

Effects of Strength Training and Vascular Occlusion

Authors

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Key words

- hypertrophy
- cross-sectional area
- leg extension

Abstract



The purpose of our study was to determine if vascular occlusion produced an additive effect on muscle hypertrophy and strength performance with high strength training loads. Sixteen physically active men were divided into two groups: high-intensity (HI = 6 RM) and moderate-intensity training (MI = 12 RM). An occlusion cuff was attached to the proximal end of the right thigh, so that blood flow was reduced during the exer-

cise. The left leg served as a control, thus was trained without vascular occlusion. Knee extension 1 RM and quadriceps cross-sectional area (MRI) were evaluated pre- and post-8 weeks of training. We only found a main time effect for both strength gains and quadriceps hypertrophy ($p < 0.001$). Therefore, we conclude that vascular occlusion in combination with high-intensity strength training does not augment muscle strength or hypertrophy when compared to high-intensity strength training alone

Introduction



Strength training has a powerful effect on muscle hypertrophy and strength. These adaptations are in response to factors such as degree of muscle tension, neural and hormonal adjustments. Muscle tension is a primary factor. As a consequence, high-intensity strength training (75–80% of 1 RM) has been recommended to achieve both muscle hypertrophy and strength gains, because low to moderate strength training (< 60% of 1 RM) does not seem to generate enough tension to produce gains of the same magnitude [3,12,13].

However, recent studies have shown that when low-intensity strength training (20 to 50% of 1 RM) is associated with vascular occlusion both hypertrophy and strength gains are similar to high-intensity training without vascular occlusion [14,20]. It has been hypothesized that the hypoxia induced by vascular occlusion produces an additive effect on muscle hypertrophy and strength gains when associated to low-intensity strength training. A possible hypothesis for the additive effect of vascular occlusion is an enhancement in motor unit recruitment, as shown by greater EMG levels [20], which may produce greater strength gains.

It is unknown whether the enhanced responses produced by vascular occlusion at low strength training loads also occur when the loading is high. Heavy training loads are conventionally used and recommended for muscle hypertrophy and strength gains and therefore represent a real world situation [13]. However, at high forces, muscle contraction per se may restrict blood flow to a similar extent as external vascular occlusion, thus negating any additional effects of cuff occlusion to high strength training loads [4,23]. Therefore, the purpose of this study was to test if vascular occlusion augments the neuromuscular adaptations to strength training with high loads.

Methods



Experimental design

Subjects participated in two familiarization sessions in which they were acquainted to experimental (e.g., quadriceps vascular occlusion) procedures. One week after familiarization sessions, individuals were tested for knee extension 1 RM. After 1 RM, test subjects were randomly divided into two groups balanced for knee extension 1 RM (two sample independent t -test, $p = 0.69$): high-intensity training (HI = 23.55 ± 3.37 years; 176.44 ± 6.89 cm and 71.44 ± 11.05 kg) and mod-

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erate-intensity training ($MI = 22.42 \pm 3.41$ years; 180.28 ± 5.84 cm, and 80.15 ± 11.78 kg). The HI group trained with an exercise load corresponding to 6 RM, while the MI group trained with a load of 12 RM. The right leg was trained with vascular occlusion and the left leg served as a control, thus was trained without vascular occlusion. Training was performed for 8 weeks, twice a week. Knee extension 1 RM and quadriceps cross-sectional area were evaluated pre- and post-training.

Subjects

Sixteen physically active male college students volunteered to participate in this study. Participants were not engaged in any form of resistance training; however, they participated in leisure activities once or twice a week (e.g., soccer, volleyball). They reported no lower extremity injury in the last six months. The subjects were instructed to keep the same level of physical activities throughout the study. The study was approved by the University's ethics committee and all subjects signed an informed consent form before participation.

Knee extension 1 RM test

The procedures performed to determine knee extension 1 RM followed the recommendations described by Brown and Weir [5]. In short, subjects performed a complete repetition starting the movement with 90° of knee flexion, extended the knee up to 180° , and then returning to the initial position. The amount of weight used in the first repetition was defined as 80% of the weight lifted in the familiarization sessions. Then, heavier weights were added until the maximum load was achieved in no more than four trials with a three-minute interval between trials. There was a $\sim 5\%$ increment in the load between trials to nearest 2.5 kg. Right and left legs were tested independently and the greatest weight lifted for each leg was considered as 1 RM.

Quadriceps cross-sectional area

Quadriceps cross-sectional area was obtained through magnetic resonance imaging (MRI) (Signa LX 9.1, GE Healthcare, Milwaukee, WI, USA). Subjects laid in the device in a supine position with straight legs. A bandage was used to restrain leg movements during the test. All images were captured from both legs because we used a contralateral training paradigm. An initial image was captured to determine the perpendicular distance from the greater trochanter of the femur to the inferior border of the lateral epicondyle of the femur, which was defined as segment length. Quadriceps cross-sectional area was measured at 50% of the segment length with 0.8-cm slices for three seconds. The pulse sequence was performed with a view field between 400 and 420 mm, time of repetition of 350 milliseconds, echo time from 9 to 11 milliseconds, two signal acquisitions, and matrix of reconstruction of 256×256 . The images were transferred to a workstation (Advantage Workstation 4.3, GE Healthcare, Milwaukee, WI, USA) to determine quadriceps cross-sectional area. In short, the segment slice was divided into components skeletal muscle, subcutaneous fat tissue, bone, and residual tissue. Then, the muscle cross-sectional area was determined subtracting the bone and subcutaneous fat area.

Training program

Both the HI and the MI groups performed unilateral knee extension exercise training. The HI group trained with a load of 6 RM and the MI group with a load of 12 RM, corresponding to $\sim 80\%$

and 60% 1 RM, respectively. In fact, exercise intensity was determined as 6 RM and 12 RM for MI and HI groups, respectively, for each set and not a percentage of 1 RM. If a subject was able to perform all sets with the established number of repetitions, the training load was adjusted in the following training session. If he could complete all sets with the determined number of repetitions minus two, training load was maintained in the next training session. However, if he was not able to perform the determined number of repetitions minus 2, the training load was decreased. The duration of both the concentric and the eccentric phases was 4 seconds (2 s for concentric and 2 s for eccentric actions). As all subjects were right handed, the right leg was trained with vascular occlusion, while the left leg (control) was trained without vascular occlusion. In the first three weeks subjects performed three sets of knee extensions for each leg. For the following two weeks they performed four sets. In the last three weeks of training individuals executed five sets for one and three sets for the remaining two weeks. Rest interval between sets was 120 seconds. The occluded leg had an air cuff placed at the inguinal fold. Vascular occlusion was kept during exercise and released during rest interval.

Determination of vascular occlusion pressure

A vascular doppler (DV-600, Martec, Ribeirao Preto, SP, Brasil) probe was placed over the tibial artery to determine blood pressure (mmHg) of vascular occlusion. A standard blood pressure cuff (width 140 mm; length 900 mm) [21] attached to the thigh (inguinal fold region) was inflated up to the point in which the auscultatory pulse of the tibial artery was interrupted. Blood pressure of vascular occlusion was kept constant through the training period. The HI and the MI groups had occlusion pressures of 125.6 ± 15.0 and 131.2 ± 12.8 mmHg, respectively.

Statistical analysis

Mixed models having group (HI and MI), time (pre- and post-test), and leg (occluded and control) as a fixed factor and subjects as a random factor, for both strength gains (1 RM) and quadriceps cross-sectional area. Whenever a significant F-value was obtained, a post hoc test with a Tukey adjustment was performed for multiple comparison purposes. Significance level was set at $p < 0.05$. Results are presented as means and standard deviations.

Results



Values for 1 RM in leg extension exercise are presented in **Table 1**. Both groups improved 1 RM values significantly from pre- to post-test ($p < 0.001$) in both legs (occluded and control). However, there were no differences between legs within or across groups, indicating that neither intensity nor vascular occlusion affected muscle strength development (**Table 1**).

Table 2 shows values of cross-sectional area for the quadriceps femoral muscle. MRI data analysis demonstrated hypertrophy in both groups (pre- to post-training) regardless of vascular occlusion and exercise intensity.

Discussion



In the present study, we did not find an additive training effect on muscle hypertrophy and strength gains when vascular occlu-

Table 1 Values for 1 RM (kg) in leg extension exercise for groups HI and MI pre- and posttreatment

Grps.	HI		MI	
	Occluded	Control	Occluded	Control
Pre	80.6 ± 17.0	79.3 ± 16.1	83.6 ± 19.1	81.4 ± 18.2
Post*	108.4 ± 17.6	108.6 ± 18.9	113.1 ± 14.8	112.0 ± 14.9

* Significant main effect for time ($p < 0.001$)

sion was combined with training intensities that mimic a real world setting. Both HI and MI groups improved cross-sectional area and 1 RM performance in the occluded and in the control leg.

Our results are contrary to data published previously, in which vascular occlusion was applied with training loads between 10 and 50% of 1 RM [1,10,17,20,26]. These studies reported a greater muscle hypertrophy in the occluded limb compared to the non-occluded limb. Takarada et al. [20] did not find any differences in hypertrophy and strength gains of the elbow flexors between training at 50% of 1 RM with vascular occlusion and training at 80% of 1 RM without occlusion. However, when compared with the same low training load (50% 1 RM) without occlusion, the occluded limb presented greater hypertrophy and strength gains. In the same way, Kubo et al. [14] compared the improvements in quadriceps femoral muscle cross-sectional area after 12 weeks of training at 20% of 1 RM with vascular occlusion, and training at 80% of 1 RM without vascular occlusion. Both groups presented similar gains in muscle hypertrophy even though training intensities were very different. These two studies demonstrated that low-intensity strength training combined with vascular occlusion produces similar muscle hypertrophy to that of high-intensity training without vascular occlusion.

There are at least two possible explanations for the difference between our results and previous ones. The first explanation is related to the duration of vascular occlusion and the second is related to the training intensity.

Most of the studies used vascular occlusion during both exercise and rest throughout the exercise session. However, our subjects reported a great degree of discomfort if occlusion was maintained during resting intervals, especially in the 6 RM group (even though no adverse effects were observed). This discomfort could be caused by the large width of our cuff, which completely occluded the blood flow (measured by the vascular doppler), compared with the cuff width used by others [18]. Thus, we decided to allow vascular reperfusion during rest. This decision may have equalized the metabolic overload, and the training load, between the non-occluded and the occluded conditions producing similar strength and hypertrophy gains.

It is possible that the effects of vascular occlusion are a normal response and a common aspect of the strength training stimulus. Due to the high degree of muscle tension produced during our training protocol, vascular occlusion may have been achieved by muscle tension itself. In this situation, the vascular occlusion produced by the cuff did not significantly alter blood flow to the limb. Accordingly, Sadamoto et al. [16] suggested that above ~50–60% of MVC, quadriceps blood flow is completely occluded. In the same way, Yamada et al. [25] emphasized that loads above 40 to 50% of the MVIC results in pressures greater than the systolic pressure occluding the blood flow. In fact, Wernbom et al. [24] observed no effect on knee extension endurance at an exercise intensity of 50% 1 RM. Therefore, our training

Table 2 Values for cross-sectional area (cm²) of quadriceps femoral muscle for groups HI and MI pre- and posttreatment

Groups	HI		MI	
	Occluded	Control	Occluded	Control
Pre	75.5 ± 9.5	75.1 ± 10.5	86.1 ± 14.5	86.6 ± 14.5
Post*	79.3 ± 12.3	79.7 ± 12.4	90.0 ± 17.9	89.4 ± 16.3

* Significant main effect for time ($p = 0.005$)

loads may have occluded the blood flow completely [6]. This would suggest that responses to vascular occlusion may be a constituent aspect of the high load strength training stimulus.

Muscle activation and endocrine response may explain the lack of effect of vascular occlusion at high training loads. Takarada et al. [20] reported similar electromyography (EMG) activity between a muscle contraction with 40% and 80% of 1 RM with vascular occlusion. In addition, at 40% of 1 RM with vascular occlusion, EMG values were greater than at 40% of 1 RM without vascular occlusion. The greater EMG activity was combined with an increase in blood lactate concentration, indicating a greater muscle metabolic demand. In addition, there is evidence that the rise in blood lactate and hydrogen ion concentration may also increase growth hormone release, enhancing muscle hypertrophy [8,9,19,20]. However, training loads greater than 50% of 1 RM could impose a very high demand to the muscle tissue changing its pH dramatically. This change in muscle pH may sensitize small diameter type III and IV afferents, which would eventually increase GH release [22]. It should be emphasized that this is speculative in light of the fact that we did not collect EMG data.

Strength gains and quadriceps hypertrophy increased without any correlation to vascular occlusion. Therefore, we conclude that vascular occlusion in combination with high-intensity strength training does not augment muscle strength or hypertrophy when compared to high-intensity strength training alone. This is in contrast to the effects of vascular occlusion on low-intensity strength training. Our data suggest that the stimulus from high-intensity strength training matches or exceeds any stimulus resulting from vascular occlusion. Indeed, the vascular occlusion that accompanies high tension contractions and the associated cellular signals may be an important aspect of high-intensity strength training. However, some caution should be exercised in interpreting our data. We had a relatively low number of subjects in our study and short duration of the training period. Furthermore, our results may not apply to multi-joint movements such as the squat and the leg press, which may require future studies to elucidate these effects.

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