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Effects of modified hybrid resistance training on concentric quadriceps femoris peak torque and eccentric hamstring peak torque in untrained healthy subjects

Wirawan Indra Priyantono[1], Damayanti Tinduh[2*], Yudith Dian Prawitri[2], I Putu Alit Pawana[2], Soenarnatalina Melaniani[3]

[1]Resident of Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Universitas Airlangga/ Dr. Soetomo General Academic Hospital, Surabaya, East Java, Indonesia;
[2]Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Universitas Airlangga/ Dr. Soetomo General Academic Hospital, Surabaya, East Java, Indonesia;
[3]Department of Epidemiology, Biostatistics, Population Studies, and Health Promotion, Faculty of Public Health, Universitas Airlangga, Surabaya, Indonesia;

*Corresponding author:
Damayanti Tinduh;
Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Universitas Airlangga, East Java, Surabaya, Indonesia;
damayanti.tinduh@fk.unair.ac.id

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ABSTRACT

Background: Leg muscular strength may decline as a result of decreased mechanical stress on the muscles brought on by the COVID-19 pandemic's physical inactivity. The hybrid training method uses the force generated by an electrically stimulated antagonist muscle to resist a voluntarily contracting agonist muscle. Due to the lack of external resistance or stability equipment, this exercise may be a good option for strengthening workouts during a pandemic. Modifications were made using conventional stimulation tools because the hybrid training system was difficult to replicate. The study's objective was to analyze the effect of modified hybrid resistance training on concentric quadriceps femoris peak torque (Q_{CON}) and eccentric hamstring peak torque (H_{ECC}).

Methods: The study was conducted at the Medical Rehabilitation Installation of Dr. Soetomo General Academic Hospital Surabaya. The subjects were 30 untrained healthy men aged 18-40 years divided into the treatment group, which received modified hybrid resistance training and the control group, which received Russian protocol neuromuscular electrical stimulation 3 times per week for 4 weeks. Due to COVID-19 infection, four participants couldn't continue in intervention. Statistical tests were carried out on subjects that were able to complete the study (treatment: 13, control:13).

Results: There were increases in 60°/sec Q_{CON} (p-value 0.005) and 120°/sec Q_{CON} (p-value 0.001) in the non-dominant leg in the treatment group. There were increases in 60°/sec Q_{CON} (p-value 0.043), 120°/sec Q_{CON} (p-value 0.014), and 120°/sec H_{ECC} (p-value 0.043) in the non-dominant leg in the control group. There is a significant difference in non-dominant 120°/sec ΔQ_{CON} between the two groups (p-value 0.036).

Conclusion: There was a more significant increase in Q_{CON} in the modified hybrid training exercises group compared to the Russian stimulation group in untrained healthy subjects.

Keywords: *concentric quadriceps peak torque, eccentric hamstring peak torque, modified hybrid training, Russian stimulation, resistance exercise*.

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INTRODUCTION

When treating Corona Virus Disease (COVID-19) infection, social limitations have a significant impact on physical activity levels.[1,2] Tison et al. measured the average daily step count in 455,404 participants from 187 countries as a measure of physical activity. They found that when the COVID-19 pandemic was declared, this average daily step count decreased by 5.5% in the first 10 days and by 27.3% in the following 30 days. Singapore, an ASEAN country, reported daily step count decreased by 20% in the following 30 days after the COVID-19 pandemic declaration.[3] A reduction in steps will result in mechanical unloading of the muscles, which lowers muscular mass and strength. Quadriceps femoris muscle strength decreased by up to 8% after two weeks of inactivity (shown by a 75% drop in daily steps).[4,5]

Muscle imbalance is another issue that develops in sedentary and untrained people.[6] Hamstring muscular strength was shown to be 30–40% lower than quadriceps muscle strength in Pringga's research on healthy, untrained subjects.[7] Anterior cruciate ligament and hamstring injuries are more likely to occur when the hamstring and quadriceps muscles are out of balance, which can also compromise the dynamic stability of the knee joint.[8] Prevention of muscle imbalance needs to be done to reduce the risk of injury during exercise. This can be done by including agonist and antagonist muscle groups, such as the hamstrings and quadriceps femoris, in regular strengthening exercises.[9]

Resistance training is a proven classic strengthening method for increasing muscle mass, strength, and function.[1] An alternative approach to resistance training is neuromuscular electrical stimulation.[10] NMES approaches have been employed in long-term sports training to improve muscle performance as well as to regain strength and muscle mass following injury or surgery.[10-13] A hybrid resistance training was created at Kurume University in Japan that uses the force produced by electrically stimulated antagonist muscles to provide resistance to the agonist muscles that voluntarily contract, such as dumbbells providing resistance to the elbow flexors during elbow curls.[13]

In comparison to conventional NMES, the hybrid training approach uses more physiological muscle recruitment patterns, and it uses fewer external stabilizers and resistance tools than traditional weight training.[14] After performing hybrid strengthening exercises three times per week for four weeks, Ito's research on healthy male individuals found that the knee flexor extensors maximum volitional contraction increased by 3.4% and their muscular mass by 5.3%.[15] According to Iwasaki's research on healthy males, performing hybrid strengthening exercises three times per week for three weeks increased muscle strength in the quadriceps femoris muscle's concentric torsion by 22% and 26% at angulation rates of 30º/sec and 180º/sec, respectively. The quadriceps femoris muscle's concentric torque increased by 28% and 33% at angulation speeds of 30º/sec and 180º/sec when exercise was sustained for up to 6 weeks.[14]

This hybrid training method may be an effective choice for strengthening exercises during a pandemic because it does not require external resistance or stabilization equipment. In addition, engaging the eccentric contraction of the antagonist's muscle while the agonist is contracting concentrically may reduce the agonist-antagonist muscle response and decrease the risk of injury. Until now, this hybrid method research has been limited to Kurume University, Japan, because the hybrid training system used is not easy to replicate. In addition, there are currently no studies on the effectiveness of using hybrid strengthening exercises that report an increase in the eccentric strength of the antagonist's muscles. This study aimed to examine the effect of hybrid strengthening exercises with modifications using conventional stimulation tools on the concentric strength of the quadriceps femoris and the eccentric strength of the hamstring. So it is hoped that this hybrid exercise can be used more widely as an option in muscle-strengthening exercises. The increase in muscle strength will be measured using an isokinetic examination to obtain the concentric peak torque of the quadriceps femoris (Qcon) and the eccentric peak torque of the hamstring (Hecc). As a comparison, the researchers used the group with the Russian protocol neuromuscular electrical stimulation as a control group.

METHOD

This experimental study was carried out at the Medical Rehabilitation Installation of Dr. Soetomo General Academic Hospital, Surabaya, using a randomized controlled trial with pre-and post-test designs. The study was conducted between November 2022 and December 2022.

The following requirements must be met in order for a subject to be included in the study: (1) untrained healthy men, not currently undergoing or have undergone a lower leg muscle strengthening exercise program with a certain intensity regularly (minimum 2x/week) either at home, at work or in a fitness center in the last 6 months, (2) between the ages of 18 and 40, (3) low or moderate physical activity level as determined by the International Physical Activity Questionnaire-Short Form (IPAQ-SF), (4) normal musculoskeletal function (strength, sensation, and normal joint range of motion), and (5) willingness to participate in the entire series of research after giving written informed consent.

The following are the exclusion criteria for this study: (1) have conditions that preclude exercise (acute inflammation of the knee joint, joint or muscle pain during active movement); (2) have conditions that preclude neuromuscular electrical stimulation (pacemaker use, allergy to stimulation electrodes); (3) have knee injuries in the lower leg that occurred within the previous three months; and (4) have engaged in muscle-strengthening exercises within the previous six months. Dropout criteria included: (1) not willing to continue the research for any reason; (2) could not complete the exercise according to the research protocol (absence for 2 consecutive practice sessions); (3) complaints of joint or muscle pain (VAS > 2) with active movement (no load) or there are signs of inflammation that appear suddenly during exercise and delayed-onset muscle soreness (DOMS) in the limbs so that the subject cannot do exercise for 2 times in a row; (4) experienced an allergic reaction to the electric pad during the study which resulted in the research subject being unable to continue the study.

The research sample was taken by consecutive sampling in which all research subjects who met the inclusion criteria were included in the study until the number of subjects was met. The subject was randomized into a treatment group and a control group using simple randomization using a lottery in a sealed envelope.

Prior to the intervention, the concentric quadriceps femoris peak torque (Qcon) and the eccentric hamstring peak torque (Hecc) will be measured in all subjects using an isokinetic strength test at angulation speeds of 60º/sec and 120º/sec.

The treatment group received modified hybrid strengthening exercises to train quadriceps muscle, which involved voluntary quadriceps contraction against electrically stimulated hamstring contraction. The control group was given Russian protocol neuromuscular electrical stimulation directly on the quadriceps muscle. In both groups, each session consisted of 10 sets with 10 repetitions, with 1-minute rest between sets. Each group gets 12 sessions that were carried out in 3 sessions per week for 4 weeks. The intervention was done on both legs.

Both groups used the same stimulation parameters: Russian stimulation consisting of a carrier with a frequency of 5000 Hz modulated at a frequency of 20 Hz (2.4 ms on, 47.6 ms off). The intensity is 80% maximal comfortable intensity which would be adjusted at the beginning of each exercise. After 4 weeks (12 times of exercise), the patient would be measured again for the dynamic control ratio of the knee joint.

SPSS version 26 was used for the statistical analysis of the data that was gathered. The Monte Carlo test was used to look at data normality. The Levene test was used to examine the homogeneity of the data. DCR values were compared between each group's pre-and post-treatment values using the Wilcoxon Signed Rank test or the paired t-test, depending on whether the data were normally distributed. If the data were normally distributed, the DCR value difference between pre-and post-treatment was compared using an independent t-test; otherwise, the Mann-Whitney test was used. If p was 0.05, the p-value was regarded as significant. Cohen's d test was used to determine effect size.

RESULTS

There were 30 subjects in total for this study, with 15 subjects in each treatment and control group. There were 2 subjects from each group that dropped out due to COVID-19 infection that prevented them from continuing intervention. Statistical tests were carried out on 13 treatment group subjects and 13 control group subjects who were able to complete the study. The average age of the subjects was 31.23 ± 2.71 years for the treatment group and 32.69 ± 3.97 years for the control group. The average body weight in the treatment group was 74.15 ± 8.64 kg, while it was 75.46 ± 11.50 kg in the control group. The average height in the treatment group was 1.70 ± 0.05 m, while it was 1.70 ± 0.06 m in the control group. The average body mass index (BMI) for the treatment group was 25.56 ± 3.64 kg/m2, while it was 26.06 ± 3.31 kg/m2 for the control group. The baseline data were all normally distributed. Based on the Levene test, there was no homogenous data between the two groups in age and non-dominant Q_{con} 120°/sec. Further statistical tests using the independent sample t-test showed that the age and non-dominant Q_{con} 120°/sec difference between the two groups was not significant, with a p-value of 0.285 and 0.811. The characteristic of the subject is shown in Table 1.

Table 2 shows the effect of modified hybrid resistance training on Q_{con} and H_{ecc} in the control group by comparing the Q_{con} and H_{ecc} values before and after 4 weeks of exercise. The normality test result with Monte-Carlo showed that the data were normally distributed, so the paired samples t-test was used at knee joint DCR. Based on statistical tests, it was found that there were significant differences in non-dominant Q_{con} 60°/sec ($p = 0.005$) and non-dominant Q_{con} 120°/sec ($p = 0.001$) values at the end of the study in the treatment group. Large effect sizes ($d > 0.8$) were found in non-dominant Q_{con} 60°/sec ($p = 0.951$) and non-dominant Q_{con} 120°/sec ($p = 1.207$).

Table 3 shows the effect of Russian NMES on Q_{con} and H_{ecc} in the control group by comparing the Q_{con} and H_{ecc} values before and after 4 weeks of exercise. The normality test result with Monte-Carlo showed that the data were normally distributed, so the paired samples t-test was used at knee joint DCR. Based on statistical tests, it was found that there were significant differences in non-dominant Q_{con} 60°/sec ($p = 0.043$), non-dominant Q_{con} 120°/sec ($p = 0.014$) and non-dominant H_{ecc} 120°/sec ($p = 0.043$) value at the end of the study in the control group. Moderate effect sizes ($0.5 \leq d < 0.8$) were found in the non-dominant Q_{con} 60°/sec ($p = 0.626$), non-dominant Q_{con} 120°/sec ($p = 0.794$) and non-dominant H_{ecc} 120°/sec ($p = 0.629$).

Table 4 compares the ΔQ_{con} and ΔH_{ecc} values between the treatment and control groups at the end of the study. The normality test results with Monte-Carlo showed that the data were normally distributed, so the independent samples t-test was used. Based on statistical tests, it was found that there was a significant difference in the non-dominant ΔQ_{con} 120°/sec value at the end of the study between the treatment and control groups ($p = 0.031$). A large effect size ($d > 0.8$) was found in non-dominant ΔQ_{con} 120°/sec ($d = 0.899$).

Table 1. Characteristic of subjects.

Characteristic	Treatment (n = 13) Means ± SD	p-value (Normality)	Control (n = 13) Means ± SD	p-value (Normality)	p-value (Homogeneity)
Age (years)	31.23 ± 2.71	0.738	32.69 ± 3.97	0.528	0.042*
Gender	male: 13		male: 13		
Body weight (kg)	74.15 ± 8.64	0.938	75.46 ± 11.50	0.993	0.236
Body height (m)	1.70 ± 0.05	0.290	1.70 ± 0.06	0.905	0.755
BMI (kg/m^2)	25.56 ± 3.64	0.771	26.06 ± 3.31	0.982	0.940
IPAQ-SF	low: 3 moderate: 10		low: 6 moderate: 7		
Dominant leg	right: 13		right: 13		
Peak torque (FtLbs)					
Q_{con} 60 Dom	96.77 ± 34.81	0.795	83.77 ± 25.71	0.746	0.232
Q_{con} 60 NonDom	88.92 ± 25.02	0.908	83.85 ± 17.46	0.662	0.448
Q_{con} 120 Dom	69.23 ± 36.37	0.932	63.77 ± 23.62	0.907	0.080
Q_{con} 120 NonDom	62.23 ± 27.48	0.868	64.31 ± 14.12	0.843	0.031*
H_{ecc} 60 Dom	79.62 ± 25.36	0.797	77.08 ± 21.18	0.827	0.528
H_{ecc} 60 NonDom	81.08 ± 25.69	0.379	71.46 ± 24.74	0.858	0.707
H_{ecc} 120 Dom	74.85 ± 22.70	0.521	73.92 ± 20.64	0.646	0.811
H_{ecc} 120 NonDom	80.15 ± 25.18	0.841	67.31 ± 20.51	0.897	0.557

***Significant if $p < 0.05$**

Table 2. **Peak torque in the treatment group before and after four weeks of intervention.**

	Before	After	p-value	Cohen's d
Peak torque (FtLbs)				
Q_{con} 60 Dom	96.77 ± 34.81	99.31 ± 28.94	0.634	0.136
Q_{con} 60 NonDom	88.92 ± 25.02	104.38 ± 26.64	0.005*	0.951
Q_{con} 120 Dom	69.23 ± 36.37	83.69 ± 23.92	0.094	0.504
Q_{con} 120 NonDom	62.23 ± 27.48	85.77 ± 20.67	0.001*	1.207
H_{ecc} 60 Dom	79.62 ± 25.36	81.38 ± 27.06	0.630	0.137
H_{ecc} 60 NonDom	81.08 ± 25.69	75.00 ± 26.71	0.277	0.316
H_{ecc} 120 Dom	74.85 ± 22.70	82.31 ± 21.65	0.071	0.549
H_{ecc} 120 NonDom	80.15 ± 25.18	78.69 ± 23.54	0.806	0.070

***Significant if p < 0.05**

Table 3. **Peak torque in the control group before and after four weeks of intervention.**

	Before	After	p-value	Cohen's d
Peak torque (FtLbs)				
Q_{con} 60 Dom	83.77 ± 25.71	88.69 ± 30.07	0.079	0.532
Q_{con} 60 NonDom	83.85 ± 17.46	92.15 ± 18.12	0.043*	0.626
Q_{con} 120 Dom	63.77 ± 23.62	72.31 ± 22.94	0.122	0.462
Q_{con} 120 NonDom	64.31 ± 14.12	73.46 ± 14.19	0.014*	0.794
H_{ecc} 60 Dom	77.08 ± 21.18	80.46 ± 22.38	0.564	0.164
H_{ecc} 60 NonDom	71.46 ± 24.74	73.31 ± 23.70	0.605	0.147
H_{ecc} 120 Dom	73.92 ± 20.64	78.31 ± 24.70	0.215	0.363
H_{ecc} 120 NonDom	67.31 ± 20.51	79.31 ± 25.10	0.043*	0.629

Significant if p <0.05

Table 4. **ΔQ_{con} and ΔH_{ecc} in treatment and control group.**

	Before	After	p-value	Cohen's d
ΔPeak torque (FtLbs)				
ΔQ_{con} 60 Dom	2.54 ± 18.72	4.92 ± 9.25	0.684	0.161
ΔQ_{con} 60 NonDom	15.46 ± 16.26	8.31 ± 13.28	0.231	0.482
ΔQ_{con} 120 Dom	14.46 ± 28.72	8.54 ± 18.50	0.538	0.245
ΔQ_{con} 120 NonDom	23.54 ± 19.50	9.15 ± 11.52	0.031*	0.899
ΔH_{ecc} 60 Dom	1.77 ± 12.92	3.38 ± 20.59	0.813	0.094
ΔH_{ecc} 60 NonDom	-6.08 ± 19.23	1.85 ± 12.54	0.227	0.488
ΔH_{ecc} 120 Dom	7.46 ± 13.59	4.38 ± 12.09	0.548	0.239
ΔH_{ecc} 120 NonDom	-1.46 ± 20.94	12.00 ± 19.07	0.099	0.672

***Significant if *p* < 0.05**

DISCUSSION

The average age of the research subjects was 31.23 ± 2.71 years in the treatment group and 32.69 ± 3.97 years in the control age. The age of the study subjects was older than the hybrid exercise study on healthy men conducted by Ito in 2004, with an age range of 22 to 24 years.[15] Another study by Iwasaki in 2006 was conducted on sedentary healthy men with an average age of 22.3 years and an age range of 20-26 years.[14] The age of the study subjects was similar to the research on leg strengthening in the same population by Pringga in 2021, namely 31.57 ± 3.95 years in the treatment group and 34.71 ± 4.03 years in the control group.[16]

The average body weight of the study subjects was 74.15 + 8.64 kg for the treatment group and 75.46 + 11.50 kg for the control group. The body weight of the study subjects was heavier compared to the study by Iwasaki in 2006, with an average body weight of hybrid training subjects 61.40 + 10.51 kg and controlled 64.79 + 9.11 kg.[14]

The height range of the study subjects was 1.60 m – 1.80 m with an average of 1.71 + 0.05 cm and 1.70 + 0.06 cm. The height of the research subjects was similar to the study by Pringga in 2021, with an average height of 1.71 + 0.06 m and 1.69 + 0.07 m.[16]

The average BMI of the treatment group was 25.56 ± 3.64 kg/m^{2}, and the control group was 26.06 ± 3.31 kg/m^{2}, which was categorized as obese grade 1 based on Asia Pacific criteria.[17] The BMI of the study subjects was higher than that of Pringga's study, with an average of 21.50 ± 2.01 kg/m^2 and 23.00 ± 2.16 kg/m^2.[16]

In the treatment group, the number of subjects with a low IPAQ-SF level was 3 people (23.1%), and a moderate IPAQ-SF level was 10 people (76.9%). In the treatment group, the number of subjects with a low IPAQ-SF level was 6 people (46.2%), and a moderate IPAQ-SF level was 7 people (53.8%). Physical inactivity will result in a decrease in the cross-sectional area of muscle fibers, a decrease in oxidative capacity, and muscle capillarization. Muscle immobilization will result in decreased force production and resistance to fatigue. Muscle unloading also reduces electromyographic activity and oxidative enzyme activity.[18]

The treatment group had a higher baseline of Q_{con} on the dominant side (60°/sec: 96.77 ± 34.81 FtLbs, 120°/sec: 69.23 ± 36.37 FtLbs) compared to the non-dominant side (60°/sec: 88.92 ± 25.02 FtLbs, 120°/sec: 62.23 ± 27.48 FtLbs). The control group had balanced baseline Q_{con} between the dominant side (60°/sec: 83.77 ± 25.71 FtLbs, 120°/sec: 63.77 ± 23.62 FtLbs) and the non-dominant side (60°/sec: 83.85 ± 17.46 FtLbs, 120°/s: 64.31 ± 14.12 FtLbs). Research on leg strengthening in the same population reported a lower baseline Q_{con}, namely 62.71 ± 16.89 FtLbs and 52.00 ± 12.07 FtLbs at a speed of 60°/sec, 48.57 ± 16.54 FtLbs and 34.43 ± 5.91 FtLbs at a speed of 120°/second.[7]

The treatment group had a lower baseline H_{ecc} on the dominant side (60°/s: 79.62 ± 25.36 FtLbs, 120°/s: 74.85 ± 22.70 FtLbs) than the non-dominant side (60°/sec: 81.08 ± 25.69 FtLbs, 120°/s: 80.15 ± 25.18 FtLbs). The control group had a higher baseline H_{ecc} on the dominant side (60°/s: 77.08 ± 21.18 FtLbs, 120°/s: 73.92 ±

20.64 FtLbs) than the non-dominant side (60°/ sec: 71.46 ± 24.74 FtLbs, 120°/s: 67.31 ± 20.51 FtLbs).

Confounding factors that were not controlled for in this study included daily activities carried out by subjects outside the study. Researchers restricted the subjects from doing strengthening exercises on the limbs during the study, but subjects can still do physical activities at work, such as walking, climbing stairs, and doing aerobic exercises with the lower limbs, such as running and cycling.

In this study, there was a significant increase in the non-dominant Q_{con} 60°/sec and Q_{con} 120°/sec before and after 4 weeks of modified hybrid resistance training. The increase in Q_{con} from this study is in line with Iwasaki's study that used 16 healthy male subjects with a sedentary lifestyle. Hybrid training is done 3 times a week for 6 weeks. Each session consists of 10 sets of 10 reps of reciprocal knee flexion and extension. Application of training for 3 weeks resulted in an increase in Q_{con} of 22% at 30°/sec and 26% at 180°/sec. The exercise was continued for up to 6 weeks and resulted in an increase in Q_{con} of 28% at 30°/sec and 33% at 180°/sec.[14]

The increase, especially in the non-dominant side of the leg, may be due to better neural adaptation. In the treatment group, Q_{con} before the intervention on the non-dominant side was lower than on the dominant side. This can be caused by the level of activation of the non-dominant leg motor unit that is lower than the dominant side due to lower muscle loading.[18] After 4 weeks of intervention, the non-dominant leg experienced a better increase in muscle strength, possibly through neural adaptation in the form of increased motor unit recruitment and firing rate.[19] Whereas on the dominant side, although there was an increase in Q_{con}, it was not significant. This may be due to the already optimal level of activation of the motor unit due to the dominance of the limbs in daily activities.

A significant increase in Q_{con} 60°/sec and 120°/sec on the non-dominant side was followed by a decrease in H_{ecc} at 60°/sec and 120°/sec. The reduction in hamstring eccentric torque was not consistent with the strengthening effect the researchers expected when the hamstring muscles contracted eccentrically under electrical stimulation in a modified hybrid strengthening exercise. This may be due to reciprocal inhibition by increased activation of the quadriceps muscle, which inhibits activation of the hamstring muscles.[20] Although most neural adaptations result in greater activation of the agonist's muscles, evidence suggests that training results in less activation of the antagonist's muscles. Reducing the force from the antagonist's muscle will result in a greater net force generated by the agonist's muscle.[21] Another possibility is the occurrence of chronic muscle fatigue in the hamstring muscles due to eccentric contractions and recruitment of type II (fast-twitch, fatigue-able) muscle fibers, which are more dominant in electrically stimulated contractions.[12]

Q_{con} and H_{ecc} results on the dominant side experienced an insignificant increase at speeds of 60°/sec and 120°/sec. This may be due to the shorter duration of the intervention compared to other hybrid strengthening exercise studies. In addition, the hybrid exercises in this study used modifications using conventional stimulation tools so that they did not allow quadriceps-hamstring reciprocal strengthening movements to occur. So that in this study, the quadriceps only got a strengthening effect from voluntary movements against hamstring contractions. In Iwasaki's hybrid exercise, the quadriceps get a strengthening effect from voluntary movements against stimulated hamstring involuntary contractions and involuntary contractions when the quadriceps is stimulated to counteract voluntary hamstring contractions.[14]

In this study, there was a significant increase in the non-dominant Q_{con} 60°/sec and Q_{con} 120°/sec after Russian NMES in the quadriceps femoris muscle. This increase is in accordance with research by Park in 2015, which reported a higher increase in maximal isometric quadriceps torque in the Russian protocol resistance and stimulation exercise group compared to resistance training alone.[22] This enhancing effect may be produced by neural adaptation pathways.[23] Significant improvement on the non-dominant side can also be caused by a higher intensity of muscle stimulation. The intensity of the last stimulation in this study was higher on the non-dominant side (37.34 ± 6.09 mA) than on the dominant side (36.59 ± 4.80 mA). A higher current amplitude will cause greater overload on the muscles resulting in a higher increase in strength.[12]

An increase in no- dominant H_{ecc} 120°/sec also occurs on the non-dominant leg, even though the hamstring is not stimulated. There are many factors that can influence this. Among others, the subject's familiarity with the eccentric isokinetic test is better and the subject's physical activity outside the study.

In this study, there was a greater increase of non-dominant Q_{con} 120°/sec in the treatment group compared to the control group. This could be due to the fact that the quadriceps contractions in the treatment group were voluntary and against hamstring resistance. Meanwhile, the quadriceps contractions in the control group were performed involuntarily with electrical stimulation and without resistance. Voluntary muscle contraction activates slow-twitch and fast-twitch muscle fibers, respectively, whereas NMES is more effective for the stimulation of fast-twitch muscle fibers. The hybrid method has the advantage of using a more normal pattern of muscle recruitment compared to conventional NMES so that strengthening becomes more effective.[14] The increase occurred at the angular speed of 120°/second because it was close to the angular speed during the hybrid modification exercise, which was 90°/second. This is in accordance with the principle of specificity of resistance training.[21]

The increase in Q_{con} after hybrid training from this study was smaller compared to Iwasaki's research which reported an increase in Q_{con} by 22% at 30°/sec and 26% at 180°/sec after the application of hybrid training for 3 weeks. This could be caused by differences in baseline where the age of the subjects in this study was older than in the Iwasaki study. Young adult individuals have a greater response to resistance training than older adults.[24]

Research on hybrid strengthening exercises is still limited to one institution at Kurume University in Japan. The difficulty of training replication lies in the complexity of hybrid training tools that are not generally available. To the knowledge of the researchers, the research on hybrid strengthening exercises with modifications using conventional stimulation tools is the first study outside the institution of Kurume University, Japan. The results showed a significant increase in the concentric peak torque of the quadriceps femoris before and after the hybrid modified strengthening exercise, the concentric peak torque of the quadriceps femoris, and the eccentric peak torque of the hamstring before and after the Russian protocol neuromuscular electrical stimulation. However, the increase that occurred was not as large as the results of a study conducted at Kurume University and did not occur in all limbs and angular speed. Modified hybrid resistance training and Russian NMES are well received with minimal side effects. Further research on modified hybrid resistance training is still needed to get clearer evidence of the effectiveness of the exercises.

This research has several limitations. First, this study used untrained healthy male subjects and involved the quadriceps femoris and hamstring muscles, so the further study should be done for other populations and other muscle groups. Second, the hybrid training in this study was carried out with modifications using conventional stimulation tools so that it does not allow antagonist-agonist reciprocal contraction in the exercise. Third, the period of hybrid strengthening exercises and Russian protocol NMES stimulation conducted in this study was shorter than in other studies. Fourth, this study did not monitor the physical activity of the research subjects outside the exercise program, which could affect the research results.

CONCLUSION

Modified hybrid resistance training for four weeks provided an increase in the concentric quadriceps femoris peak torque and no difference in the eccentric hamstring peak torque. Russian protocol neuromuscular stimulation for four weeks provided an increase in the concentric quadriceps femoris peak torque and the eccentric hamstring peak torque. Modified hybrid resistance training provided a greater increase in the concentric quadriceps femoris peak torque compared to the Russian protocol neuromuscular electrical stimulation group.

RESEARCH ETHICS

This research has been approved by the Research Ethics Committee, Dr. Soetomo General Hospital, with ethical clearance number 0522/KEPK/XI/2022.

CONFLICT OF INTEREST

There is no conflict of interest in writing this research report.

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AUTHOR CONTRIBUTION

All authors have made the same contribution in writing the report on the results of this study, from the stage of proposal preparation, data search, and data analysis, to the interpretation of research data and presentation of the final report.

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