The Use of Occlusion Training to Produce Muscle Hypertrophy

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SUMMARY

LOW-INTENSITY OCCLUSION (50–100 MM HG) TRAINING PROVIDES A UNIQUE BENEFICIAL TRAINING MODE FOR PROMOTING MUSCLE HYPERTROPHY. TRAINING AT INTENSITIES AS LOW AS 20% 1 REPETITION MAXIMUM WITH MODERATE VASCULAR OCCLUSION RESULTS IN MUSCLE HYPERTROPHY IN AS LITTLE AS 3 WEEKS. A TYPICAL EXERCISE PRESCRIPTION CALLS FOR 3 TO 5 SETS TO VOLITIONAL FATIGUE WITH SHORT REST PERIODS. THE METABOLIC BUILDUP CAUSES POSITIVE PHYSIOLOGIC REACTIONS, SPECIFICALLY A RISE IN GROWTH HORMONE THAT IS HIGHER THAN LEVELS FOUND WITH HIGHER INTENSITIES. OCCLUSION TRAINING IS APPLICABLE FOR THOSE WHO ARE UNABLE TO SUSTAIN HIGH LOADS DUE TO JOINT PAIN, POSTOPERATIVE PATIENTS, CARDIAC REHABILITATION, ATHLETES WHO ARE UNLOADING, AND ASTRONAUTS.

INTRODUCTION

The American College of Sports Medicine recommends lifting a resistance of at least 65% of one's 1 repetition maximum (1RM) for 6–12 repetitions to achieve muscle hypertrophy under normal conditions. It is believed that anything below this intensity rarely produces substantial muscle hypertrophy or strength gains (2). Occlusion training can provide a unique beneficial mode of exercise in the clinical setting because it produces positive training adaptations, at the equivalent to physical activity of daily life (10–30% of maximal work capacity) (1). Muscle hypertrophy has recently been shown to occur during exercise as low as 20% of 1RM with a moderate vascular occlusion (33). Low-intensity occlusion training has also been shown to be quite beneficial to athletes (35), patients in postoperative rehabilitation specifically anterior cruciate ligament (ACL) injuries, cardiac rehabilitation patients, and the elderly (34,37). Some research indicates that occlusion training might also be beneficial for astronauts in space (12).

Low-intensity occlusion training can benefit many in and out of the clinical setting. Occlusion training can be used by athletes to give them a break from all the stress associated with high-intensity resistance training. It could be an effective stimulus to use during an unloading phase for athletes because it results in a positive training adaptation, although causing little to no muscle damage (35). Many people are unable to withstand the high mechanical stress placed upon the joints during heavy resistance training, namely, the elderly. Low-intensity resistance training with occlusion may help decrease the risk of sarcopenia by allowing the elderly to train their musculoskeletal system while keeping the overall intensity very low. The purpose of this article will be to cover the cause and effect of occlusion training on a practical and physiological level and to further describe populations in which occlusion training is safe and appropriate (Table 1).

PHYSIOLOGY OF OCCLUSION TRAINING

Under normal conditions, slow-twitch fibers are recruited first, and as the intensity increases, fast-twitch fibers (FT) are recruited as needed. Under ischemic conditions, FT fibers are recruited even if the intensity is low (24). Aerobic motor units, which are normally recruited at light loads, would be expected to fatigue more rapidly during blood flow restriction. Exercise with occlusion requires the recruitment of the larger fast motor units, which are normally only recruited during stronger efforts (22). Integrated electromyography (iEMG) has shown that occlusion causes the activation of a sufficient number of FT fibers at these low intensities (35,38).

Madarame et al. (19) sought to determine whether occlusion training causes a crossover effect as is seen with regular (nonoccluded) resistance training. The subjects in both groups performed an unrestricted single arm bicep curl at 50% 1RM for 3 sets of 10. The rest between sets was 180 seconds to diminish the hormonal response to

KEY WORDS:
blood flow restriction; low intensity; resistance exercise; sarcopenia

Table 1
Effects of occlusion training

Marker	Effect (↔,↓,↑)	Reference
Mechanisms for muscle hypertrophy (human)		
Lactate	↑	(10,28,34,35,38)
Growth hormone (GH)	↑	(1,9,19,27,28,34,35,39)
Ribosomal S6 kinase 1 (S6K1)	↑	(9)
Norepinephrine (NE)	↑	(35)
Insulin growth factor-1 (IGF-1)	↑	(34)
Noradrenaline (NA)	↑	(12,19)
Muscle-specific ring finger 1 (MuRF1)	↑	(7)
Myogenic differentiation 1 (MyoD)	↑	(7)
Cyclin-dependent kinase inhibitor 1A (p21)	↑	(7)
Eukaryotic translation elongation factor 2 (eEF2)	↑	(9)
Myostatin (GDF-8)	↓	(7)
Measures of strength and muscle (human)		
One repetition maximum	↑	(1,19,23)
Isometric strength	↑	(1,23,32,36,39)
Isokinetic strength	↑	(5,33,36,38,39)
Isometric torque	↑	(19,23,32)
Isokinetic torque	↑	(34,38,39)
Muscular endurance	↑	(13,33,36)
Postactivation potentiation	↑	(23)
iEMG	↑	(23,35,38)
Cross-sectional area (CSA)	↑	(1,19,36,38,39)
Effects of chronic occlusion in rats		
Heat shock protein 72 (HSP 72)	↑	(14)
Nitric oxide synthase-1 (NOS-1)	↑	(14)
Lactate	↑	(15,14)
Cross-sectional area (CSA)	↑	(15,14)
Myostatin (GDF-8)	↓	(15)
Fiber-type switch	Slow→fast	(15)
Markers for muscle damage		
Creatine kinase	↔	(35)
Lipid peroxide	↔	(35)
Myoglobin	↔	(1)

exercise. After the arm curl, both groups performed a knee extension and knee flexion exercise, with one group performing the exercises with and the other without blood flow restriction. They found that resistance exercise with occlusion for leg muscles caused increases in the size and strength of arm muscles that had undergone normal resistance training, even though the intensity was much lower than that, which would cause muscle hypertrophy under normal conditions. The authors also found that occlusion exercise for leg muscles did not cause any changes in untrained arm muscle, which they suggested could be attributed to any systemic factors (growth hormone [GH] and noradrenaline) released after the occlusive exercise. These factors might be involved in this cross-transfer effect, but local exercise stimulus, even at low intensity, is absolutely necessary for muscle hypertrophy.

Physiologically, occlusion training results in several changes to the body in both human and animal models. Metabolic by-product accumulation seems to be the primary mechanism behind the benefits seen with occlusion training. Whole blood lactate (10,34), plasma lactate (9,28,34,38), and muscle cell lactate (15,14) accumulation due to the blood flow restriction results in increased GH. This is significant because GH has shown to be stimulated by an acidic intramuscular environment (38). Evidence indicates that a low pH stimulates sympathetic nerve activity through a chemoreceptive reflex mediated by intramuscular metaboreceptors and group III and IV afferent fibers (41). Consequently, the same pathway has recently been shown to play an important role in the regulation of hypophyseal secretion of GH (11,41). One study showed an increase in GH approximately 290 times greater than baseline measurements (35). This increase in GH levels is higher than what is typically seen with regular resistance training (18,17). Heat shock protein 72 (HSP 72), nitric oxide synthase-1 (NOS-1), and myostatin seem to also contribute to the increase in muscle cross-sectional area (CSA) (3,14,21,20,25,31,40). Kawada and Ishii (15) found that 2 weeks of chronic occlusion in rats caused a fiber-type shift from slow to fast. They attributed this to the additional recruitment of large motor units and their associated type II fibers at the expense of rapid fatigue in slow oxidative fibers during blood flow restriction.

HSP 72 levels have been shown to be increased in response to occlusion training (14). HSP 72 is induced by such stressors as heat, ischemia, hypoxia, and free radicals. HSP 72 acts as a chaperone to prevent misfolding or aggregation of proteins. An increase in HSP 72 content has been shown to attenuate atrophy so that it may play a role in occlusion-induced muscle hypertrophy (25). Increased expression of NOS-1 has also been shown to stimulate muscle growth through increased satellite cell activation (3,40). Myostatin is a negative regulator of muscle, and mutations of this gene result in overgrowth of musculature in mice, cattle, and humans (21,20,31). Myostatin gene expression is significantly decreased in response to occlusion training (14).

Fujita et al. (9) have shown that low-intensity resistance training increases ribosomal S6 kinase 1 (S6K1) phosphorylation and muscle protein synthesis. They suggest that enhanced mammalian target of rapamycin (mTOR) signaling may be another important cellular mechanism that may in part explain the hypertrophy induced by low-intensity occlusion training. S6K1 is involved in the regulation of messenger RNA (mRNA) translation initiation and seems to be a critical regulator of exercise-induced muscle protein synthesis and training-induced hypertrophy (4,29). Signaling to S6K1 also inhibits eukaryotic translation elongation factor 2 (eEF2) kinase, which reduces eEF2 phosphorylation and thus promotes translation elongation (42).

A follow-up study showed that REDD1 (regulated in development and DNA damage responses 1), which is normally expressed in states of hypoxia, is not increased in response to occlusion training even though hypoxia-inducible factor-1 alpha (HIF-1α) is elevated. A reduced REDD1 mRNA expression may prove to be important because a reduction in REDD1 would relieve inhibition on mTOR, promoting a stimulation of mTOR signaling, mRNA translation, and muscle cell growth (7). Possible explanations for the increase in HIF-1α without the increase in REDD1 might be that there is another unknown factor that influences the transcription of REDD1, so although HIF-1α may upregulate REDD1, another factor that is increased to a greater extent by exercise may result in downregulation of HIF-1α, resulting in a net decrease in REDD1. There might also be a factor that inhibits or stimulates HIF-1α effects on REDD1 expression, so even though HIF-1α expression is higher, its activity is not. Also, occlusion training itself may increase HIF-1α but then reperfusion after exercise may inhibit its action.

STUDIES DEMONSTRATING THE EFFICACY OF OCCLUSION TRAINING

Although there have been numerous studies of occlusion training, the 3 described below clearly identify the benefits and the mechanisms involved. Kawada and Ishii sought to investigate the effects of occlusion on muscular size at either the cellular or subcellular level on a rat model. Veins from the rat's hind leg were occluded followed by 14 days of normal cage time. At the conclusions of the experimental period, fiber CSA increased 34% in the occluded group compared with the control. HSP 72 and NOS-1 were both significantly elevated above control, whereas myostatin was significantly decreased. They found no change in insulin growth factor-1 (IGF-1), which they suggest could mean that IGF-1 may not always be essential for muscle hypertrophy if HSP 72, NOS-1, and myostatin change in favor of muscular growth (14). Abe et al. (1) have also suggested that IGF-1 may not be increased with occlusion training due to the low intensity of the exercise.

Abe et al. (1) wanted to determine the acute and chronic effects daily physical

activity combined with vascular occlusion would have on muscle size, maximum dynamic and isometric strength, and blood hormonal parameters. Acutely, they compared the effects of a single bout of walking with and without occlusion on 11 healthy untrained men (n = 6 for occlusion and n = 5 for control). For the chronic study, they compared the effects of walking with and without occlusion on 18 healthy untrained men (n = 9 for occlusion and n = 9 for control). The subjects walked on a treadmill 6 d/wk for 3 weeks using 5 sets of 2-minute bouts at 50 m/min, with a 1-minute rest between bouts with occlusion and without occlusion. Occlusion training increased thigh muscle CSA and volume in just 3 weeks with occluded walking. The estimated muscle–bone CSA continually increased in the occluded group, and the resultant increase was constant throughout the training period, increasing by approximately 2% per week. Isometric strength of the knee extensors was also increased in the occluded group. Blood markers of muscle damage were unchanged as measured by creatine phosphokinase and myoglobin. Although there was no change in IGF-1 and cortisol, GH increased immediately after and 15 minutes post exercise compared with the control (1).

Occlusion has been shown to cause an increase in GH (1,9,19,27,28,34,35,39). However, Takarada et al. (35) showed the largest rapid increase when they investigated the hormonal and inflammatory responses to low-intensity resistance exercise with vascular occlusion in male athletes. Subjects performed bilateral leg extension exercise occluded. They found an increase in whole blood lactate that was twice as large as the control group, which was likely caused by local hypoxia and the suppression of lactate clearance within the muscle subjected to the occlusion. Norepinephrine (NE) was also elevated in the occluded group, and the time course of changes in concentrations of both NE and GH seemed to be closely similar to that of lactate. The concentration of GH was approximately 290 times as high as that before exercise (35). This magnitude of increase in GH concentration was larger by a factor of approximately 1.7 than that previously reported for high-intensity resistance exercise with a short rest period, indicating that the exercise with occlusion can provoke strong endocrine responses even at an extremely low intensity (18,17).

There were no changes in creatine kinase or lipid peroxide levels between groups, which suggested that no serious muscle damage occurred. They did find that the concentration of interleukin-6 (IL-6) gradually increased but was only slightly higher than in control (35). They thought that the slight elevation could mean microdamage, but IL-6 has been shown previously to increase with the contraction of a muscle (8,26). IL-6 concentration measured 90 minutes after exercise was still less than one fourth of that reported for eccentric exercise. iEMG activity was significantly higher in the occluded group compared with control, and this elevated activation level of the muscle at a low level of force generation may be related to a hypoxic intramuscular environment, in which motor units of more glycolytic fibers are to be activated to keep the same level of force generation. The authors concluded that an extremely light resistance exercise combined with occlusion greatly stimulates the secretion of GH through regional accumulation of metabolites without considerable tissue damage (35).

OCCLUSION EXERCISE PRESCRIPTION

Occlusion training was originally developed in Japan where it is better known as KAATSU training (30). The occlusion training system seems most effective when used with the lower limbs due to the large muscle groups. The biceps brachii are much smaller in CSA than the quadriceps, and the metabolic stress induced by partial vascular occlusion would be less widespread and might potentially attenuate some of the lactate responses to muscular work (28). Although not as effective, Takarada et al. have demonstrated that low-intensity occlusion training can also provide benefits in the upper body as well (38). Occlusion can occur from using a KAATSU apparatus or more practically through elastic knee wraps. Elastic knee wraps can be wrapped around the proximal part of the target muscle (Figures 1–4). The pressure can be relatively low as Sumide et al. (33) have showed beneficial effects occurring at levels as

Figure 1. How to begin the occlusion for the knee extensors.

Figure 2. Completion of the practical occlusion.

low as 50 mm Hg, although most will use a pressure of 100 mm Hg because it is a sufficient stimulus to restrict venous blood flow, which causes pooling of blood in capacitance vessels distal to the cuff, ultimately restricting arterial blood flow (23).

A typical low-intensity prescription would involve an intensity of 20–50% of 1RM with a 2-second cadence for both the concentric and eccentric actions. The 1RM is calculated from the maximum amount of weight you can lift once under normal blood flow conditions. Three to five sets of each exercise are completed to volitional fatigue. This is done to ensure that there is a high metabolic buildup. The rest periods are 30 seconds to 1 minute in length and occur between every set, with the occlusion still being applied (5,6,27,35,36,39). At the conclusion of the last set, blood flow is restored to the muscle. Cook et al. (6) compared different protocols of occlusion using percent maximal voluntary contraction (%MVC) and found that 20% MVC with continuous partial occlusion was the only protocol that elicited significantly more fatigue than the higher intensity protocol.

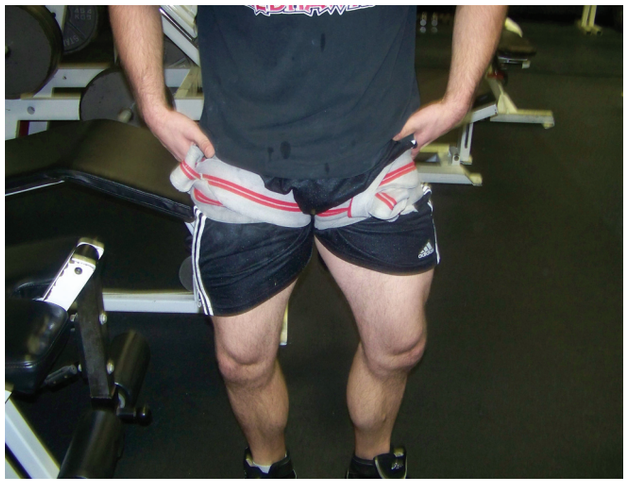

Figure 3. The practical occlusion after wrapping.

APPLICABLE POPULATIONS

Patients who are injured, specifically ACL injuries, have been shown to benefit from an occlusive stimulus. With knee surgery, suppressing the disuse atrophy of thigh muscles has been regarded as important because the rehabilitation usually takes a prolonged period to regain the original muscular strength. Takarada et al. (37) showed that when an occlusion was present even without an exercise stimulus, it was effective in diminishing the disuse atrophy of knee extensors 3 days after surgical operation. Because occlusion training allows individuals to train at much lower intensities with the benefits of higher intensity training, it may be highly useful for other postoperative populations and for improving muscular function in the bedridden older population.

Low-intensity occlusion training may also be useful in the cardiac rehabilitation setting because occlusion has been shown to significantly stimulate the exercise-induced GH, IGF, and vascular endothelial growth factor responses with the reduction of cardiac preload during exercise (34). GH and IGF-1 have been established as regulators of cardiac growth, structure, and function, and GH has been applied for treatment of congestive heart failure (16). In a study by Takano et al. (34), low-intensity exercise with occlusion induced significant exercise-induced GH responses as compared with exercises at the same intensity without occlusion. Further research should be done with occlusion in this setting, but it does appear promising.

Astronauts are also a unique population that could benefit from occlusion training. During spaceflight, several health concerns arise due to the changes in cardiovascular function that occur due to weightlessness. When gravitational hydrostatic gradients are abolished, there is a shift of intravascular fluid from the capacitance vessels of the legs and lower body centrally toward the head. Elevations of capillary blood pressure and increased capillary perfusion pressure in tissues of the head have been shown to cause facial intracranial

Figure 4. Practical occlusion for the knee extensors.

edema and headache. After spaceflights, regardless of the duration, almost every astronaut experiences orthostatic hypotension and reduced upright exercise capacity, which is likely attributed to the microgravity-induced hypovolemia, decreased baroreflex responsiveness, decreased skeletal muscle tone, and increased venous compliance. Iida et al. (12) showed that when occlusion was applied on both thighs in supine subjects, it induced the hemodynamic, hormonal, and autonomic alterations that were very similar to standing. They conclude that occlusion training may be a promising and safe method to counter symptoms of orthostatic intolerance and muscle atrophy in astronauts.

CONCLUSIONS

In conclusion, low-intensity occlusion training offers a unique beneficial training mode for promoting muscle hypertrophy. Training at intensities of 20% 1RM and receiving the equivalent benefit of training at 65% 1RM have positive implications for a variety of populations, particularly the elderly who physically cannot handle high mechanical loads (33). This is also unique because studies are showing hypertrophy in as little as 3 weeks with GH increases of 290 times over baseline (35).

Future research on occlusion training should focus on studying the health risks associated with long-term use and determine populations in which this type of training may be contraindicated (6). Although the research has yet to define populations in which occlusion training is dangerous, we postulate that those with endothelial dysfunction should not use occlusion training because of the reduction in blood flow. Research should also further study the microdamage to blood vessels and subtle changes in blood flow, both of which may stimulate thrombosis (38). Also, one should seek to evaluate the gene expression at later stages of postexercise recovery after occlusion and in response to occlusion training (7). Finally, studies should begin to focus on the local regulators of muscular growth, such as growth factors and reactive oxygen species, to elucidate the mechanism for the present cooperative effects of exercise and occlusive stimuli (39).

PRACTICAL APPLICATION

Low-intensity occlusion training provides a unique beneficial training mode for several different populations. Research has shown us that moderate vascular occlusion causes numerous positive physiologic adaptations at loads as low as 10–30% of maximal work capacity (1). Typically, 3 to 5 sets to volitional fatigue with 30-second to 1-minute rest between sets (5,6,27,35, 36,39). Occlusion can be applied with a KAATSU apparatus or more practically through elastic knee wraps. The pressure only needs to be high enough to block venous return (~50–100 mm Hg) (23,33). Occlusion training can be applied to athletes; patients in postoperative rehabilitation, specifically ACL injuries; cardiac rehabilitation patients; the elderly; and even astronauts to combat atrophy and when applied with exercise to induce muscle hypertrophy (12,34,35,37).

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