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Evaluation of Quadriceps and Hamstring Muscles' Elastrographic Properties after Anterior Cruciate Ligament Reconstruction

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SUMMARY

Background. Tissue stiffness measurement by ultrasound elastography is commonly used for internal organs and tendons. In this study, rectus femoris, vastus medialis, vastus lateralis, biceps femoris, and semitendinosus muscles' stiffness of patients who underwent anterior cruciate ligament reconstruction surgery was followed up by ultrasound elastography.

Methods. 19 male recreational athletes aged between 18-40 years who had undergone anterior cruciate ligament reconstruction surgery with semitendinosus grafting method were included in the study. All patients received a standardized home exercise program and a standardized supervised rehabilitation program. Thigh muscle stiffness measurements were performed at post-operative first-week, first-month, second-month, and third-month.

Results. There was a significant difference between non-operated and operated knees at first measurement ($p < 0.05$). The second measurement was higher than the first, and the third measurement was higher than the second for both legs ($p < 0.05$). Rehabilitation process has increased muscle stiffness of both legs, and there was still a significant difference between non-operated and operated knees at third month ($p < 0.05$).

Conclusions. Post-operatively decreased thigh muscle stiffness increases with physical rehabilitation. Therefore, ultrasound elastography can be used as an additional follow-up tool. Moreover, theoretically it might be a return to sports criteria if baseline values are available.

KEY WORDS

Anterior cruciate ligament reconstruction; follow-up; muscle stiffness; rehabilitation; ultrasound elastography.

BACKGROUND

Anterior cruciate ligament (ACL) reconstruction is one of the most common surgeries in recent years. Although the surgical technique is critical for the success of the operation, well-structured rehabilitation is as crucial as surgery (1, 2). Despite numerous studies on this topic, postoperative anterior cruciate rehabilitation protocols and objective criteria for follow-up have not yet been standardized (3-5). Ultrasound elastography is a method used to show the structural properties of the tissue. This method measures

the hardness of the tissue in terms of quality and quantity (6). The tissue hardness value is expressed in kilopascals (7). Increasing evidence (8-11) shows that shear-wave elastography can be used to measure the mechanical properties of musculoskeletal tissue in clinical practice (**figure 1**).
This study aims to measure the hardness of the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, and semitendinosus muscles by elastography after the rehabilitation of anterior cruciate ligament repair and to investigate whether it can be used as an objective criterion for follow-up.

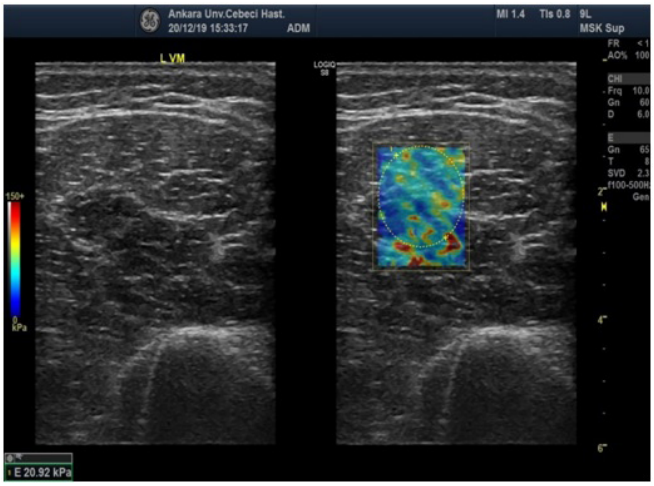

Figure 1. Elastographic evaluation of Vastus Medialis muscle.

MATERIALS AND METHODS

Study design and ethics approval

The study was designed as a prospective study to be held between April 2019 and August 2019. Participants were followed up at post-op first-week, first-month, second-month and third-month.
The study is approved by the Ethics Committee of Ankara University Faculty of Medicine (number: 05-410-19). The informed consents of all participants were obtained. The study meets the ethical standards of the journal (12).

Participants

The participants were recruited from the sports medicine outpatient clinic in Ankara University. 19 male recreational athletes aged between 18-40 who underwent ACL repair (with or without meniscal repair) were included in this study. The reconstruction methods other than the semitendinosus grafting method and patients with chronic illnesses (*e.g.* hypertension, diabetes mellitus, connective tissue disorders) were excluded.

Procedure

At the post-op first-week, elastography measurements, manual circumference measurements, and questionnaires were performed in the outpatient clinic, and home exercises were taught as a standard procedure to be applied until the third week. The patients started rehabilitation in our clinic in the third week. At the post-op first month, manual circumference measurements at mid-thigh and 5 cm superior to the patella, shear-wave elastography measurements (Logiq S8 XD Clear 2.0 Shearwave 9-12 Mhz linear probe, S., 2018) were performed. Also, International Knee Documentation Committee (IKDC) Score and LYSHOLM questionnaires were applied. The same procedures were repeated at the post-op second and third month. The measurements were made by a single person at the same time of the day, with 30 days between them, with clothes that would not tighten the thigh and with a similar level of fatigue.

Rehabilitation protocol

Rehabilitation protocol is presented in the **Supplements** section.

Elastography measurements

All elastosonography measurements were performed by a single musculoskeletal radiologist, who has ten years of experienc in the field, for five muscles around the thigh. In these measurements, the locations of the muscles were marked and muscle thickness was measured. The marking of the locations of the muscles was determined according to the Seniam Criteria (13). To achieve standardization, the points determined by anatomical markers were taken into consideration and the probe angle was placed perpendicular to the muscle orientation and skin as possible in 4 different muscles. For the vastus lateralis, measurements were obtained in the transverse-oblique plane, since the VL fibers in the distal 2/3 thigh were relatively oblique when the probe was positioned perpendicular to the skin.
3 measurements were taken from each region according to the literature(14) and their average was recorded. During the second and third measurements of the patient, the first USG images were simultaneously evaluated by the radiologist on a second computer screen. In consecutive USG examinations, it has been paid attention that the probe angle and the measurement area are the same as the first measurement area.

Questionnaires

The IKDC and LYSHOLM questionnaires are subjective scales that reveal the functional status of the knee. They were both adapted to Turkish (15, 16).

Statistical analyses

Statistical analyses were performed with the SPSS for Windows 20 package program. Spearman correlation coefficient was used to evaluate the elastography values of the operated and intact extremities and manual circumference measurements within themselves, and the Mann-Whitney U test was used to compare them with each other. The significance value for the results was accepted as $p < 0.05$.

RESULTS

Descriptives

The descriptive statistics for sociodemographic data are presented in **table I**.

Comparison of 1st, 2nd, and 3rd elastography measurements of rectus femoris, vastus lateralis, biceps femoris, and semitendinosus muscles

In the elastography measurements of these muscles, the second measurement for both knees was higher than the 1st and the 3rd measurement was higher than the second (**table II**). There was a statistically significant increase in both knees in the measurements ($p < 0.05$).

Table I. General characteristics of patients.

	Mean ± SD**	Minimum	Maximum
Age (years)	30.05 ± 7.84	18	40
Height (cm)	180.1 ± 5.63	171	189
Weight(kgs)	81.4 ± 16.38	57	108
BMI*(kg/m2)	25.1 ± 4.22	17.5	31.5

*BMI: Body-Mass Index; **SD: Standard Deviation.

Table II. Elastographic increase of the measured muscles.

	Operated knee (Mean ± SD*)			Non-operated knee (Mean ± SD*)		
	1st month	2nd month	3rd month	1st month	2nd month	3rd month
Rectus femoris	12.36 ± 3.14	14.63 ± 3.43	16.66 ± 4.46	14.66 ± 3.14	17.07 ± 3.73	17.59 ± 4.1
Vastus lateralis	6.04 ± 2.86	7.91 ± 3.20	8.98 ± 3.71	9.46 ± 4.44	10.54 ± 5.14	10.65 ± 5.01
Biceps femoris	15.44 ± 5.49	19.24 ± 5.49	20.08 ± 5.69	19.09 ± 7.16	21.73 ± 7.79	21.77 ± 7.77
Semitendinosus	16.05 ± 5.65	20.28 ± 5.72	21.37 ± 5.46	20.43 ± 5.85	24.56 ± 6.67	26.27 ± 7.07
Vastus medialis	11.58 ± 3.19	13.27 ± 3.52	15.06 ± 2.98	13.06 ± 2.95	16.07 ± 3.96	16.7 ± 4.29

*SD: Standard Deviation.

Comparison of 1st, 2nd, and 3rd elastography measurements of vastus medialis muscle

In the elastography measurements of the vastus medialis muscle, a statistically significant increase was found only in the operated knee ($p < 0.05$) (**table II**).

Elastographic increase of 5 different muscles in the operated knee

The hardness of 5 different muscles has increased by time (**figure 2**).

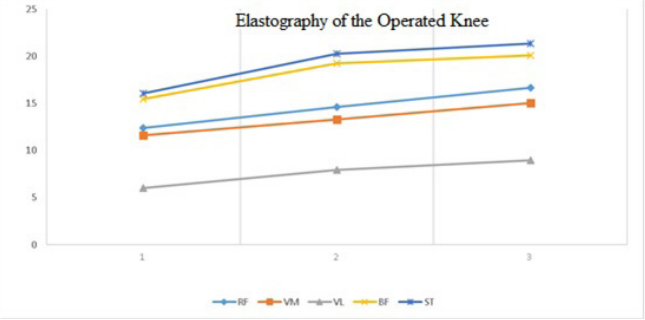

Figure 2. Elastographic Increase of 5 Different Muscles.

Manual circumference measurements

Circumference measurements over 5 cm above the patella and mid-thigh resulted in a statistically significant increase after rehabilitation ($p < 0.05$) (**table III**).

Table III. Circumference measurements of thigh in operated and non-operated knees.

	Operated knee (Mean ± SD*)			Non-operated knee (Mean ± SD*)		
	1st month	2nd month	3rd month	1st month	2nd month	3rd month
5 cm above patella	40.79 ± 3.55	41.97 ± 3.6	42.45 ± 3.58	42.74 ± 3.65	43.47 ± 3.8	43.92 ± 3.75
Mid-thigh	54.5 ± 6.12	55.95 ± 5.8	57.03 ± 5.42	56.68 ± 5.5	57.74 ± 5.5	58.53 ± 5.45

*SD: Standard Deviation.

Comparison of the 1st, 2nd, and 3rd measurements of IKDC and Lysholm Questionnaires

After rehabilitation, the second measurement was higher than the 1st and the 3rd measurement was higher than the 2nd in the questionnaires for both knees. These increases were statistically significant ($p < 0.05$).

Elastography-Questionnaire correlation

The correlation between elastography results and questionnaire scores after rehabilitation was not statistically significant ($p > 0.05$).

Percentage increase of 5 different muscles in the operated knee by elastography

After rehabilitation, the percentage increase between the 1st and 2nd measurements of the rectus femoris, vastus lateralis, biceps femoris, and semitendinosus muscles was higher than the percentage increase between the 2nd and 3rd measurements. For the vastus medialis muscle, this was found to be the opposite.

DISCUSSION

The most important finding of the study was the increase of thigh muscles' stiffness of patients who underwent rehabilitation. As percentage increased between the 1st measurement and the 3rd measurement, the highest increase was found in vastus lateralis. The semitendinosus muscle, which was used as a graft, was in the second row. The percentage increase between the 1st and 2nd measurements was higher than the percentage increase between the 2nd and 3rd measurements. So, it seems that ultrasound elastography might be a method for postoperative follow-up for anterior cruciate ligament reconstructed patients.

Circumference measurements made 5 cm above the patella and mid-thigh level, increased significantly in the follow-up. No statistically significant correlation was found between muscle stiffness and IKDC-Lysholm questionnaires, contrary to the study conducted by Zhang *et al.* (17). But, functional questionnaires include activities such as kneeling, squatting and jumping which are challenging activities for an early post-operative patient. Therefore, statistically insignificant increase in the questionnaires could be attributed to this.

The fact that the sample consisted of only males and that it included a relatively small number of patients can be considered as the limitations of the study. On the other hand, including patients with similar activity levels, all operated with the same technique and a close follow-up period for a relatively long time with a standard rehabilitation program can be considered as the strength of the study.

In a study by Zhang *et al.* (17), Achilles tendon elastography was performed at 12, 24, and 48 weeks after the operationon 26 patients who underwent Achilles tendon repair. There was an increase in elastography measurements in all measurements. In the same study, a statistically significant correlation was found between The American Orthopedic Foot and Ankle Score (AOFAS) and elastography results (17). While the current literature (7, 18-20) is mostly related to tendon elastography in the musculoskeletal field, our study shows elastographic changes in muscle groups and is thought to help identify deficiencies in the rehabilitation phase.

Andonian *et al.* (21) have shown the effect of endurance exercise on elastographic muscle measurement; 50 volunteers of marathon athletes were measured before, in the middle of the race, at the end of the race and 48 hours after the end of the race. Rectus femoris, vastus medialis and vastus lateralis muscles were examined. While the highest values were found in the measurements made in the middle of the run, it was observed that the stiffness values measured 48 hours after the end of the run returned to the pre-run levels. In the same study considering the mid-run values, the highest elastography values were obtained in the rectus femoris similar to our study. However, while the lowest values were obtained from the vastus medialis in that study, in our study it was obtained from the vastus lateralis.

Botanlıoğlu *et al.* (22) have compared patients with patellofemoral pain syndrome with a control group and it was found that the elastographic values of the vastus lateralis muscles were similar in both groups, but the vastus medialis' stiffness values of the patellofemoral pain syndrome group were significantly lower.

When these studies are evaluated together, it is thought that elastographic stiffness measurements of muscles may be a promising method in the future to follow rehabilitation progress, physiological or pathological variations and responses to certain type of exercises. Theoretically, if the baseline values for a person are available, it might be used as one of the criteria for return to sports, but more studies are needed to back up this idea.

CONCLUSIONS

With the progression of rehabilitation after anterior cruciate ligament reconstruction surgery, the stiffness of thigh muscles also increases, indicating that muscle stiffness may be a possible follow-up tool for patients.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

REFERENCES

1. Wright RW, Haas AK, Anderson J, *et al*. Anterior Cruciate Ligament Reconstruction Rehabilitation: MOON Guidelines. Sports Health 2014;7(3):239-43.
2. Ciccotti MG, Lombardo SJ, Nonweiler B, Pink M. Non-operative treatment of ruptures of the anterior cruciate ligament in middle-aged patients. Results after long-term follow-up. JBJS 1994;76(9):1315-21.
3. Saka T. Principles of postoperative anterior cruciate ligament rehabilitation. World J Orthop 2014;5(4):450-9.
4. Shelbourne KD, Foulk DA. Timing of surgery in acute anterior cruciate ligament tears on the return of quadriceps muscle strength after reconstruction using an autogenous patellar tendon graft. Am J Sports Med 1995;23(6):686-9.
5. Shelbourne KD, Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. Am J Sports Med 1990;18(3):292-9.
6. Ophir J, Alam SK, Garra BS, *et al*. Elastography: Imaging the elastic properties of soft tissues with ultrasound. J Med Ultrason 2002;29(4):155.
7. Drakonaki E, Allen G, Wilson D. Ultrasound elastography for musculoskeletal applications. Br J Radiol 2012;85:1435-45.
8. Gennisson J-L, Deffieux T, Fink M, Tanter M. Ultrasound elastography: principles and techniques. Diagn Interv Imaging 2013;94(5):487-95.
9. Taylor L, Porter B, Rubens D, Parker K. Three-dimensional sonoelastography: Principles and practices. Phys Med Biol 2000;45:1477-94.
10. Sacks CD, Gallo RA, Kong L, Cortes DH. Identifying Differences in Elastographic Properties of Calf Muscles and Tendons Across Subsets of Tennis Players. Muscles Ligaments Tendons J 2021;292-300.
11. Gatz M, Betsch M, *et al*. Effect of a 12-week Eccentric and Isometric Training in Achilles Tendinopathy on the Gastrocnemius Muscle: an Ultrasound Shear Wave Elastography Study. Muscles Ligaments Tendons J 2020;10(1):92-9.
12. Padulo J, Oliva F, Frizziero A, Maffulli N. Basic principles and recommendations in clinical and field science research: 2018 update. Muscles Ligaments Tendons J 2018; 8(3):305-7.
13. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2000;10(5):361-74.
14. Zardi EM, Franceschetti E, Giorgi C, Palumbo A, Franceschi F. Reliability of quantitative point shear-wave ultrasound elastography on vastus medialis muscle and quadriceps and patellar tendons. Med Ultrason 2019;21(1):50-5.
15. Celik D, Coskunsu D, Kilicoglu O, Ergonul O, Irrgang J. Translation and Cross-cultural Adaptation of the International Knee Documentation Committee Subjective Knee Form Into Turkish. J Orthop Sports Phys Ther 2014;44:1-30.
16. Celik D, Coşkunsu D, Kiliçoğlu O. Translation and cultural adaptation of the Turkish Lysholm knee scale: ease of use, validity, and reliability. Clin Orthop Relat Res 2013;471(8):2602-10.
17. Zhang L, Wan W, Wang Y, *et al*. Evaluation of Elastic Stiffness in Healing Achilles Tendon After Surgical Repair of a Tendon Rupture Using In Vivo Ultrasound Shear Wave Elastography. Med Sci Monit Int Med J Exp Clin Res 2016;22:1186–91.
18. Taljanovic MS, Gimber LH, Becker GW, *et al*. Shear-Wave Elastography: Basic Physics and Musculoskeletal Applications. Radiogr a Rev Publ Radiol Soc North Am Inc 2017;37(3):855-70.
19. Porta F, Damjanov N, Galluccio F, Iagnocco A, Matucci-Cerinic M. Ultrasound elastography is a reproducible and feasible tool for the evaluation of the patellar tendon in healthy subjects. Int J Rheum Dis 2014;17(7):762-6.
20. Krepkin K, Bruno M, Raya JG, Adler RS, Gyftopoulos S. Quantitative assessment of the supraspinatus tendon on MRI using T2/T2* mapping and shear-wave ultrasound elastography: a pilot study. Skeletal Radiol 2017;46(2):191-9.
21. Andonian P, Viallon M, Le Goff C, *et al.* Shear-Wave Elastography Assessments of Quadriceps Stiffness Changes prior to, during and after Prolonged Exercise: A Longitudinal Study during an Extreme Mountain Ultra-Marathon. PLoS One 2016;11(8):e0161855.
22. Botanlioglu H, Kantarci F, Kaynak G, *et al.* Shear wave elastography properties of vastus lateralis and vastus medialis obliquus muscles in normal subjects and female patients with patellofemoral pain syndrome. Skeletal Radiol 2013;42(5):659-66.

SUPPLEMENTS

Standardized home exercise program
First 3 weeks, repeated everyday.

Isometrics
Adduction with a towel between knees (30 repetitions, 5-10 seconds for each rep);
Adduction with a towel between ankles (30 repetitions, 5-10 seconds for each rep);
Extension with a towel under the knee (30 repetitions, 5-10 seconds for each rep);
Extension with a towel under the heel (30 repetitions, 5-10 seconds for each rep).

Straight Leg Raises (SLRs)
Hip Flexion (3 sets, 10 repetitions for each set);
Hip Extension (3 sets, 10 repetitions for each set);
Hip Abduction (3 sets, 10 repetitions for each set);
Hip Adduction (3 sets, 10 repetitions for each set).

Range of Motion Exercises
Assisted knee flexion with a towel (15 repetitions, 5-10 seconds for each rep);
Prone Hang for knee extension (total of 5 minutes with short breaks in between).

Standardized rehabilitation program in clinic
From 3rd week until 3rd month, repeated every other day.

Warm-up
With bicycle ergometer (5 minutes, 50 watts resistance and 50 rpm)

Straight Leg Raises (SLRs) with weights
Hip Flexion (3 sets, 10 repetitions for each set);
Hip Extension (3 sets, 10 repetitions for each set);
Hip Abduction (3 sets, 10 repetitions for each set);
Hip Adduction (3 sets, 10 repetitions for each set).

Resistance Band Exercises
Hip adduction (3 sets, 10 repetitions for each set);
Hip abduction (3 sets, 10 repetitions for each set);
Hip extension (3 sets, 10 repetitions for each set);
Hip flexion (3 sets, 10 repetitions for each set);
Hip external/internal rotation (3 sets, 10 repetitions for each set).

Open Kinetic Chain Exercises
Knee extension (beginning with assisted to active) (3 sets, 10 repetitions for each set);
Knee flexion (beginning with assisted to active) (3 sets, 10 repetitions for each set).

Closed Kinetic Chain Exercises
Squats (beginning with wall squats and box squats to active with weights) (3 sets, 10 repetitions for each set);
Leg press (3 sets, 10 repetitions for each set).

Proprioception Exercises
Standing on the wobble board with one and two legs (eyes open and closed) (30 seconds, 3 sets);
Half-squats on wobble board with double and one leg (eyes open and closed) (30 seconds 3 sets).

Gait Training
Walking forward, backwards and sideways for total of 10 minutes on treadmill.

Stretching
Hamstring Stretching (15 repetitions, 5-10 seconds for each rep);
Calf Stretching (15 repetitions, 5-10 seconds for each rep);
Quadriceps Stretching (15 repetitions, 5-10 seconds for each rep).