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A Literature Based Study on the Effectiveness of Neuromuscular Electrical Stimulation (NMES) on Quadriceps Strength And Knee Function or Movement following ACL Reconstruction of the Knee

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Abstract –

Background: Anterior cruciate ligament (ACL) reconstruction affects both muscle strength and function of the knee. Standard rehabilitation protocols include strengthening of the muscles through voluntary exercise. Earlier studies have suggested that NMES could enhance muscle strength. However, there are varying evidences on the effectiveness of NMES in improving muscle strength or knee movement and function. The main aims of this study are to review findings from studies on the 1. effectiveness of NMES in improving quadriceps strength following reconstruction of ACL rupture; 2. effectiveness of NMES in improving knee movement or function following reconstruction of ACL rupture.

Method: A literature-based study design was chosen to address the aims of this study. Ten studies were retrieved and reviewed using critical appraisal skills programme (CASP) tools and the physiotherapy evidence base (PEDro) scale.

Result: Studies revealed that the effects of NMES on quadriceps strength were moderate. Few of the studies which included knee movement or function as a patient outcome reported improvements in the movement of the knee. The small sample sizes of most of the RCTs compromised the applicability of the findings to a larger and more heterogeneous population. There was also variation in the parameters used in NMES application. This could also account for the differences of the effects of the intervention on both quadriceps strength and knee movement or function. The reviewed studies also did not follow-up the patients in the long term. It is not clear whether the effects of NMES are sustained over time.

Conclusion: Neuromuscular electrical stimulation could yield moderate improvements on quadriceps strength and knee movement or function. It is recommended that future studies should employ large sample sizes to reduce bias in the findings of the study. It is also recommended that follow-up will be conducted in the long term to determine the long-term effects of this intervention.

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INTRODUCTION

Anterior cruciate ligament (ACL) rupture is one of the most debilitating and incapacitating injuries to the knee (Cowling and Steele 2001). 80,000 to 250,000 ACL injuries occur annually (Fu et al. 2008).Various treatment options such as ACL reconstruction or surgery are available to reduce the morbidity of this condition (Bach et al. 2002).

It has been suggested that ACL reconstruction is associated with muscle strength deficits and might

be caused by the loss of intraligamentous mechanoreceptors (Richardson et al. 2006). With the above-mentioned effects of ACL reconstruction, it is essential to address muscle strength, function, and knee stability in the rehabilitation process after surgery. Neuromuscular electrical stimulation (NMES), a treatment intervention utilising electricity to stimulate muscles and nerves, has been recommended by clinicians and physiotherapists to restore and maintain muscle strength, function, and knee stability post-ACL reconstruction (Fu et al. 2008).

Lake (1992) proposed two mechanisms of how neuromuscular electrical stimulation works to enhance muscle strength and augment muscle mass. The first mechanism suggests that NMES enhances muscle strength the same way as that of the voluntary exercise.The other mechanism proposes that muscle strength produced by NMES is caused by the reversal of voluntary recruitment order with a selective augmentation of type II muscle fibres. These proposed mechanisms have been the basis of various studies dwelling on the application of neuromuscular electrical stimulation on various medical conditions and its importance to rehabilitation programmes.

This study aims to investigate the effectiveness in improving quadriceps strength following reconstruction of ACL rupture. This study also aims to investigate the effectiveness of NMES in improving knee movement following reconstruction of ACL rupture.

METHODOLOGY

Inclusion and Exclusion Criteria

Studies published in English and conducted in the last 10 years that that used NMES as a form of intervention together with standard care in a population who have undergone ACL were included in the literature reviews.Studies included improvement of quadriceps strength and knee movement or knee function as key patient outcomes.Systematic reviews were also included.

Exclusion criteria include non-English studies; studies which were performed on the elderly and the very young such as those age 18 years old and younger; studies which were published more than 10 years ago; studies which used NMES after surgical procedures other than ACL.

EXTRACTION OF STUDIES

Key words like 'neuromuscular electrical stimulation', 'anterior cruciate ligament reconstruction', 'quadriceps strength', and 'knee function' were used in retrieving studies from Medline, Pubmed, CINAHL, EBSCO and COCHRANE databases.Manual search was also done in print journals from the University library.The 10 studies all met the inclusion criteria for this paper.

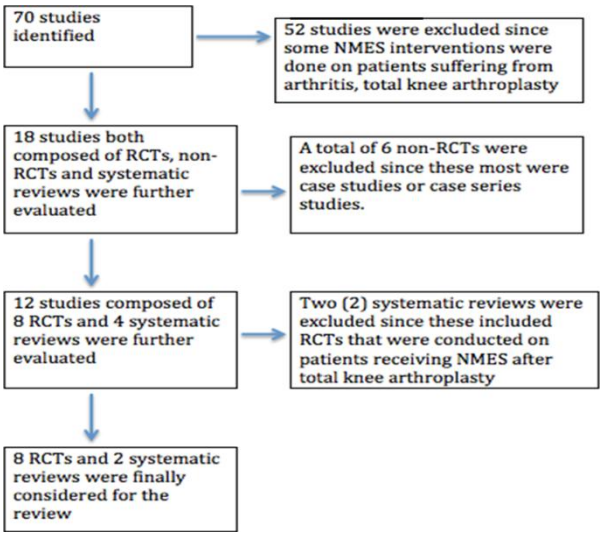

Figure 1. Selection of the 10 Studies

CRITICAL APPRAISAL

The Critical Appraisal Skills Programme (CASP) critiquing tool for RCTs and systematic reviews were used to analyse the 10 studies (CASP 2006). The Physiotherapy Evidence Database (PEDro) scale was also used to provide the level of physical therapy evidence that the extracted studies have.

RESULT:

All 10 studies utilising the randomised controlled trial study design utilised NMES as a supplement to a standard rehabilitation protocol. The control groups of these studies used the standard rehabilitation protocol as the intervention while the experimental groups utilised a combination of NMES and the standard rehabilitation protocol. The degree of NMES stimulation, however, differed in each of these studies. There were also differences in treatment outcomes and in the number of experimental groups.

Table 1. Summary of Studies

Authors and Title	Study Design, Sample Population Intervention	Findings	Implication (s) in Physiotherapy Practice
Feil et al. (2011) 'The effectiveness of supplementing a standard rehabilitation program with superimposed neuromuscular electrical stimulation after anterior cruciate ligament reconstruction: a prospective, randomised, single-blind study	Prospective, randomised, single-blind controlled trial 131 patients were randomised to 1 of 3 interventions. A total of 96 patients completed the study.Study was conducted in Germany The first group or control received the standard rehabilitation programme while the second and third groups received NMES. The second group received the traditional NMES while the last group received a garment-integrated NMES.	Garment-integrated NMES significantly improved patient outcomes as compared to standard rehabilitation with standard NMES or standard rehabilitation only. The results were also precise since the investigators used the p-value to report the level of significance of the interventions. PEDro scale- 7/10	The results could be applied to current practice since the sample population were composed of healthy individuals who suffered from ACL rupture. The same treatment could be provided in local care settings. The study could also provide important information to policy makers and other physiotherapists since the study suggested that garment-integrated NMES was more effective than standard NMES. This intervention was suggested to improve knee function by improving knee strength and allowed extension of the knee. Meanwhile, the benefit reported in the study outweighed any harm or cost associated with the preparation of the study and in the recruitment of the study participants.

Fitzgerald et al. (2003)' A modified neuromuscular electrical stimulation protocol for quadriceps strength following anterior cruciate ligament reconstruction'	Randomised clinical trial, with intervention groups blinded to the study N= 43 subjects Study was conducted at Pittsburgh, USA Control group- received standard rehabilitation Experimental group- NMES with standard rehabilitation	At 12 weeks of rehabilitation, the experimental group reported greater quadriceps strength (effect size 0.48) At 16 weeks- higher levels of knee function (effect size of 0.65). Many of the participants in the experimental group advanced to agility training after 16 weeks of the intervention. PEDro scale- 6/10	Modified NMES could improve quadriceps strength and knee function compared to standard rehabilitation. However, the effect size is small.
Ross (2000) 'The effect of neuromuscular electrical stimulation during closed kinetic chain exercise on lower extremity performance following anterior cruciate ligament reconstruction'	Randomised controlled trial N= 20 patients (no drop out) Study was conducted in USA Control group- closed kinetic chain (CKCh) exercise following ACL reconstruction Experimental group- closed kinetic chain exercises with NMES following ACL reconstruction CKCh exercise: unilateral squat, lateral step-up test, anterior reach test Interventions were given for four weeks	Significant differences were seen in the cadence, stance time of the involved limb, walking velocity and flexion-excursion of the affected knee during stance in the experimental group as compared to control group. The strength of the quadriceps muscle was directly correlated with the flexion-excursion of the knee during stance. PEDro scale- 3/10	When NMES is used in conjunction with exercise, quadriceps strength is increased and achieved more normal gait patterns.
Bax et al. (2005) 'Does neuromuscular electrical stimulation strengthen the quadriceps femoris? A systematic review of randomised controlled trials'	Systematic review 35 trials were reviewed Control group- exercise alone Experimental group- exercise supported with NMES	Findings from the study suggested that the randomised controlled trials yielded varying pieces of evidence on the effectiveness of NMES with volitional exercise with most studies reporting significant differences between controls. The findings of the review suggested that NMES is applicable when patients are unable to do volitional exercise PEDro scale- none (systematic review)	The study suggested that NMES could improve quadriceps strength if coupled with volitional exercise.
Paternostro-Sluga et al. (1999) 'Neuromuscular electrical stimulation after anterior cruciate ligament surgery'	Randomised controlled trial N= 39 patients who underwent ACL surgery Control group- early exercise alone Experimental group 1- NMES and exercise therapy regimen Experimental group 2- transcutaneous electrical nerve stimulation and exercise	Patients were followed up at 6 weeks, 12 weeks and 52 weeks. There were no statistical differences among groups in terms of the following: -Isometric and isokinetic torque in both flexor and knee extensor muscles PEDro scale- 5/10	This study had a small sample size and was not sufficiently powered in order to determine a treatment effect. Physiotherapists could use the findings of this study when deciding if they should use NMES for their patients. While NMES improved quadriceps strength in other studies, Paternostro-Sluga et al. (1999) did not find significant differences on exercise alone and exercise supplemented with NMES in improving isometric and isokinetic torque of the flexor and knee extensor muscles.
Risberg, M. et al. (2004) 'A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type?'	Systematic Review 33 Randomised Controlled Trials Randomised controlled trials that investigated different rehabilitation programmes on surgically and non-surgically treated ACL injuries in adult patients	Rehabilitation programs should include 1. Weight bearing programs that include chain exercises at knee joints. Motions should not be more than 60 degrees Kinetic chain exercises should be performed for knee flexion. The angles should be greater than 40 degrees but not straining or stressing the ACL and patellofemoral joint. 2. Isometric quadriceps strength is significantly improved if NMES is used as support to standard rehabilitation PEDro scale- none since systematic review	The review included studies, which were three decades old. The authors suggested that most of the RCTs included in the review had relatively small sample sizes, which limited the findings of the study. There were also variable parameters used by the different RCTs when applying NMES. While there were some pieces of evidence on the effectiveness of NMES on improving quadriceps strength, there were no pieces of evidence from the reviewed studies on whether this could improve knee movement/function.
Snyder-Mackler, L. et al. (1991)' Electrical stimulation of the thigh muscles after reconstruction of the anterior cruciate ligament. Effects of electrically elicited contraction of the quadriceps femoris and hamstring muscles on gait and on strength of the thigh muscles'	Randomised controlled trial N= 10 patients Control group- volitional exercise alone Experimental group- volitional and NMES	Compared to volitional exercise group, the group that received NMES significantly improved flexion-excursion of the knee during stance and improved quadriceps strength. Patients in this group also had more normal gait patterns. PEDro scale- 3/10	NMES could be used to hasten restoration of quadriceps strength and normal gait following ACL surgery. It could also be used to improve flexion-excursion of the knee. However, the study had a very small sample population and this limited the generalisability of the study.
Snyder-Mackler et al. (1995) 'Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. A prospective, randomised clinical trial of electrical stimulation	Randomised controlled trial N= 110 patients Intervention 1 (n=31) high intensity NMES and closed kinetic chain (CkCh) chain exercise Intervention 2 (n=34) high-level volitional exercise Intervention 3 (n=25)- low-intensity NMES and CkCh Intervention 4 (n=20) – combined high and low-intensity NMES and CkCh	Quadriceps strength of the involved side was 70% that of the healthy limb in the groups that received high-intensity NMES Quadriceps strength was 57% and 51%, respectively, in the groups receiving volitional exercise alone and low-intensity NMES Knee movement: significantly correlated with quadriceps strength ($p<0.05$) PEDro scale- 5/10	NMES could be used for patients with low compliance on volitional exercise
Liber et al. (1996) 'Equal effectiveness of electrical and volitional strength training for quadriceps femoris muscles after anterior cruciate ligament surgery/	Randomised controlled trial N= 54 patients Intervention group- exercise and NMES Control group- Exercise	NMES and voluntary muscle contraction were equally effective in strengthening quadriceps muscles weakened by surgical repair after ACL. PEDro scale 6/10	Knee extension torque and quadriceps strength in both groups were similar and not significantly different. NMES would show similar benefit as exercise alone.
Draper, V. and Ballard, L. (1991) 'Electrical stimulation versus electromyographic biofeedback in the recovery of quadriceps femoris muscle function following anterior cruciate ligament surgery	Randomised controlled trial N= 30 patients Intervention group- NMES and exercise Control group- EMG biofeedback and exercise	Findings from the study suggested that EMG biofeedback and exercise significantly increased quadriceps strength as compared to NMES and exercise. Patients received 30 hertz of NMES for 6 weeks. Patients received a total of 105 NMES sessions. PEDro scale 4/10	The training intensity received by patients in the EMG biofeedback group was seen to be greater. This was suggested to contribute to greater improvements of the quadriceps strength as compared to the group receiving NMES and exercise. Training intensity influence outcome such as improvement of quadriceps strength. .

In one study, one group received a garment-integrated NMES (Feil et al. 2011). In this study, the investigators recruited and enrolled 131 patients and randomised them to three groups. The first group or control received the standard rehabilitation programme while the second and third groups received NMES. The second group received the traditional NMES while the last group received a garment-integrated NMES.

Outcome measures for the study included isokinetic strength of the injured and uninjured knees when extended at 90 and 180 degrees. Functional tests of proprioception were also assessed. Assessment was conducted at baseline and measurements were done 6 weeks, 12 weeks and 6 months after the intervention. Findings of the study suggested that the group receiving the standard rehabilitation programme supported with garment-integrated NMES significantly ($p<0.001$) improved extensor strength of the knee and knee movement following ACL reconstruction at 6 months follow-up.

A critique of the study using CASP revealed that the investigators asked a clearly focused question. The interventions were well explained as shown in table 1. The population studied were composed of patients who underwent ACL reconstruction. However, the study failed to explain its eligibility criteria and only detailed the number of patients included in the study and the age range of the group.

The results were presented using a comparison of the findings of the experimental groups against the control group. The patient outcomes were used to determine if significant differences existed between traditional NMES, garment-integrated NMES and the control group.

Finally, the results could be applied to current practice since the sample population were composed of healthy individuals who suffered from ACL rupture. The same treatment could be provided in local care settings. The study could also provide important information to policy makers and other physiotherapists since the study suggested that garment-integrated NMES was more effective than standard NMES. This intervention was suggested to improve knee function by improving knee strength and allowed extension of the knee.

In the PEDro Scale of evidence, Feil et al. (2011) did not explain their eligibility criteria. However, there was random allocation but no concealed allocation. In an earlier study conducted by Fitzgerald et al. (2003), a modified NMES protocol was used to determine whether it would improve quadriceps strength after ACL reconstruction.

DISCUSSION

The different studies reviewed in this paper suggested that NMES, when coupled with exercise, is more effective in improving the quadriceps strength of patients when compared to standard rehabilitation only. However, only a few of the studies suggested that NMES could also improve knee movement or knee function. An evaluation of the RCTs and the systematic reviews suggested that the outcome of improvement on knee movement or knee function was not included as one of the patient outcomes measured by the investigators. Further, the studies also suggested that different NMES parameters were used. For instance, the RCTs (Feil et al 2011; Fitzgerald et al. 2003; Ross 2000; Paternostro-Sluga et al. 1999; Snyder-Mackler et al. 1995, 1991; Liber et al. 1996; Draper and Ballard 1991) had inconsistencies on the duration, intensity and frequency of NMES application.

Interestingly, the thematic analysis showed that a number of the patients in the RCTs and systematic reviews used patient self-treatment. This would show that in actual practice, NMES would not be difficult to administer since patients could operate the NMES stimulators by themselves. On the other hand, Kim et al. (2010) noted that the low levels of electrical stimulation might not yield sufficient effect on quadriceps strength.

The lack of generalisability, as seen by the relatively small sample size of the RCTs and the systematic reviews, is another issue that should be considered when applying NMES in actual practice. Greenhalgh (2010) explained that RCTs with very few sample sizes could limit the applicability of the findings to a larger and more heterogeneous population. As stressed earlier, sustainability of the intervention in improving quadriceps strength or knee movement or function is another issue. Most of the patients were followed-up at varying number of weeks with some patients followed up at 16 weeks to determine the benefits of NMES. However, a common observation in the findings of the study was that the effects of NMES declined over time. It is unclear whether NMES should be administered for prolonged periods and at regular intervals to elicit long-term effects on both quadriceps strength and knee function or movement. It should also be noted that in the study by Fitzgerald et al. (2003), prolonged NMES intervention, such as 16 weeks duration, would help hasten the healing and return to normal activities of athletes with ACL rupture injuries. Further, studies on the impact of NMES on knee movement or function are few. Hence, it would be difficult to make generalisations on the efficacy of NMES in improving knee movement or function.

IMPLICATIONS TO PRACTICE

This review suggests that NMES could help patients recover quadriceps strength and knee function following ACL reconstruction surgery. However, the effect of this intervention on quadriceps strength is only moderate while there are still not enough studies supporting the effectiveness of NMES on improving knee movement. The different RCTs and systematic reviews used NMES with standard exercise rehabilitation and compared this to standard exercise only or EMG biofeedback. The results showed better or moderate improvements when NMES was used as an adjunct to exercise.

CONCLUSION

Findings from this study revealed that quadriceps strength could improve with the introduction of NMES with standard rehabilitation or exercise therapy. However, the improvements were only moderate.

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