The effects of partial vascular occlusion on gaining muscle strength

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ABSTRACT

Objective: To investigate the effects of low-intensity resistance exercise associated with vascular occlusion in strength and muscle volume. **Method:** We performed a systematic review in electronic databases: Science Direct, PEDro, and Pubmed, in which were reviewed only randomized clinical trials with a score over 50% according to the PEDro scale. **Results:** During the survey 440 articles were pre-selected and reviewed, but in the final selection only seven articles met all inclusion criteria and specifications set. **Conclusion:** We conclude that low-intensity exercise with blood occlusion is an effective alternative in inducing muscle hypertrophy and is seen as a new possibility of targeted muscle training for young people and seniors. However, we need more studies, for there are still points that remain unclear, such as pain and discomfort during training.

Keywords: exercise, hypertrophy, muscle strength

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INTRODUCTION

The reduction of blood flow to the muscle during resistance exercises has been shown as beneficial to gaining muscle hypertrophy and strength, similar to the gains with traditional high-intensity resistance training, but using less intensity.[1]

Blood flow is an important component in the transport of oxygen to the muscle during its activity. In sub-maximum exercise, it is necessary to increase and maintain blood flow to adequately supply the oxygen demand and to remove by-products and residues from active muscles.[2]

According to Wernbom et al.[3] in prescribing resistance exercises, the intensity of training or the load used is considered the most important variable. The intensity of resistance training is often quantified in terms of the maximum weight that can be lifted, called the maximum repetition (1 MR). They also believe that the weight must be at least 60% of the 1 MR in order to stimulate increased strength. For muscular hypertrophy, loads of 6-12 MR are generally recommended, which correspond to 70 to 80% of 1 MR. However, in the clinical setting, many times it is difficult and also contraindicated to use maximum loads, for example, in rehabilitation soon after a sports injury.

Rooney[4] and Schott[5] have stated that increased resistance and gain in muscle mass have a direct connection with muscle fatigue and the internal accumulation of metabolites. Similar results were found using tourniquets for partial restriction of blood flow to the muscle during low-resistance training to increase muscle strength.[1]

It is believed that restriction of blood flow during low-intensity exercise increases endurance, phosphorylation, and muscle protein synthesis in addition to promoting increased strength as much as conventional resistance training with heavy loads. However, the cellular mechanism responsible for gaining strength and hypertrophy induced by blood flow restriction (BFR) is not fully understood.[6] It has been suggested that with vascular occlusion there is a stimulation of the local metabolism, which in turn stimulates a subsequent increase in growth factors, primarily recruiting the fast-twitch fibers and increased protein syntheses.[7,8]

Recent studies have shown that muscle training with moderate restriction of blood flow can induce the same increase in muscle volume as with exercises training with heavy loads.[7,9] Nevertheless, this thinking is not unanimous since some studies find no difference between conventional training and that using partial occlusion.[10]

OBJECTIVE

The object of this study was, via a systematic review of current literature, to investigate the effects in resistance training with vascular occlusion on gains in strength and muscle volume, and to determine whether low-intensity resistance exercises with reduced blood flow would increase the muscle capacity comparably to the same exercise with no occlusion.

METHOD

During the period between August of 2010 and March of 2011, a systematic review was made of the literature in the databases of PEDro, Science Direct, and PubMed by two independent reviewers, who selected only works published in the English language to study. During the collection phase there was no restriction as to the year the study was published, as long as it dealt with a relatively new way of strengthening. The keywords used for finding works in the databases were: muscle strengthening, ischemia, resistance training, and muscle.

The review was broadened by searching through the bibliographical references of relevant studies, soliciting studies published by specialists, and searches in other sources.

Evaluation of the studies

To evaluate their quality, the methodology of each selected randomized clinical trial (RCT) was scored using the PEDro scale, a very popular instrument for grading the characteristics of clinical studies.[11] The scale is composed of 11 items (except for item one which, unlike the other items, is only pertinent to outside validity) and each satisfactory item contributes one point to the overall score (from 0 to 10). Two evaluators graded the studies separately regarding the presence or absence of the scale's quality indicators. Moderate levels of reliability between the examiners have been demonstrated by the PEDro scale.[12] In case of disagreements between the examiners, they would meet to come to a consensus. The cutoff point used for analyzing the works was five, which corresponded to 50% of the scale, since studies with scores of 6 and up were considered to have good methodology, and studies with lower scores were considered to have shortcomings.

RESULTS

After the initial selection based on title and keywords a total of 440 articles were found. At the end of the selection only seven articles fulfilled all of the established inclusion criteria and specifications (Figure 1).

Of the 7 studies found, 4 of them worked with an elderly population, 3 with youths, and only one studied the effects of post-operative ischemic strengthening and the majority of those chose to study the male gender. One of them had a mixed sample of males and females to evaluate.

The summary of the data from each article is found in Table 1, which shows that the pressure used in the vascular occlusion (VO) varied between 0 and 250 mmHg. In regards to the measuring of strength, all the clinical trials presented in our review used a dynamometer for this evaluation, and all of them obtained significant increases in muscle strength showing the groups of subjects who did exercises with occlusion, being comparable with the groups who did the same exercises in the conventional way.

One important bit of data that was revealed in four of the clinical studies included in the review was the cross-sectional area of the muscle being studied. In three of them, the final results indicated an increase of this area in the groups who did the exercise associated with VO, and only one of them did not indicate an increase of the cross-sectional area; this increase did not occur in any of the groups studied.

DISCUSSION

This systematic review included 7 RCTs that examined the benefits of ischemic vascular occlusion in the work of gaining muscle strength. With the data gathered from the studies, we can affirm that ischemia has become an important resource in the work of muscle building, especially of the quadriceps, the muscle evaluated in 6 of the 7 RCTs; they all had satisfactory results regarding increased strength.

Takarada et al.[13] evaluated the effects of resistance exercises associated with partial vascular occlusion and the increased muscle

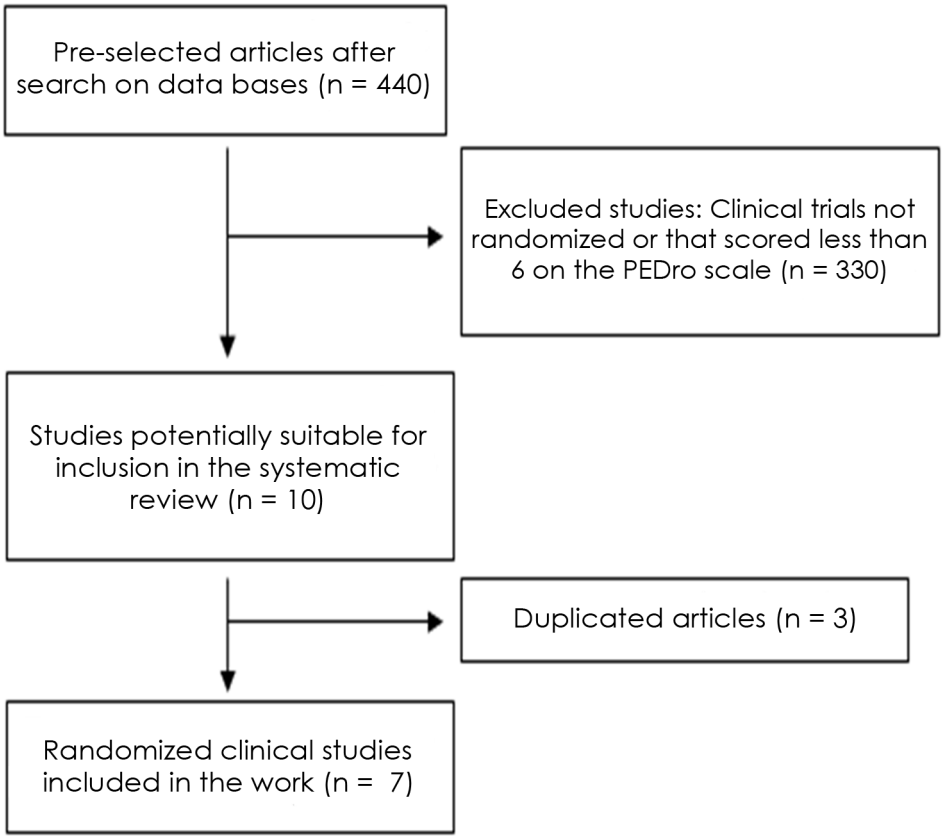

Figure 1. Flowchart of the selected studies

tropism in the elbow flexors of elderly females. For this the individuals were divided into two groups: low intensity with occlusion (LIO) between 30 and 50% of a maximum repetition; and low intensity with no occlusion (LI). The average occlusion pressure during the whole training period was 110.0 (LIO group) and 17.1 mmHg (LI group).

The exercise program lasted 4 months and was done twice a week. In each series the subjects did three series of strength exercises, separated by a one-minute break.

At the end of the experiment, it was observed that the LIO group showed an increase in cross-sectional area as well as in isokinetic strength of the elbow flexor musculature when compared with the LI group. Such exercises suggest that resistance exercises less than 50% of 1 MR are effective in inducing muscle hypertrophy, associated with increased strength, when combined with vascular occlusion.

Similar results were found in the study by Yokokawa et al.[14] also done with the elderly, with the intention of comparing the effects of LIO with dynamic balance exercises (DBE) on 51 individuals divided into two groups: an LIO group (n = 24) and a DBE group (n = 27). Performance, balance, and muscle strength were evaluated in both groups. In addition, blood tests from 11 of the LIO participants were analyzed for growth hormone (GH) and lactates, for reduced blood flow to muscles is considered likely to induce growth hormone secretion.

Using a pair of special elastic straps, suitable pressure was applied to the proximal parts of the thigh during the low-intensity training. The level of pressure applied during training was determined by initial blood pressure and age. A pressure level of around 70 mmHg was set for the thighs, so that the peripheral flow of blood would not be jeopardized. The maximum pressure was set at 1.2 times the systolic pressure of the individuals, or at a subjectively tolerable level.

The program lasted for 8 weeks and the patients were instructed to make 6 different movements with the lower limbs. Improvements were noticed after this period, but no difference was found as to performance or balance. The muscle strength in the legs was significantly greater in the LIO group than the DBE group. The growth hormone was noticeably augmented after the occlusion exercise. According to the authors, these results suggest that LIO must be viewed as one of the most promising physical exercise programs oriented towards the healthy elderly.

Ohta et al.[4] investigated the effects of muscle training exercises for 16 weeks with a moderate restriction of blood flow after the reconstruction of the anterior cruciate ligament (ACL) starting at the flexor tendon of the knee in 44 patients (25 men and 19 women). They were divided into two groups and their rehabilitation was exactly equal, distinguished only by the partial restriction of blood flow with a pressure of 180 mmHg in one of the groups during a strengthening exercise in closed kinetic chain exercises.

After 16 weeks of treatment there was a significant increase in the strength of the flexor and extensor musculature in the knees of those who worked with ischemia, in addition to a significant increase in the cross-sectional area of these muscles in relation to the group who did traditional strengthening work.

Thirty-seven healthy elderly males were divided into 3 groups:[15] group 1 was submitted to high-intensity resistance training, group 2 did low intensity resistance training exercises associated with vascular occlusion, and group 3 was the control. For blood restriction, elastic straps were positioned on the proximal portion of the thigh that would pneumatically inflate and apply pressure inside connected to an electronic control system that would reach a maximum pressure of 160 mmHg. Blood samples were collected before and after six weeks of resistance training to measure any changes in the bone formation (bone alkaline phosphatase and type I collagen). After the 4 months of monitoring there was a significant increase in the percentages of bone alkaline phosphatase, with 21% for the low-intensity training group with vascular occlusion and 23% with the high-intensity resistance training group, as compared with the control group, which indicates an increase in the rate of bone formation and is associated with an increase in bone mineral density (BMD).

The serum concentrations of bone alkaline phosphatase and type I collagen in both resistance training protocols favor bone formation. Therefore, in spite of the use of low mechanical loads, the low-intensity exercise with vascular occlusion is an effective alternative compared to the traditional high-intensity resistance exercise in improving bone density among elderly men; moreover, the fact that it works with a diminished resistance creates

Table 1. Randomized clinical trials selected for the study

Study	PEDro score	Sample (n)	Muscle group	Program	Evaluation	Outcome
Takarada et al. (2000)	7	24 elderly females (average age 58 years)	Elbow flexors	One group did the LIO exercises (0-100 mmHg) with a load of 50% of 1 RM, and the other did the LI exercises with the same load twice a week for 16 weeks	Arterial blood flow (Doppler ultrasound), serum lactate (blood sample), muscle strength (isokinetic dynamometer), and muscle cross section area (magnetic resonance)	The results show significant increases in isokinetic strength and muscle cross section (hypertrophy) in the group that did the LIO exercises in comparison with the group that did LI exercises
Yokokawa et al. (2008)	6	51 elderly males (more than 65 years of age)	Quadriceps	One group did the LIO exercises (75-150 mmHg) and the other group did dynamic balance exercises. The training was done twice a week for 8 weeks where old people were designated to do 6 types of exercise for the legs	Performance on 4 functional tests (reaction time, timed up and go test, ten-meter walking time, maximum step distance), balance, muscle strength (dynamometer), serum dosage of the growth hormone (GH), and lactate (blood sample)	There was no significant difference between the groups as to performance and balance. Muscle strength and GH rate showed a significant increase in the group that did the LIO exercises over the dynamic balance group
Ohta et al. (2003)	7	44 patients of both genders after surgery on the anterior cruciate ligament (average age of 29 years)	Knee flexors and extensors	One group did the LIO exercises (180 mmHg) and the other group did LI exercises twice a day, 6 days a week, for 8 weeks after surgery	Muscle force (isokinetic dynamometer), cross-sectional area of muscle (magnetic resonance), diameter of muscle fiber by type of fiber of the vastus lateralis (biopsy)	The results showed that the group that did the LIO exercises had a significant increase in muscle strength and hypertrophy, however there was no significant difference in the increase in the diameter of the muscle fiber of the vastus lateralis between the two groups
Karabulut et al. (2011)	7	37 adult males (average age of 56.8 years)	Quadriceps	The elderly were divided into 3 groups: one group did the LIO exercises (40-240 mmHg), the 2nd group did high-intensity resistance exercises, and the 3rd group was the control. The program was done 3 times a week for 6 weeks	Muscle force (isokinetic dynamometer), volumetric bone mineral density (quantitative peripheral tomography), bone markers (blood sample)	The serum concentrations of bone alkaline phosphatase, type I collagen, and muscle strength increased significantly in both the resistance training protocols. Therefore, in spite of the use of a low mechanical load, the low-intensity exercise with vascular occlusion is an effective alternative compared with traditional high-intensity resistance exercise in improving the bone health in older males
Ozaki et al. (2011)	7	18 elderly people (average age of 68 years)	Quadriceps	One group walked on a treadmill with vascular occlusion (120-200 mmHg) and the other group followed the same protocol, but without the vascular occlusion (control). The training was done 4 times a week for 10 weeks where both groups did 20 minutes on a treadmill at an intensity that gave 45% of the heart rate reserve (HRR)	Cross-section area and muscle volume (magnetic resonance), muscle force (isokinetic dynamometer), estimated peak of VO_2 max, functional ability (Up and go test, chair-stand test)	According to the results, the group that did the walking associated with vascular occlusion significantly increased the cross-sectional area, volume, and muscle strength in relation to the control group. As regards the max VO_2 peak, both groups showed similar results
Sumide et al. (2009)	7	21 healthy young male subjects (average age 22.1 years)	Quadriceps	The exercise was done 3 times a week for 8 weeks where the first group did the exercise with no occlusion (0 mmHg). The 2nd group did the exercise with an occlusion of 50 mmHg. The 3rd group did the exercises with a pressure of 150 mmHg, and the 4th group used 250 mmHg	Muscle force and total muscle work (isokinetic dynamometer), cross-sectional area of muscle (magnetic resonance)	The results point to a significant increase in muscle strength and total muscle work in the groups with occlusion in relation to the group that did not have occlusion. However, there was no increase in the cross sectional area of the muscle in either of the two groups
Karabulut et al. (2010)	6	14 healthy young males (average age 23.9 years)	Quadriceps	The individuals were divided into 2 groups: one group did the LIO exercises (120 mmHg) and the other group did the LI. Each participant made two maximal voluntary isometric contractions (MVIC) before and after 5 series of 20 repetitions with a constant external dynamic resistance during leg extension exercises at 20% of a maximum repetition	Maximum isometric force (isokinetic dynamometer), voluntary muscle activation (electromyography)	The authors suggested that neuromuscular fatigue during the session with vascular restriction could be due to a combination of central and peripheral fatigue since the CON group had drops in the peak value of contraction, but an increase in VA% from the pre- and post-exercise, indicating that peripheral fatigue would probably be the factor responsible for the diminished values of MVIC

* LIO: Low intensity with occlusion; ** LI: Low intensity, no occlusion

less stress and overloading on the joints while giving the same benefits.

Ozaki et al.[1] examined the increased volume of the thigh and the muscle strength using low-intensity training and the restriction of blood flow (RBF) of the leg while walking,

seeking a gain in tropism among elderly individuals and an increase in the volume of oxygen consumption (VO_2). Two groups were formed: the first did walking with a restriction of blood flow, made up of 10 individuals with an average age of 64 years, and the other was a control group made up of 8 individuals with an average age of 68. Both groups did 20 minutes on a treadmill at an intensity level corresponding to 45% of the heart rate reserve (HRR), which was determined for each participant via their heart rate maximum. The training sessions were done 4 days a week for 10 weeks.

One week before the beginning of the study the walking speed was adjusted for each participant during a submaximum walking test and the exercise load for each participant was determined and maintained throughout the training period. The RBF group used pressure straps (160-200 mmHg) on both legs during the training and the cuff pressure was released immediately after the session. After the end of the training, a magnetic resonance scan was done on each leg to evaluate whether there had been an increase in cross-sectional area (3.1%, $p < 0.01$) or muscle volume (3.7%, $p < 0.01$), as well as isometric strength (5.9%, $p < 0.05$), or isokinetic strength (over 22%, $p < 0.05$). There was also an increase in strength in the RBF group, but not in the control group. The estimated VO_2 peak during the ergometric test increased ($p < 0.05$) and was correlated with the oxygen pulse in both groups. In conclusion, the authors reported a significant improvement in the RBF group concerning strength and muscle volume among older women.

It is well known that exercise programs are frequently associated with pain, especially when elderly individuals are submitted to high-intensity resistance training (> 65% 1 MR). However these exercises are linked to an increase in arterial pressure and the risk of injuries. Based on these findings, low-intensity resistance exercises combined with vascular occlusion could be a safe and useful method to build muscle hypertrophy.

Sumide et al.[16] did a study to investigate the ideal compression force necessary to reduce the blood flow in muscles during resistance exercises with the objective of gaining muscle strength and endurance without causing discomfort to the subjects. Twenty-one individuals were randomly divided into 4 groups according to the various applications of vascular pressure in the proximal region of the thigh: in the first group the exercises were done with no pressure (Group with 0 pressure); in the second group the exercises were done with a pressure of 50 mmHg (Group with 50 pressure); in the 3rd group the exercises were done with a pressure of 150 mmHg (Group with 150 pressure); and in the 4th group they were done with a pressure of 250 mmHg (Group with 250 pressure).

They evaluated isokinetic muscle strength at angular velocities of 60° and 180° per second, muscle resistance, and cross-sectional area of the extensor muscles of the knees. The exercise was done 3 times a week for a period of 8 weeks at an intensity of around 20% of a maximum repetition to lift the extended leg along with hip adduction.

A significant increase in strength at 180° per second was observed after the exercise in all those individuals associated with vascular occlusion. The muscle work also significantly increased in the 50 and 150 mmHg pressure groups ($p < 0.05$, $p < 0.01$). There was no significant increase in the cross-sectional area of the knee extensor muscle in any group. In conclusion, resistance exercise with relatively low-pressure vascular occlusion is potentially useful in increasing muscle strength and resistance without causing any discomfort.

Karabulut et al.[17] investigated the mechanisms responsible for neuromuscular fatigue during low-intensity exercises with blood flow restriction. Fourteen men participated in two experimental trials, one of which did low-intensity exercises with vascular restriction (VR group), while the other, which had no VR, was considered the control group (CON). Each participant made two maximal voluntary isometric contractions (MVIC), before and after 5 series of 20 repetitions with a constant dynamic external resistance during the leg extension exercises, with 20% of a maximum repetition and a rest of 30 seconds. The VR group wore an elastic strap on the proximal part of the thigh to restrict the blood flow.

The participants were instructed to do knee flexion and extension at a constant speed of about 1.5 seconds for each concentric and eccentric action. Surface electromyography (SEMG) was used to investigate the subadjacent mechanisms and the neuromuscular fatigue of the Vastus Lateralis muscle before, during, and after the 5 series of repetitions done at 20% of 1 MR. The authors reported a greater significant diminution in MVIC (13%). In addition, the CON group resulted in increases in the SEMG amplitude (3%) and in the percentage of voluntary activation (VA% = 3.5%); the vascular restriction condition caused significant reductions in the values of the pre and post-exercise VA% (13.0%, $p = 0.04$) and alterations in the pre and post-exercise SEMG amplitude (12.0%, $p = 0.03$). Significant reductions in the SEMG and VA% amplitudes in the VR group could indicate an inhibition in the central motor units, resulting in an additional decline in the capacity to generate force after VR exercises. The authors suggested that neuromuscular fatigue during the VR session could come from a combination of central and peripheral fatigue, since the peak contraction values dropped in the CON group, even though there was an increase in the VA% before and after the exercise, indicating that peripheral fatigue was probably the main factor responsible for the diminution of the MVIC values.

Seeing such studies as were found in the literature, it seems that partial ischemic occlusion could become an important resource in building muscle strength. When we consider strength training without overloading the joints, any gain seems impossible, but when we introduce ischemia, where the muscle works 20 to 30% of its maximum effort, and we find the same results as with conventional strength training, this becomes a promising alternative in the field of rehabilitation.

Another important fact is that ischemic strengthening is proving itself effective in the rehabilitation of patients in regards to gaining strength and muscle tropism, however, several problems remain to be explained, such as pain and discomfort during the workout and the possible effects on circulation including thrombosis and edema, which demand more attention during the execution of such exercises.[9]

The fact that we limited ourselves to those reports in the English language and in only 3 databases constitutes a bias in the present study, however, we point out that we made this choice thinking that English is the language where today there is a greater number of publications from researchers of different countries and the databases we chose are those we judged to be the most important within the area of health.

Another factor that must be carefully analyzed is the fact that we found a great variety of samples in the studies we selected (people old and young, healthy and disabled), which calls for a rigorous methodological evaluation of these studies, also evaluating their results, before we extrapolate such findings into our clinical practices, since the physiological response of each group manifests in a different way.

CONCLUSION

Through the present study we can conclude that low intensity exercise with restricted blood flow is an effective alternative in building muscle hypertrophy, being seen as a new treatment possibility, used not only in post-operative rehabilitation, but also as a physical training program oriented towards youth, athletes, and the healthy elderly. Meanwhile, in spite of being a safe and useful method of gaining muscle mass and strength, more studies are necessary for several things remain to be explained, such as pain and discomfort during the workout due to the cuff, and possible effects on circulation due to the occlusion, including thrombosis and edema, necessitating greater attention as to the safety of this training.

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