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Application of Blood Flow Restriction in Resistance Exercise Assessed by Intramuscular Metabolic Stress

Okita K[1]* **and Takada S**[2]

[1]*Department of Sport Education, Hokusho University, Japan*
[2]*Department of Cardiovascular Medicine, Hokkaido University Graduate School of Medicine, Japan*

Abstract

Background: Skeletal muscle bulk and strength are becoming important therapeutic targets in exercise therapy. However, in standard resistance training intensive loads are placed on muscles, which make it difficult for weak subjects. Recently, studies have reported that low-intensity resistance training with blood flow restriction (BFR) effectively increased muscle bulk and strength equivalent to those of high-intensity resistance training despite using a lower mechanical load, although the exact mechanism and its generality have not yet been clarified.

Methods and results: We investigated the intramuscular metabolism during low-intensity resistance exercise with BFR and compared it with that of high-intensity and low-intensity resistance exercises without BFR using ^{31}P-magnetic resonance spectroscopy. We found that metabolic stress in skeletal muscle estimated as the phosphocreatine depletion and intramuscular pH decrease during low-intensity resistance exercise with BFR were significantly greater than those in low-intensity resistance exercise without BFR, but were significantly lower than those in high-intensity without BFR. The recruitment of fast-twitch fiber evaluated by inorganic phosphate splitting occurred less in low-intensity resistance exercise with BFR compared to high-intensity without BFR.

Conclusions: The metabolic stress in skeletal muscle during low-intensity resistance exercise was significantly increased by applying BFR, but did not generally reach that during high-intensity resistance exercise. Therefore, we also argued about several important points concerning the optimization of a protocol for resistance exercise with BFR. In this mini review, we introduced the effectiveness and optimization of low-intensity resistance training with BFR based on our previous studies.

Keywords: Resistance training; Skeletal muscle; Energetic metabolism; Blood flow restriction; Magnetic resonance spectroscopy

Introduction

Skeletal muscle bulk and strength are now becoming important therapeutic targets in exercise therapy [1,2]. In order to get more muscle bulk and strength, we have to perform high-intensity resistance training with mechanical load greater than 65% of one repetition maximum (1 RM) [3-5]. However, such intensive loads could not be often applied for weak subjects.

In recent years, several lines of studies have provided the compelling data showing that low-intensity resistance training with blood flow restriction (BFR) leads to muscle hypertrophy and strength increase [6-18], and results in adaptations equal to those of high-intensity resistance training [17,18]. The researchers suggested that the supplementation of low-intensity resistance exercise with BFR might provide additional stress and enhanced recruitment in the skeletal muscle fibers, but the exact details were not clarified.

Metabolic stresses such as depletion of phosphocreatine, an increase in inorganic phosphate, a decrease in intramuscular pH, and lactate accumulation have been also suggested to be potent stimuli for obtaining training effects [19-21]. It was speculated that BFR might advance the metabolic stress and also the recruitment in the skeletal muscle even during low-intensity resistance exercise. Lately, we elucidated the intramuscular energetic metabolism during low-intensity resistance exercise with BFR by using ^{31}P-magnetic resonance spectroscopy (^{31}P-MRS), which could evaluate the metabolic by-products, pH and muscle fiber recruitment in exercising muscle [22]. This mini review presents our important findings concerning application of BFR in resistance exercise and discusses the future evolution of this training manner.

Exercise with Blood Flow Restriction

Actually, there is a large variety of methods in previous papers demonstrating dramatic muscle hypertrophy and strength increase with exercise with BFR and might be also no standard protocol. They have employed various exercise intensities ranging from 20 to 50% 1 RM and pressure ranging from 100 to 300 mmHg [6-18]. There are generally the two major concepts in the resistance training with BFR. One is to increase the training effects more than those obtained by usual resistance training procedures [8,17] especially in physically active people and athletes. The other is to obtain the favorable effects of resistance training without using a conventional high-intensity exercise load especially in inactive, female, senior persons and/or diseased persons [7,15]. We followed the latter concept and designed the investigation. We employed 20% 1 RM as low-intensity resistance exercise and 65% 1 RM as high-intensity resistance exercise, in accord with the majority of previous studies [6,7,10,15,18] and the recommendation of the American College of Sports Medicine [3]. We also precisely controlled the exercise conditions (such as load and

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***Corresponding author:** Koichi Okita, Department of Sport Education, Hokusho University, 23 Bunkyodai, Ebetsu 069-8511, Hokkaido, Japan, Tel: +81-11-386-8011; Fax: +81-11-387-1542; E-mail: okitak@hokusho-u.ac.jp

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repetition) to exactly compare the effects between different protocols [12-14,22].

Methods

Measurement of intramuscular metabolic stress during resistance exercise

Details of the measurements were described in our previous studies [12-14,22]. We employed young, healthy subjects without orthopedic or cardiovascular diseases. Subjects performed unilateral plantar flexion exercises in a 55-cm bore, 1.5-tesla superconducting magnet (MagnetomVision VB33G; Siemens, Erlangen, Germany). The experimental exercises were set for 2 min with 30 repetitions per 1 min, lifting the weight 5 cm above ground. Exercise protocols were as follows: low-intensity resistance exercise using 20% 1 RM, 20% 1 RM with BFR and high-intensity resistance exercise using 65% 1 RM. In 20% 1 RM with BFR, an 18.5-cm-wide pressure cuff was placed around the thigh of the right leg. The air pressure was inflated for 10 seconds before the exercise protocol, and promptly released after the exercise was finished. BFR was carried out using 130% of the subject's resting systolic blood pressure with a pneumatic rapid inflator, following the report by Takano et al. [15]. Intramuscular metabolism was measured with an 80-mm surface coil placed under the muscle belly of the right gastrocnemius. The data were obtained at rest and every 30 sec during exercise (Figure 1). Intramuscular phosphocreatine and pH were estimated by well-established manners [23,24].

Results

Intramuscular metabolism during exercise with blood flow restriction

Intramuscular phosphocreatine and pH was significantly decreased in 20% 1 RM with BFR and H, but not in 20% 1 RM without BFR. Changes of phosphocreatine and pH in 20% 1 RM with BFR were significantly greater than those in 20% 1 RM without BFR. However, those in 20% 1 RM with BFR were significantly lower than those in 65% 1 RM without BFR (Figure 2).

By applying BFR, additional changes of intramuscular metabolites and pH were obtained even during low-intensity resistance exercise. However, these changes did not necessarily reach the level of those during high-intensity resistance exercise. There was a wide range of individual response to this exercise. Contrary to the speculations by previous studies [8], the results have suggested that the metabolic stress in skeletal muscle during low-intensity resistance exercise with BFR is not generally equivalent to that in high-intensity resistance exercise [22]. It is inconceivable that everyone would get the same favorable training effects from a uniform procedure of resistance exercise with BFR.

Discussion and Perspectives

The metabolic stress in skeletal muscle during low-intensity (20% 1 RM) resistance exercise was significantly increased by applying BFR, but did not necessarily reach the level of that during usual high-intensity (65% 1 RM) resistance exercise without BFR. This new method of resistance training needs to be examined for optimization of the protocol to reach equivalence with the high-intensity resistance training.

Optimization of a protocol for resistance training with blood flow restriction

In a resistance exercise with BFR, skeletal muscle stress could be varied by exercise load, number of repetition, duration, and cuff pressure according to subject's tolerance [13]. Although our data showed that the muscular metabolic stress could not generally reach the level of those during high-intensity resistance exercise, it is possible that an increase (30 ~ 40% 1 RM) of exercise intensity might greatly enhance intramuscular metabolic stress during BFR exercise (Figure 3) [12].

The cuff pressure for BFR seems to be another important factor of determining training stress. We employed the pressure of 130% of the subject's resting systolic blood pressure following the report by Takano et al. [15]. In the previous study [22], we showed that the combination of low BFR pressure (below systolic pressure) at a load of 20% 1 RM in the BFR protocol created significantly lower metabolic stress than that during the moderate BFR pressure protocol (above systolic pressure). The applied BFR pressure would need to be higher than the blood

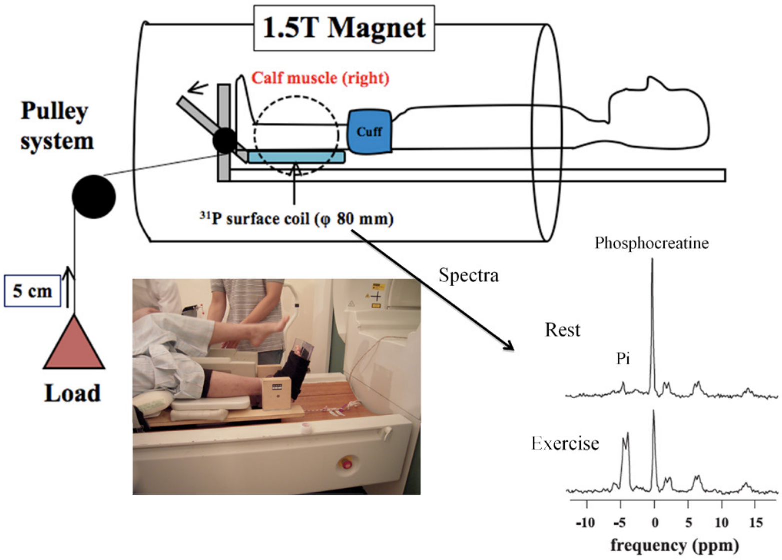

Figure 1: Measurement of intramuscular energetic metabolism in whole body magnet resonance apparatus. Pi, inorganic phosphate.

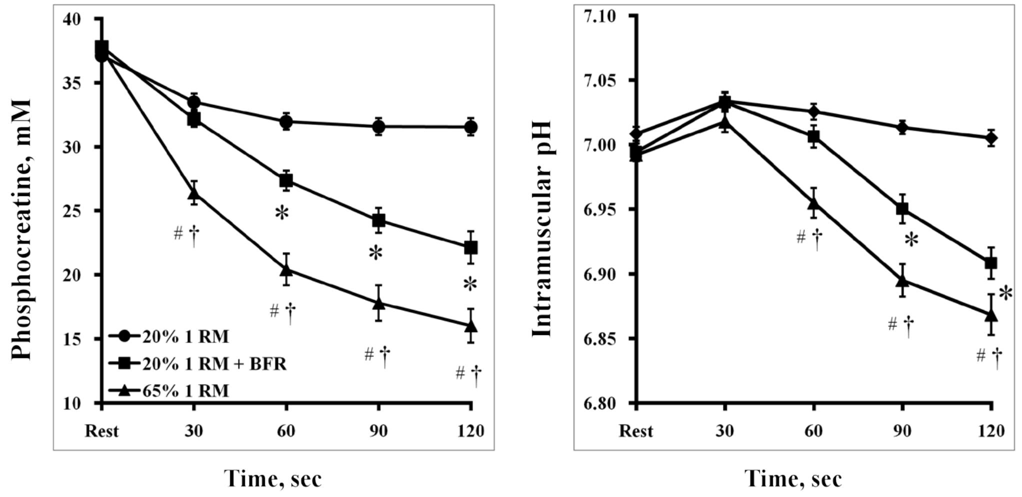

Figure 2: Time course of changes in phosphocreatine and intramuscular pH during resistance exercise with 20% 1 RM (circle), 20% 1 RM with BFR (square), and 65 % 1 RM (triangle) in 26 healthy subjects (22 ± 4 yr). Values are means ± SE. Significant differences are shown between 20% 1 RM and 20% 1 RM with BFR. $^{\#}$Significant differences are shown between 20% 1 RM and 65 % 1 RM. †Significant differences are shown between 20% 1 RM with BFR and 65% 1 RM. The level of significance was p<0.05. BFR, blood flow restriction.

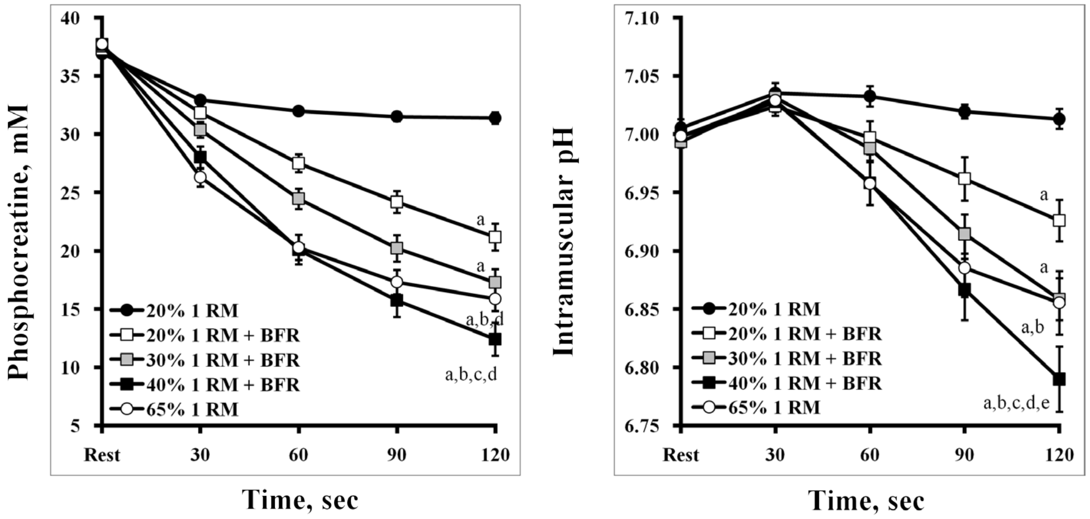

Figure 3: Time course of changes in phosphocreatine and intramuscular pH during resistance exercisewith 20% 1 RM (black circle), 20% 1 RM with BFR (white square), 30% 1 RM with BFR (gray square), 40% 1 RM with BFR (black square), and 65 % 1 RM (black square) in 12 healthy subjects (20 ± 1 yr).Values are means ± SE. ^{a}Significant difference (p<0.05) from L. ^{b}Significant difference (p<0.05) from 20% 1 RM with BFR. ^{c}Significant difference (p<0.05) from 30% 1 RM with BFR. ^{d}Significant difference (p<0.05) from 20% 1 RM with BFR. ^{e}Significant difference (p<0.05) from 65% 1 RM.BFR, blood flow restriction.

pressure level during exercise. We also showed a little additional effect of raising cuff pressure on muscular metabolic stress. However, the level of BFR pressure might occasionally need to be selected according to the exercise intensity and subject's status.

Third important point is concerning the total exercise volume (intensity×repetition). Basically, muscle metabolic stress is dependent on work rate, intensity×frequency (repetition rate). However, in BFR exercise muscular by-products progressively accumulated because of interruption of recovery even in relaxation period (metabolic freeze effect) [25,26]. Therefore, effective muscle stress might be achieved by increasing exercise volume, simply total repetitions without changing intensity and/or frequency. Thus, less intensity with increasing repetitions might become effective.

Implications in ^{31}P-MRS measurements during BFR exercise

^{31}P-MRS can measure the high-energy metabolites, pH and also fast-twitch (FT) fiber recruitment in exercising muscle. It has been known that the metabolic stress parameters, such as lactate and H+ in blood level, are correlated to the elevated post exercise growth hormone (GH) concentration [27,28]. In addition, the metabolic stress might stimulate some other hormonal release and cytokine production, including insulin-like growth factor 1 and interleukin-6 as well as GH [6,13,15]. Those growth factors and cytokines have been suggested to regulate muscle growth/hypertrophy [29,30]. FT fiber recruitment might be also an important factor for successful muscle hypertrophy and strength gain by resistance training [3,4]. Therefore, ^{31}P-MRS is an extremely useful tool for examining the effects of various modes of exercises. Recently, we confirmed that enhanced metabolic stress, defined as phosphocreatine depletion and intramuscular pH decrease, proportionally contributed to training effects, muscle hypertrophy and strength gain [14].

Summary

In this mini review, we showed the usefulness and effectiveness of resistance exercise with blood flow restriction by using a novel technique with ^{31}P-MRS. We hope that this unique procedure will be widely applied in physical therapy.

Grants

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