Resistance Training With Blood Flow Restriction Using the Modulation of the Muscle’s Contraction Velocity

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SUMMARY

There is an increasing interest in developing low-intensity resistance training methods to reduce both the mechanical stress on joints in individuals from different age groups and the risk of injuries in athletes. Blood flow restriction resistance training (BFRRT) has been shown to be an effective method for improving muscular function, using low and moderate load intensity. Therefore, the purpose of the present article is to highlight the main metabolic and neuromuscular adaptations to BFRRT and to suggest an alternative implementation of BFRRT through the modulation of the velocity of the muscle contraction.

INTRODUCTION

An emerging field of study in resistance training (RT) is the development of low-intensity training methods aimed to reduce the mechanical stress on muscle joints as well as keeping or improving the positive adaptations observed with traditional practices of RT. This trend has been driven by the need to increase the number of potential users of RT by reducing the risks associated with its practice.

Several studies have confirmed the health benefits of regular RT, including decreased obesity among children (32,41,55) and adolescents (56), reduced risk of metabolic syndrome (9,15), and delayed onset of sarcopenia (5,7,22). However, all of these uses of RT involve working by individuals from different age groups that require continuous supervision, compliance to strict safety guidelines, and a careful selection of the intensity level. Even in athletes, sometimes it is necessary to reduce the intensity of training loads because the mechanical stress on joints associated with common training activities, such as lifting and weight bearing, if not performed in a progressive way, can increase the risk of injury (3,10,19,36).

Recent studies have shown that training intensity can be reduced by performing RT with blood flow restriction resistance training (BFRRT), thereby taking advantage of the neuromuscular and metabolic conditions created by the application of an external wrapping device, such as a pressure cuff or a tourniquet.

Therefore, the purpose of this article is to present the main neuromuscular and metabolic advantages linked to BFRRT and to propose an alternative way to reduce muscle’s blood flow through the modulation of the speed of contraction.

FROM CLINICAL ISCHEMIA TO BLOOD FLOW RESTRICTION RESISTANCE TRAINING

The term “ischemia” comes from the Greek language (ischein = to suppress; haimas = blood) and refers to an absolute or relative shortage of blood supply to an organ. The capacity to tolerate an ischemic condition is organ specific; human muscle can tolerate ischemia between 2 and 4 hours at normothermia (13). In 1904, Cushing introduced the pneumatic tourniquet, a device able to...
compress blood vessels by using a gas source to inflate a cylindrical bladder. This replaced the Esmarch's bandage that sometimes induced nerve palsy. The use of the pneumatic tourniquet was essential to restrict blood flow during operations on the lower extremities. Despite the significant increase in safety compared with previous techniques, it became important to study human metabolism during and after tourniquet ischemia, in particular to understand whether the few reported complications were consequences of the direct pressure applied by the tourniquet to a nerve or were consequences of tissue changes.

In 1975, Haljanä and Enger (21) studied the cellular metabolism of human skeletal muscles during clinical ischemia for the first time. They found that during the course of an operation, a marked decrease in the high-energy phosphate pool and an accumulation of lactate were observed in the occluded leg, compared with the non-ischemic control extremity. Larsson and Hultman (26), using percutaneous needle biopsy techniques, studied the energy metabolism of 16 patients with knee injury after 1.5–2.5 hours of ischemia. They showed a reduction in energy substrates during BFRRRT, resulting in reduced adenosine triphosphate and phosphorylcreatine with the concomitant increase of adenosine monophosphate, adenosine diphosphate, creatine, and lactate. Sjöholm et al. (43), using the same techniques as Larsson, reported decreased pH, from 7.1 to 6.8, after 2 hours of occlusion in the quadriceps muscle of 13 patients undergoing an operation for knee injury. However, the metabolic changes observed during tourniquet ischemia during an operation or at rest remain small when compared to those associated with working.

In 1992, Moritani et al. (35) studied the neuromuscular response in handgrip muscles during repeated contractions at 20% of maximal voluntary contraction (MVC) during normal blood circulation and arterial occlusion. The metabolic state of active muscles is involved in the regulation of recruitment and rate-coding patterns of the motor unit (MU) during exercise because they observed a significant increase in mean MU spike amplitude and frequency during the contractions under arterial occlusion. These findings indicate that, when oxygen availability is reduced, fast-twitch (FT) fibers are recruited, even if the training intensity is low. Sundberg (44) found a greater depletion in glycogen content in FT than in slow-twitch fibers in the trained leg with a reduced blood flow compared with the control, confirming that glycolytic fibers have to be activated to sustain the required force under hypoxic intramuscular conditions.

Takarada et al. (46) supposed that, if the muscle had been forced to contract during blood flow restriction, thereby reducing the clearance of metabolites by the blood, the intramuscular accumulation of these would have been elevated even with low-intensity exercises. In their study, 6 young male athletes performed 5 sets of knee extensions at 20% of 1 repetition maximum (1RM), with an interset rest period of 30 seconds and a specially designed tourniquet applied to the proximal end of their thighs. Plasma concentrations of lactate, norepinephrine, and growth hormone (GH) were significantly greater under blood flow restriction (46).

In the same study, analysis of the integrated electromyographic activity during the concentric phase of the movement showed a value 1.8 times larger in BFRRRT condition compared to RT performed without blood flow restriction. This confirmed that, even though the same force was generated, BFRRRT produced a greater activation level in the muscle, agreeing with the previous findings of Moritani et al. (35).

BFRRRT is a safe training modality (31,37) that can be adopted by persons of different age groups and has been shown to increase cross-sectional area (CSA) in older women (48), highly trained athletes (47), and healthy men (2,61). Abe et al. (1) studied the day-to-day changes in muscle CSA and strength over 1 week of 2 daily training sessions at 20% 1RM with blood flow restriction.

They found an increase of 3.5 and 17% in CSA and in maximum voluntary isometric strength in the quadriceps muscle, respectively. Despite the 2 sessions of RT per day for 1 week, the levels of muscle damage markers were not elevated. The authors concluded that BFRRRT at low intensity allows for faster recovery, such that RT can be performed more frequently, thereby generating a more rapid hypertrophic response.

Subsequent studies confirmed that plasma GH is greatly increased using BFRRRT (16,38,45,49), leading some authors to speculate that the rapid increase in CSA of muscle fibers often observed after this type of training is mediated by the action of GH on insulin-like growth factor 1 (IGF-1) (2). However, a few recent studies are questioning the role played by GH in enhancing myofibrillar protein synthesis (59,60), suggesting that this hormone is rather more linked to the synthesis of matrix collagen in skeletal muscle and tendon (11,14). Therefore, factors other than the increase in GH and IGF-1 seem implicated in the increase in muscle strength and size observed after BFRRRT. These include activation of the mammalian target of rapamycin signaling pathway (16,20) and decreased myostatin (12,27,25).

Furthermore, it has been hypothesized that rapid recruitment of FT fibers (29,33) together with training to failure (29) and cell swelling (28) can be the key factors that explain the positive training-induced adaptations observed with BFRRRT. The majority of the studies investigating BFRRRT produced the blood flow restriction with the application of an external mechanical pressure, using a wrapping device like a pneumatic restriction...
cuff, in the proximal part of the trained muscle. However, it is also possible to decrease muscle's blood flow without the application of an external device by considering the physiological role played by the intramuscular pressure (IP) and the relaxation time.

**THE MODULATION OF MUSCLE OXYGENATION THROUGH THE VELOCITY OF CONTRACTION AND THE REDUCTION OF RELAXATION TIME**

**INTRAMUSCULAR PRESSURE AND RELAXATION TIME**

Blood flow during rhythmic muscle contractions involves the alternation between an increase and decrease of arterial inflow. The decrease is because of the amplified IP during the contraction cycle (both eccentric and concentric phases), whereas the increase is seen during relaxation time, i.e., the time elapsed between 2 successive contractions (57).

An isometric contraction results in the reduction of blood flow followed by active hyperemia when the contraction ceases (58). Therefore, IP and relaxation play a fundamental role in regulating hematic flow into the muscle. Sjøgaard et al. (42) demonstrated that IP increases almost linearly with % MVC and becomes equivalent to mean arterial blood pressure at around 50% of MVC. In this condition, according to the equation of Hagen-Poiseuille, no blood flows into the muscle. This observation is consistent with previous studies that showed that an isometric contraction at a force over 40% of MVC suppresses both the inflow and outflow of blood to and from the muscle (6,34).

The magnitude of the IP results is also influenced by the muscle mass involved in the contraction (34) and the architecture of the fibers (39). The relaxation period between contractions also modulates muscle oxygenation because blood flow occurs mainly during this period (4,24,57). Therefore, methods that increase IP and reduce the relaxation time between muscle contractions are an alternative way to create a hypoxic condition without using an external mechanical device.

**THE ROLE OF THE SPEED OF CONTRACTION ON MODULATION OF MUSCLE OXYGENATION**

In 2005, Tanimoto et al. (53) compared the muscle oxygenation levels and lactate concentrations between BFRRT using external mechanical compression and 3 other types of exercise regimens. In their study, 6 young male bodybuilders and power lifters performed 3 sets of knee extensions with an interset rest period of 1 minute using 4 different protocols:

1. BFRRT with low-intensity exercise at 30% 1RM with vascular occlusion through a specially designed elastic belt, performed at normal speed (1 second for lifting, 1 second for lowering).
2. Medium-intensity exercise at 50% 1RM with slow movement (3 seconds for lifting, 3 seconds for lowering, 1-second pause, and no relaxation phase) and tonic force generation (LST).
3. High-intensity exercise (HI) at 80% 1RM performed at the same speed as BFRRT.
4. Isometric exercise at 50% 1RM that consisted of keeping a 45° knee angle for 56 seconds, the same load as LST exercise (isometric).

All exercise regimens produced a large decrease in muscle oxygenation, compared with resting levels, but only BFRRT, LST, and HI caused an increase in lactic acid production. This study confirmed that performing RT at low intensity with a slow contraction speed effectively decreases muscle oxygenation and increases blood lactate. However, as outlined by the authors, if the speed of contraction becomes too slow, the mechanical force produced will be insufficient to give rise to increased lactate concentrations.

These results are consistent with the low lactate levels observed when protocols based on extremely slow contraction modalities are compared with traditional methods (17,23). High metabolic accumulation, because of the changes of intramuscular environment, can enhance the adaptive stimulus given by muscle’s blood flow restriction (28,29).

Based on previous results by Tanimoto et al. (53), Tanimoto and Ishii (50) proposed a moderate intensity (approximately 50% 1RM) RT that was designed to fulfill the need for a sustained contraction with concomitant high production of force, using a contraction modality of 3 seconds for both the eccentric and the concentric phases of the movement with a 1-second pause and no relaxation time. They called this modality LST, referring to the intensity of the external load, the slow speed of the movement, and the tonic force generated. In order to promote muscle hypertrophy, Loenneke and Pujol (30) suggested to train at intensities as low as 20%1RM. A typical prescription would involve three to five sets of each exercise to volitional fatigue with short rest periods.

Several studies showed that the variation of the time between the eccentric and concentric phase of the muscle’s contraction produces specific fiber-type adaptations as well as mitochondrial and sarcoplasmatic protein synthesis (8,18,40).

Several studies have confirmed the capacity of this method to increase muscle size and strength, both in single and multijoint exercises (51) and multijoint exercises (50,52,54). However, LST seems unfavorable for increasing dynamic sport movements because of the ineffective use of the stretch-shortening cycle and the inertia of the movement (50).

**SUMMARY AND CONCLUSIONS**

According to some studies in the literature, neuromuscular and metabolic benefits related to BFRRT, could be reached through the modulation of the velocity of the muscle’s contraction. The phenomenon, associated with blood flow restriction, can help coaches to reduce the intensity and
volume of RT without losing the benefits associated with its practice. Coaches can modulate blood restriction by simply increasing the duration of the concentric and eccentric phases of movement and by reducing the relaxation time (the pause between full repetitions). Thus, it is more correct to refer to an optimal zone for the duration of the repetition, leading to a prolonged time under tension coupled with a relatively significant number of repetitions that will lead to an adequate metabolite accumulation into the muscle. A load at 50% 1RM at slow speed is adequate to generate a sufficient IP that can immediately reduce the muscle’s blood flow, whereas heavier loads would rapidly lead to fatigue and to an increasing difficulty of the trainee in maintaining adequate exercise duration.

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