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Blood flow restricted resistance exercise induced thigh muscle cross-sectional area rather than traditional resistance exercise

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Abstract

Introduction: Traditionally, resistance exercise stimulates growth hormone (GH) secretion and leads to muscle hypertrophy in a load-dependent manner; however, new research demonstrates that blood flow restricted resistance exercise (BFR) produces potent GH responses that are similar to or exceed those produced following high-load resistance exercise. The purpose of the present study was to examine the effects of BFR resistance exercise versus traditional resistance training (TRT) on GH levels and thigh muscle cross-sectional area (CSA).

Material & Methods: Twenty untrained healthy men volunteered to participate in this study. The subjects were divided into BFR resistance exercise group (4 sets with 20-50 % of 1-RM in each station with 30-60 second of rest) or TRT group (4 sets with 6-12 maximal repetitions at 70-80% of 1-RM in each station with 2-3 minute of rest) randomly. All the subjects executed five resistance exercises selected to stress the thigh muscle groups in the following order: leg press, squat, leg extension, prone leg curl, and dead lift. BFR resistance exercise and TRT consisted of 50-60 min of station weight training per day, 3 days a week, for 8 weeks. Thigh muscle CSA and GH concentration were measured before and after the intervention.

Results: The results showed that maximum strength in each station was increased after BFR resistance exercise and TRT ($P<0.05$). Thigh muscle CSA also was increased after BFR resistance exercise and TRT; however the increase in thigh muscle CSA was higher in resistance exercise with BFR than TRT. For GH no significant differences were observed after the BFR resistance exercise and TRT methods.

Conclusions: The data suggest that BFR resistance exercise method is a superior method for thigh muscle CSA in compare to the TRT method.

Keywords: Blood flow restriction, Resistance training, Muscle hypertrophy, Growth hormone.

1. Introduction

Growth hormone (GH) is a polypeptide hormone considered to have both anabolic and catabolic properties. Specifically, GH acts as a repartitioning agent to induce fat metabolism toward mobilization of triglycerides, and stimulating cellular uptake and incorporation of amino acids into various proteins, including muscle (1). In addition to exerting effects on muscle tissue, GH also is involved in the regulation of immune function, bone modeling, and extracellular fluid volume (2). It is well-documented that resistance exercise is a stimulus for both acute and chronic hormone responses (3,4). GH is a hormone that has been studied extensively because of its potential role in muscular adaptations to resistance exercise (4). Previous literature suggests that the magnitude of the acute endocrine response is influenced by the intensity and volume of the resistance exercise, with high volume, moderate to high intensity protocols eliciting greater GH responses (4). Traditional high-load resistance training performed in excess of 70% of one-repetition maximum (1RM) is recommended as an optimal stimulus for muscle hypertrophy and strength and tendon cross-sectional area (CSA) (5,6).

Blood flow restriction (BFR) exercise is a novel exercise modality in clinical settings, which induces muscle hypertrophy and strength with low to moderate training intensity through increased anabolic processes mediated by BFR (usually with cuff inflation) (7). Similar to traditional high intensity protocols, low intensity BFR resistance exercise has been shown to acutely increase serum hormone levels and blood lactate in men (8,9). BFR improves training adaptations (10), such as muscle hypertrophy, muscle strength (11,12), endurance (13) and acute hormonal responses (14), with minimal adverse cardiovascular or muscular effects (15). In healthy adults, BFR resistance exercise yields muscle hypertrophy and strength comparable to heavy-load resistance training (16), using loads as low as 30% of 1-RM (11). In addition to the improvement in muscle strength and hypertrophy, BFR resistance exercise was proven to be safe, with no significant differences following training in resting creatine kinase, interleukin-6, insulin-like growth factor 1 (IGF-1) or hemostatic markers (17). Recent clinical studies indicated that BFR resistance exercise is a safe method even for the patients with cardiovascular diseases (18,19). Kambič et al. (2019) reported that BFR resistance exercise is safe and associated with significant improvements in muscle strength in patients with coronary artery disease (18).

The effects of low intensity BFR resistance exercise on thigh muscle CSA and hormonal responses in compare to the traditional resistance training (TRT) are not well known. The purpose of this study was to determine whether the acute hormone response to exercise differed between low intensity BFR resistance exercise and traditional high-intensity resistance exercise in untrained healthy men. We hypothesized that low intensity BFR resistance exercise would elicit similar endocrine responses and muscle CSA as a TRT session.

2. Materials and Methods

Subjects

Twenty untrained healthy men aged 20-30 years (age: 24.5 ± 3.0 mean ± SD) who were taking oral contraceptives volunteered for this study. Subjects were screened with a health status questionnaire prior to participation in this study. They also completed physical activity questionnaire to provide information about exercise participation history. None of the men had been engaged in a regular resistance training program for the previous six months prior to the study. Men were excluded if they had any orthopedic conditions that prevented them from exercising or if they had been diagnosed with any endocrine-related disorders. The subjects gave written informed consent before participation. The Institutional Review Board at the Islamic Azad University, Marvdasht branch approved this study. Thereafter, the subjects were divided into BFR resistance exercise group (n=10) or TRT group (n=10) randomly.

Measurements

Anthropometric and body composition measurements

Height and body mass were measured, and body mass index (BMI) was calculated by dividing body mass (kg) by height (m^2). Body fat percentage was assessed by skinfold thickness protocol. Skinfold thickness was measured sequentially, in chest, abdominal, and thigh by the same investigator using a skinfold caliper (Harpenden, HSK-BI, British Indicators, West Sussex, UK) and a standard technique.

Exercise training

Two familiarization sessions were designed to habituate subjects with the testing procedures and laboratory environment. The main aim of these sessions was to familiarize subjects with different resistance exercises using weight-training machines and also to familiarize them with performing the 1-RM test. Maximal strength was determined using a concentric, 1-RM (20), as previously described (21). The warm-up consisted of riding a stationary bicycle for 5 min, two sets of progressive resistance exercises similar to the actual exercises utilized in the main experiment, and 2-3 min of rest accompanied by some light stretching exercises. After the warm-up, subjects performed the 1-RM test, and the heaviest weight that could be lifted once using the correct technique was considered as 1-RM for all the exercises and used to calculate the percentage of resistance. During the familiarization sessions, it was ensured that all the subjects used the correct techniques for all exercises prior to taking part in the main test sessions. The subjects in BFR resistance exercise and TRT groups executed five resistance exercises selected to stress the thigh muscle groups in the following order: leg press, squat, leg extension, prone leg curl, and dead lift. BFR resistance exercise and TRT consisted of 50-60 min of station weight training per day, 3 days a week, for 8 weeks. TRT was performed in 5 stations and included 4 sets with 6-12 maximal repetitions at 70-80% of 1-RM in each station with 2-3 minute of rest.

In this study, blood flow restriction was created by using air pressure gauge with 5 cm band and pressure of 100 mm Hg in the upper extremity of the leg of subjects. BFR resistance exercise training was performed in 5 stations and included 4 sets with 20-50 % of 1-RM in each station with 30-60 second of rest. General and specific warm-up were performed prior to each training session, as explained for the 1-RM determination, and each training session was followed by cool-down.

Biochemical analyses

Resting blood samples (5 ml) were taken at the same time before and after 8 weeks intervention and blood sample was obtained by venipuncture. Serum obtained was frozen at -22 °C for subsequent analysis. The GH level was measured in duplicate using an electrochemiluminscent method by Roche (Cobas e411 model, Germany) instrument. The sensitivity of measurement was 0.1 ng/ml.

Determination of thigh muscle CSA

Housh et al. (1995) equations were used for thigh muscle CSA estimation (22). Knapik et al (1996) reported that this method applicable for use in populations studies of young, healthy, active men and women (23). The mid-thigh circumferences were measured to nearest 0.1 cm with a tape fitted with a Gulick handle using the procedures described by ACSM (2005) (24). The anterior thigh skinfolds were measured to nearest 0.5

mm with Harpenden caliper by standard technique (24). The mid-thigh circumstance and skinfold measurements were taken midway between the inguinal crease and the proximal border of the patella. All anthropometric dimensions were taken by the same tester who had previously demonstrated test-retest reliability of r > 0.90. Quadriceps, hamstrings and total thigh muscles CSA were estimated by following equations (22):

$$\text{Quadriceps CSA} = (2.52 \times \text{mid-thigh circumference (cm)}) - (1.25 \times \text{anterior thigh skinfold (mm)}) - 45.13$$

$$\text{Hamstrings CSA} = (1.08 \times \text{mid-thigh circumference (cm)}) - (0.64 \times \text{anterior thigh skinfold (mm)}) - 22.69$$

$$\text{Total thigh muscle CSA} = (4.68 \times \text{mid-thigh circumference (cm)}) - (2.09 \times \text{anterior thigh skinfold (mm)}) - 80.99$$

Statistical analysis

Results were expressed as the mean ± SD and Shapiro-Wilk Test was applied to evaluate the normal distribution of variables. Paired t-test and independent sample t-test were used to assess the between and inter-group changes. The significance level of this study was set at P<0.05 and the data were analyzed using SPSS software for windows (version 17, SPSS, Inc., Chicago, IL).

3. Results

Anthropometric and body composition parameters of the subjects are presented in Table 1. The anthropometric and body composition parameters were similar between two groups.

Table 1. Demographic characteristics (mean ± SD) of the subjects at baseline

	TRT group (n=10) (mean±SD)	**BFR group (n=10) (mean±SD)**
Age (year)	26.6±2.1	22.4±2.2
Height (cm)	177.0±6.7	176.3±4.2
Body mass (kg)	79.4±10.7	80.1±11.2
BMI (kg/m^2)	25.4±3.6	25.8±4.1
Body fat (%)	9.1±4.5	9.7±5.3

There were no differences in strength between groups at baseline (Table 2). Our results showed that muscle strength increased after 8 weeks TRT and BFR in leg press, squat, leg extension, prone leg curl, and dead lift (P<0.05). The results revealed that the increase of maximum strength in leg extension, squat, prone leg curl, and dead lift was higher after 8 weeks TRT compared to the BFR method (P<0.05). For leg extension no significant differences were observed between TRT and BFR methods.

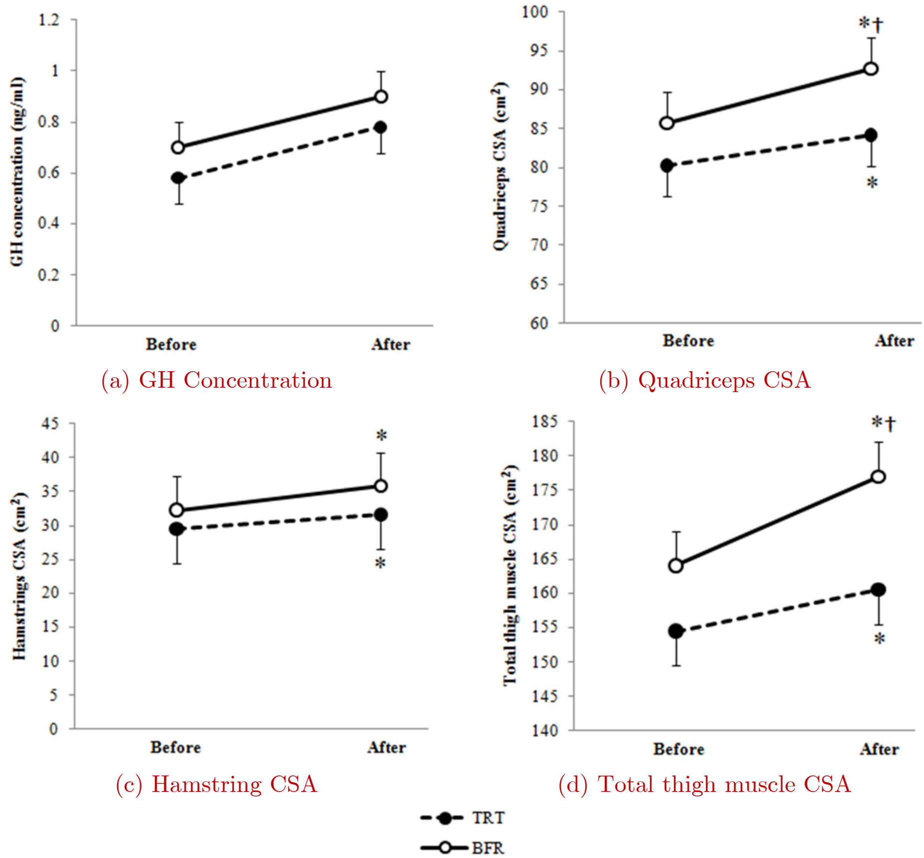
Table 2. Maximum strength (mean ± SD)
of the subjects before and after training

	Baseline (mean±SD)	After intervention (mean±SD)	Paired t-test (Sig)	Independent t-test (Sig)
Leg press (kg)				
TRT (group)	180.0±11.5	222.5±14.9	0.001*	0.47
BFR (group)	183.5±10.8	233.0±16.6	0.001*	
Squat (kg)				
TRT (group)	75.5±6.8	97.0±9.7	0.001*	0.58
BFR (group)	79.5±4.9	99.5±10.1	0.001*	
Leg extension (kg)				
TRT (group)	46.0±3.9	63.0±6.3	0.001*	0.04*
BFR (group)	45.5±3.6	58.5±6.2	0.001*	
Prone leg curl (kg)				
TRT (group)	45.0±5.7	65.6±5.9	0.001*	0.01*
BFR (group)	46.0±3.1	60.5±7.6	0.001*	
Dead lift (kg)				
TRT (group)	49.0±5.1	69.5±6.8	0.001*	0.001*
BFR (group)	51.5±4.1	64.0±6.1	0.001*	

Data are the mean ± SE of baseline and final values of the maximum strength changes in each group. Comparison different significance between TRT and BFR group after 8 weeks was determined by using the ANCOVA test. *P<0.05.

Changes of GH concentration and thigh muscle CSA in response to TRT and BFR resistance exercise are presented in the Figure 1. Our results revealed that quadriceps CSA, hamstring CSA and total thigh muscle CSA increase after TRT and BFR resistance exercise (P<0.05). The increase of quadriceps CSA and total thigh muscle CSA was higher after

BFR resistance exercise in compare to the TRT method. Data indicated that although GH concentration was increased after TRT and BFR resistance exercise but it did not achieve statistical significance.



(a) GH Concentration (b) Quadriceps CSA (c) Hamstring CSA (d) Total thigh muscle CSA

Figure 1. Changes of GH concentration and thigh muscle CSA in response to TRT and BFR resistance exercise

* Significant differences between Pre and Post training ($P<0.05$)

† Significant differences between TRT and BFR resistance exercise group ($P<0.05$)

4. Discussion

The purpose of the present study was to examine the effects of BFR resistance exercise versus TRT on GH levels and thigh muscle CSA in untrained healthy men. Our results indicated that maximum strength increases after 8 weeks of TRT and BFR resistance exercise but the amount of maximum strength was higher in the TRT method in compare to the BFR resistance exercise.

Resistance exercise pertains to a wide range of activities leading to muscle contractions as a response to resistance to an external force. Several previous studies have confirmed the various effects of resistance training; overload stress following resistance training reportedly increases muscle strength and the cross-sectional area of muscle fibers and improves muscle function (25). According to the literature, the increased ability of a muscle to generate force following resistance training was related to two important changes: the adaptation of the muscle fiber (26,27) and the extent to which the motor units can activate the muscle (28,29). Increase in the cross-sectional area of skeletal muscle was the result of increased size (hypertrophy) of the FT type of muscle fiber. Hypertrophy of the FT muscle fiber was caused by the increased synthesis of the myofibrillar proteins, actin and myosin (27).

Improvement in the ability of the motor unit to activate the muscle following resistance training has been inferred on the basis of several studies reporting increased strength without changes in the cross-sectional area of the muscle (30). Electromyography has been used to measure change in motor unit activity following maximal contraction, reflex potentiation, and synchronization. Data provided by EMG indicated that resistance-trained muscle exhibited recruitment of a greater number of motor units and a greater firing rate of each motor unit during a maximal contraction than untrained or less-trained muscle. The researchers of these studies concluded that the increased number of motor units firing at a high frequency facilitated increased activation of the muscle and, therefore, increased ability of the muscle to generate force (28).

Our results revealed that quadriceps CSA, hamstring CSA and total thigh muscle CSA increase after TRT and BFR resistance exercise. The increase of quadriceps CSA and total thigh muscle CSA was higher after BFR resistance exercise in compare to the TRT method.

Research has demonstrated that BFR resistance training resulted in increased muscular strength (31,32), hypertrophy (33,34), localized endurance (35), and cardiorespiratory endurance (33,36). Hypothetically speaking, the potential mechanisms for these adaptations may include (a) hypoxia-induced additional or preferential recruitment of fast-twitch (FT) muscle fibers, (b) greater duration of metabolic acidosis via the trapping and accumulation of intramuscular protons (H^+ ions) and stimulation of metaboreceptors, possibly eliciting an exaggerated acute systemic hormonal response, (c) external pressure-induced differences in contractile mechanics and sarcolemmal deformation, resulting in enhanced growth factor expression and intracellular signaling, (d) metabolic adaptations to the fast glycolytic system that stem from compromised oxygen delivery, (e) production of reactive oxygen species (ROS) that promotes tissue growth, (f) gradient-induced reactive hyperemia after removal of the external pressure, which induces intracellular swelling and stretches cytoskeletal structures that may promote tissue growth, and (g) activation of myogenic stem cells with subsequent myonuclear fusion with mature muscle fibers (37,38). Mousavian et al. (2017) reported that low-intensity eccentric resistance training with BFR increases serum level of HGF and MyF5 gene expression in non-athlete subjects. These two factors play key role in activation and proliferation of satellite cells (39).

At the end, data indicated that although GH concentration was increased after TRT and BFR resistance exercise but it did not achieve statistical significance. Growth hormone levels spike after the performance of various types of exercise (40). An exercise-induced increase in GH has been highly correlated with the magnitude of type I and type II muscle fiber hypertrophy (41). It is postulated that a transient GH increase may lead to an enhanced interaction with muscle cell receptors, facilitating fiber recovery and stimulating a hypertrophic response (42). In line with the our results, previous studies also reported that neither TRT alone nor BFR alone increase circulating GH concentrations, while the combination of low-load resistance exercise with BFR produces a robust increase in GH (43,44). This suggests that the coupling of these two modalities produces an adjunct elevation in circulating GH that appears to be reliant on both local muscle ischemia and physical exertion (15). The accumulation of metabolic byproducts produced by exercising muscle is involved in the hypothalamicstimulated release of GH (45). Specifically, metabolic acidosis in the form of lactate accumulation is involved in GH release, as evidenced by Luger et al. (1992) who infused lactate to produce the same serum concentrations observed during an exercise bout and observed roughly half the GH response resulting from exercise (45). In our study, we did not measure lactate concentration to evaluate the relationship between lactate concentration and GH levels, however previous studies indicated that lactate concentration may play a lesser role in GH secretion following BFR resistance exercise than others have suggested (32,43).

5. Conclusion

In conclusion, BFR resistance exercise can produce a significant increase in thigh muscle CSA in healthy men. Generally our results suggested that BFR resistance exercise is a superior method for thigh muscle CSA in compare to the TRT method.

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Conflict of interests: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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