Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2, 1-7
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i2.4407

Comparison of maximum voluntary isometric contraction of the quadriceps muscle after modified hybrid training with NMES in untrained healthy subjects

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Abstract: Reduced muscle strength is often caused by decreased of physical activity and sedentary lifestyle. Neuro-Muscular Electrical Stimulation (NMES) Russian Protocol and hybrid training system are alternative methods for strengthening exercises to increase muscle strength. This study aimed to analyze the effect of Hybrid modification strengthening exercise and Russian NMES protocol on Quadriceps Femoris muscle strength in healthy untrained subjects. Twenty-four subject, untrained healthy male aged 25-45 years, divided into the Modified Hybrid Training (MHT) Group (n=12) and the Neuro-Muscular Electrical Stimulation (NMES) Group (n=12). Both groups received intervention 3 times per week for 4 weeks (12 sessions). Maximum Voluntary Isometric Contraction (MVIC) of quadriceps muscle measured before and after intervention. There was improvement in the MVIC of quadriceps muscle in MHT group (dominant limb $p = 0.001$, non-dominant limb $p = 0.001$) and NMES group (dominant limb $p = 0.001$, non-dominant limb $p < 0.001$). There was no significant difference in the change of MVIC (ΔMVIC) of the quadriceps muscle between the Hybrid method and NMES groups on both legs. Both Modified Hybrid Training (MHT) and the Neuro-Muscular Electrical Stimulation (NMES) are effective in increasing quadriceps muscle MVIC with comparable result.

Keywords: *Hybrid training system, Maximum voluntary isometric contraction, Muscle strength, Neuro-muscular electrical stimulation, Russian current.*

1. Introduction

*R*educed muscle strength and mass can be caused by disease, injury, sedentary lifestyle, decreased physical activity, inactive locomotor conditions or immobilization. Such conditions can affect muscle structure and strength, result in weakness or impaired muscle function of the lower limbs [1]. Decreased muscle strength resulting in decreased body function and increased incidence of falls [2].

Physical inactivity and especially prolonged sitting habits involve impaired protein regulation mechanisms, due to reduced muscle contraction levels in daily life by maintaining a prolonged sitting position. Short-term studies have shown the unhealthy potential of inactivity in one day, with secondary acute effects of prolonged sitting shown even in the productive age population. Lower limb skeletal muscles that clearly experience reduced muscle strength are obtained in prolonged sitting habits [3]. There is a reduction in the diameter and number of muscle fibers, especially those of the fast contraction

History: Received: 27 November 2024; Revised: 9 January 2025; Accepted: 20 January 2025; Published: 23 January 2025
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type (type II) compared to the slow type (type I) which decreases from an average of 60% in young inactive people to 30% after reaching the age of 80 years who are at risk of obesity sarcopenia [4]. Electromyography (EMG) examinations on inactive subjects found that more than 65% inactive thigh muscles result has decrease of maximum voluntary contraction strength by 4 [5].

Resistance training is any form of active exercise in which dynamic or static muscle contractions are against an external force or load applied manually or mechanically. Resistance training has several benefits, including increased strength and improved muscle function in performing specific activities [6]. Its main therapeutic benefits include increased muscle strength. Hoffman et al explained that the body's physiological adaptation to muscle strengthening training is that there is an increase in muscle recruitment during resistance training in the first two weeks, after which there will be an increase in muscle mass after four weeks of resistance training [7]. Based on meta-analysis studies, physical activity is needed, including aerobic exercise activity, and muscle strengthening exercises, are essential for healthy aging and the prevention of sarcopenia [8]. Another method of resistance training is the use of electrical stimulation (ES) to increase muscle strength in weak or paralyzed muscles, by using electrical stimulation of muscles and nerve cells through the skin to the point of muscle movement using electrodes to produce muscle contractions [9]. Several recent studies have shown that ES affects new motor learning and in performing conventional exercise training programs [10].

The hybrid training method is a training method developed at Kurume University, Japan. Hybrid training uses the force generated by electrically stimulated antagonist muscles/ ES to provide resistance to voluntarily contracting agonist muscles, such as dumbbells providing resistance to the elbow flexors during an elbow curl. A study by Iwasaki and colleagues in healthy men reported an increase in muscle strength in the concentric torque of the quadriceps muscle after hybrid strengthening training with a frequency of 3 times/week for 6 weeks. The hybrid training approach has several advantages, namely the use of a more physiological muscle recruitment pattern compared to traditional NMES and the use of stabilizers and external resistance devices is minimal compared to traditional resistance training [11]. A study by Borzuola, et al. [12] showed that the highest improvements of muscle strength were found when NMES was superimposed on sub-maximal exercises involving both concentric and eccentric contractions [12].

This study analyze the comparison of muscle strength with the Maximum Voluntary Isometric Contraction (MVIC) parameters of the quadriceps muscle using surface electromyography (s-EMG) after modified hybrid training with the NMES Russian protocol in untrained healthy individuals.

2. Material and Methods

This study is a randomized controlled trial carried out at the Department of Physical Medicine and Rehabilitation, Dr. Soetomo General Academic Hospital, Surabaya, Indonesia, from January to February 2023. Ethical clearance for this study was granted under number 0522/KEPK/XI/2022 by the Health Research Ethics Committee of Dr. Soetomo General Academic Hospital in Surabaya, Indonesia. All subject signed the informed consent prior to the study.

The subjects of the study were 24 men randomized into Modified Hybrid Training (MHT) Group (n=12) and the Neuro-Muscular Electrical Stimulation (NMES) Group (n=12). Group randomization was performed through simple randomization using a lottery method conducted with sealed envelopes. The study sample was taken by consecutive sampling. The inclusion criteria were: 1) Age 22 - 45 years, 2) Healthy untrained male, 3) Normal musculoskeletal function (normal strength, sensation and range of motion of joints), 4) Low or moderate physical activity level according to International Physical Activity Questionnaire-Short Form (IPAQ-SF), and 5) Willing to participate and finished the study protocol by signing informed consent. The exclusion criteria were: 1) Having contraindications for exercise (knee joint acute inflammation, muscle of joint pain with active movement, joint instability), 2) Having contraindications for NMES (use of a pacemaker, allergy to stimulation electrodes), 3) Having an injury to the knee joint and surrounding soft tissue in the lower leg in the last 3 months, and 4) Involved in a muscle strengthening program in the last 6 months in the form of resistance training or nutritional intake. The dropout criteria were: 1) Subjects are unwilling to continue the study for any reason, 2) Subjects are unable to complete the exercise according study protocol (absent from 2 consecutive exercise sessions), 3) Subjects has complain muscle or join pain with active movements without load (Visual Analog Scale > 2), inflammation signs that appear suddenly during exercise, and delayed-onset muscle soreness (DOMS) in the lower legs that unable the subject do the exercise for 2 consecutive session, and 4) Subjects experience an allergic reaction due to electric pad that unable the subject to continue the session.

Subjects in the Modified Hybrid Training (MHT) Group were prescribed electrical stimulation targeting the hamstring muscle. The hip flexed to 90 degrees and the knee flexed to 100 degrees, the patient was positioned upright and leaned as comfortably as possible. Stimulation electrodes were applied to the motor belly of the hamstring muscle, ensuring a minimum distance of 2 inches between electrodes. Voluntary knee extension contractions were executed when the subject experienced electrical stimulation in the hamstring.

Subjects in the Neuro-Muscular Electrical Stimulation (NMES) Group were prescribed electrical stimulation targeting the quadriceps muscle. The patient was positioned in a relaxed manner with the hip flexed between 10 and 20 degrees and the knee flexed between 10 and 20 degrees. A small pillow supported the knee, and the distal part of the lower leg was secured with a strap to facilitate isometric contraction. Stimulation electrodes were applied to the motor belly of the quadriceps muscle, ensuring a minimum separation of 2 inches between the electrodes.

In both groups, each session comprised 10 sets of 10 repetitions, with a 1-minute rest period between sets. Each group underwent 12 sessions, conducted three times per week over a span of 4 weeks. The intervention was applied to both legs. Both groups prescribed identical stimulation parameters: Russian stimulation with a frequency of 5000 Hz modulated at 20 Hz (2.4 milliseconds on, 47.6 milliseconds off). The intensity was set at 80% of the maximal comfortable level and was adjusted at the beginning of each exercise. The electrical stimulation was administered using the Myomed 632 (Enraf-Nonius) stimulator.

Maximum voluntary isometric contraction of quadriceps muscles measured with surface EMG before the intervention and after 4 weeks (12 sessions). The data obtained analyzed using SPSS 24.0 for Windows™ program. Descriptive data presentation is carried out to determine average and standard deviation of the data. Data normality test is carried out using the Monte Carlo test with considered normal distribution if $p > 0.05$. Data homogeneity test is analyzed using the Levene test and considered homogeneous if $p > 0.05$. Muscle endurance before and after intervention within each group analyzed using paired t-test and between groups using an independent t-test. The effect size calculated (Cohen's d) and p is considered to be significant if < 0.05.

3. Results

The scubjects of this study were 24 healthy untrained male subject randomly divided into 12 subjects each in the Modified Hybrid Training Group (n=12) and the Neuro-Muscular Electrical Stimulation Group (n=12). All subjects able to complete intervention (12 sessions), no other adverse events occurred during the study period. Subjects are all right leg dominance and categorized as low or moderate physical activity based on the International Physical Activity Questionnaire-Short Form (IPAQ-SF) questionnaire. The characteristic of subject shown in Table 1.

ISSN: 2576-8484
Vol. 9, No. 2: 1-7, 2025
DOI: 10.55214/25768484.v9i2.4407

Table 1.
Characteristic of subject.

Variable	MHT (n = 12) Means ± SD	p^a	NMES (n = 12) Means ± SD	p^a	p^b
Age (Years)	31.17 ± 2.73	0.83	32.42 ± 4.01	0.49	0.08
Body weight (kg)	73.42 ± 8.53	0.92	75.50 ± 11.26	0.96	0.16
Body height (Meters)	1.71 ± 0.05	0.53	1.70 ± 0.07	0.85	0.20
BMI (kg/m²)	25.25 ± 3.45	0.62	25.97 ± 3.10	0.97	0.96
IPAQ-SF score					
Low	3 (25%)		6 (50%)		
Moderate	9 (75%)		6 (50%)		
Maximum voluntary isometric contraction (MVIC)					
Quadriceps dominant leg pre-intervention (mV)	0.16 ± 0.07	0.66	0.12 ± 0.04	0.91	0.09
Quadriceps non-dominant leg pre-intervention (mV)	0.15 ± 0.05	0.86	0.13 ± 0.06	0.81	0.54

Note: [a]Analyzed using Monte-Carlo test
[b]Analyzed using Levenne test
*Statistically significant at $p < 0.05$.

Table 2 shows that there is a significant difference ($p < 0.05$) in the MVIC of the Quadriceps muscles in both groups at the dominant and non-dominant leg, before and after intervention. Table 3 shows the MVIC of Quadriceps muscle in both groups after 4 weeks of intervention. There was no difference between two groups in the quadriceps muscle and MVIC in the dominant leg ($p = 0.327$) and the non-dominant leg ($p = 0.312$) with moderate effect size in the dominant leg (d = 0.41) and in non-dominant leg (d = 0.42). Table 4 shows Quadriceps muscle ΔMVIC in both dominant and non-dominant leg were comparable in both groups.

Table 2.
Analysis of Maximum Voluntary Isometric Contraction (MVIC) within each group.

Group	Maximum voluntary isometric contraction (MVIC)	Pre-intervention (Means ± SD)	Post-intervention (Means ± SD)	p^a	Cohen's d
MHT	Quadriceps dominant leg (mV)	0.16 ± 0.07	0.28 ± 0.11	0.001*	1.31
	Quadriceps non-dominant leg (mV)	0.15 ± 0.05	0.28 ± 0.10	0.001*	1.39
NMES	Quadriceps dominant leg (mV)	0.12 ± 0.04	0.23 ± 0.10	0.001*	1.25
	Quadriceps non-dominant leg (mV)	0.13 ± 0.61	0.24 ± 0.09	<0.001*	1.63

Note: [a] Analyzed using Paired t-test
* Statistically significant at $p < 0.05$.

Table 3.
Analysis of Maximum Voluntary Isometric Contraction (MVIC) between group post intervention.

Maximum voluntary isometric contraction (MVIC)	MHT group (Means ± SD)	NMES group (Means ± SD)	p^a	*Effect* size
Quadriceps dominant leg (mV)	0.28 ± 0.11	0.23 ± 0.10	0.327	0.41
Quadriceps non-dominant leg (mV)	0.28 ± 0.10	0.24 ± 0.09	0.312	0.42

Note: [a] Analyzed using Independent *t*-test
*Statistically significant at $p < 0.05$.

Table 4.
Analysis of delta maximum voluntary isometric contraction (ΔMVIC) between group.

ΔMaximum voluntary isometric contraction (ΔMVIC)	MHT group (means ± SD)	NMES group (means ± SD)	p^a	*Effect* size
Quadriceps dominant leg (mV)	0.12 ± 0.09	0.11 ± 0.09	0.911	0.05
Quadriceps non-dominant leg (mV)	0.12 ± 0.09	0.11 ± 0.07	0.727	0.14

Note: [a] Analyzed using Independent *t*-test
*Statistically significant at $p<0.05$.

4. Discussion

In this study, there was a significant improvement ($p < 0.05$) in the quadriceps muscle MVIC of MHT group in both dominant and non-dominant legs before and after intervention. These result are line with systematic review by Borzuola, et al. [12] stated the highest improvements of muscle strength were found when NMES was superimposed on sub-maximal exercises involving both concentric and eccentric contractions [12].

The improvement in MVIC in this study could be due to increased neural adaptation or increased muscle mass after resistance training. Resistance training results in increased muscle size, muscle strength, and muscle power through several mechanisms, ranging from skeletal muscle hypertrophy and changes in muscle architecture to neural adaptations such as increased motor unit activation and supraspinal adaptations [13]. Resistance training has been shown to cause neural adaptations in the form of increased motor unit recruitment and firing rate [14]. The body's physiological adaptation to muscle strengthening training is an increase in muscle recruitment that occurs in the first 2 weeks, after which there will be an increase in muscle mass after 4 weeks of resistance training [7]. The results of this study differ from study by Permatasari, et al. [15] using isotonic quadriceps and hamstring muscle strengthening exercises twice a week for 6 weeks on the non-dominant leg of 7 healthy sedentary male showed no improvements in quadriceps, hamstring and gastrocnemius muscle amplitude when performing single leg hops Permatasari, et al. [15]. One possibility is the difference in muscle activity measurement techniques. The study by Permatasari, et al. [15] conducted measurements while performing single leg hops, while our study used maximal isometric contractions against resistance. The simplest muscle contraction is static isometric contraction. EMG isometric contraction and muscle length are constant under constant conditions. The magnitude of the force is determined by the number of active motor units and the frequency of muscle recruitment of each unit. Increasing the number of active motor units and/or increasing the frequency of muscle recruitment of some units will result in increased EMG and force, in other words, EMG activity will increase as muscle force increases [16].

The activity of all muscles increases with increasing load. The lowest quadriceps muscle activation occurs when standing, then increases with the squatting position and reaches its peak when starting to rise, then decreases again as it returns to the standing position. The lowest hamstring muscle activation occurs when standing and tends to be stable when squatting, then increases and reaches its peak when rising. This shows that muscle activation assessed by EMG is proportional to the load and muscle work, where the greater the load and muscle work, the greater the muscle activation [17]. The effect size is large in both legs and is greater on the non-dominant side ($d = 1.39$) than the dominant side ($d = 1.32$). These results indicate that the significant difference in strength increases between the two legs is more striking in the non-dominant leg. This interpretation is based on the lower baseline values in the non-dominant leg before the intervention, which led to a more substantial change in strength compared to the dominant leg.

In this study, there was a significant improvement ($p < 0.05$) in the MVIC of the quadriceps muscle in both the dominant and non-dominant legs before and after 4 weeks of administering the Russian Neuromuscular electrical stimulation protocol. A large effect size ($d > 0.8$) was obtained in the MVIC of the Quadriceps of the Dominant Leg ($d = 1.25$) and the MVIC of the Quadriceps of the Non-Dominant Leg ($d = 1.63$). This increase in MVIC value is in line with research conducted by Silahudina, et al. [18] comparing biceps brachii muscle strengthening exercises using free weights and resistance bands on the biceps brachii muscle which was carried out 2 times a week for 4 weeks on both arms of 12 healthy untrained male subjects was able to provide significant improvements to the MVIC of the biceps brachii muscle after completing the exercise. Improvements were obtained in both types of exercise and no differences in the benefits of exercise were found between treatment groups [18].

The improvement in MVIC in this study could be due to increased neural adaptation after NMES administration. NMES uses electrical currents to produce muscle contractions in innervated muscles. Muscle contractions produced by electrically stimulated action potentials are similar to physiological contractions and can therefore be used for a variety of similar clinical applications, including muscle strengthening, muscle re-education and edema control [19]. Research in experimental models and in human subjects confirms that NMES can also increase muscle mass by about 1% and improve muscle function by about 10-15% after 5-6 weeks of exercise [20]. This study showed that the MVIC of the non-dominant quadriceps muscle with a larger effect size in increasing muscle strength after electrical stimulation, based on lower baseline data compared to the dominant side.

In this study, there was comparable change in the Quadriceps muscle MVIC in both groups before and after 4 weeks of intervention. Maximum voluntary isometric contraction is a safe and simple method for assessing muscle strength and provides more objective data than manual muscle testing [21]. Changes in MVIC after muscle strengthening exercises are associated with adaptive modifications in the neuromuscular system. Strengthening exercises will increase corticospinal stimulation because the subject performs each repetition in a controlled manner. Increased corticospinal cell stimulation is projected to spinal motor neurons that control muscles and causes increased muscle strength. In addition, hypertrophy of the trained muscles will also cause an increase in muscle strength and an increase in MVIC [13, 22].

This study has limitations. First, this study only used healthy untrained male subjects and only measure quadriceps muscles so that the results cannot be generalized. Second, the hybrid strengthening exercise in this study was carried out with modifications using conventional stimulation tools, so that it did not allow for reciprocal agonist antagonist strengthening movements in the exercise. The period of hybrid strengthening exercise and Russian protocol NMES stimulation carried out in this study was shorter than other studies. Third, this study did not limit the physical activity of the research subjects outside the exercise program which could affect the results of the study.

5. Conclusions

Both the hybrid modified strengthening exercise method and the Russian neuromuscular electrical stimulation protocol improved the MVIC of quadriceps muscle in the dominant and nondominant legs. There was no difference in changes of MVIC quadriceps muscle between the two interventions. Both approaches are regarded as appealing, time-efficient, and effective alternatives to resistance exercise for individuals aiming to enhance MVIC.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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