# Comparing the Effect of Transcutaneous Electrical Nerve Stimulation, Biofeedback Electromyography and Functional Electrical Stimulation on Quadriceps Disinhibition after Anterior Cruciate Ligament Reconstruction

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## Abstract

**Introduction:** Patients who undergo ACL injury can resume their normal activity although quadriceps strength and activity might be weak or limited after the surgery. The present study aimed to compare the effect of Transcutaneous Electrical Nerve Stimulation (TENS), Functional Electrical Stimulation (FES) and Biofeedback Electromyography (B-EMG) on improvement in quadriceps strength and mean value of VMO activation pattern (MVVA) among patients with reconstruction of ACL. **Materials and Methods:** The study was designed as a randomized control trial. 102 patients, who filled a demographic questionnaire relating to important factors mainly age, height, and weight before the intervention, (all sportsmen) were randomly divided into four groups known as, FES (n=21), TENS (n=21), B-EMG (n=22) and control (n=38). In this study, hand-held dynamometry and biofeedback electromyography were respectively used to assess Quadriceps strength and MVVA. All samples were evaluated at three different time intervals, including prior to the, after and 4 weeks after the treatment. Additionally, all four groups received Ice pack around the knee and Michle Duck exercise therapy protocol. The treatments provided totally lasted 3 to 5 weeks. The participants in 4 groups received TENS, FES and B-EMG as their main treatments 5 times a week for 45, 15 and 15 minutes successively. **Results:** The mean scores of MVVA and quadriceps strength after the intervention and after the follow-up increased significantly in all four groups. However the effect of FES on MVVA in comparison with TENS and control group was statistically meaningful in favor of FES group. (As instructed here the last sentence omitted) **Conclusion:** TENS, FES and B-EMG in combination with cryotherapy and exercise as well as the combination of cryotherapy and exercise can reduce VMO inhibition and improve quadriceps strength in patients who undergo ACL reconstruction. However FES in combination with cryotherapy and exercise can be the most effective one.

**Key words:** Quadriceps Inhibition- ACL Reconstruction - Functional Electrical Stimulation- TENS- Biofeedback

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## Introduction

Rupture of the anterior cruciate ligament (ACL) is common and costly. Approximately 250,000 ACL injuries occur in the United States annually at an average cost of $25,000 per reconstruction. ACL reconstruction is third among the most common surgeries performed by surgeons (1). Although ACL reconstruction restores static knee stability and rehabilitation improves functionality, patients often return back to activity with diminished quadriceps strength (2). Quadriceps weakness is related to defectively /less functional performance, the potential for re-injury and is also linked to the development of post-traumatic osteoarthritis (3) that occurs in more than 50% of ACL reconstructed limbs. As the peak age for ACL rupture is 16, it is likely that a significant number of adults in 20 to 30 age range suffer from the debilitating symptoms associated with osteoarthritis (4). In spite of the fact that the precise mechanism(s) of quadriceps weakness associated with ACL reconstruction are unknown, there is evidence suggesting that quadriceps activation failure (QAF) and possible quadriceps muscle atrophy are primarily responsible for strength deficits (5). QAF which is common after undergoing ACL reconstruction (6) is the inability in completely volitionally contracting the muscle due to some alterations in neural signaling. On the other hand, muscle atrophy occurring after ACL reconstruction is thought to be manifested because of some alterations in selective fiber atrophy, muscle architecture, or even as a consequence of QAF (7). These factors, when are taken together, explain more than half of the variance in quadriceps strength deficits post-ACL injury (8); consequently, QAF and muscle atrophy are attractive factors to be examined as effective element in improving the quadriceps strength. Quadriceps activation failure which has been suggested by many researchers to be an underlying factor contributing to strength deficits is called a limiting factor in joint rehabilitation(6), as a result alterations in neural activity should be addressed before engaging in exercise (5).

It is important to note that traditional rehabilitation methods have not focused on improving the quadriceps activation before muscle strengthening (10). It has been suggested that clinicians should first restore quadriceps activation. Once volitional activation is improved, a more optimal neural environment should allow strength gains to be realized (5). The importance of the quadriceps muscle in knee joint health necessitates the development of the rehabilitative approaches capable of improving the recovery of quadriceps strength (11). While the effect of methods such as exercise therapy, cryotherapy, transcutaneous electrical nerve stimulation (TENS), functional electrical stimulation(FES) and biofeedback electromyography (B-EMG) has been investigated in the previous studies and the positive influences of them have been already reported (12,13,14,15,16) there has been no study carried out to compare these methods and to find out the most effective one. The present research aimed to compare the effect of TENS, FES and B-EMG on improving the quadriceps strength and mean value of VMO activation pattern (MVVA) in patients experiencing the reconstruction of ACL with those in control group. This is the first RCT to investigate the disinhibitory effects of a battery of interventions. However, the current research does have limitations.

## Materials and Methods

The study was designed as a randomized control trail and had the ethics certification from the medical ethics committee of Tehran Medical Sciences University. Patients who were diagnosed with ACL reconstruction based on their medical history and examination were selected and introduced by orthopedists to participate in this study.

The purpose of the study was explained to the participants and those with inclusion criteria, including age range between 18 and 40 years, 14 day time interval after ACL reconstruction by hamstring out graft and minimum 60 degree flexion ROM, were enrolled in the study after completion of a consent form. Patients with unusual pain or effusion, infection, concomitant surgery (except *meniscectomy*) and second or third revision were excluded.

***Participants***

A total of 102 patients with average age of 25.07 years old (all sportsmen) were randomly divided into four groups of TENS (n=21), FES (n=21), B-EMG (n=22) and control (n=38) by using random blocks with volume 4 by PROC Plan method. It is worth mentioning that 8 participants who were put into control group left the study, six of them after the first evaluation and two of them after the second evaluation. There was also one patient in B-EMG group who left the group after the second measurement.

Hand-held dynamometry and biofeedback electromyography were used to measure quadriceps strength and MVVA, respectively among all the participants.

In this study all patients filled a demographic questionnaire relating to age, height, and weight before the intervention. All samples were assessed prior to treatment, 3 weeks after of treatment and after the 4 week follow up, by a physiotherapist who was not informed about the intervention groups allocations.

***Measurements***

Dynamometery was performed by a hand-held dynamometer device (model FG5100, Lutron, Taiwan) (Figure 1) which had been calibrated by the manufacturer before running the study to measure quadriceps strength. A padded strap connected to the dynamometer lever arm, was fixed around the ankle proximal to medial malleolus. The participants were asked to push maximally against the pad, trying to straighten leg from the knee but without increasing knee extension. The first practice was performed and discarded, followed by two further attempts which were recorded in Newton (N). The mean of these two attempts was calculated finally as quadriceps strength parameter(s) (17, 18). The dynamometry test was run in sitting position with the knee flexed in 60 degrees. Quadriceps contraction between 60 to 90 degrees is the least harmful for ACL graft fixation (20).

A biofeedback electromyography device (model, Myo Trac infiniti SA9800, Canada) was employed to perform Biofeedback electromyography. This device which had been calibrated by the manufacturer prior to the study could measure MVVA.

***Table 1.*** Comparison of height, weight and age on the basis of groups

| | | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | *P*-value |
|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | |
| **Height (cm)** | Control | 177.66 | 7.62 | 1.24 | 175.15 | 180.16 | 0.45 |
| | BEMG | 178.32 | 7.18 | 1.53 | 175.13 | 181.50 | |
| | FES | 175.29 | 6.57 | 1.43 | 172.29 | 178.28 | |
| | TENS | 176.10 | 6.36 | 1.39 | 173.20 | 178.99 | |
| | Total | 176.99 | 7.06 | 0.70 | 175.60 | 178.38 | |
| **Weight (kg)** | Control | 78.53 | 9.35 | 1.52 | 75.45 | 81.60 | 0.85 |
| | BEMG | 81.05 | 13.19 | 2.81 | 75.20 | 86.89 | |
| | FES | 78.86 | 10.30 | 2.25 | 74.17 | 83.55 | |
| | TENS | 79.29 | 11.52 | 2.51 | 74.04 | 84.53 | |
| | Total | 79.29 | 10.79 | 1.07 | 77.17 | 81.41 | |
| **Age (year)** | Control | 24.45 | 5.23 | 1.11 | 22.14 | 26.77 | 0.642 |
| | BEMG | 25.21 | 5.12 | 0.83 | 23.53 | 26.89 | |
| | FES | 26.24 | 5.80 | 1.26 | 23.60 | 28.88 | |
| | TENS | 24.38 | 5.29 | 1.15 | 21.97 | 26.79 | |
| | Total | 25.09 | 5.28 | 0.52 | 24.05 | 26.13 | |

***Table 2.*** Descriptive values of baseline parameters in four groups

| Variable | Groups | Mean (SD) | Q1 | Median | Q3 | IQR |
|---|---|---|---|---|---|---|
| **mean value of VMO activation pattern (MVVA) (mv)** | BEMG | 59.9 (26.58) | 41.2 | 55.8 | 75.6 | 34.4 |
| | CONTROL | 55.61 (27.4) | 32.28 | 53.55 | 78.13 | 45.85 |
| | FES | 56.89 (24.58) | 34.2 | 56.8 | 75.3 | 41.1 |
| | TENS | 66.32 (32.45) | 32.45 | 67 | 86.59 | 54.14 |
| **Quadriceps Muscle Strength (N)** | BEMG | 63.27 (44.37) | 27.45 | 51.4 | 97.28 | 69.83 |
| | CONTROL | 57.56 (23.12) | 44.27 | 56.25 | 67.07 | 22.8 |
| | FES | 59.77 (29.24) | 37.3 | 55.2 | 82.65 | 45.35 |
| | TENS | 64.74 (30.45) | 45.35 | 62.9 | 88 | 42.65 |

***Table 3.*** Comparison of mean of MVVA in 3 episodes

| Time | DF | Sum of squares | Mean Square | F | *P*-value |
|---|---|---|---|---|---|
| **Before** | 3 | 1674.7 | 558.25 | 0.72 | 0.541 |
| **AFTER** | 3 | 5857.4 | 1952.4 | 1.55 | 0.205 |
| **Follow** | 3 | 20845.6 | 6948.5 | 3.4 | 0.02 |

***Table 4.*** The results of variance analysis to investigate the effect of intervention groups for mean of MVVA

| | DF | Sum of squares | Mean Square | F | *P*-value |
|---|---|---|---|---|---|
| **Group** | 3 | 20995.3 | 6998.4 | 2.41 | 0.071 |
| **Time** | 2 | 760724.9 | 380362.4 | 647.1 | <0.0001 |
| **Time*Groups** | 6 | 7382 | 1230.4 | 2.09 | 0.055 |

***Table5.*** Results of Kruskal Wallis Test to compare the percent (age) of change of MVVA and quadriceps strength in 4 groups

| Percent changes of MVVA | *P*-value | Percent changes of quadriceps strength | *P*-value |
|---|---|---|---|
| **After-Before** | 0.595 | After-Before | 0.628 |
| **Follow Up-After** | 0.034 | Follow Up-After | 0.843 |
| **Follow Up-Before** | 0.9 | Follow Up-Before | 0.899 |

***Table 6.*** The results of Kruskal Wallis Test to compare every 2 groups before the intervention and after the follow-up for the percent (age) of change of MVVA

| Sample1-sample2 | Test statistic | Std error | Std. test statistic | Sig | Adj.sig |
|---|---|---|---|---|---|
| **FES-Control** | 20.175 | 8.45 | 2.508 | 0.012 | 0.073 |
| **FES-BEMG** | 210288 | 9.027 | 2.358 | 0.018 | 0.110 |
| **FES.TENS** | -22.952 | 9.131 | -2.514 | 0.012 | 0.072 |
| **Control-BEMG** | 1.112 | 7.927 | 0.140 | 0.888 | 1.000 |
| **Control-TENS** | -2.777 | 8.045 | -0.345 | 0.730 | 1.000 |
| **BEMG-TENS** | -1.665 | 9.027 | -0.184 | 0.854 | 1.000 |

***Table7.*** Mean comparison of Quadriceps strength in 3 episodes

| Group | DF | Sum of squares | Mean Square | F | *P*-value |
|---|---|---|---|---|---|
| **Before** | 3 | 882.06 | 294.02 | 0.3 | **0.826** |
| **AFTER** | 3 | 3575.28 | 1191.7 | 1.02 | **0.385** |
| **Follow** | 3 | 8498.81 | 2832.93 | 1.63 | **0.187** |

***Table 8.*** The results of variance analysis o to investigate the effect of the intervention groups for mean of Quadriceps strength

| | DF | Sum of squares | Mean Square | F | P-value |
|---|---|---|---|---|---|
| **Group** | 3 | 9871.3 | 3290.4 | 1.05 | 0.373 |
| **Time** | 2 | 494509.4 | 247254.7 | 653.4 | <0.0001 |
| **Time *Groups** | 6 | 3084.7 | 514.12 | 1.36 | 0.233 |

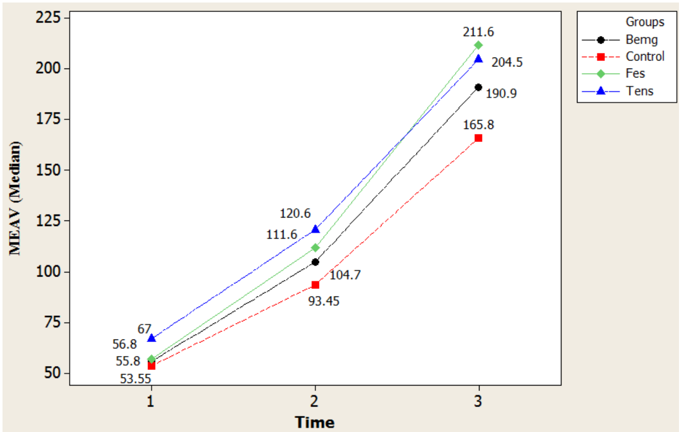
There were two recorder electrodes used, one was placed 4 cm above the midpoint of patella base and the other one, 3 cm medially, over the VMO. The ground electrode was placed 2–3 cm below the patella on the medial side of tibia (16) (Figure 2). The patients were then asked to perform maximal isometric quadriceps contraction during the work period for 5 seconds and to relax the muscle during the rest period for 10 seconds. This cycle was repeated for 3 times and mean contraction value of each contraction was recorded in millivolt (mv). The average of these three (values????) was considered as MVVA variable which is an indicator of muscle activity or the rate of disinhibition of VMO (16). Finally, the EMG-biofeedback test was performed in sitting position with the knee extended (17).

***Interventions***

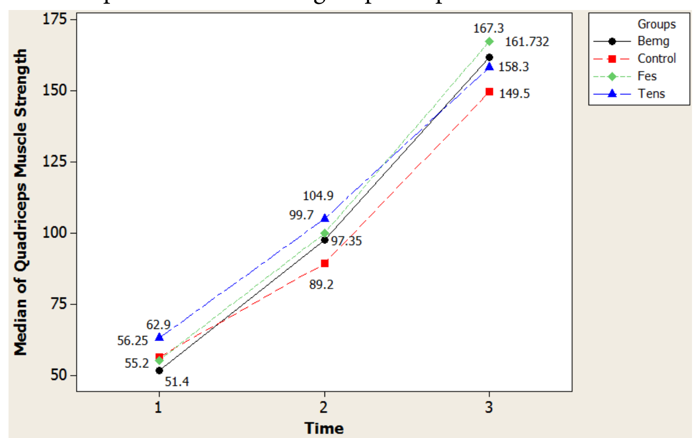
All four groups received Ice pack around the knee, 8 times per day, every 2 hours for 15 minutes in 3 weeks of intervention (12) and Michle Duck exercise therapy protocol (20) in 3 weeks of intervention and during follow up which lasted for 4 weeks.

The TENS group received the conventional TENS through a TENS device (model 710L, Novin, Iran) which had been calibrated by the manufacturer before running the study, with a pulse width of 150µs, pulse rate of 150Hz lower than muscle contraction intensity. The treatment, lasting for 3 weeks, was given to the participants 5 times a week. During the treatment which took 45 minutes four electrodes were placed around the patella in a crossed mode (21) (Figure 3).

To provide the FES group with the treatment (FES), a FES device (Myomed 133 Enraf-Nonius, Netherlands) with a pulse width of 350 µs, pulse rate of 50 Hz, on/off of 10/50 seconds and with maximally tolerable intensity was used for 3 weeks. The subjects in this group received 15 minute treatment 5 times per week. During every session one electrode was placed 4 cm superior and 3 cm medial to the mid-point of patella over VMO and the other electrode was placed 10 cm above the first one, over the VM. The FES was used in sitting position with the knee extended (22) (Figure 4).Biofeedback training was performed with the Biofeedback electromyography device used for MEAV measurement. The patients were asked to perform maximal isometric quadriceps contraction during the work period (5 seconds) and to relax during the rest period (10 seconds). The treatment lasted 3 weeks and it was given 5 times a week for 15 minutes per session. The patients had to contract their quadriceps muscle more strongly by increasing the threshold value every day. Electrodes placement was similar to what had been done for MEAV measurement. The EMG-biofeedback training was performed in sitting position with the knee extended (16) (Figure 2).




***Graph 1.*** Line plot of MVVA median percent (age) changes in 3 episodes




***Graph2.*** Line plot of *Quadriceps Strength* median percent (age) changes in 3 episodes


***Figure 1.*** Dynamometer device used in this study

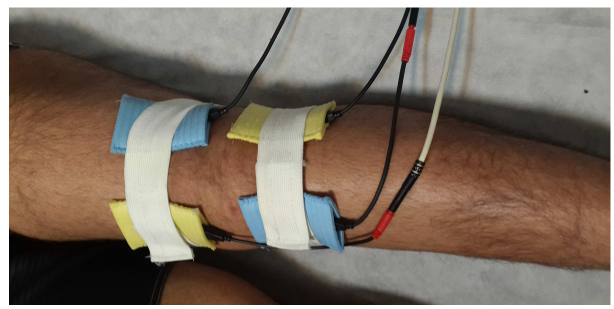


***Figure 3***. Location of the TENS electrode

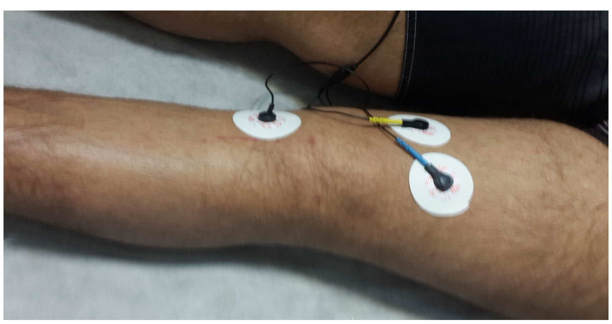


***Figure2.*** Location of B-EMG electrodes

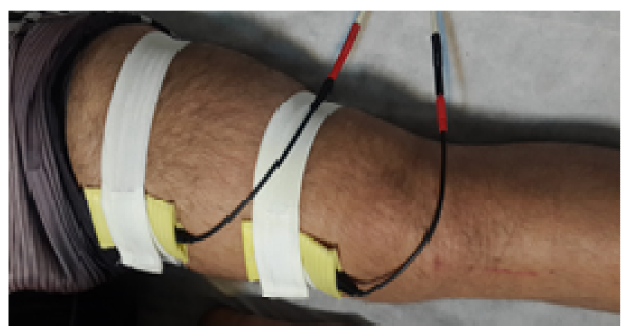


***Figure 4.*** Location of the FES electrodes

## Results

The results of one way ANOVA test demonstrated that demographic characteristics of patients in four groups were the same (Table 1).

The Shapiro Wilks Test showed that response variables changes had a non-normal distribution in all four groups of TENS, FES, B-EMG and control. Descriptive values of baseline parameters in four groups are presented in table 2.

ANOVA test was employed to evaluate the average score of Quadriceps Strength and MVVA before the intervention.According to the results obtained, no statistically significant difference was detected among 4 groups for these baseline parameters (Table 3 & 7).

***Mean value of* VMO activation pattern (MVVA)**

The scores of all groups were evaluated before the intervention, after the intervention and after the follow-up by using one way ANOVA test. There was no statistically significant difference between 4 groups regarding the average values of MVVA prior to and after the intervention (P=0.54 & P=0.205 respectively) while a significant difference was detected between 4 groups after the follow-up (*P*=0.02) (Table 3).

In order to investigate the effect of the time on the average values of MVVA in each group, repeated measures ANOVA was used. Based on the results, there was statistically significant upward trend of MVVA in 4 groups. (*P*<0001) (Table 4).

Pairwise comparison of the percent of changes (percentage change) demonstrated although, the percent change scores of MVVA in 4 groups, between post intervention and after the follow-up was statistically significant (p=0.034), there was no significant difference between post intervention and after the 4 week follow-up (*P*=0.9), and between pre and post intervention (*P*=0.595) (Table 5). The results of Kruskal Wallis Test applied to compare every 2 groups illustrated a significant difference in average of MVVA before the intervention and after the follow-up on the basis of 0.1 significance level (*P*=0.073 and *P*=0.072) in favor of FES group (Table 6) in FES and control groups as well as FES and TENS groups.

***Results of Quadriceps Strength in 60 degrees of flexion***

The scores of quadriceps strength related to all groups were evaluated before the intervention, after the intervention and after the follow-up. There was no statistically significant difference between 4 groups in regard to the average values of *Quadriceps Strength* before the intervention, after the intervention and after the 4 week follow-up (*P*=0.826, *P*=0.385 and *P*=0.187respectively) (Table 7).

With the passage of time, there was a statistically meaningful improvement in all four groups after the intervention and the 4 weeks of follow-up (*P*<0001) (Table 4).

As can be seen from the graph 2, all four groups experienced an ascending pattern of improvement in 3 episodes; however, the effect of FES was more prominent especially between after the intervention and the 4 week follow-up. The lowest percent (age) of changes was related to control group.

Results of Kruskal Wallis Test used to compare the percent of changes (percentage change) among 4 groups showed that the percent change (percentage change) scores of *Quadriceps Strength* in 4 groups was not significant at the time interval between post intervention and after the 4 week follow-up (*P*=0.843), between pre and post intervention (*P*=0.628) and between pre intervention and after the 4 week follow-up (*P*=899) (Table 5)

The results of Kruskal Wallis Test employed to compare every 2 groups demonstrated that there was no statistically significant difference regarding the average values of *Quadriceps Strength* between the groups at any particular time.

## Discussion

Rupture of the anterior cruciate ligament (ACL) is common and costly among sportspeople (1). ACL reconstruction restores static knee stability and rehabilitation improves functionality so that patients are often able to start to be active again, even though their quadriceps strength might become lessened (2). Quadriceps weakness is related to defectively/less functional performance, the potential for re-injury and it is also linked to the development of post-traumatic osteoarthritis (3). It is important to note that the traditional rehabilitation methods have not focused on improving the quadriceps activation before muscle strengthening (10), but it has been recently suggested that clinicians should first restore quadriceps activation (11). Although the effects of some methods such as exercise therapy, cryotherapy, transcutaneous electrical nerve stimulation (TENS), functional electrical stimulation (FES) and biofeedback electromyography (B-EMG) on quadriceps activation and strength have been reported in the previous literature (12, 13, 14, 15, 16), there has been no study conducted to compare these methods in order to find the most effective one. The purpose of this study was to investigate the effect of TENS, FES and B-EMG on improvement in Arthrogenic quadriceps inhibition and weakness after ACL reconstruction in comparison with the control group. The results obtained showed that a significant difference was observed average values of MVVA and *Quadriceps Strength* among before the intervention, after the intervention and after the 4 week follow-up in each group by the time (*P*<0001) (Tables 4 and 8). In addition, a comparison between every 2 groups, FES and control groups as well as FES and TENS groups, showed a meaningful difference in average values of MVVA before the intervention and after the follow-up (*P*=0.073 and *P*=0.072) in favor of FES group (Table 6). On the other hand, regarding the average values of *Quadriceps Strength*, there was no statistically significant difference between them and at any particular time but here again the effect of FES group appeared to be more prominent. As graph 1 and 2 clearly demonstrate, all four groups experienced an upward trend in average values of MVVA and *Quadriceps Strength* in 3 episodes. While the effect of FES was more prominent, the control group comprised the lowest percentage of changes.

As a result, TENS, FES and B-EMG in combination with cryotherapy and exercise as well as cryotherapy with exercise can reduce VMO inhibition and improve quadriceps strength in patients who have ACL reconstruction. However, FES in combination with cryotherapy and exercise can be the most effective treatment and cryotherapy with exercise can be the least effective one.

Functional electrical stimulation (FES) is a clinical modality that “overrides” muscle activation failure by directly stimulating the inhibited alpha motor neurons, resulting in an involuntary contraction of the inhibited muscle. Because FES exogenously stimulates the muscle, large diameter, Type II muscle fibers are thought to be selectively recruited (22). This results in a greater potential for muscle force production, as Type II muscle fibers are utilized to produce higher force (23). In addition, FES has been assumed to limit muscle atrophy (24). Fitzgerald *et al.* have reported that FES in combination with exercise results in greater quadriceps strength than exercise alone at approximately six to 12 weeks post-ACL reconstruction (25). Conversely, Sisk *et al.*, Draper *et al.* and Paternostro-Sluga *et al.* have reported that FES does not provide any additional benefit to quadriceps strength than traditional exercise (26, 27, 28). However, these articles self-reported methodological flaws, such as high pre-operative strength in the treatment groups and variability in FES parameters utilized across trials. Although there is contradicting evidence in the literature regarding the benefits of FES, the majority of published data, as well as recent systematic reviews recommend FES in conjunction with exercise as an intervention to successfully target strength deficits following ACL reconstruction (15, 29, 30).

However, the recent systematic review by Matthew *et al* has supported TENS as the most effective modality on disinhibition of quadriceps muscle after ACL reconstruction (14), this study showed that TENS in comparison with FES and B-EMG, was less effective. There is also some evidence which did not show statistical significance between TENS and cryotherapy as well as TENS and exercise therapy (13, 21).

Previous literature has demonstrated that using B-EMG can increase activation and strength of the affected musculature (16, 31, 32). In addition to these findings, a systematic review conducted by Lepley *et al.* reported that EMG biofeedback improves quadriceps strength better than exercise alone (33). The recent study by Florea provided evidence that B-EMG can acutely increase corticomotor excitability (19). These results are consistent with the results of the current study. Although the effect of FES was more prominent in this study, there was no significant difference between FES and B-EMG groups for both parameters. Hence, the application of EMG biofeedback may be an effective therapy to improve quadriceps strength post-ACL reconstruction. In a separate study conducted by Draper and colleagues, EMG biofeedback was reported to be more effective at restoring quadriceps strength at six week post-ACL reconstruction than electrical stimulation therapy (27). However, it should be noted that the maximal intensity of the electrical stimulation imposed to the quadriceps muscle in this study was relatively low, thus the training intensity of the electrical stimulation may not have been high enough to induce quadriceps strength gains; whereas the intensity of the electrical stimulation used in this study was as tolerable as possible to gain maximal strength and may be this factor made FES intervention more effective than B-EMG.

In summary, FES in conjunction with exercise and cryotherapy appears to be more promising intervention to improve quadriceps activity and strength post-ACL reconstruction. Additionally, improvements achieved via this intervention also appear to translate into improved movement and functional outcomes.

Short term follow up and non-normal distribution of baseline parameters due to the participation of different sportsmen are likely to have impacted the results of this RCT. Recommendations are given for future clinical trials to improve methodological quality and longer term follow up. It is also suggested that clinical practice guidelines in the application of FES following ACL reconstruction be developed.

## Conclusion

TENS, FES, BEMG in combination with cryotherapy and exercise as well as cryotherapy with exercise can reduce VMO inhibition and improve quadriceps strength in patients who have ACL reconstruction. While FES in combination with cryotherapy and exercise can be the most effective treatment, cryotherapy with exercise can be the less effective. Therefore, it can be concluded that FES appears to be a more promising intervention to improve quadriceps activity and strength post-ACL reconstruction. Further clinical studies are required to prove this hypothesis.

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None

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***Authors’ contributions:***
All authors made substantial contributions to conception, design, acquisition, analysis and interpretation of data.

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