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Comparison of the effects of resistance training with and without vascular occlusion in increases of strength and hypertrophy: a review of the literature

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Abstract. The literature indicates that adaptations to resistance training with and without blood flow restriction appear to occur differently. Aim: To compare the effects of RT with and without BFR in strength and hypertrophy gains and understand the mechanism of adaptation between two methodologies. Moreover, check the influence of volume training in these gains. Methods: In this review of the literature, were selected by two independent reviewers, articles in English of Pubmed database. These articles were clinical trials and evaluated strength and / or hypertrophy gains. The following keywords were used: blood flow restriction training, ischemic exercise strength, low load resistance training, restriction of blood flow, training and exercise. For this review were selected 16 articles. Results: In the articles selected for this study, all assessed strength and nine also hypertrophy gains. Furthermore, only three controlled the volume of training and two performed surface electromyography. Conclusion: in the short term, the RT would have a tendency to increase muscle strength greater than the LI-BFR and hypertrophy respond similarly in the two methodologies. This would indicate that neural adaptation interferes in the early stages of training only in the RT. The volume of training appears doesn't to influence the increase of strength and hypertrophy in LI-BFR Finally, we need long-term studies to identify how adaptations occur for strength and hypertrophy in these two methodologies.
Key words: *review, resistance training, muscle strength, hypertrophy, ischemia.*

Introduction

It is widely diffused in literature that the resistance training (RT) allows strength and hypertrophy gains (1-3). To allow optimal gains, the training should be performed with loads between 65-80% 1RM (one repetition maximum) and frequency of training between two and three times per week, at least (4). Moreover, larger volumes of training appear enable better muscle adaptations in comparison with low volumes (3, 5). The mechanisms of the adaptation to RT in the early stages occur through neural adaptations (6, 7) due the enhanced voluntary activation of muscles that perform the movement (agonist), adequate activation assisting muscles (synergists) and those with the opposite muscle action to agonists (antagonists) (6-8). After certain period of time neural adaptations reach a plateau and the hypertrophy gains would have key role in strength gains (6, 7).

Even though this training allows important results, some subjects can't perform it, like elderly and post operation athletes, due the mechanical stress generated in the joint. In this context, the low intensity strength training with blood flow restriction (LI-BFR) has been emerged. It consists of an external cuff pressure applied in the exercising limb for restrict venous return generating metabolic accumulation in the trained muscle (9). This methodology has been demonstrated through many studies with similar strength and hypertrophy gains to conventional training (10-13).

Takarada and colleagues (12) reported increased strength and muscle cross-sectional area from resistance training at 50% 1RM. According the authors, the strength gains in this study were a consequence of muscle hypertrophy. Yamanaka et. al. (14) reported increased strength in occlusion group after four weeks training in bench press and squat exercises in college football players. Nevertheless, there is no standardization to design low-load strength training with BFR programs and it is also unclear the mechanisms that allow the strength and hypertrophy improvements.

Studies have been suggested strength and hypertrophy improvements from low-intensity strength training with BFR at intensities between 20% and 50% 1RM (10, 11, 15). The pressure used for restriction of blood flow (there are disagreement between studies) would be between 100-300mmHg (9).

Most studies suggest 3-5 sets with 30-60 seconds of rest (11, 16, 17). The mechanisms that would allow strength and hypertrophy improvements would be the metabolic accumulation and increased in lactate production (16, 18). Moreover, appear to influence in this gains the greater growth hormone (GH) response and mTOR (mammalian target of rapamycin) and S6K1 (ribosomal S6 kinase 1) phosphorylation that are directly involved in protein synthesis (17, 18). However, little is known about long term strength and hypertrophy adaptations in this type training. Performing a meta-analysis, Loenneke et. al. (15) created "Theoretical Reverse Pattern" to explain the strength and hypertrophy improvements with blood flow restriction (BFR). According to the authors, hypertrophy is the major mechanism for the strength gains that take place early in the training (4ª week). After that, hypertrophy would increase at constant rate, and the mechanism for strength gain could be predominantly by neural adaptation (10ª week). Therefore, the mechanism for strength gain would be in an opposite way to RT, where strength gains occur by means of neural adaptations following hypertrophy to be responsible by this gain.
Therefore, the aim of this study is, through a literature revision, to compare the effects of RT with and without BFR in strength and hypertrophy gains and understand the mechanism of adaptation between two methodologies. Moreover, check the influence of volume training in these gains.

Material and Method

Clinical trials that evaluated strength and/or hypertrophy parameters, before and after training period involving blood flow restriction were selected. The period of selection was March to June of 2014. It was included articles of database PUBMED published between 2009 and 2014.
The keywords used for selection of articles were: "low load resistance training", "training", "exercise" and "blood flow restriction training", "ischemic strength exercise" and "restriction of blood flow". Moreover, only articles in English language were being selected. Selection of the articles was performed by two reviewers in an independently way. They read the title and abstract selecting only the clinical trials that evaluated strength and/or hypertrophy.

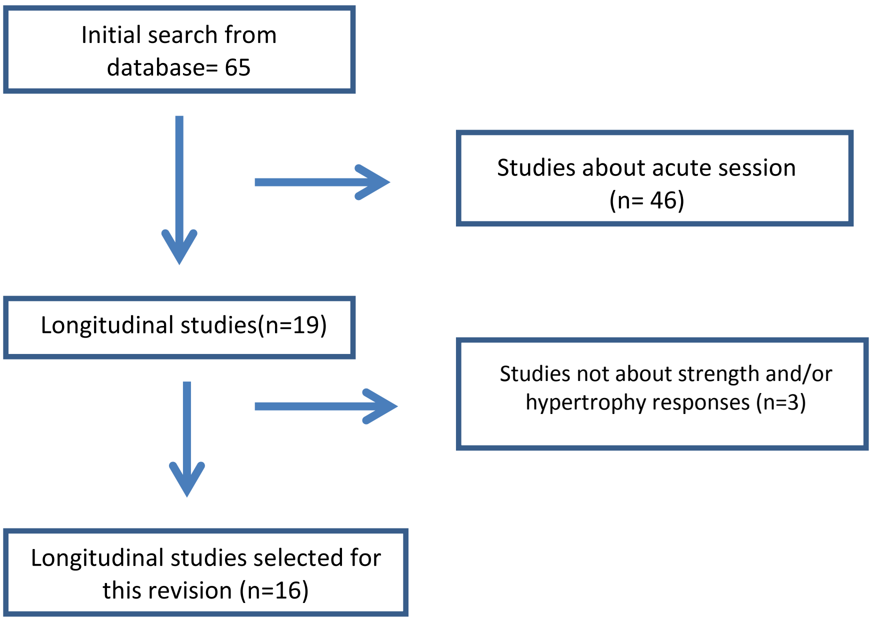

Figure 1. Flow diagram for this review

Results

Initially, 65 articles were identified, but only 19 clinical trials were selected. A last selection was performed searching those that evaluated strength and/or hypertrophy parameters during the intervention. Because of that, were excluded three articles remaining, thus, with 16 articles for analysis. The studies included in this revision, all analyzed strength parameters and nine also analyzed hypertrophy.

The exercise protocols used were biceps curl, bench press, knee extensor, plantar flexion and squat. The training duration ranged from two until ten weeks. Only three experiments controlled training volume. The electromyography analysis occurred in two studies. The articles selected are described in Table I.

Discussion

As described in literature, low-intensity resistance training with blood flow restriction allows strength and hypertrophy improvements similar to conventional resistance training (11, 12, 26). Thus, the aim of this study was compare the effects of RT with and without BFR in strength and hypertrophy gains and understand the mechanism of adaptation between two methodologies. Moreover, check the influence of volume training in these gains.

Table I. Summary of the studies using blood flow restriction to increase strength and hypertrophy

Author (Year)	Strength						Hypertrophy			Volume of trainig	Length of training
	1RM (kg)			MVC (N)							
	BFR	HI		BFR	HI		BFR	HI			
	SDT	SGT	SDG	SDT	SDT	DEG	SDT	SDT	SDG		
Godawa et. al. (2012)[19]	S: +	S: +	BFR*								10
	BP: X	BP: X	X								
Yasuda et. al. (2010)[20]	BP:+						TB e PM: +				6
Cook et. al. (2014)[21]	S: +										3
	BP: +										
Yasuda et. al. (2011)[22]	BP: +	BP: +	HI*	BP: X	BP: +	X	TB e PM: +	TB e PM:+	X	CONTROLLED	6
Yasuda et. al. (2012)[23]				CON B: +			+				6
				EXC B: X			+				
Ramis (2014)[24]	B: +	B: +	X	B: +	B: +	X	B: +	B: +	X	CONTROLLED	8
	KE: +	KE: +	HI*	KE: +	KE: +	HI*	KE: +	KE: +	X		
Patterson; Ferguson (2010)[25]	PF: +			PF: +							4
Takada et. al. (2012)[26]	PF: +						PF: +				4
Patterson; Ferguson (2011)[27]	PF: +			PF: +							4
Evans et. al. (2010)[28]				PF: +							4
Madarame et. al. (2011)[29]	S: +						+				10
Manimmanakor et. al. (2013)[30]				KE: +			+				5
Clark et. al. (2011)[31]				KE: +	KE: +	X					4
Martín-Hernández et. al. (2013)[32]	KE - LV: +	KE: +	HI*				LV: +	+	X	CONTROLLED	5
	KE - HV: +						HV: +				
Karabulut et. al. (2013)[33]	KE: +	KE: +	HI*								6
Nielsen et. al. (2012)[34]				KE: +							3
Laurentino et. al. (2012)[35]	KE: +	KE: +	X				+	+	X		8

Legend: *1RM=one repetition maximum, MVC=maximum voluntary contraction, BFR= blood flow restriction group, HI= high intensity group, SDT= significant difference after training, SDG= significant difference between groups, S=squat, BP= bench press, PF: plantar flexion, KE= knee extensor, B= biceps, Con= concentric, Ecc= eccentric, TB= triceps brachii, PM= pectoralis major, LV= low volume, HV= high volume, +:significant increase after training, X: there was no significant difference after training, BFR*:significant difference between groups whit greatest improvements for BFR, HI*: significant difference between groups whit greatest improvements for HI*.*

In this literature revision it was possible to perceive that almost studies, independently of training duration, the strength gains were similar between LI-BFR and RT or with a tendency for greater gains in the last. About hypertrophy improvements the results indicate, in most, similar gains for two groups. However, there are studies in this revision with no longer duration than ten weeks to demonstrate how would happen long term adaptations.

The RT enables strength improvements since early phases of training without hypertrophy, so it could be speculated that these strength gains could be accounted on neural adaptation. Subsequently, an increase in muscle mass was observed (7, 15). On the other hand, in LI-BFR studies the increase in strength levels occurred concomitantly to hypertrophy improvements, with a rise between 5ª and 8ª week. Therefore, it would occur gains in consequence of neural adaptation after 10ª week only (15). These hypotheses that would explain differences in adaptations between these two types of training were mentioned in meta-analysis write by Loenneke et al. (15) that described "Theoretical Reverse Pattern".

It can be suggested that in training with duration until ten weeks the values for strength would have a tendency to be greater in the high intensity group (performed the RT) in comparison to occlusion (performed LI-BFR). Clark et al. (31) observed, after four weeks of training, strength improvements to HI (13%) and BFR (8%) groups in isometric strength, without significant difference between groups. A study of Nielsen et al. (34) evaluated strength parameters after a three week training. They found 10.6% of isometric strength gains by maximal voluntary contraction (MVC) in occlusion group at the end of this period. On the other hand, Seynnes et al. (36) found, in knee extensor, isometric strength gains in RT of 38.9 ± 5.7%. These results appear to demonstrate that in RT would exist a tendency to greater strength improvements in early phases of training.

Karabulut et al. (33) found significant difference on strength levels for the high intensity group (HI) in comparison to occlusion group (BFR) in six weeks of training, 31,2% and 19,1%, respectively. Other study that met similar results was the Yasuda et al. (22). The intervention occurred during six weeks where the volunteers performed the bench press exercise, divided in three experimental groups: BFR, HI and combined (HI+BFR). The weekly frequency was three times, where the combined group trained twice for BFR and once for HI.

After six weeks there was an increase in dynamic strength (1RM) in HI (19,9%), combined (15,3%) and BFR (8,7%) and isometric strength only in HI (11,3%) and Combined (6,6%). The strength improvements would suggest greater responses for the HI group and combined that could be related to neural adaptations (22). Among the studies analyzed only two reported strength gains significantly greater for BFR than HI. According Cook et al. (21), the physical level of those subjects would help in a faster adaptation and, so, greater gains to strength and hypertrophy than normal subjects. The duration of training could be observed only with 10 weeks on these studies. Thus, it will be important future studies with longer duration of training to verify additional effects on strength and hypertrophy.

The hypertrophic response in LI-BFR takes place since early period of training and keeps a constant rate after four weeks (15). In RT the hypertrophy has an exponential rise after six weeks. However, before this is possible to achieve hypertrophy increase (7). For Folland Williams (6), the increase in muscle mass is result a larger period of adaptation with a linear increase in first months of training. Therefore, appear that hypertrophy in BFR responds since first week of training and in RT occur a considerable increase after first weeks, which would indicate difference in adaptation between those two methodologies.

In a training of eight weeks the hypertrophy gains had not significant difference between BFR (6,3%) and HI (6,1%) group which performed knee extensor exercise. To a certain extent, these results can be explained by decrease myostatin gene expression in two groups (35). Similarly, Martín-Hernández et al. (32) applying five weeks of training not met significant difference between groups for muscle thickness in rectus femoris (7,5%) and vastus lateralis (9,9%). On the other hand, Yasuda et al. (22) in six weeks of training observed significant difference comparing muscle cross sectional area of triceps for BFR (8,3%) with HI (8,6%) and pectoralis major BFR (8,3%) for HI (17,6%). These different findings can be related with exercise performed.

The two first experiments used knee extensor and had similar results. However, Yasuda et al. (22) evaluated strength and hypertrophy parameters by bench press exercise showing better results for HI. The hypertrophy gains appear be greater in muscle groups of the upper-arm, because quadriceps muscles are more required in activities of daily life (6).

Whereas not every studies were analyzed hypertrophic response, this prevents an analysis with more detail. Moreover, the different evaluation methods (muscle thickness and cross sectional area) also difficult the comparison. Despite this, the studies that compare gains between HI and BFR showed similar results, having only one study with greater response for HI. These findings appear to agree with "Theoretical Reverse Pattern" proposed by Loenneke et al. (15).

The technique commonly used to evaluate neural adaptations in exercise is surface electromyography (SEMG) (6, 8). The increase in neural activation in muscle is related with large recruitment of motor units, and consequently, increase strength in RT (7). In this methodology, studies already demonstrated increase in neural activation after period of training (36-38).

Higbie et al. (37) assessed neural activation after ten weeks of knee extensor training with volunteers assigned to eccentric (EC), concentric (CC) training group and control group (CG). After period ten weeks there was significant increase in neural activation in the EC and CC groups mainly assessed specific muscle actions used in training. Thus, the authors suggested that neural adaptations would result from specific pattern of activation of muscle actions used in training. This specific neural adaptation would be correlated with increase in strength in EC and CC group. In the same way Aagaard et al. (38) using 14 weeks of RT observed improvements in neural adaptation at rectus femoris (RF), vastus lateralis (VL) and vastus medialis (VM) in early phase of contraction. However, there are not many studies in BFR using this method. In the studies selected for this revision only two assessed neural adaptations.

In the resistance training with blood flow restriction performing biceps exercise there was not alteration of eletromyographic activity after eight weeks of training, happening increase only in HI group. Nevertheless, in knee extensor exercise there was increase only in BFR group (24). In a session of biceps exercise happened rise muscle activation in concentric action in comparison to eccentric (23). As occurred hypertrophy and strength gains at the end of experiment (six weeks of training) appear that concentric phase is more important for those adaptations than eccentric actions.

Takarada et al. (10) in a session of biceps exercise observed similar levels of activation in muscle fibers by EMG between BFR and HI. On the other hand, Wernbom et al. (39) did not observe changes in muscle activation in quadriceps between BFR and LI (low intensity) in a session of knee extensor exercise.

Although literature have demonstrated increase of neural activity due RT the same still is controversial in LI-BFR. Problems with positioning electrodes, variable impedance of the skin, subcutaneous fat and muscle morphology prevent an analysis more detailed (6, 8). Furthermore, the interpretation of increase eletromiographic signal due greater influence of neural drive can be simplified (6). Moreover, suggest that the increase of recruitment of motor units would be related only with increase of EMG signal would be believe that training could not change by other ways the activation of those fibers (7). Others methods how electric stimulation and intramuscular electromyography appear attenuate interference of those factors (7, 8). Thus are necessary more studies measuring neural activity after training program to understand possible differences in neural adaptations between RT and LI-BFR.

In the present revision only three studies controlled volume of training (VT). According to Sale (7) VT can be one of these factors that interfere the result of training, and consequently, in comparison between researches.

Martín et al. (32) assessed the influence of VT in LI-BFR. The authors observed significant difference for the parameters of strength in HI group in comparison with BFR HV (high volume) and BFR LV (low volume). However, there was no significant difference between the two training protocols with occlusion, indicating that VT would have its interference attenuated in that methodology. In that study VT was greater for HI group in comparison the other two, which could explain greater values for this group. According Loenneke et al. (40) the LI-BFR allows strength and hypertrophy gains with lower volumes of training due metabolic accumulation induced by hypoxic, generating greater recruitment of fast twitch fibers. Other investigation that controlled VT (similar between three groups) was Yasuda et al. (22) where values of strength and hypertrophy were significantly greater for HI and Combined (HI+BFR) in comparison to BFR.

These values would indicate that intensity in occlusion group was not sufficient to generate neural adaptation and strength gains were related with hypertrophy improvements, unlike the HI group (22). Other important aspect is that Combined group even having performed more sessions with occlusion obtained values

significantly greater than BFR. Those gains would have happened because of specificity of strength training in Combined group (22).
The control of this variable also was made in a study of eight weeks assessing biceps and knee extensor exercise. After the end of the experiment levels of strength were greater, but don't significant to HI group in comparison to BFR. When compared between groups there was significant increase to HI in knee extensor. In respect to hypertrophy there was not significant difference between two protocols of training, even though in HI and BFR has been found gains in the muscle mass (24).
It appears that greater VT don't increase strength and hypertrophy levels in LI-BFR, unlike RT that appears to be influenced for this variable. When used VT similar between the two methodologies the RT would allows greater improvements. However, few studies controlled VT, so other investigations are necessary to elucidate the influence from that variable in LI-BFR.
An important factor to be observed is that there is a very heterogeneous sample, since elderly until athletes, requiring attention to interpretation of the data. These heterogeneous samples would be explained by lack restriction of the population in the search of articles.

Conclusion

In the present revision of the literature the studies demonstrated that there is a tendency for greater strength improvements to RT than LI-BFR. This would indicate that neural adaptation interferes in early phases of training only in RT. Similar values of hypertrophy were demonstrated between two methodologies in the short term studies (until 10 weeks). These findings would be agree with "Theoretical Reverse Pattern" proposed by Loenneke et al. (15). Moreover, greater VT appears doesn't influence the increase of strength and hypertrophy in LI-BFR. Nevertheless, are necessary more studies to demonstrate the influence the VT in LI-BFR. Lastly are necessary studies in the long term that check the strength and hypertrophy responses in RT and LI-BFR to investigate possible differences in adaptations between two methodologies. For this, would be important asses the neural adaptation in the long term too.

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