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Recovery of Quadriceps Strength and Knee Function Using Adjuvant EMG-BF After Primary ACL Reconstruction

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Abstract

Introduction: Immobility and limited usage of operated limbs lead to weakness and atrophy of the muscle after anterior cruciate ligament (ACL) reconstruction. However, training programs for preventing biomechanical risk factors such as lower limb alignment and increased muscular contraction are very limited. Thus, the current study was carried out to evaluate the recovery of quadriceps muscle strength and the improvement of knee function using adjuvant electromyographic biofeedback (EMG-BF) after ACL reconstruction.

Methods: This prospective randomized controlled trial was conducted among 40 patients (20 = EMG-BF group, 20 = Control group) with ACL reconstruction, who were referred to Akhtar Hospital from 2021 to 2022. In the EMG-BF group, EMG BFB was added to the standard rehabilitation protocol, and in the control group, the standard rehabilitation protocol with full postoperative weight-bearing, knee brace (zero degree of extension, 90 degrees of flexion), and electrical stimulation with maximal voluntary isometric knee extension was performed. Each group was intervened for 4 weeks and three sessions of 30 minutes per week. It should be noted that each patient participated in 16 outpatient physiotherapy sessions after surgery. Nicholas Hand-Held Dynamometer (HHD) was used for measuring quadriceps strength, and Knee Outcome Survey-Activities of Daily Living (KOS-ADLs) and Knee Outcome Survey Sports Activities Scale (KOS-SAS) questionnaires were used for assessing the knee function.

Results: Four weeks after the treatment, the EMG-BF group showed a significant increase in quadriceps strength ($P = 0.0001$). Quadriceps strength had a significant difference before and after 4 weeks of intervention ($P = 0.0001$), but in the control group, no significant difference was observed ($P = 0.368$). The EMG-BF group had a significant increase in KOS-ADLs and KOS-SAS scores after 4 weeks of intervention ($P = 0.0001$).

Conclusion: In our study, isometric strengthening of quadriceps with adjuvant EMG-BF significantly increased the strength of quadriceps and knee function during 4 weeks. EMG-BF is a low risk, low cost, and less invasive intervention and has high safety and adjustment ability. It is a valuable adjuvant method for achieving better functional recovery in a shorter time.

Keywords: Electromyographic biofeedback; Adjuvant method; Quadriceps strength; Rehabilitation; Anterior cruciate ligament reconstruction.

Introduction

Anterior cruciate ligament (ACL) injury weakens 5%-40% of quadriceps strength.[1] Immobility and limited usage of operated limbs lead to the weakness and atrophy of the muscle after ACL reconstruction. The most muscular weakness happens in the first months after the reconstruction of ACL, and the interior part of quadriceps is affected more. Recovery of strength and function of quadriceps muscle is the primary focus of rehabilitation protocols of ACL. Therefore, starting strengthening exercises of quadriceps muscle during the first days after knee operation is very important

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for reducing muscular atrophy. Recovery of muscular strength is a determinant factor for patient's return to activity after the reconstruction of ACL.[1-3] After ACL reconstruction, the extra contraction of quadriceps muscle could lead to increased vertical strengths on the knee joint, a tendency to reduced movement of the knee joint during foot collision with the ground, knee stiffness, and endangered knee mobility and stability.[4] These would result in disrupted neuromuscular control of the lower limb, delay in return to exercise activities, and increased secondary injury to ACL after its reconstruction. Thus, neuromuscular exercises should be with concomitant strengthening exercises.[5,6] However, training programs for preventing biomechanical risk factors such as lower limb alignment and increased muscular contraction are very limited.

One of the common methods is electrical stimulation (ES); in this method, branches of intramuscular motor nerves are activated and cause muscle contraction. ES has previously been assessed by many researchers. Electromyographic biofeedback (EMG-BF) is another method used for increasing muscular activity and contraction.[7,8] Despite ES, biofeedback requires patients to be involved in all levels of the nervous system during second learning for the contraction of quadriceps.

Biofeedback is an instrument that uses myoelectric signals to help retraining of muscles, and depending on diagnosis, it could be applied for the reduction or enhancement of muscle activity.[9] Many studies have supported biofeedback for the rehabilitation of neural and musculoskeletal systems during the past decade. In early studies, the focus of researchers was on the quadriceps head and knee. However, ample evidence exists now and biofeedback is used for other orthopedic injuries in different situations. During 1990-1991, Drapper and Ballard studied EMG-BF effect on the function of quadriceps muscle after the reconstruction of ACL, and they reported that biofeedback is more effective than ES only for the facilitation of knee extension recovery.[10]

Several studies on patients with patellofemoral pain syndrome have acknowledged the effectiveness of EMG-BF in combination with conventional quadriceps muscle training for the improvement of symptoms and muscle strength.[11-14] Studies also indicate the increasing recovery of knee extension and range of motion and higher output of EMG by using biofeedback after knee operation.[15,16]

Usefulness and effects of EMG-BF combined with training on the extension range of the knee joint have been reported previously.[17,18] Up to our knowledge, no evidence exists on the effectiveness of EMG-BF as an adjuvant method with isometric exercises for improving treatment efficacy or knee function after ACL reconstruction in the Iranian population. Accordingly, in the present study, we tried to apply EMG-BF as an adjuvant method in rehabilitation protocols of orthopedic patients.

In this study, we evaluated the effects of isometric quadriceps amplification combined with adjuvant EMG-BF and isometric exercise alone to determine whether, after ACL reconstruction, each of the two programs had advantages over the other over a 4-week training period. Does either of these two programs have an advantage over the other in choosing a rehabilitation protocol to improve knee function and recover quadriceps muscle strength over a 4-week training period?

Materials and Methods

Sampling Method

Forty patients were selected sequentially using the simple non-random sampling method, and they were randomly divided into two groups of 20.

Methods

In this randomized clinical trial (identifier: IRCT20211113053048N1; https://www.irct.ir/trial/60043), 40 patients after ACL reconstruction were recruited in Akhtar Hospital, Tehran, Iran, from 2021 to 2022. Inclusion criteria included participants aged between 18 and 30 years confirmed ACL rupture based on clinical examination and MRI by an orthopedic surgeon, participants aged between 18 and 30 years confirmed ACL rupture based on clinical examination and MRI by an orthopedic surgeon, semitendinosus and gracilis tendon autograft, ability to move without orthopedic aids before and after surgery, unilateral ACL reconstruction, at least 2 weeks after surgery, and consent was based on participating in the study. Participants with pain and inflammation of the knee, a history of neuromuscular disease, different length of the lower limbs, substance use, a history of systemic peripheral and central nerve diseases with ataxia, a history of taking medications affecting balance, a history of psychiatric disorders, visual and auditory diseases, performing other therapeutic and physiotherapeutic methods during the study, body mass index (BMI) > 35 kg/m^2, non-consent to participate in the study were excluded from the study. Sixteen physiotherapy sessions were done for each patient by the same therapist. Then, the participants were divided into two intervention and control groups based on a random number table.

Intervention group (EMG-BF): EMG-BF was added to the standard rehabilitation protocol. These patients underwent a maximum voluntarily isometric contraction with an EMG-BF guide. EMG-BF (manufactured by Thought Technology, Canada), BioGraph Infiniti Software, and EMG MyoScan-Pro™ Sensor - T9401M-60 sensors were used. Applied electrodes were tripolar silver chloride and T3402M-Triode Electrodes with a standard distance of 20 mm. The used sensor was configured based on Low Sampling Rate and measurement of root mean square (RMS) SEMG. Device's impedance was 1 000 000 MΩ and common mode rejection ratio > 130 dB CMRR.

To decrease impedance, we cleaned the skin by shaving hairs and using cotton and ethanol-C2H5OH) %70. Electrodes were placed on VMO muscles. The VMO muscle electrode was placed obliquely, 55 degrees above muscle's bulk, 4 cm above patellar edge, 3 cm distant from the medial side of upper patellar edge and 20 mm apart. The reference electrode was placed on tibia tuberculous. The intervention was done every other day for 4 weeks and 12 sessions. Patients' follow-up was recorded before the intervention and after 12 sessions of intervention. Furthermore, before the intervention, the participants were trained about the method of intervention and biofeedback. On the first day after the first examinations, the intervention was done in a separate quiet room in the lab. The intervention started during the first week after surgery. Each group underwent intervention for 4 weeks, and they received 3 sessions of intervention for 30 minutes weekly. After the intervention, the function and strength of muscle were measured by the same method of measurement before the intervention.

EMG-BF included exercises for the improvement of vastus medialis and real-time visual and auditory control by computer. The exercises constituted a maximum isometric extension of knee, standing on one foot, mini squats, and so on. In each session, the patient had to increase his own EMG threshold level.

Control group: In this group, standard rehabilitation was performed with full weight bearing after surgery, knee brace (zero degree extension and 90 degree flexion) and electrical stimulation with maximal voluntary knee isometric extension (Figure 1).

Measurement of the Knee Function

The KOS self-reported questionnaire was used to measure the function of the knee joint. This questionnaire assesses knee disorders with two mini scales: Knee Outcome Survey-Activities of Daily Living (KOS-ADLs) and Knee Outcome Survey Sports Activities Scale (KOS-SAS), showing different knee injuries with one score. The ADLs scale has 14 items related to daily activities: 6 items related to the effect of knee symptoms on performing usual daily activities (pain, stiffness, swelling, weakness, and feeling of giving out, and claudication) and 8 items for limitations in functional activities (going upstairs and

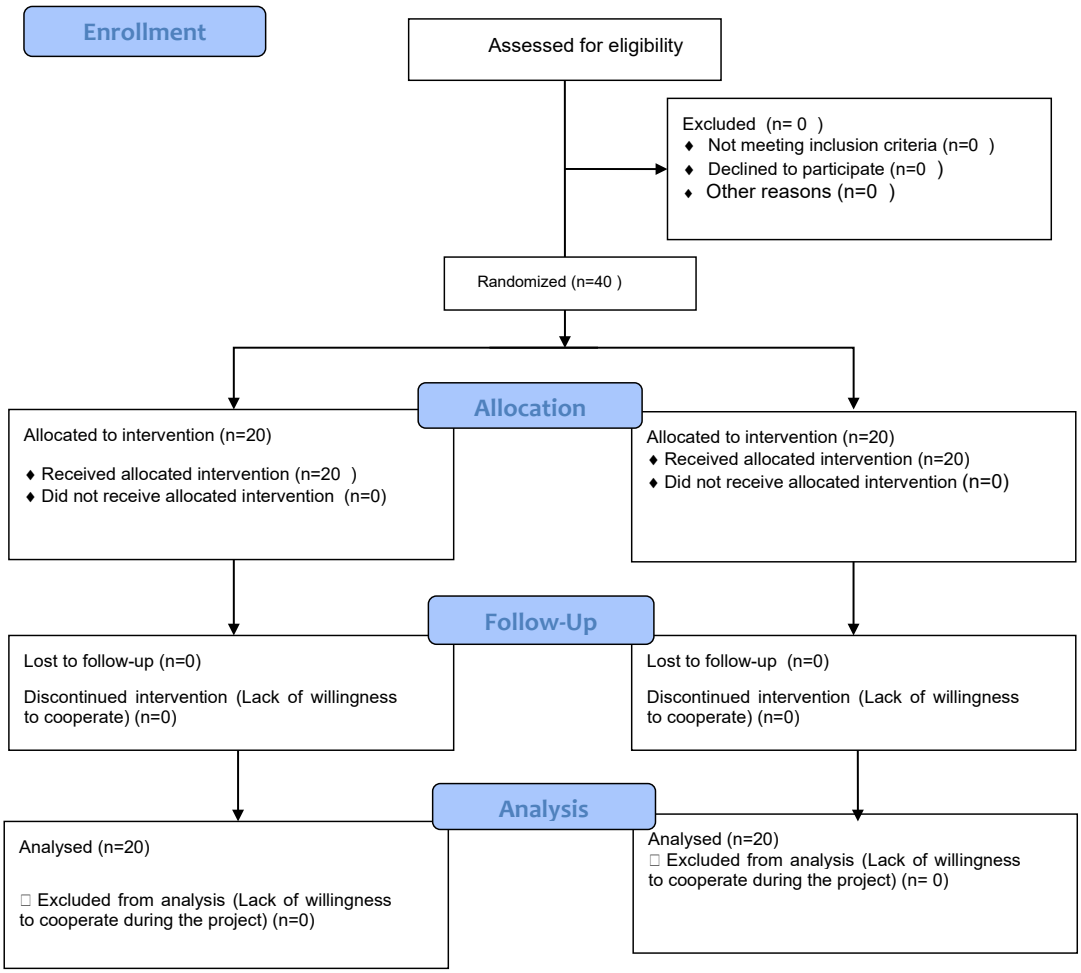

Figure 1. Consort diagram

downstairs, standing, kneeing, squatting, sitting cross-legged, and standing up from a chair).[19]

The SAS scale has 11 items related to exercise and leisure activities: 7 items related to the effect of knee symptoms on the ability to perform exercise and leisure activities (pain, stiffness, swelling, weakness, and complete or partial feeling of giving out) and 4 items for such skills as running, jumping, landing, sudden stop, rapid movement, rapid displacement, and rotation).[20]

Each question is scored from 0-5, and the ADLs score is from 0-70 and the SAS score from 0-50. The total score is represented in percent; lower percent shows more disability.

Measurement of Quadriceps Strength

Nicholas Hand-Held Dynamometer (HHD) was used for measuring quadriceps strength (Figure 2). Previous techniques for manual measurement of muscle strength have lower reliability because of difficult application in the clinic setting and being dependent on the experience of therapists. However, in this technique (HHD), therapists' judgment is not important in spite of the other techniques. HHD is a digital tool for measuring strength with the measurement ability of assessing 0-199.99 kg. Participants before the test have a calm body warm-up, performing stretching activities in a static cycle. These repeated exercises are performed progressively by the patient; in this way, in the first stage, the person applies 25%, the second stage, 50%, the third stage, 75%, and the fourth stage, 100% of his total power, all these contractions are done in the standard position. During the test, strength pads should be placed 2 inches above the lateral malleolus in front of the leg. In 5 seconds, participants should reach the maximum contraction; meanwhile, the test taker holds the tool and fixes the pelvis. The start of the contraction is with this order: push up against tool direction, push with whole strength, push with more power, relax, and after this the strength level is read and recorded.[21] The tool is calibrated before use (Figure 3).

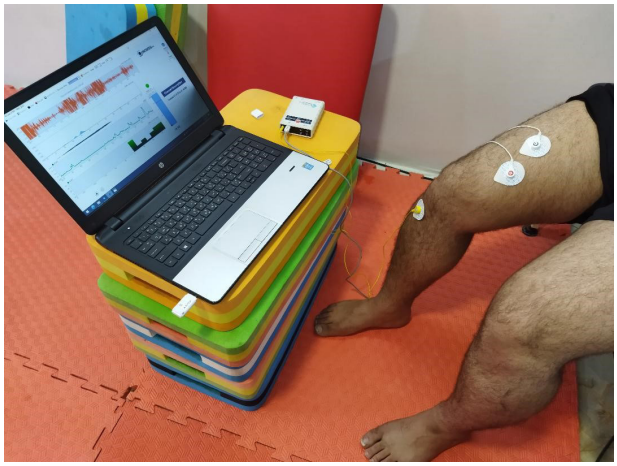

Figure 2. Measurement of Maximum Muscle Strength Test, and Isometric Contraction Using Nicholas Hand-Held Dynamometer

Statistical Analysis

The coded data then were entered in SPSS software version 19. Mean and standard deviation were measured for quantitative variables such as age. The mean comparison of the two groups was performed by the t-test, Mann-Whitney U test, and paired t-test. The Kolmogorov-Smirnov test was used for testing the distribution of the data. $P < 0.05$ was considered significant.

Results

Participants in this study were 40 males. Demographic characteristics of the two groups are shown in Table 1.

The comparison of quadriceps strength between the two groups is depicted in Table 2. Four weeks after the treatment, the EMG-BF group showed a significant increase in quadriceps strength.

Table 3 shows the comparison of knee function based on the KOS-ADLs score. The EMG-BF group had a significant increase in the KOS-ADLs score after 4 weeks of intervention.

Table 4 describes the comparison of knee function based on the KOS-SAS score between the two study groups. The KOS-SAS score had a significant increase in the intervention group after 4 weeks.

Quadriceps strength had a significant difference before the intervention and 4 weeks after the intervention ($P = 0.0001$), but in the control group, no significant difference was observed ($P = 0.368$).

Changes of KOS-ADLs before the treatment and 4 weeks after the treatment were significantly different in both EMG-BF ($P = 0.0001$) and control groups ($P = 0.007$). Moreover, the KOS-SAS score had a significant difference before the intervention and 4 weeks after the intervention in both EMG-BF ($P = 0.0001$) and control groups ($P = 0.021$).

Discussion

Up to our knowledge, this is the first investigation which assessed the effect of isometric strengthening of quadriceps muscle with an adjuvant method of EMG-BF after the ACL reconstruction of the Iranian population.

The current study showed that quadriceps strength and knee function has a significant improvement by using 4 weeks of isometric strengthening of quadriceps muscle with EMG-BF. EMG-BF is a physiotherapeutic technique that is applied in combination with other exercise programs, such as strengthening exercises for pain relief and muscle strengthening in knee osteoarthritis.[22-26] Strengthening exercise with an EMG-BF guide with active muscle involvement encourages patients to play an active role in achieving therapeutic rehabilitation targets during the exercise and training course.[7,24]

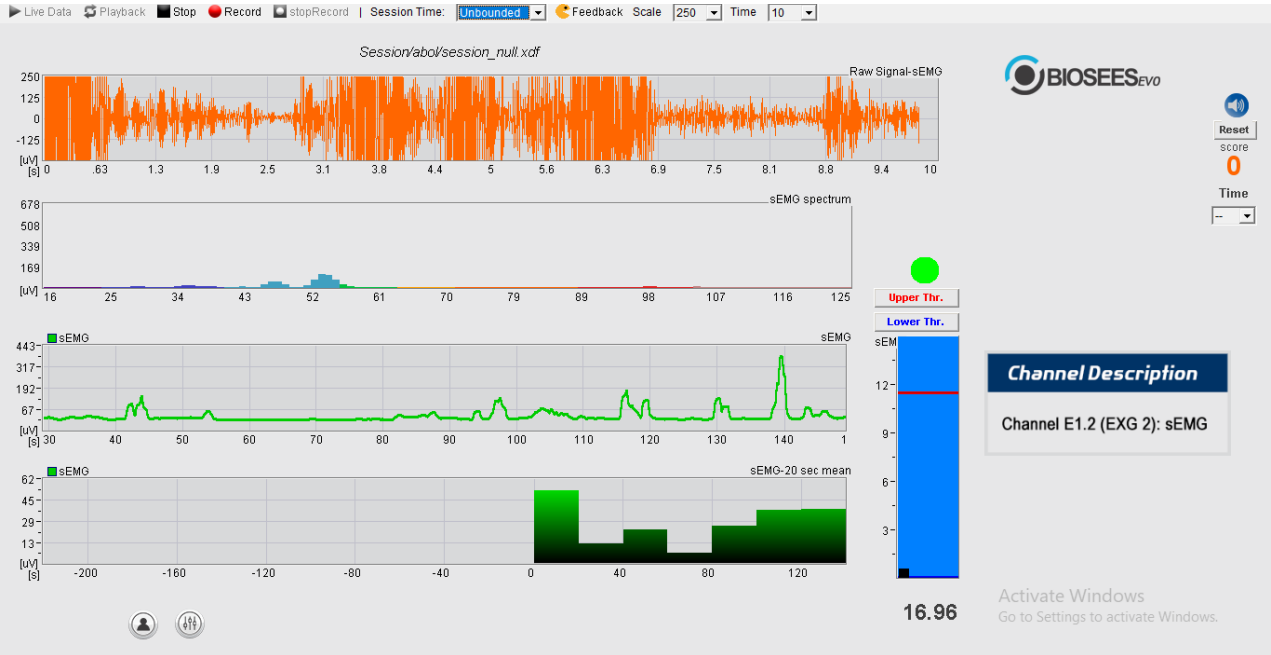

Figure 3. Measurement of Maximum Muscle Strength Test, and Isometric Contraction using Nicholas Hand-Held Dynamometer

Table 1. Comparison of Demographic Characteristics of the Two Study Groups

Variable	EMG-BF Group	Control Group	*P* Value
Age (y)	3.2 ± 23.2	3.5 ± 22.9	0.633
Weight (kg)	14.1 ± 73.4	14.9 ± 76.3	0.499
Height (cm)	8.8 ± 176.4	6.2 ± 176.2	0.934
BMI (kg/m^2)	3.3 ± 23.5	3.8 ± 24.4	0.399

Table 2. Comparison of Quadriceps Strength Between the Two Study Groups

Muscle Strength (kg)	EMG-BF Group	Control Group	*P* Value
Baseline level (before treatment)	1.2 ± 14.9	1.1 ± 15	0.891
After 4 weeks	1.1 ± 19.5	1.2 ± 16	0.0001

Table 3. Comparison of Knee Function Based on KOS-ADLs Score Between the Two Study Groups

KOS-ADLs Score (%)	EMG-BF Group	Control Group	*P* Value
Baseline level (before treatment)	7.4 ± 68.8	8.2 ± 62.2	0.012
After 4 weeks	7.4 ± 79.8	7.2 ± 65.5	0.0001

Table 4. Comparison of Knee Function Based on KOS-SAS Score Between the Two Study Groups

KOS-SAS Score (%)	EMG-BF Group	Control Group	*P* Value
Baseline level (before treatment)	9.0 ± 50.7	8.9 ± 50.0	0.834
After 4 weeks	7.3 ± 68.3	7.5 ± 53.0	0.0001

Strengthening exercises are performed with the guide of a specific biofeedback device that records measured muscular tone and tension in microvolts using superficial or needle electrodes.[7,8,27,28] In this method, patients could be informed of their own muscular tension changes (decrease or increase) visually or auditorily. Thus, they could control and correct their own muscular tension by using a biofeedback device.[8,29]

Study Limitations

All the patients of this investigation were male; thus, the results could not be generalized to females. The follow-up period of the patients was 4 weeks. Isometric strengthening of quadriceps with adjuvant EMG-BF after ACL reconstruction needs to be assessed in a longer follow-up period.

Although EMG-BF is used frequently in a headache and a stroke, its application in exercise and musculoskeletal disorders is limited. The current study indicated that using an adjuvant EMG-BF method with isometric exercises of quadriceps could be a potential therapeutic method for improving muscle strength and function of the knee joint in the rehabilitation of patients after ACL reconstruction. Furthermore, strengthening exercise with EMG-BF combined with isometric exercises of quadriceps is possible and has the potential for maximizing the recovery of patients after ACL reconstruction in the rehabilitation period. Additionally, EMG-BF helps to initiate primary and intense exercises if the patient has limitations for performing dynamic strength techniques.

Conclusion

In our study, isometric strengthening of quadriceps with adjuvant EMG-BF significantly increased the strength of quadriceps and knee function during 4 weeks. EMG-BF is a low risk, low cost, and less invasive intervention and has high safety and adjustment ability. Also, EMG-BF is a valuable adjuvant intervention method for achieving

functional goals faster. For more definite clinical recommendation, future studies with longer follow-up periods and higher sample sizes are recommended.

Competing Interests

The authors claim no conflict of interest.

Ethical Approval

This study was approved by ethical committee of Shahid Beheshti University of Medical Sciences under the ethical approval code of "IR.SBMU.RETECH.REC.1399.1014"

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