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Director: Fernando Emilio Valladares Fuente

Email: fernando.valladares@upr.edu.cu

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Translated from the original in Spanish **Review article**

Partial restriction of blood flow with endurance, physiological foundation and training methodology

Restricción parcial de flujo sanguíneo con resistencia, fundamento fisiológico y metodología de entrenamiento

Restrição parcial do fluxo sanguíneo com resistência, fundamentação fisiológica e metodologia de treinamento

Priscila del Carmen Reyes Reyes[1*]

[1]Catholic University Cardinal Silva Henriquez. Chile.

*Corresponding author: priscila.reyesr89@gmail.com

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ABSTRACT

Blood flow restriction training has turned out to be an alternative that achieves results similar to those achieved by high intensity training. The present article offers the result of a research where, a bibliographical review was carried out to inquire about the effectiveness in increasing muscle strength, as well as to analyze the mechanisms of action and methodology of practical application, through the method of partial restriction of blood flow with endurance to low loads. The reviewed literature supports the positive effects of this method to generate hypertrophy and increase muscle strength, both in the healthy population and in the rehabilitation period. The main mechanisms proposed as mediators of this adaptation are increased secretion of growth hormone, intracellular signaling via anabolic and catabolic pathways, and the contribution of inflammatory or edematous processes. It was recommended to work with loads between 20 and 40 % of a maximum repetition and with a volume of 75 repetitions per session with training between 2 and 4 times a week, for a minimum of three weeks. The effects on neurological adaptation were discussed, without supporting evidence. It was concluded that the method of partial restriction of blood flow generates an increase in strength and hypertrophy and is recommended as a complementary and alternative method to high intensity exercise, in populations that are necessarily unable to train at high intensities.

Keywords: Strength training, muscle hypertrophy, partial restriction of blood flow, KAATSU.

RESUMEN

El entrenamiento con restricción del flujo sanguíneo ha resultado ser una alternativa que logra resultados similares a los conseguidos por el entrenamiento de alta intensidad. El presente artículo ofrece el resultado de una investigación, en la que se realizó una revisión bibliográfica para indagar sobre la efectividad en el aumento de fuerza muscular, así como analizar los mecanismos de acción y metodología de aplicación práctica, mediante el método de restricción parcial de flujo sanguíneo con resistencia a bajas cargas. La literatura revisada respalda los efectos positivos de este método para generar hipertrofia y aumento de fuerza muscular, tanto en población sana como en periodo de rehabilitación. Los principales mecanismos propuestos como mediadores de esta adaptación son la elevación en la secreción de hormona del crecimiento, la señalización intracelular vía anabólica y catabólica y la contribución de procesos inflamatorios o edematosos. Se recomendó trabajar con cargas entre el 20 al 40 % de una repetición máxima y con un volumen de 75 repeticiones por sesión con entrenamiento entre 2 a 4 veces por semana, durante un tiempo mínimo de tres semanas. Se discutió sobre los efectos en la adaptación neurológica, sin existir evidencia que lo respalde. Se concluyó que el método de restricción parcial del flujo sanguíneo genera aumento de fuerza e hipertrofia y se recomienda como método complementario y alternativo al ejercicio de alta intensidad, en poblaciones que necesariamente se ven imposibilitadas de entrenar a altas intensidades.

Palabras clave: Entrenamiento de fuerza, hipertrofia muscular, restricción parcial del flujo sanguíneo, KAATSU.

SÍNTESE

O treinamento com restrição do fluxo sanguíneo provou ser uma alternativa que alcança resultados similares aos alcançados pelo treinamento de alta intensidade. Este artigo oferece o resultado de uma pesquisa, na qual foi realizada uma revisão de literatura para investigar a eficácia no aumento da força muscular, bem como para analisar os mecanismos de ação e metodologia de aplicação prática, utilizando o método de restrição parcial do fluxo sanguíneo com resistência a cargas baixas. A literatura revisada apóia os efeitos positivos deste método para gerar hipertrofia e aumentar a força muscular, tanto na população saudável quanto no período de reabilitação. Os principais mecanismos propostos como mediadores desta adaptação são a elevada secreção hormonal de crescimento, a sinalização intracelular através de vias anabólicas e catabólicas e a contribuição de processos inflamatórios ou edematosos. Foi recomendado trabalhar com cargas entre 20 a 40% de uma repetição máxima e com um volume de 75 repetições por sessão com treinamento entre 2 a 4 vezes por semana, por um tempo mínimo de três semanas. Os efeitos sobre a adaptação neurológica foram discutidos, mas não há evidências que sustentem isto. Concluiu-se que o método de restrição parcial do fluxo sanguíneo gera maior força e hipertrofia e é recomendado como um método complementar e alternativo ao exercício de alta intensidade, em populações que são necessariamente incapazes de treinar em altas intensidades.

Palavras-chave: Treinamento de força, hipertrofia muscular, restrição parcial do fluxo sanguíneo, KAATSU.

INTRODUCTION

According to Peitz *et al.* (2018) and Voet *et al.* (2019), strength exercise aimed at increasing muscle mass has become a common objective in training programs, both in high-performance athletes and in people who carry out physical activity programs and enjoy its benefits at any age, from pre-pubertal ages up to nonagenarians. In the same lines, it is suggested that this type of training generates improvements in the quality of life in people with sarcopenia, both in older adults and in cancer survivors (Lu *et al.,* 2021; Soriano-Maldonado *et al.,* 2019).

As a result of a systematic review, Santos *et al.* (2022) report that strength and muscle hypertrophy training is currently mostly worked on the basis proposed by the American College of Sports Medicine (ACSM). In their meta-analysis study, Schoenfeld *et al.* (2017) concluded that strength training is effective in producing muscle hypertrophy when performed at intensities greater than 60% of 1 repetition maximum (1 RM), whether in training for beginners and intermediate individuals or advanced training.

However, Backx *et al.* (2017) state that in certain circumstances it is practically impossible to carry out training progressions towards higher intensities to obtain muscle strength and hypertrophy, as happens in individuals who have suffered sports injuries or of another type or in people with disabilities, limiting pathologies or simply with maladjustment to load.

Faced with such problems, Biazon *et al.* (2019), Yasuda *et al.* (2012) and Takarada *et al.* (2000) report a new training methodology at low loads. This method is described in the literature as superimposed partial vascular occlusion training, KAATSU training (KAATSU by its trade name in Japan) (Shen *et al.,* 2020), occlusive training, or blood flow restriction training (BFR training), (Tegtbur *et al.,* 2020). All these works postulate that this therapeutic alternative obtains results similar to those achieved by high intensity training.

Although this method can be applied to both endurance and aerobic exercises (Christiansen *et al.,* 2019; Pereira-Neto *et al.,* 2021) it is in endurance training at low workloads that emphasis has been placed in this review, mainly due to its possible contribution to the sports population, in which injuries are an important cause of days lost, with long times of recovery and impossibility of early training at high loads (Burboa *et al.,* 2017).

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Therefore, the objective of this bibliographical review focused on investigating the effectiveness in increasing muscle strength, through the method of partial restriction of blood flow with endurance to low loads, as well as analyzing its mechanisms of action and methodology of practical application. To meet the objective, a critical analysis was carried out on scientific research published from the year 2000, in English and Spanish as the main languages. The search was carried out in the Medline databases, using the Pubmed search engine. In the search strategy, terms included in the Thesaurus Medical Subject Headings (MeSH) were used. The keywords used were blood flow restriction training, occlusive training, KAATSU training.

DEVELOPMENT

Origin of the method of partial restriction of blood flow

The KAATSU Method, originally from Japan, is a new concept of training that proposes a methodology that combines low-intensity exercise with tissue hypoxia in order to increase strength and muscle hypertrophy, (Wilk *et al.,* 2018). In Western countries, it is mainly known as occlusive training or blood flow restriction training (BFR). This concept has existed for almost 50 years, but it was not until the mid-1980s when it was popularized in Japan, by Sato (2005) who marketed it under the name KAATSU with which it has been popularized to this day.

Physiological foundations of low load endurance blood flow restriction training

The mechanisms with endocrine response, in training with blood flow restriction with endurance to low loads (BFR-RE), are the ones that present the greatest empirical evidence. Already in the year 2000, Takarada *et al.* (2000) demonstrated in a group of patients undergoing BFR-RE training that growth hormone (GH) concentrations reach a level 290 times higher than the individual's previous resting level. Furthermore, in this same study, it was observed that the concentration of IL-6 increased gradually and remained at a higher level in control patients, even 24 hours after exercise.

The increase in growth hormone is explained because the obstruction of venous blood flow during exercise causes a large number of metabolites to accumulate in the body; which leads to metabolic stress and an increase in the accumulation of lactic acid, (Sharifi *et al.,* 2020). Meanwhile, an increase in lactic acid concentrations in the blood can cause the promotion of secretion of anabolic hormones, such as GH, testosterone and insulin - like growth factor 1 (IGF-1) (Lixandrao *et al.,* 2015).

Yinghao *et al.* (2021) in their single-blind clinical trial, observed significant changes in GH during BFR-RE training and concluded that this exercise modality did indeed increase GH levels in young men and that the increase in cuffing resulted in higher levels of hormone secretion. Furthermore, they recognized that increased GH levels generated increased anabolic potential in young men.

Protein synthesis

The increase in muscle protein synthesis through this method is explained by the mechanical muscle tension generated in conjunction with muscle contractions that leads to increased signaling of the intracellular anabolic and catabolic pathways and intensifies muscle protein synthesis (Wilk *et al.,* 2018).

Concomitantly, Nyakayiru *et al.* (2019) demonstrated that BFR performed at rest does not increase myofibrillar protein synthesis rates in vivo in humans, as this increase exists only when BFR is combined with endurance exercises at low loads, so vascular occlusion should be performed in training where there is muscle contraction to generate effects on protein synthesis.

Safety factors of the BFR-RE method

BFE-RE and the Fibrinolytic System

BFR-RE training has shown the capacity to regulate the fibrinolytic pathway even after a single exercise session, both in healthy young participants and in elderly patients with coronary artery disease (CAD) (Patterson *et al.,* 2019). Apparently, BFR-RE training stimulates the fibrinolytic system, since it has been shown that training sessions with BFR-RE increase tissue plasminogen activator (TPA, a protein that degrades thrombus in epithelial cells) in healthy participants (Madarame *et al.,* 2013).

BFR-RE and population at risk of venous thromboembolism

Venous thromboembolism (VTE), which includes deep vein thrombosis (DVT) and pulmonary embolism (PE), is a common and life-threatening disease, (Tritschler *et al.,* 2018). Risk factors for VTE have been established which are a combination of endogenous characteristics such as obesity and genetic factors or exogenous triggers such as major surgery, pregnancy or hormonal contraception (Davis *et al.,* 2017 and Keenan and Knuttinen, 2018).

Studies addressing post-training BFR-RE blood coagulation factors including D-dimer, fibrin breakdown products (FDP) and creatine kinase (CK) in elderly subjects have shown no adverse effects (Yasuda *et al.,* 2012).

It was reported in 2013 that there is no increase in blood coagulation factors after using the BFR-RE method in an elderly population with ischemic heart disease (Madarame *et al.,* 2013). Despite this, the prior application of the clinical prediction rules is suggested to assess the probability of VTE in subjects who will undergo BFR-RE training, in order to thus establish the appropriate candidates.

BFR Training methodology

The vascular occlusion technique in the muscle is performed using a compressive sphygmomanometer around the proximal area of the limb to be trained, which produces external pressure. When the compression cuff is inflated, gradual mechanical compression of the blood vessels is generated resulting in partial restriction of arterial blood flow distal to the cuff, affecting venous flow below the sphygmomanometer, preventing venous return (Nyakayiru *et al.,* 2019) and compression of the proximal arteries results in muscle tissue hypoxia (Yinghao *et al*., 2021).

On the other hand, the decrease in venous blood flow promotes the accumulation of blood within the capillaries of the occluded extremities (Sato, 2005), which is often reflected in erythema. Additionally, when flow restriction is combined with muscle contractions, the intramuscular pressure under the sphygmomanometer increases, further disturbing blood flow (Patterson *et al.,* 2019).

Determination of cuff pressure in BFR-RE training

The amount of pressure required to generate partial restriction of blood flow to an extremity depends on the individual's limb girth or body composition and the width, length, and material of the sphygmomanometer (Patterson *et al.,* 2019). Cuff pressure is established in relation to the occluding blood pressure (AOP) used during exercise (% AOP), according to Patterson *et al.* (2017) and this is done by inflating the sphygmomanometer to the point where blood flow ceases (100 % AOP) and a percentage of that pressure (eg, 40-80 % AOP) is used during the exercise.

Martin-Hernandez *et al.* (2011) in the bibliographical review state that, due to the diversity of devices and occlusion levels established by different authors, the occlusion pressure of the cuff does not determine the results of the training and indicates "(...) other devices that do not allow pressure control (or allow to do it less precisely), such as straps, elastic bands or velcro tapes, can be used to train in ischemia, especially outside the laboratory" (p 3).

In contrast, Patterson *et al.* (2019) conclude that the greater the pressure applied to the restriction of blood flow, the greater the cardiovascular response, associated with general malaise. Therefore, it is recommended to set the pressure during training based on the AOP measurement, with pressures ranging from 40 to 80 % of the AOP, due to the evidence supporting its efficacy.

Exercise load

Cuff pressure applied during exercise can also be determined to some extent by the exercise load Lixandrao *et al.* (2015) report that for most people exercising with loads corresponding to 20-40 % of 1 RM is likely to maximize muscle growth and strength; but when the loads used are at the lower end of this recommendation (for example, 20 % of 1-RM) then higher pressure (80 % AOP) may be necessary to elicit muscle growth. However, more studies are required to confirm this.

Most research has applied this methodology to the elbow flexors and knee extensors, so it is unknown if other muscle groups require a different pressure recommendation. In the literature, it is reported in most cases that training should be carried out at loads between 20 and 40 % 1RM because this range of loads produces muscular adaptations when combined with BFR (Biazon *et al.,* 2019; Patterson *et al.,* 2019; Takarada *et al.,* 2000 and Yasuda *et al.,* 2012).

Volume

In the BFR-RE literature there is a common and frequently used set-repetition scheme involving 75 repetitions in four sets of exercises, with 30 repetitions in the first set and 15 repetitions in each subsequent set (Patterson *et al.,* 2019 and Yasuda *et al.,* 2012).

Rest periods

Studies recommend that rest between sets should be short, between 30 seconds and 1 minute (Martín-Hernández, 2011). It is verified that with periods of 30 seconds of rest, skeletal muscle hypertrophy and increased muscle strength are achieved (Yasuda *et al.,* 2012). It is not recommended to exceed 30 seconds of rest, because metabolic stress is not increased and thus there is no skeletal muscle adaptation (Patterson et *al.,* 2019).

Frequency and duration

It is reported that between 2 to 4 weekly sessions are conducive to generating skeletal muscle adaptation. Erickson *et al.* (2019) report that in people undergoing prehabilitation with BFR-RE, prior to anterior cruciate ligament reconstruction who train frequently for three weekly sessions, for four weeks and post-surgical treatment of three weekly sessions, for four to five months, generate significant improvements in strength levels and increases in cross-sectional area of the quadriceps.

Regarding the duration of training with BFR-RE, in most studies muscle hypertrophy and strength adaptations have been observed in periods of time longer than three weeks (Martín-Hernández *et al.,* 2011; Patterson *et al.,* 2019; Pereira-Neto *et al.,* 2021 and Yasuda *et al.*, 2012).

Laurentino *et al.* (2011), in their experimental study with physically active male subjects, conclude that in four-week training sessions, the BFR-RE (20 % 1RM) methodology generates gains in cross-sectional area and maximum strength similar to traditional high-intensity training. intensity (80 % 1RM).

Effectiveness of the BFR-RE method on muscle hypertrophy and strength

There is currently evidence of the results of vascular occlusion training in a broad generation of people that includes young people and older adults (Centner *et al.,* 2019), users who need injury rehabilitation (Hughes *et al.,* 2017) and sports population (Wortman *et al.,* 2021).

Bennett and Slattery (2019); Hughes *et al.* (2017); Laurentino *et al*. (2011) and Pereira Neto *et al.* (2021) have reported that partial restriction training achieved effects similar to traditional high-intensity training, improvements in maximal strength gains and/or skeletal muscle hypertrophy were observed, and various types of muscle strength were shown to improve in response. to this intervention, including isotonic, isometric, and isokinetic dynamic forces (Takarada *et al.,* 2000), as well as the rate of strength development/explosive force capacity (Nielsen *et al.,* 2017).

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A meta-analysis on the effectiveness of the BFR-RE method in the athlete population establishes that BFR can lead to improvements in strength, muscle size, and sports performance markers in healthy athletes. Furthermore, it concludes that the combination of traditional endurance training with BFR may allow athletes to maximize athletic performance and maintain good health (Wortman *et al.,* 2021).

A study conducted in older adults on kaatsu training demonstrated improvements in the quality of simple walking exercise, especially in those populations in which strength training with heavy loads is contraindicated (Clarkson *et al.,* 2017).

However, Wilk *et al.* (2018) do not recommend the use of BFR-RE as the only training, but rather as a complementary exercise, since the mechanisms by which the increase in muscle strength is generated are not the same as those used by traditional high-intensity exercise. intensity, where there is an increase in strength due to neural adaptations.

Cook *et al.* (2018) report, in an experimental study, that despite the fact that the BFR-RE achieves increases in muscle strength and hypertrophy just like those obtained in high-load training, no neuromuscular changes are evident and suggest research to explore this scope. Also, Shen *et al.* (2020) state that this training method can cause underlying hypoxia and neurotransmitter dysfunction related to neuromuscular fatigue and associated with ischemic muscle pain, since it is essential to explore the hypoxic and neurodegenerative events induced by this training before promoting it.

CONCLUSIONS

According to the literature, the KAATSU method, as training that combines the partial restriction of blood flow with endurance to low loads, proved to be an effective method to increase muscle strength and hypertrophy, both in healthy sedentary, physically active individuals and athletes, as well as in older people and individuals in rehabilitation period.

The main mechanisms proposed as mediators of this adaptation were the increase in GH secretion, intracellular signaling via anabolic and catabolic pathways, and the contribution of inflammatory or edematous processes.

Regarding the applied methodology, 75 repetitions per session were considered an appropriate training volume. The most suitable intensities were those that were between 20 % and 40 % of 1 RM, with recovery periods of 0.5 to 1 minute between series. It was proposed that if you work 2 to 4 times a week for a minimum of three weeks, significant results are obtained.

Despite its effects on increasing muscle strength and hypertrophy, it is recommended that this method be used as a complement to high-intensity training, since there appears to be no neuromuscular adaptation and it is associated with ischemic muscle pain. Future research is needed to address this area; however, it was a plausible alternative in the rehabilitation of athletes who found themselves unable to train high loads.

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The authors have participated in the writing of the work and analysis of the documents