Effectiveness of the Early Strengthening of the Thigh Muscles on the Outcomes of Anterior Cruciate Ligament Reconstruction(ACL-R): A Randomized Clinical Trial

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ABSTRACT

Objective: There is insufficient information on the effectiveness of the early strengthening of the quadriceps muscle in the candidates for Anterior Cruciate Ligament Reconstruction. Therefore, the current study aimed to assess the effectiveness of early interventions for strengthening the abductor, adductor, extensor, flexor, and pronator muscles in pain management, range of motion, quality of life (QOL), and functions of patients following ACL-R operation.

Materials and Methods: This single-blind clinical trial was performed in 2018-19 on 48 candidates for ACL-R at Tabriz University of Medical Sciences. The intervention was initiated 2 days after the surgery, and patients were allocated to two intervention and control groups. The test group received the strengthening intervention, while the control group only benefitted from conventional care, and early physiotherapy was commenced in this group. Subsequently, the outcomes of the two groups were compared using the timed up and go test, stair climb test, 6-minute walk test, muscle strength, visual pain scale, and quality-of-life questionnaire.

Results: In the intervention group, the knee extension range of motion (P=0.007) and knee external rotator strength (P=0.047) significantly increased. On the other hand, the knee flection range of motion (P=0.96), QOL (P=0.414), performance on the 6MWT test (P=0.088), and thigh abductor muscle strength (P=0.225) were not significantly different between the two groups.

Conclusion: According to the results of the present study, both traditional and early physiotherapy approaches can improve unilateral ACL-R outcomes by strengthening the thigh muscles.

Keywords: ACL-R, Physiotherapy, Thigh muscle strengthening

INTRODUCTION

Results of several studies have demonstrated the weakness of the thigh adductor muscles (41%-50%), knee flexors (22%-46%), knee extensors (44%-54%), external rotators (46%-47%), and internal rotators (37%-38%)[1]. The primary role of thigh abductors is to stabilize the thighs in a frontal plate[2,3]. During the standing phase in walking, the weakness of the weight-bearing abductor thigh muscles leads to leaning towards the opposite side and displacing the gravity point to the non-weight-bearing side. This can increase knee adductor torque and pressure on the medial side of the knee[4,5].

In later stages of knee osteoarthritis (before indication for surgery), the strength of the abductor muscles decreases. These patients change walking patterns, walking speed, stride length, and the time leaning on the injured knee to avoid pain and reduce the pressure on the damaged cartilage and knee-buckling[6]. These coping strategies and the reduced activity levels can weaken the thigh abductor muscles at this stage. There is sufficient evidence showing muscle weakness after the knee arthroplasty operation[7]. The main reasons for the continuation of muscle weakness include post-operative pain and avoiding pressure on the operated limb. One month after the surgery, the strength of the

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thigh abductor muscles decreases by 18%, but this weakness is not as severe as that of the knee extensor muscles (36%). As a result, the latter muscles are in priority for strengthening interventions[8].

There is a direct relationship between the strength of the thigh abductor muscles and the clinical outcomes of ACL-R[9]. A study has reported that the strengthening of the thigh abductors after strengthening the quadriceps plays an essential role in improving different functions of patients, such as promoting walking and standing on one leg, stair climbing test (SCT), timed up and go test (TUG), 6-minute walk test (6MWT), and figure of 8 walk test (F8WT)[9]. However, it has little effect on the patients' satisfaction and their complaints. Studies on the effectiveness of strengthening thigh muscles in patients with the replaced knee are generally conducted in two different periods[10]. Some have been completed before the surgery, and others commenced 2-48 months after the operation and exclusively focused on the abductor muscles. Their results indicated that strengthening thigh abductor muscles in different pre- and post-operative stages can be beneficial. However, according to the available evidence, this approach has not influenced the patient-reported outcomes, such as the data acquired by questionnaires. Therefore, the current study was designed and performed to assess the effectiveness of early strengthening interventions for the abductor, adductor, extensor, flexor, and external rotator muscles of the thigh on pain control, range of motion, quality of life (QOL), and patients' function following ACL-R.

MATERIALS AND METHODS

Study Design: This single-blind randomized controlled clinical trial was conducted on 48 patients (44 women and 4 men) who had undergone the ACL-R operation at Shohada and Imam Reza hospitals affiliated with Tabriz University of Medical Sciences, Iran. Based on the inclusion and exclusion criteria, these individuals were allocated to the control group (who received conventional care) and the intervention group (who received both traditional care and thigh muscle strengthening interventions). Participants were included in the study through the convenience sampling method.

Blind Randomization: Randomization was conducted according to the random allocation method. In this approach, 12 pieces of paper with the 'A' mark (the control group) and 12 with the 'B' mark (the test group) were tossed and mixed in a container. Each participant randomly picked a piece of paper, which was not returned to the container. Patients were unaware of the letters ('A' or 'B') denoted to groups. It should be mentioned that the statistician was also unaware of the patient allocation system, and therefore, the study was conducted as a single-blind randomized controlled trial.

Inclusion and Exclusion Criteria: The inclusion criteria were male or female gender, age range of 50-85 years, use of a two-part prosthesis, body mass index (BMI) lower than 40, and cement fixation approach. The exclusion criteria entailed any movement disorder or history of surgical operation, cognitive disorders, abnormal blood pressure, uncontrolled diabetes, being on the list for another operation during the study period, any contraindication for the surgery, and patients' unwillingness to cooperate. Moreover, cases that experienced postop complications, such as hemarthrosis, infection, fracture, wound-healing defect, and deep venous thrombosis, were excluded from the research.

Intervention: Treatment sessions commenced on the second day after the operation on an every-other-day basis. For all patients, Bursts TENS current with the frequency of 150 Hz and the pulse period of 150 microseconds was applied for 20 min. Electrodes were inserted at the two sides of the surgical line (two above and two below the patella), and the current was adjusted to the patients' tolerance. Simultaneous with the electric current, IR was applied to the quadriceps femoris muscle.

All exercises were conducted as three sets of 10 repeats a day (one set in the presence of the therapist and two at home). For pain measurement, the visual analog scale (VAS) consisting of 11 levels was used, with 0 indicating no pain and 10 representing the worst imaginable pain. The flection and extension range of the subjects were measured using a bevel. The center of the tool was fixed on the lateral epicondyle of the femur, with its upper arm paralleled with the long axis of the bone to the side of its great trochanter, and the lower arm parallels with the long axis of the fibula toward the lateral ankle. In order to assess the QOL of the participants, the 36-item short form survey (SF-36) was used, which consists of eight subscales, namely physical function, role physical, bodily pain, general health, vitality, social functioning, role emotional, and mental health, that evaluate the two aspects, physical and psychological health. These subscales scored 0 100, and higher scores show better health status. The test was carried out as follows:

Timed Up and Go Test (TUG): Patients were asked to stand up from an armchair with a specific height, walk for 3 m as fast as they could, and then return to the armchair and sit on it. The test was conducted with ordinary shoes using a walker. The time was measured using a chronometer since standing up from the armchair until sitting on it again.

Stair Climbing Test (SCT): The subjects were asked to climb standard stairs with bilateral handrails as quickly as possible. The patients were allowed to use the handrails. The time was measured using a chronometer.

6-Minute Walk Test (6MWT): The participants were requested to walk as far as they could in 6 min using a walker (if necessary), and the distance was measured using a measuring tape and was recorded.

The strength of the flexors and extensors of the knee, abductors, extensors, as well as the internal and external rotators of the thigh, were measured for each using a hand dynamometer (PCE-FM 1000) following the instructions[4]. All parameters were measured before and after the 10-session treatment period.

Data Analysis: The SPSS software version 22 was utilized to analyze the data. Before the analysis, the Kolmogorov-Smirnov test was applied to investigate the normality of data distribution. When the data were normal, the paired t-test was used in each group, and the independent t-test was utilized to compare the two groups. When the data were not normal, non-parametric tests, including the Wilcoxon rank test instead of paired t-test and Mann-Whitney test instead of independent t-test, were used. In all analyses, $P<0.05$ was considered significant.

Ethical Considerations: The current study was approved by the Ethics Committee of Tabriz University of Medical Sciences (IR.TBZMED.REC.1397.946 and IRCT NO: IRCT20180925041138N2). All participants enrolled in the study after being informed about it and signing informed consent. Extra costs were imposed neither on the participants nor the insurance organizations.

RESULTS

In this study, 48 participants (44 women and 4 men) with a mean age of 62.42±3.59 years, mean height of 163±14.24 cm, mean weight of 72.29±5.19 kg, and mean BMI of 32±3.41 kg/m^2 were included in the research according to the study inclusion and exclusion criteria,

as presented in table 1. Prior to the study, the measured variables did not demonstrate any significant differences between the two groups, indicating the homogeneity of the groups. Comparing all dependent variables before and after the intervention revealed a significant difference, indicating that both treatment approaches were effective.

As shown in table 2, pain severity (P=0.03) and the measured time in the step test (P=0.033) post-intervention were significantly lower in the test group than in the control group. In addition, the strength of the hamstring, flexors, extensors, and thigh adductor muscles post-intervention was significantly higher in the test group than in the control group. However, the time spent on the TUG test (P=0.133) after the intervention did not significantly differ between the two groups. According to table 2, post-intervention, the knee extension range (P=0.007) and the strength of the external rotator muscle of the thigh (P=0.047) significantly increased in the study group compared with the control group. On the other hand, the knee flexion range (P=0.960), QOL (P=0.414), length of motion in 6MWT (P=0.088), and strength of the thigh abductor muscle (P=0.225) were not significantly different between the two groups.

DISCUSSION

In the current study, both groups received TENS current and transcutaneous heat (IR), both activating the pain control mechanisms. Burst TENS current was used in this research with a 150 Hz frequency and a pulse time of 150 microseconds. This is considered an intense short modality with physiological effects which can alleviate pain through activating both pain control mechanisms (pain threshold control and endorphin secretion). Electrical stimulation of the fibers of A-beta mechanical receptors can decrease the sensitivity of WDR cells to pain stimulants and lead to the development of postsynaptic inhibitory signals, reducing pain perception. Furthermore, the activation of A-delta fibers can stimulate some impulses in the midbrain, which move towards the lower parts of the spinal cord and alleviate pain through the descending pain management system and inhibit the pain neurons.

Stimulation of A-delta fibers through exciting the intermediate neurons in the posterior horn along with the secretion of morphine and encephalin can inhibit the signals sent to the C fibers of the central nervous system and alleviate pain. In addition, transcutaneous heat reduces pain by stimulating the efferent fibers through the pain threshold control mechanism and diminishing muscle spasm following the stimulation of the afferent neural receptors of muscle spindles and Golgi tendons. Moreover, strengthening muscles can improve joint stability and prevent involuntary movements, decreasing spasms and pain[1].

Harixavan et al.[11] compared the effectiveness of thigh abductor strengthening exercises and traditional interventions for pain alleviation in two groups of patients with knee arthroplasty surgery. They observed that although pain significantly decreased in both groups, no significant difference was noted between the two groups. The inconsistency between their results and ours could be because, in addition to strengthening thigh abductors, we also focused on strengthening the adductor, flexor, extensor, and lateral rotator muscles of the thigh. In another study, Robinson et al.[12] mentioned that the weakness of the abductor and external rotator muscles of the thigh could decrease eccentric adduction and internal rotation of the thigh during weight-bearing activities. This decreased control can lead to the internal rotation of the femur under the patella and misalignment of the patellofemoral joint, exacerbating pain. Therefore, it can be concluded that a more remarkable increase in the external rotator muscle strength might be associated with more effective pain alleviation in this group of patients. Moreover, Binnel et al.[13] demonstrated that strengthening the abductor and adductor muscles of the thigh can stabilize the trunk and pelvis in the frontal plane and reduce the knee adductor torque, which could have led to more effective pain control in the intervention group in comparison with the control group. This change can be attributed to strengthening the thigh adductor muscles in this group.

The range of motion limitation during the first two or three weeks following the ACL-R may be attributed to post-operative pain, severe swelling of the knee, patient anxiety, and compensatory spasm of the muscles. Two mechanisms can be proposed for the increased range of motion of the joint following heat therapy: 1) the analgesic effect of heat raises the stretch tolerance of the soft tissue, and 2) heat can augment the reshaping capacity of the tissue. Moreover, the effects of

Table 1: Comparison of dependent variables with normal distribution between the intervention and control groups post-intervention using independent t-test

Dependent variable		Difference of Means	Standard error difference	95% Confidence interval		t	P
				Maximum	Minimum		
Range of motion	Flexion	-0.167	3.278	6.631	-6.965	-0.051	0.960
	Extension	-4.083	1.381	-1.218	-6.948	-2.956	0.007
Quality of life		3.667	4.406	12.804	-5.471	0.823	0.414
6MWT		53.707	30.082	116.094	-8.679	1.785	0.088
Thigh external rotator		1.351	0.641	2.682	0.021	2.107	0.047
Thigh abductor		0.904	0.724	2.407	-0.598	1.248	0.225

Table 2: Comparison of dependent variables with normal distribution between the control and intervention groups using the Mann-Whitney test

Dependent variable	Z	P
Pain	-2.155	0.03*
TUG	-1.790	0.073
STEP	-2.136	0.033
Quadriceps	-1.501	0.133
Hamstring	-2.281	0.023*
Thigh flexor	-2.050	0.040
Thigh extensor	-2.194	0.028*
Thigh adductor	-2.050	0.040

heat on the viscosity and expansion capacity of the collagen fibers have been well documented[14,15].

The therapeutic effects of heat in enhancing the joint range of motion could be attributed to the enhancement of pain and muscle spasms. Therefore, one of the mechanisms of the improvement in the range of motion in both groups might be pain alleviation by the modalities. It may be suggested that as the exercises that enhance the range of motion were similar in the two groups, the range of motion was not significantly different. However, it was expected that strengthening thigh muscles would result in an improved range of motion by activating the synergic muscles of the knee. Heiberg et al.[16] indicated that knee range of motion could significantly vary from one week to three months following the operation. However, it does not have a significant fluctuation 3-9 months after the surgery. According to a study by Cornosht et al.[17], the most significant improvement in the knee flexion range of motion occurs in the fourth week post-intervention, and the most prominent enhancement in the extension range of motion is achieved during the first two weeks following intervention. The most significant improvement in the flexion range of motion occurs 3 months after the surgery, and the most favorable enhancement of the extension range is attained 6 months after the intervention. In the research by Heiberg et al.[16], the flexion range did not improve up to 9 months postop, while the extension range was not different from its pre-operative state.

In this study, QOL was assessed utilizing the SF-36. Pain and spasm alleviation was the leading cause of promoted QOL. The SF-36 evaluated both physical and psychological health. The improvement in the QOL of the participants in both groups may be attributed to pain control which led to spasm alleviation and risen ranges of motion. Movement is one of the most critical aspects of both individual and social life, and any hindrance to motion can seriously affect psychological health. Many factors are involved in the healthy movement process, such as pain intensity, range of motion, muscle strength, and stability of the joints. It was found that strengthening the thigh muscles would lead to increased stability of the proximal section, healthy movement, enhanced personal functions, and higher social confidence, which would ultimately improve the quality of their lives. The lack of significant difference between the two groups may be due to the short interval between surgery and assessment. Scash et al.[18] reported that in the initial post-operative stages, performing the tasks which had been difficult and painful became pain-free, enhancing the patient's satisfaction and improving QOL. According to the studies conducted by Piva[19], Alnahdi[20], and Scash[1], there is no relationship between muscle strength and QOL, which contradicts our findings.

The main objective of this study was to investigate the effectiveness of early muscle-strengthening interventions compared with the traditional approach to the function of patients who had undergone ACL-R. Following the ACL-R, the general weakness of the lower limb muscles and movement difficulties, such as decreased speed of climbing and descending stairs and difficulty standing up from a chair compared to an individual of the same age. The main focus of most studies on the outcomes of ACL-R is on the interventions and exercises on the knee itself. This may be argued that other joints, particularly the hip, can be responsible for the disability and malfunction following ACL-R surgery. Several studies have demonstrated that in patients with knee osteoarthritis, there is a weakness in the thigh abductor muscles in comparison with healthy individuals[21].

In the initial post-operative stages of ACL-R, patients' functions decrease, and this malfunction improves 1-6 months after the surgery, and the most significant improvement occurs 1-3 months after the operation. It should be noted that this limitation of movement may persist up to 1 year after the surgery. It appears that the observed improvement in the functions of the two groups after ten sessions was due to the alleviation of pain and spasm, as well as the increased range of motion and strength of the lower limb muscles. Favorable results depend on the strength of the quadriceps and thigh abductor muscles. Alnahdi et al.[20] investigated the relationship between the strength of the quadriceps muscle and patients' functions. These authors indicated that when these muscles become stronger, the results of TUG, SCT, and 6MWT improve. The same strength of these muscles in the test and control groups may cause the lack of significant difference in the improvement of the elapsed time in the TUG and the distance in the 6MWT one month after the surgery in the current study. Patients with stronger lower limbs have less difficulty performing everyday tasks, which indicates a relationship between the strength of the lower limb muscles and functional performance.

One of the thigh quadriceps muscle functions is to synchronize flexion during walking. Therefore, the weakness of this muscle can lead to an asymmetrical walking pattern and a diminished ability to walk and climb stairs. Decreased strength of this muscle can persist for several years after the surgery, and its strengthening can lead to recovery 3-12 months' post-intervention. Moreover, one of the main functions of the thigh abductor muscle is to maintain the stability of the trunk and pelvis while walking, particularly standing on one leg phase, controlling the alignment of the limb, and transferring weight from the lower limb to the pelvis. The weakness of this muscle is responsible for the functional impairments of the elderly. According to Piva et al.[19], the relationship between the weakness of the thigh abductor muscles and physical performance is three times higher than that of the quadriceps muscle. Based on the study by Hariksavan et al.[11], which included control and intervention (strengthening of the quadriceps muscles) groups, the outcomes of TUG 1 and 3 months following surgery were not significantly different. However, in both groups, there were improvements due to strengthening the quadriceps muscles and pain alleviation. Most malfunctions occur during the first month postop due to the weakness of the quadriceps and thigh abductor muscles at this time, and three months after the operation, the outcomes become similar to those before the surgery, and most improvements are observed one year later. One year after surgery, the intervention group demonstrated more significant performance improvements. The mentioned study confirms the findings of the current research, and it can be proposed that if the current intervention was continued for a more extended period, the results in the test group would become more prominent compared to the control group. The results of Scash et al[1]. were consistent with the present investigation and showed that strengthening thigh muscles is not necessary for improving functional outcomes 6- and 26-weeks following ACL-R.

Post-intervention, the strength of knee extensor and flexors, as well as the flexors, extensors, adductors, and external rotators of the thigh, had significant differences. In both groups, significant increases were observed. The alleviation of pain and enhancement of blood circulation following the aforementioned modalities provides a favorable environment for the muscles in terms of providing nutrients to them, thereby facilitating muscle repair and hemostasis. The ultimate result is the improved strength of muscles.

The weakness of thigh abductor muscles before surgery results from the altered walking pattern, decreased walking speed, reduced stride length, longer standing on both legs, and diminished activity. This weakness persists after surgery due to lower weight-bearing because of pain and the altered walking habit developed before the operation. The results of Levid[22] and Harixavan[11] are in line with our findings.

They demonstrated that the decline in the strength of the quadriceps and thigh abductor muscles due to reduced weight transferring to the operated limb continues until one month after the operation.

CONCLUSION AND RECOMMENDATIONS

According to the findings of the current study, it can be generally asserted that both traditional and early thigh strengthening physiotherapy approaches can be effective in improving the operation outcomes following ACL-R. The traditional physiotherapy approach was more effective on some variables than other variables when combined with thigh muscle strengthening. In addition, several studies have shown that strengthening thigh muscles along with usual treatments can be influential in improving the outcomes of ACL-R several months postop. Consequently, in order to promote the outcomes of ACL-R, it is proposed that physiotherapists commence early thigh muscle strengthening interventions besides their usual treatment plans. The main limitations of the present study were incomplete follow-up measures due to the unavailability of the patients and the operation of subjects by different surgeons because of selecting the participants from two hospitals. Studies on larger samples in the field of ACL-R are recommended. Moreover, preliminary evaluations and later assessments several months after the surgery should be taken into consideration.

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