced *via* hamstring autografting. The advantages of this surgical technique include the following: a) the intact remnant may protect the autograft and

maintain its blood supply, providing support for the healing process in the autograft; b) sparing the intact portion of the ACL fibers may maintain some proprioceptive innervation of the ACL, thus providing faster and safer return to sports activity.⁴⁻⁶

Earlier studies have shown that sparing the intact portion of the ACL has a positive effect on joint stability, joint position sense, and functional scores in patients that undergo surgical reconstruction of partial ACL lesions^{1,7-9}; however, no study has examined the ability of this surgical technique to restore isokinetic muscle strength in patients with partial ACL lesions. As such, the present study aimed to assess isokinetic muscle strength following surgical reconstruction of partial ACL lesions. It was hypothesized that this surgical procedure would result in optimal isokinetic muscle strength.

MATERIALS AND METHODS

Patient Selection

This prospective, controlled clinical study was conducted between January 2010 and January 2012 at a tertiary care hospital, and included 13 recreational athletes with partial ACL lesions scheduled to undergo surgical reconstruction. All of the surgical reconstructions were performed by the same orthopedic surgeon using knee arthroscopy. In all ACL reconstructions the remnant ACL was preserved and reinforced *via* hamstring autografting. The study protocol was approved by the Local Ethics Committee and all the patients provided written informed consent to participate in the study.

Patients that were diagnosed with partial ACL tear based on physical examination including lachmann test, anterior drawer test and pivot shift test, and MRI. The patients with an ACL with >50% of its integrity preserved, bridging the tibia and femur according to arthroscopic evaluation were included. The patients with a history of knee surgery or fracture in the affected and contralateral knee, and those with Posterior Cruciate Ligament (PCL) lesion and meniscus tears in the affected knee were excluded.

Surgical technique

In all cases after sterile preparing and draping we exsanguinate the leg and inflate the tourniquet established inferolateral and inferomedial portals touching the edges of patella tendon starting 1 cm distal to the inferior pole of patella. The medial portal must touch the edge of the patella tendon because if it is placed more medial, the tibial guide may not stay seated in the intercondylar notch with the knee in full extension. An optional outflow portal can be established superiorly.

After a diagnostic arthroscopy we identified and removed the torn remnant AM bundle. It is not necessary to denude the tibial insertion of the native AC tissue. Infact, retaining the insertion of the native ACL helps seal the edges of the ACL

graft at the joint line and does not result in roof impingement if the tibial tunnel has been appropriately positioned. Then we removed the synovium and soft tissue in the notch to expose the lateral edge of the PCL and removed any of the ACL origin from the over-the-top position using an angled curette and shaver.

We inserted the tibial guide through the medial portal to advance the guide into the intercondylar notch. The tip of the guide was 9.5 mm wide (If the guide makes contact and deforms the PCL as it enters the intercondylar notch, perform a lateral wall plasty). We removed bone in 1 to 2 mm wides livers from the lateral wall until the tip of the guide passes into the notch without deforming the PCL, which creates a wide enough area for an 8 to 10 mm wide graft. We attentioned not to remove any bone from the intercondylar roof since the roof anatomy is crucial for proper positioning of the tibial guide-pin in the sagittal plane using the 55 degree tibial guide.

In fully extend the knee we inserted the 55 degree tibial guide through the anteromedial portal that touches the medial edge of the patella tendon into the intercondylar notch between the PCL and lateral femoral condyle to ensure adequate width of the notch for the ACL graft. We visualized that the tip of the guide was captured inside the notch and that the arm of the 55 degree tibial guide contacted the trochlea groove.

We drilled the tibial guide-pin through the lateral hole in the bullet until it striked the guide intraarticularly then removed the bullet from the tibial guide and remove the guide from the notch then tapped the guide-pin into the notch and assess its position.

The tibial guide-pin was properly positioned in the coronal plane when it enters the notch mid way between the lateral edge of the PCL and the lateral femoral condyle and the guide-pin aims 8 mm front of the PCL, 8 mm nearby the posterior horn of lateral meniscus.

We prepared the tibial tunnel and reamed the tibial cortex with a reamer with the same diameter as the prepared ACL graft. We checked for PCL impingement by placing the knee in 90 degrees of flexion and inserting the impingement rod into the notch and checked for roof impingement by placing the knee in full extension.

For the femoral tunnel, we inserted the size specific femoral aimer through the tibial tunnel with the knee in flexion in 90 degrees. The size of the "off-set" of the femoral aimer was based on the diameter of the ACL graft and was designed to create a femoral tunnel with a 1 mm back wall. We extended the knee and hook the tip of the femoral aimer in the over-the-top position. Allow gravity to flex the knee until the femoral guide seats on the femur. Rotate the femoral aimer a quarter turn lateral away from the PCL, which positions the femoral guide-pin farther down the lateral wall of the notch minimizing PCL impingement then we drilled a pilot hole in the femur through the aimer and removed femoral aimer, knee was still at flexion at 90

degrees.

Then we drilled the guide-pin through the anterolateral femoral cortex passed a cannulated reamer the same diameter as the ACL graft over the guide-pin and reamed the femoral tunnel and confirmed the back wall of the femoral aimer is only 1 mm thick and the center of the femoral tunnel is midway between the apex and base of the lateral half of the notch. A femoral tunnel placed correctly down the side wall does not allow room for a second posterolateral tunnel. In femoral drilling first of we drilled the endobutton drill to the cortex and measured then we drilled the femoral hole according to the length of the tendon graft. At last we passed the tendon from tibial hole to femoral hole with the proprior endobutton.

Study Protocol

Following surgical reconstruction, all of the patients underwent the same rehabilitation and exercise program for 2-3 months. In the first 2 weeks post-surgery, the patients were instructed to use crutches and braces. Patients underwent a home-based exercise program for the first 2 weeks post surgery, and then full weight bearing was allowed without the brace. The patients began rehabilitation by performing closed-chain kinetic exercises during postoperative weeks 3 and 4, cycling after week 6, and straight flat-surface running after 12 weeks.

Patient Evaluation

The primary outcome parameter was isokinetic muscle strength of the knee muscles, and secondary outcome parameters were single leg stance test (SLST) and the Cincinnati knee-rating scores. These outcome parameters were recorded before surgery and at 3 months post-surgery, and clinical outcome was compared between the treated knee and non-treated (contralateral) knee. Isokinetic muscle strength of the knee muscles was tested using a Biodex isokinetic dynamometer (Biodex Corp., Shirley, New York, USA) at 2 angular velocities for the knee extensor and flexor groups during isometric contraction. Isokinetic knee strength at 60° s^{-1} and 180° s^{-1} was measured in both knees. All of the participants completed 5 maximal repetitions at 60° s^{-1} and after 30-60 s of rest the participants completed 5 maximal repetitions at 180° s^{-1} . The peak torque (Nm) for knee extension and knee flexion for each leg at each of the 2 speeds was tested and recorded. SLST score was measured using a Biodex Balance System SD (BBS) (Biodex, Shirley, NY, USA), which is designed to measure postural stability on a stable or unstable surface. The BBS includes a circular platform that is free to move in the anterior-posterior and medial-lateral axes simultaneously. This device was designed to measure the degree of tilt in each axis, providing an average sway score. It consists of 8 springs located underneath the outer edge of the circular platform, which provide resistance to movement. Resistance levels range from 8 (most stable) to 1 (least stable). The participants stood on the BBS platform supported on 1 leg and looking at the display. All

trials were performed without shoes. This test consisted of 3 trials 20 s in duration for each leg, with a 1 min rest between trials.

The Cincinnati knee-rating scale¹⁰ was originally designed to assess ACL injuries and consists of symptom rating subscales for pain, swelling, and a sense of instability, physical examination, laxity of the knee on instrumented testing, daily activities, sports activity level, and radiographic findings. Maximum subscale scores are as follows: symptoms: 20; functional daily and sports activities: 15; physical examination (knee effusion, range of motion, tibiofemoral, and patellofemoral crepitus): 25; knee stability (arthrometer and pivot-shift): 20; radiographic findings: 10; and functional testing: 10. The total score ranges from 0 to 100 and is the sum of all subscale scores. Higher scores indicate higher levels of knee function. This scale is reliable, valid, and responsive to clinical changes.

Statistical Analysis

Statistical analysis was performed using SPSS v.15.0 (SPSS Inc., Chicago, IL, USA). Qualitative variables are presented as proportion and percentage. Quantitative variables are presented as mean \pm SD (range). Comparisons between the treated knee and non-treated (contralateral) knee were performed using the Mann-Whitney U test (non-parametric test). The sample size 13 patients per treatment group was based upon a sample size calculation, with an anticipated mean difference of 7 in Cincinnati knee-rating scores between the groups, and a standard deviation of 4, allowing for a p -value of 0.05 and power of 0.72.

RESULTS

The study included 13 recreational athletes with a mean age 32.92 ± 7.11 years. The mean time from trauma to ACL reconstruction was 2.73 ± 3.05 years. In all, 7(53.8%) surgeries were performed on right knees, *versus* 6(46.2%) on left knee. All the injuries were sustained while player soccer ($n=11$) or basketball ($n=2$). No postoperative complications were observed.

Peak isokinetic torque of the knee extensors at 60° s^{-1} was 151.38 ± 55.13 Nm in the treated knees, *versus* 210.07 ± 61.60 Nm in the non-treated knees. Peak isokinetic torque of the knee extensors at 180° s^{-1} was 115.76 ± 37.13 Nm in the treated knee, *versus* 142.0 ± 41.97 Nm in the non-treated knees. Peak isokinetic torque of the knee extensors at 60° s^{-1} and 180° s^{-1} did differ significantly between the treated and non-treated knees ($p=0.03$). Peak isokinetic torque of the knee flexors at 60° s^{-1} was 82.46 ± 29.74 Nm in the treated knees, *versus* 104.15 ± 29.74 Nm in the non-treated knees. Peak isokinetic torque of the knee flexors at 180° s^{-1} was 73.38 ± 22.73 Nm in the treated knees, *versus* 82.76 ± 24.53 Nm in the non-treated knees. Peak isokinetic torque of the knee flexors at 60° s^{-1} and 180° s^{-1} did not differ significantly between the treated and non-treated knees ($p>0.05$) (Table 1). Compared to the non-treated knees at 3 months post surgery, isokinetic knee flexion at 60° s^{-1} and 180° s^{-1} in the

treated knees exhibited 78.8% and 89% recovery, respectively. At 60° s⁻¹ and 180° s⁻¹ isokinetic knee extension in the treated knees exhibited 71.9% and 80.9% recovery, respectively.

SLST scores for the treated and non-treated knees were 3.90±1.29 and 3.62±1.47, respectively; the difference was not significant (*p*=0.44). Cincinnati knee-rating scores for the treated and non-treated knees were 91.61±6.92 and 98.57±4.32, respectively, and the difference was significant (*p*=0.01) (Table 2). Comparison of preoperative and postoperative results—including the primary and secondary outcome parameters—showed that the knee flexors and SLST scores exhibited significant improvement (*p*<0.05), whereas knee extensors and the Cincinnati knee-rating scores did not improve significantly (*p*<0.05) (Table 3).

DISCUSSION

To the best of our knowledge the present study is the

first to investigate the ability of ACL remnant-preserving surgery to restore isokinetic muscle performance in patients with partial ACL lesions. The present findings show that the surgical technique described herein for the treatment of partial ACL lesions had a positive effect on knee flexor isokinetic muscle strength and joint postural stability in the early post surgical period; however, a positive effect on knee extensor isokinetic muscle strength was not observed.

Definitive indications for ACL remnant-preserving surgical techniques have not been reported; however, such indications as a partial rupture of the AM and PL bundle, an ACL remnant bridging the femur and tibia with a thickness of >50% of the native ACL, and laxity of <5 mm have been suggested.^{8,11,12} In the present study all the participants had an ACL with ≥50% of its integrity preserved bridging the tibia and femur, based on arthroscopic screening for the remnant-preserving surgical technique.

Peak Isokinetic Torque	Knee Extensors		<i>p</i> Value	Knee Flexors		<i>p</i> Value
	Operated Knee	Non-operated Knee		Operated Knee	Non-operated Knee	
at 60°/s (Nm)	151.38±55.13	210.07±61.60	0.03	82.46±29.74	104.15±29.74	0.23
at 180°/s (Nm)	115.76±37.13	142.0±41.97	0.03	73.38±22.73	82.76±24.53	0.14

Bold values indicate a *p* value <0.05.

Table 1: Comparison of the peak isokinetic torque of the knee flexors and extensors between the operated and non-operated knees at third months after the surgery.

	Operated knee	Non-operated knee	<i>p</i> value
SLST score	3.90±1.29	3.62±1.47	0.44
Cincinnati knee-rating score	91.61±6.92	98.57±4.32	0.01

Bold values indicate a *p* value <0.05.

Table 2: Comparison of the SLST and the Cincinnati knee-rating scores between the operated and non-operated knees at third months after the surgery.

	Before Surgery	At 3 rd months after surgery	<i>p</i> value
Peak Isokinetic Torque			
Knee extensors at 60°/s (Nm)	135.62±68.21	151.38±55.13	0.13
Knee extensors at 180°/s (Nm)	98.15±42.25	115.76±37.13	0.08
Knee flexors at 60°/s (Nm)	60.23±25.84	82.46±29.74	0.02
Knee flexors at 180°/s (Nm)	52.54±27.35	73.38±22.73	0.04
SLST score	1.90±1.02	3.90±1.29	0.03
Cincinnati knee-rating score	75.21±8.95	91.61±6.92	0.12

Bold values indicate a *p* value <0.05.

Table 3: Comparison of the primary and secondary outcome parameters between the before surgery and at third months after the surgery.

Numerous studies have indicated that ACL reconstruction with remnant preservation will yield better clinical outcomes, including proprioception, revascularization, and knee stability, than the standard ACL reconstruction procedure.^{13,14} The primary aim of ACL reconstruction is to restore the biomechanical stability of the knee joint. The positive affect on knee stability in response to remnant-preserving surgery for partial ACL lesions has been reported.^{11,15,16} In the present study pre-operative and postoperative knee joint postural stability in patients with partial ACL tear were compared. The patients that underwent ACL reconstruction using the remnant-preserving technique had significantly higher SLST scores after the surgery than before. In addition, there was a non-significant difference in the SLST scores between the treated and non-treated knees 3 months post surgery.

Saving ACL remnants during ACL reconstruction may have some advantages for knee muscle strength. ACL remnants can be beneficial during the start of post-surgical rehabilitation by providing additional mechanical strength while the graft is healing; thusly, the recovery of muscle strength can occur more rapidly and easily. Earlier studies reported that quadriceps strength recovered more slowly than hamstring strength after ACL reconstruction. Rosenberg et al¹⁷ reported that quadriceps strength recovered to 82% and hamstring strength to 90% at 12-24 months post ACL reconstruction. Kobayashi et al¹⁸ reported that quadriceps muscle strength recovered to approximately 90% of the level of the non-treated side at 24 months post ACL reconstruction, whereas hamstring muscle strength had already recovered to approximately 90% at 6 months. In the present study hamstring strength almost recovered to 80%-90% and quadriceps strength almost recovered to 70%-80% of the level of the non-treated side 3 months post surgery. Saving ACL remnants might have accelerated the healing process in the knee muscles, as reported in the above-mentioned studies.

Earlier studies reported that quadriceps muscle deficit was greater than hamstring muscle deficit following standard ACL reconstruction. Natri et al¹⁹ reported quadriceps deficit of 15% and hamstring deficit of 9% in patients with ACL reconstruction a mean 4.3 years post surgery. Kobayashi et al¹⁸ reported quadriceps muscle deficit of 12-27% at 12 months post ACL reconstruction, *versus* hamstring muscle deficit of 7-9%. In the present study muscle strength between the treated and non-treated knees was compared 3 months post surgery and there wasn't a significant difference in hamstring muscle strength between sides; however, quadriceps muscle strength was significantly lower in the treated knees. In agreement with the studies mentioned above, in the present study quadriceps muscle deficit was greater than hamstring muscle deficit in patients that underwent remnant-preserving surgery for partial ACL lesions. Because of the synergistic action between the ACL and hamstring muscle, the hamstring muscle plays a major role in the muscle activity that is required to maintain stabilization of knees with ACL lesions, which is why the hamstring muscle group may have less deficit the than quadriceps muscle group.

Some studies reported data for patients with ACL reconstruction based on such functional knee rating scales as the International Knee Documentation Committee (IKDC) Scale, Lysholm Scale, and Tegner Scale, all of which reported that there wasn't a significant difference at final follow-up between the patients that underwent remnant-preserving surgery and standard surgery.^{11,15,20,21} however, one study reported that the Lysholm score in patients that underwent remnant-preserving surgery was significantly higher at final follow-up than in those treated *via* standard surgery.²² In the present study the Cincinnati Knee-Rating Scale, which is the most sensitive test for evaluating functional limitations due to ACL injuries, was used for functional assessment. Cincinnati knee-rating scores were significantly lower in the treated knees than in the non-treated knees; however, the Cincinnati knee-rating scores were higher post surgery than before surgery.

ACL remnant-preserving surgery can increase the risk of developing cyclops lesions and loss of knee range of motion.⁶ In the present study none of the patients had cyclops lesion formation or loss of knee range of motion following surgery. The present study has some limitations, of which the most important is the lack of a control group of patients that underwent standard ACL reconstruction. In addition, the patient population was small and only short-term follow-up was employed.

CONCLUSIONS

Based on the present findings, we think that the surgical techniques described herein, which spares the intact portion of the ACL, can have a positive effect on isokinetic muscle strength of the knee flexors and on joint postural stability during the early post surgery period; however, the long-term outcome of this technique on isokinetic muscle strength, knee stability, and functional knee scores must be determined *via* additional research.

CONFLICTS OF INTEREST: None.

REFERENCES

1. Siebold R, Fu FH. Assessment and augmentation of symptomatic anteromedial or posterolateral bundle tears of the anterior cruciate ligament. *Arthroscopy*. 2008; 24: 1289-1298. doi: [10.1016/j.arthro.2008.06.016](https://doi.org/10.1016/j.arthro.2008.06.016)
2. Borbon CA, Mouzopoulos G, Siebold R. Why perform an ACL augmentation? *Knee Surg Sports Traumatol Arthrosc*. 2012; 20: 245-251. doi: [10.1007/s00167-011-1565-2](https://doi.org/10.1007/s00167-011-1565-2)
3. Buda R, Di Caprio F, Giuriati L, Luciani D, Busacca M, Giannini S. Partial ACL ruptures augmented with distally inserted hamstring tendons and over-the top fixation: an MRI evaluation. *Knee*. 2008; 15(2): 111-116. doi: [10.1016/j.knee.2007.12.002](https://doi.org/10.1016/j.knee.2007.12.002)
4. Liu W, Maitland ME, Bell GD. A modeling study of partial

- ACL injury: simulated KT 2000 arthrometer tests. *J Biomech Eng.* 2002; 124(3): 294-301. doi: [10.1115/1.1468636](https://doi.org/10.1115/1.1468636)
5. Adachi N, Ochi M, Uchio Y, Iwasa J, Ryoke K, Kuriwaka M. Mechanoreceptors in the anterior cruciate ligament contribute to the joint position sense. *Acta Orthop Scand.* 2002; 73(3): 330-334. doi: [10.1080/000164702320155356](https://doi.org/10.1080/000164702320155356)
6. Junkin DM Jr, Johnson DL. ACL tibial remnant, to save or not? *Orthopedics.* 2008; 31: 154-159. doi: [10.3928/01477447-20080201-13](https://doi.org/10.3928/01477447-20080201-13)
7. Adachi N, Ochi M, Uchio Y, Sumen Y. Anterior cruciate ligament augmentation under arthroscopy. A minimum 2-year follow-up in 40 patients. *Arch Orthop Trauma Surg.* 2000; 120: 128-133. doi: [10.1007/s004020050028](https://doi.org/10.1007/s004020050028)
8. Ochi M, Adachi N, Uchio Y, et al. A minimum 2-year follow-up after selective anteromedial or posterolateral bundle anterior cruciate ligament reconstruction. *Arthroscopy.* 2009; 25: 117-122. doi: [10.1016/j.arthro.2008.10.011](https://doi.org/10.1016/j.arthro.2008.10.011)
9. Sonnery-Cottet B, Lavoie F, Ogassawara R, Scussiato RG, Kidder JF, Chambat P. Selective anteromedial bundle reconstruction in partial ACL tears: a series of 36 patients with mean 24 months follow-up. *Knee Surg Sports Traumatol Arthrosc.* 2010; 18: 47-51. doi: [10.1007/s00167-009-0855-4](https://doi.org/10.1007/s00167-009-0855-4)
10. Barber-Westin SD, Noyes FR, McCloskey JW. Rigorous statistical reliability, validity and responsiveness testing of the Cincinnati knee rating system in 350 subjects with uninjured, injured, or anterior cruciate ligament - reconstructed knees. *Am J Sports Med.* 1999; 27(4): 402-416.
11. Park SY, Oh H, Park SW, Lee JH, Lee SH, Yoon KH. Clinical outcomes of remnant-preserving augmentation versus double-bundle reconstruction in the anterior cruciate ligament reconstruction. *Arthroscopy.* 2012; 28: 1833-1841. doi: [10.1016/j.arthro.2012.05.886](https://doi.org/10.1016/j.arthro.2012.05.886)
12. Yoon KH, Bae DK, Cho SM, Park SY, Lee JH. Standard anterior cruciate ligament reconstruction versus isolated single-bundle augmentation with hamstring autograft. *Arthroscopy.* 2009; 25: 1265-1274. doi: [10.1016/j.arthro.2009.05.020](https://doi.org/10.1016/j.arthro.2009.05.020)
13. Kazusa H, Nakamae A, Ochi M. Augmentation technique for anterior cruciate ligament injury. *Clin Sports Med.* 2013; 32: 127-140. doi: [10.1016/j.csm.2012.08.012](https://doi.org/10.1016/j.csm.2012.08.012)
14. Muneta T, Koga H, Ju YJ, Horie M, Nakamura T, Sekiya I. Remnant volume of anterior cruciate ligament correlates preoperative patients' status and postoperative outcome. *Knee Surg Sports Traumatol Arthrosc.* 2013; 21: 906-913. doi: [10.1007/s00167-012-2023-5](https://doi.org/10.1007/s00167-012-2023-5)
15. Hong L, Li X, Zhang H, et al. Anterior cruciate ligament reconstruction with remnant preservation: a prospective, randomized controlled study. *Am J Sports Med.* 2012; 40: 2747-2755. doi: [10.1177/0363546512461481](https://doi.org/10.1177/0363546512461481)
16. Maestro A, Suarez-Suarez MA, Rodriguez-Lopez L, Villa-Vigil A. Stability evaluation after isolated reconstruction of anteromedial or posterolateral bundle in symptomatic partial tears of anterior cruciate ligament. *Eur J Orthop Surg Traumatol.* 2013; 23: 471-480. doi: [10.1007/s00590-012-1018-8](https://doi.org/10.1007/s00590-012-1018-8)
17. Rosenberg TD, Franklin JL, Baldwin GN, et al. Extensor mechanism function after patellar tendon graft harvest for anterior cruciate ligament reconstruction. *Am J Sports Med.* 1992; 20(5): 519-525; discussion 525-526.
18. Kobayashi A, Higuchi H, Terauchi M, Kobayashi F, Kimura M, Takagishi K. Muscle performance after anterior cruciate ligament reconstruction. *Int Orthop.* 2004; 28: 48-51. doi: [10.1007/s00264-003-0502-5](https://doi.org/10.1007/s00264-003-0502-5)
19. Natri A, Järvinen M, Latvala K, Kannus P. Isokinetic muscle performance after anterior cruciate ligament surgery. *Int J Sports Med.* 1996; 17(3): 223-228. doi: [10.1055/s-2007-972836](https://doi.org/10.1055/s-2007-972836)
20. Demirağ B, Ermutlu C, Aydemir F, Durak K. A comparison of clinical outcome of augmentation and standard reconstruction techniques for partial anterior cruciate ligament tears. *Eklemler Hastalıkları Cerrahisi.* 2012; 23: 140-144.
21. Zhang Q, Zhang S, Cao X, Liu L, Liu Y, Li R. The effect of remnant preservation on tibial tunnel enlargement in ACL reconstruction with hamstring autograft: a prospective randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc.* 2012; 22(1): 166-173. doi: [10.1007/s00167-012-2341-7](https://doi.org/10.1007/s00167-012-2341-7)
22. Qi J, Chen J, Chen S, et al. Prospective study on anterior cruciate ligament reconstruction with preserving remnant anterior cruciate ligament by allograft ligament. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi.* 2010; 24: 917-921.