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Research Paper

Neuromuscular Adjustments of the Quadriceps Muscle After Eccentric Resistance and Concentric Resistance Training

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ABSTRACT

Introduction: Deficiency in the neural control of movement is associated with poor posture and skeletal muscle injuries. Exercise training is commonly reported as an intervention to improve neuromuscular activity. However, maximizing the effectiveness of exercise interventions for improving neural control of movement has been less investigated. The purpose of the current study was to examine improvement in neuromuscular activity (e.g., muscle fiber conduction velocity) and quadriceps function after eccentric resistance training versus concentric training.

Materials and Methods: A total of 24 men participated in this study and were randomly divided into eccentric training (n=12) and concentric training groups (n=12). Maximal voluntary isometric contraction (MIVC) of quadriceps, vertical jumping, and multichannel surface electromyography (EMG) signals were recorded before and 12 weeks after resistance eccentric and concentric training. Muscle fiber conduction velocity (MFCV) and root mean square (RMS) were computed using raw EMG signals.

Results: The percentage increases in MVIC and vertical jumping after eccentric resistance training were significantly higher than those after concentric training ($P<0.05$). Likewise, eccentric exercise resulted in a higher increase in MFCV and RMS of EMG than concentric exercise ($P<0.05$).

Conclusion: A higher increase in neuromuscular activity and quadriceps performance observed after eccentric exercise may indicate that eccentric resistance training is more effective in improving neuromuscular activity and muscle function.

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1. Introduction

Deficiency in the neural control of movement is associated with poor posture and skeletal muscle injuries. Muscle fiber conduction velocity (MFCV) and root mean square (RMS) of electromyography (EMG) are commonly used as neuromuscular variables to monitor motor control changes within the skeletal muscle. MFCV reflects the propagation velocity of the action potential along the membranes of muscle fibers, while RMS of EMG provides some information about motor unit recruitment, motor unit firing rate, and neural drive from central nervous system to muscle fibers [1-4]. Previous studies have shown changes in MFCV and EMG variables after exercise training [3, 5, 6]. For example, Vila-Cha [1] reported that motor unit conduction velocity increased after 12 weeks of endurance and strength training, indicating that electrophysiological properties have changed after exercise training. Besides, neuromuscular adaptation to exercise training depends on muscle contraction type [7]. Although all types of exercise training may result in significant neuromuscular adaptation, it is not always clear which type of exercise is best for maximizing adaptation gains.

It has been reported that muscle adaptations observed after eccentric exercise are different from those observed after isometric and concentric exercise [8, 9]. During eccentric exercise, a greater tension develops within the skeletal muscle results in muscle fiber damage and muscle soreness [10-13]. An increase in sarcolemma membrane permeability has also been reported after eccentric exercise, most likely due to muscle fiber damage [14]. Therefore, changes in muscle fiber membrane properties after an eccentric exercise may affect the propagation velocity of the action potential. Additionally, eccentric contraction is characterized by different neural control of movement compared with isometric and concentric exercises. This factor may further contribute to changes in neuromuscular activity within the skeletal muscle. The purpose of this study was to investigate the changes in neuromuscular activity of quadriceps muscle and its association with muscle function after resistance eccentric and concentric training. Quadriceps muscle plays an essential role in explosive movement during sport and daily activities. Thus, maximizing the effectiveness of exercise training for neuromuscular adaptation within the quadriceps may help improve human performance.

It is hypothesized that changes in neuromuscular activity and muscle function after eccentric exercise are different from concentric training. The result of this study may help understand mechanisms underlying motor control changes after eccentric exercise.

2. Materials and Methods

Study subjects

A total of 24 men (Mean±SD age: 21.2±2.5 y, Mean±SD body mass: 73.5±11.9 kg, Mean±SD height; 1.77±0.06 m) were recruited for the study. The participants were randomly assigned to two groups: eccentric training group (n=12) and concentric training group (n=12). All subjects were inactive (being defined as exercising once a week or less) and not involved in any regular exercise training for at least one year before the experiment.

Resistance training protocols

The subjects performed eccentric exercise in the supine position on a weight-training machine (Universal Gym, USA). The subject lowered the load in an eccentric mode from the initial position (full knee extension=180º) to the end position (knee flexion=90º) in a controlled maneuver. The subject was asked to maintain a cadence of 2 during the lifting phase, 1 during the lockout, and 3 during the lowering phase, in time with the metronome (frequency=1 Hz). Two assistants help the subject bring the leg to the initial position (full knee extension=180º) to avoid muscle fatigue and or injury during the concentric phase. In the concentric group, the load was lifted from the initial position (knee flexion=90º) to the end position (full knee extension=180º) in a controlled maneuver using the same training machine (Universal Gym, USA) and in the same position as an eccentric training group. Each subject performed one repetition maximum (1-RM) using concentric contraction, and workload for exercise training was defined as 80% of 1-RM. All subjects in both groups performed 3 sets of 12 repetitions with 80% of the 1-RM with 3 minutes of rest in between. For each subject, 1-RM was measured every week, and the weights were adjusted accordingly.

Maximal knee extension force

The maximal knee extension force was measured using a load cell. The subject performed Maximal Isometric Voluntary Contraction (MIVC) of quadriceps in 90º of knee flexion by pulling a strap connected by a chain to a load cell and foot ankle. Visual feedback of force was provided on an oscilloscope. The subject performed three 5-s MVIC of quadriceps muscle with 2 min rest in between. The subject was encouraged to generate the greatest force. The highest MIVC among the three MVICs was selected as the reference value.

Vertical jumping

The subject was asked to stand, feet parallel, heels touching the ground, position the body parallel to the wall, and extend the arms, marking the highest distance reached with the fingertips. Then, he was asked to jump with the dominant leg and touch the highest point reached. The distance between the highest point reached in the stand position and the highest point reached in the vertical jumping was measured. Each subject performed two vertical jumps, and the highest jumping was considered the reference value.

Multichannel Surface Electromyography (EMG) recording:

Multichannel surface EMG signals were recorded using an EMG amplifier (EMG-USB2+, OT Bioelettronica, CMMR>95 dB; Figure 1). One adhesive array (inter-electrode distance 5 mm, electrodes 5 mm×1 mm) was placed on the distal region of the vastus medialis muscle along with the muscle fiber orientation and innervation zone [14]. Before placing the electrode array, the shape of the action potentials was visually inspected using a metal liner array. The metal liner array was moved on the muscle to find a good propagation of action potential with respect to the innervation zone. The skin was prepared and cleaned with alcohol before electrode placement. A conductive gel was also used to record a high-quality signal. EMG signals were amplified bipolar (bandwidth 10–500 Hz), sampled at 2048 Hz, and stored after 12-bit A/D conversion. The electrode array was placed on the distal region of the VM muscle with respect to the muscle fiber orientation and innervation zone.

Signal analysis

MFCV was estimated within the epoch of 250 ms from high-quality signals showing a good propagation of the action potentials with respect to the innervation zone [15]. The delay time of each action potential obtained via decomposition between the two adjacent electrodes along the fibers is τ di, then the conduction velocity of the ith Motor Unit Action Potential (MUAP) can be estimated as CVi=d ie/t di, where d ie is the inter-electrode distance.

Accordingly, the Root Mean Square (RMS) of EMG was computed for non-overlapping signal epochs of 250 ms and averaged to obtain one representative value for RMS.

$$\chi rms=\sqrt{\frac{1}{T_2-T_1}}\int_{T_1}^{T_2}[f(t)]^2dt$$

The square of the function defines the continuous waveform. Continuous function (or waveform) f(t) is defined over the interval {\display style T_{1}\leq t\leq T_{2}} T1 ≤t ≤T2.

The value obtained from 250 ms was averaged within the 5-s MVIC contractions. For the statistical analysis, the percentage change between pre-exercise value and post-exercise value was calculated.

Statistical analysis

An independent t-test was used to compare the mean values of two different training groups (eccentric and concentric) for muscle function (MIVC and vertical jumping) and EMG variables (MFCV and RMS) at pre-exercise conditions. One-way analysis of variance (ANOVA) with repeated measures was used to evaluate changes in MVIC and vertical jumping from pre-exercise to post-exercise condition with training group (eccentric and concentric) as independent factors. Moreover, 2-way ANOVA with repeated measures was used to assess changes in MFCV and RMS across maximal isometric contraction at the post-exercise session (% change) for eccentric and concentric training groups as an independent factor. A post hoc test with ANOVA was used to make pairwise comparisons among sample means. Statistical analysis and drawing graphs were performed by SPSS and Excel software v. 20, respectively. $P<0.05$ was considered a significant level for statistical procedures.

3. Results

Table 1 presents Mean±SD values for MIVC, RMS, and MFCV, for eccentric (n=12) and concentric (n=12) training group.

Muscle function

Muscle function (MIVC and vertical jumping) and EMG variables (MFCV and RMS) were not significantly different between the two training groups at pre-exercise ($P>0.05$). A significant increase in maximal isometric quadriceps strength (F=81, df=22, $P>0.0001$) and vertical jumping (F=31.3, df=22, $P>0.001$) were observed after 12 weeks of resistance eccentric and concentric training. The increase in vertical jumping for the eccentric group was significantly higher than the concentric group ($P>0.05$; Figure 2). The increased MVIC for the

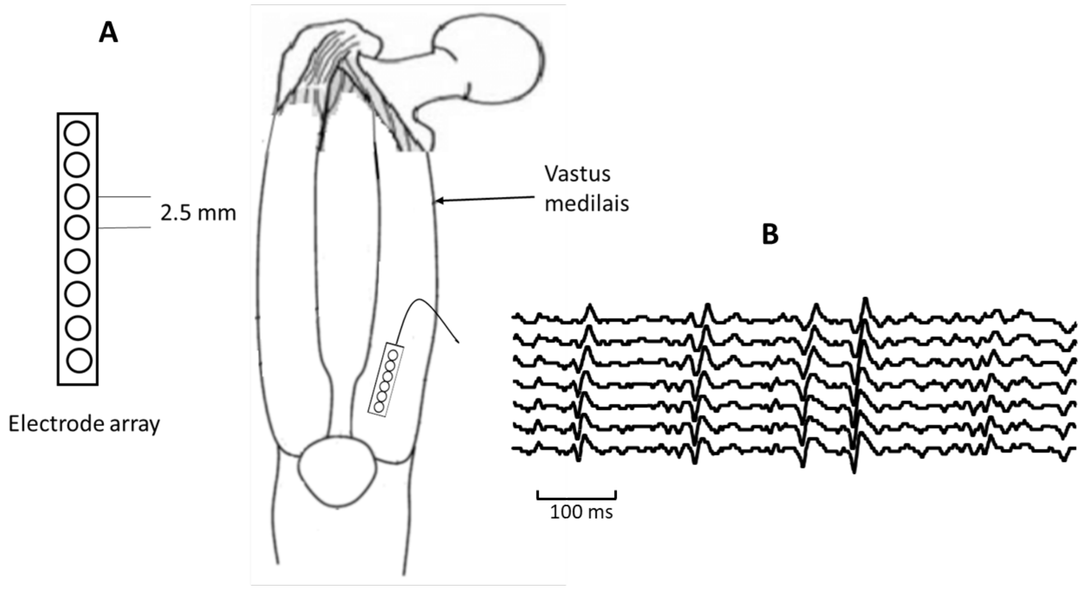

Figure 1. Schematic Representation of Electrode Array Position on the Vastus Medialis (VM) Muscle (A), and Associated Multichannel Surface EMG Signal (B), Recorded During Maximal Isometric Voluntary Contraction

eccentric group was also significantly greater than that in the concentric group.

EMG variables

A significant increase in MFCV was observed after 12 weeks of resistance eccentric and concentric training (F=42.8, df=22, P>0.0001). An interaction was also observed between the training groups (concentric and eccentric) and testing sessions (pre-exercise and post-exercise). Eccentric training resulted in a higher increase in MFCV than the concentric group (F=11.8, df=22, P>0.007; Figure 3).

A significant increase in RMS of EMG was observed after 12 weeks of resistance eccentric and concentric training (F=35.5, df=22, P>0.0001). An interaction was also observed between the training groups (concentric and eccentric) and the testing session (pre-exercise and post-exercise). The eccentric group reflected a greater increase in RMS of EMG at the post-exercise testing session than the concentric training group (F=10.5, df=22, P>0.009; Figure 4).

Table 1. Descriptive statistics for Maximal Isometric Voluntary Contraction (MIVC), Root Mean Square (RMS), and Muscle Fiber Conduction Velocity (MFCV)

Variables	Mean±SD		
	Training group	Pre-training	Post-training
MIVC (kg)	Eccentric	53.2±4.9 *	78.3±6.7
	Concentric	51.4±4.5 *	65.3±5.9
RMS (uV)	Eccentric	149.5±15.1 *	452.6±38.6
	Concentric	156.5±14.8 *	384.3±29.9
MFCV (m/s)	Eccentric	4.5±0.37 *	5.4±0.44
	Concentric	4.2±0.35*	4.7±0.39

* Indicates differences between pre-training and post-training sessions (P<0.05). No significant difference was observed between the two training groups at the pre-training condition (P>0.05).

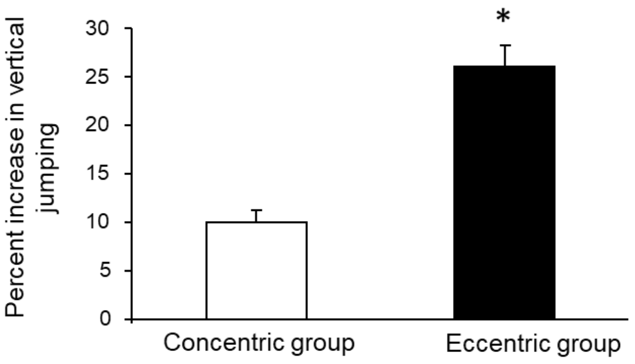

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Figure 2. Percentage Increase in vertical jumping (Mean±SE,%) after 12 weeks concentric (white) and resistance eccentric (black) training

* Indicates that eccentric training resulted in a greater increase in vertical jumping than concentric training (P<0.05).

4. Discussion

The current study investigated changes in neuromuscular activity and muscle function after resistance eccentric versus concentric training. The main findings of this study showed that 12 weeks of eccentric resistance training resulted in a significantly greater increase in MFCV and RMS of EMG compared to concentric training. Moreover, quadriceps strength and vertical jumping after 12 weeks of eccentric training were significantly greater than concentric training. The result indicates that eccentric resistance training is more effective than resistance concentric training to improve neuromuscular adaptation and muscle performance.

Regarding muscle performance, all subjects in both training groups could perform maximal voluntary isometric contraction and achieve a higher force level than pre-training session. An increase in muscle force after resistant training can be explained by neural mechanisms underlying force development, such as motor unit discharge rate and or motor unit recruitment [16].

The increased maximal isometric force after 12 weeks eccentric training program (30.1%±3.37%) was also significantly higher than those observed after 12 weeks of concentric training (21.5%±2.3%). Additionally, eccentric training resulted in a greater increase in vertical jumping than concentric training, indicating that improvement in mechanisms underlying explosive

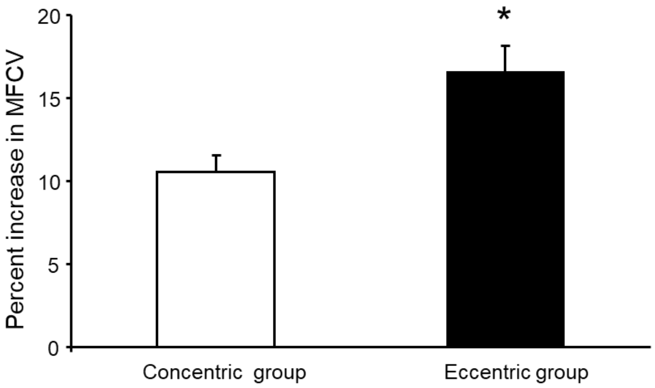

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Figure 3. Percentage increase in Muscle Fiber Conduction Velocity (MFCV) (Mean±SE,%,) after 12 weeks concentric (white) and resistance eccentric (black) training

* Indicates that eccentric training resulted in a greater increase in MFCV than concentric training (P<0.05).

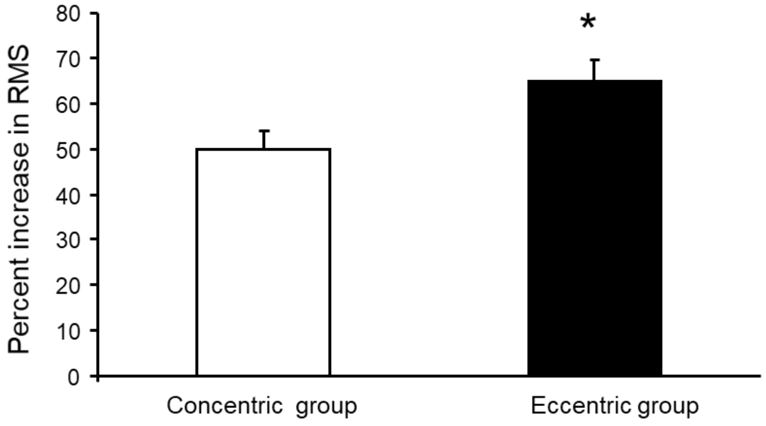

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Figure 4. Increase in Root Mean Square of EMG (RMS) (Mean±SE, %) after 12 weeks concentric (white) and resistance eccentric (black) training

* Indicates that eccentric training resulted in a greater increase in EMG RMS than concentric training ($P<0.05$).

movement to be significantly larger following eccentric resistance training compared to resistance concentric training. Accordingly, previous studies also showed a higher increase in muscle strength and vertical jumping after dynamic stretching exercises. Carvalho et al. [17] demonstrated that strength training combined with stretching plyometric exercises could improve muscle force and vertical jumping performance.

Likewise, previous studies showed that both concentric and eccentric resistance training programs contribute to a significant increase in muscle strength of the lower and upper limbs, and eccentric training was more effective than concentric training to increase muscle strength [18-20].

Regarding electromyography, a significant increase in MFCV of the vastus medialis oblique muscle was observed after 12 weeks of resistance eccentric and concentric training. However, the main result of this study shows that eccentric training resulted in a larger increase in MFCV compared to concentric training. Likewise, eccentric training resulted in a greater increase in RMS of EMG as compared to concentric training. Higher MFCV observed after eccentric strength training may be explained by preferential recruitment of fast-twitch motor units. It has been reported that eccentric contraction is associated with the preferential recruitment of fast-twitch motor units compared to isometric and concentric contraction [21]. The fast-twitch motor units are characterized by a higher recruitment threshold, and a higher firing rate produces faster muscle fiber conduction velocity and muscle force [21-23]. Therefore, a higher vertical jumping observed after eccentric training can be explained by greater recruitment of fast-twitch muscle fibers within the quadriceps muscle. The role of the quadriceps muscle and fast-twitch muscle fibers for vertical jumping performance has been reported in previous studies [24].

Additionally, a larger increase in RMS of EMG after eccentric training indicated that eccentric exercise contributed to the rise in motor units recruitment and or motor units discharge rate within the quadriceps muscle [25]. It has been shown that strength training using eccentric action results in a greater cortical activation that can enhance neural transmission in the corticospinal pathways and increase the excitability of motor neurons [26]. In summary, the result of the current study showed that eccentric resistance exercise could contribute to a greater neuromuscular adaptation than concentric exercise, most likely by increasing neural transmission to muscle fibers and or reduction in recruitment threshold of fast-twitch motor units.

Study implications

Deficits in postural balance are related to the poor neuromuscular activity. Therefore, greater improvement in neuromuscular activities and muscle performance observed after eccentric resistance training may indicate that exercise intervention using eccentric action is more effective to improve postural balance and, as a consequence, reduce the risk of associated skeletal muscle injuries.

5. Conclusion

The result of the current study showed a higher increase in quadriceps function and neuromuscular activity after eccentric training. A higher increase in neuromuscular activity observed after eccentric exercise may indicate that the tension combined with stretching effectively induces neuromuscular adaptations to training. The result of this study may provide useful knowledge to develop exercise and or rehabilitation training programs to improve muscle performance.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles were observed in this study.

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Authors' contributions

Conceptualization, data collocation and analyzing, writing the manuscript, and training management: Fatemeh Azizi Chouchan; Training management, and data collection: Sadegh Cheragh-Birjandi; Data collocation and analyzing, review, and editing: Zahra Izanloo; Supervision, review, and editing: Nosratollah Hedayatpour.

Conflict of interest

The authors declared no conflict of interest.

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