VASCULAR OCCLUSION STRENGTH TRAINING: AN ALTERNATIVE TO HIGH RESISTANCE STRENGTH TRAINING.

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ABSTRACT

Traditional high-load resistance strength training induces hypertrophy of skeletal muscle and increases maximal strength, whilst low-load resistance training protocols typically induces local muscular endurance without any significant increase in hypertrophy or strength. However, recent evidence suggests that when low-load resistance strength training protocols are combined with vascular occlusion, the muscle hypertrophy and strength response is similar to or even greater than traditional high-load resistance exercise. Vascular occlusion is a technique that involves reducing blood flow to muscle during exercise training via an inflated compressive cuff or tourniquet. While the mechanisms that result in muscular adaptations are relatively unknown, acute responses to training such as an increase in motor unit recruitment, in particular the preferential recruitment of type II fibres, and the increase in circulating human growth hormone, have been well characterised.

This type of training would be suitable to a host of common pathologies where heavy resistance strength training is not possible such as the elderly, patients in early rehabilitation following injury, or where muscle atrophy and weakness occur due to the effects of inactivity or disease. For athletes, rapid increases in strength while training at such low intensities may be of interest, however, research in this population is limited.

KEY WORDS - Strength, Muscle Hypertrophy, Rehabilitation, KAATSU Training, Ischemia.

INTRODUCTION

It is well known that resistance training induces hypertrophy of skeletal muscle and increases maximal strength. The American College of Sports Medicine (ACSM) suggest that in order to maximise hypertrophy and gain strength, a training program should utilize high-load resistance exercises (1). High resistance (or heavy-load) strength training (HRST) programs typically utilise contractile loads greater than 65% of one repetition maximum (1 RM), 3-6 sets per session, and a training frequency of 3-5 days per week (2). In comparison, when a high number of repetitions (15-20 or more) are performed during low-load resistance strength training (LRST) using loads less than 60% 1 RM, the primary adaptation to training is an increase in local muscular endurance without any considerable increase in muscle strength and/or hypertrophy (1). However, recent evidence suggests that when LRST is combined with vascular occlusion (LVO) that strength and hypertrophy increase similarly or to an even greater extent than traditional HRST (3-5). LVO is a form of strength training that was popularized in Japan by Yoshiaki Sato in the 1980’s, where it is commonly known as KAATSU training (Figure 1) (6). LVO involves placing a pneumatic cuff around the proximal portion of a limb, which is inflated during exercise to a pressure that is at a minimum greater than diastolic blood pressure (i.e. >80 mmHg) and may be up to ~300 mmHg (7, 8). Figure 1 provides web links to information about KAATSU equipment and use during exercise. To apply occlusion a KAATSU apparatus may be used which allows for greater control of the occlusion pressure. However, elastic wraps or tourniquets may be more practical for coaches and athletes. LVO involves performing three sets of 15 or more repetitions using loads that range from 10-50% 1 RM. While LVO is most often used during isolation exercises of the upper (e.g. bicep curl; Figure 1) or lower-limbs (e.g. knee extension), vascular occlusion can also be used during whole body dynamic movements such as walking (2-4) or full-body circuit training (5). However, occlusion is typically only sustained for a short period of time (<15 min) as the relative safety of chronic occlusion is unknown and may result in some form of deleterious effects (e.g. damage to blood vessels). Therefore, LVO is likely to be more suited to shorter duration resistance strength training than prolonged duration dynamic exercise.
Figure 1 - Links to information from static web pages showing images of KAATSU equipment and use during exercise. * In this video the subject completes 4 sets of dumbbell bicep curl exercises (65 reps; 15 seconds rest between sets). Note the KAATSU Master apparatus connected to the pressure cuffs positioned around the most proximal part of the upper arm. Towards the end of the bout, note the colour change between the shoulder and the arm (appears more red in colour) indicating the restricted blood flow from the applied occlusion. All web links accessed on 24/7/2011.

The physiological mechanisms responsible for the subsequent gain in strength and hypertrophy following LVO remain speculative. In addition, it would seem that the adaptations that occur with LVO are not caused by one single phenomenon, but rather a combination of neural, endocrine, and metabolic factors (13). Therefore, it has been suggested that an acute alteration of motor unit recruitment (4, 5, 14) and the release of human growth hormone (hGH) (15-17) are of primary importance given that these contribute to the gain in strength and hypertrophy seen following traditional HRST.

A better understanding of LVO may have important implications for athletes that require rapid gains in strength and hypertrophy, or for populations that have limited strength-training capacities such as the elderly, patients in early rehabilitation following injury, or where muscle atrophy and weakness occur due to the effects of inactivity or disease. Therefore, to induce strength and hypertrophy without injury, training modalities that promote these two adaptations to resistance training without the use of high-loads should be of special interest.

This review will focus on the acute responses to LVO, and the adaptations to strength and hypertrophy over short training periods. In addition, the modifiable characteristics of LVO will be reviewed, as these are likely contributors to forming prescription guidelines. Finally, a discussion of future practical applications of LVO will be presented.

TRAINING RESPONSES

It is generally accepted that the initial increase in strength that occurs during the first 3 to 5 weeks of HRST is driven by altered motor unit recruitment patterns, that are not accompanied by a proportional increase in hypertrophy (18). For example Goto et al. (19) showed that 6 weeks of HRST (leg press and leg extension training) increased maximum strength by 9-15%, but hypertrophy by only 4% (measured by quadriceps cross sectional area [CSA]). However, when HRST is conducted over more prolonged periods (>8 weeks) the further gain in strength is then driven more by morphological adaptations, such as hypertrophy, with little further adaptation to motor recruitment. This was shown by Takarada et al. (5) following 16 weeks of HRST where bicep curl strength increased by 23% and was similar to the degree of hypertrophy of biceps brachii (18%).

While HRST is typically recommended to bring about the greatest increase in maximal strength and hypertrophy, recent evidence suggests that LVO may result in similar gains, and that these gains may be evident within an earlier timeframe. The study by Takarada et al. (6) also examined a LVO group that trained twice per week over the 16 week period. Subjects performed a dumbbell bicep curl exercise at ~40% 1 RM for three sets to volitional fatigue separated by a 1 minute recovery period. The mean occlusion pressure during exercise was 110 mmHg and was applied for approximately 5 minutes and then immediately released upon completion of exercise. Following LVO training strength and hypertrophy increased to a similar extent to the HRST group (18% and 20%, respectively). Although this longer training period demonstrates that the increase in strength and hypertrophy are similar between HRST and LVO, over shorter timeframes LVO has been shown to induce hypertrophy within the initial 3-5 week training period that is typically expected to be brought about by altered motor recruitment patterns with little hypertrophy. In one study,
subjects completed LVO for 2 weeks that resulted in a 17% increase in mean fibre CSA (20). In comparison, Campos et al. (21) had subjects participate in HRST that induced a similar increase in CSA (19%) but over a longer training period (8 weeks). While this study only evaluated hypertrophy at the beginning and end of training, Abe et al. (22) monitored hypertrophy every 2 weeks over a 12 week HRST period and observed a gradual increase in both upper- and lower-body hypertrophy. However, this increase was only significantly elevated from baseline at 6 weeks. In contrast, LVO has been shown to induce a significant increase in hypertrophy even after one week of training (23, 24).

While significantly different loads are utilised between HRST and LVO, both achieve similar gains in strength and hypertrophy. This suggests that the adaptations following LVO may be partly driven by the higher training volumes (sets x reps). A typical LVO program may involve up to 75 repetitions or possibly more, whereas the 3–6 sets of up to 8 repetitions recommended during HRST will result in only 48 repetitions being performed. However, when matched for the same volume and intensity of training, LVO has been shown to be a superior method for increasing strength and hypertrophy when compared to LRST without occlusion, and indicates that the occlusion stimulus is required for the muscular adaptations observed, rather than being a direct result of the higher training volumes with reduced loads. Yasuda et al. (25) had subjects complete four sets of 30% 1 RM bench press exercise for a total of 75 repetitions while either non-occluded, or elastic cuffs inflated to 160 mmHg placed at the most proximal area on both arms above the bicep. No change in strength or hypertrophy occurred in the control group following 2 weeks of training. However, LVO increased 1 RM strength by 6%, while hypertrophy of the triceps brachii and pectoralis major increased by 8% and 16%, respectively (25). In another study, LVO increased quadriceps strength (14%) and hypertrophy (15%) that were significantly greater than LRST without occlusion (3.2% for strength; data not shown for CSA) (26).

From these studies described above, it appears clear that LRST combined with occlusion can induce similar muscle adaptations to HRST yet with significantly reduced loads, and that these adaptations become apparent within a significantly reduced time course. As such, this challenges the notion that high-load resistance exercises are required in order to elicit maximal gains in strength and hypertrophy. In addition, the applied occlusion appears to be a necessary stimulus for muscle adaptations during LVO, and therefore, suggests that the altered intramuscular environment within the active muscle during training provides the initial physiological response that ultimately enhances muscle adaptation at these low loads.

MECHANISMS OF OCCLUSION TRAINING

While the exact mechanisms for the gains in strength and hypertrophy following LVO remain speculative, it has been suggested that similar mechanisms to those responsible for the gains observed with HRST are likely contributors. As such, the gains in strength and hypertrophy following LVO are expected to be due to ‘normal’ mechanisms of cell growth and protein synthesis in response to the repeated training and occlusion stimuli (i.e. hypoxia or accumulation of metabolic by-products). Current evidence suggest that acute responses associated with LVO, such as a higher degree of type II muscle fibre recruitment and stimulation of hGH secretion are the most likely responses that contribute to increasing strength and hypertrophy, and are therefore reviewed in more detail below.

Acute responses associated with occlusion training

Human muscle is comprised of fibres of different type (generally categorized as type I, IIa, and IIx). However, single motor units are comprised of fibres of identical type. The most generally accepted physiological classification for motor units are, (a) small, slow contracting, fatigue resistant motor units (comprising type I fibres); (b) intermediate sized, fast contracting, fatigue resistant motor units (comprising type IIa fibres); and (c) large, fast contracting, rapidly fatigable motor units (comprising type IIx fibres). Under normal exercise conditions Hennemans’ size principle dictates that motor units are recruited from smallest to largest as contractile force increases. Therefore, small motor units that have slow contractile times (i.e. time to peak force), produce a relatively small amount of tension, and have a greater resistance to fatigue are recruited earlier to satisfy the initial low-level contractile demand. As exercise intensity increases, intermediate sized motor units that comprise fast-twitch (type IIa) fibres, produce moderate tension, and are vulnerable to fatigue are recruited next. When these pool of motor units are all fully recruited but can no longer satisfy the contractile demand larger motor units that comprise type IIx fibres are then recruited. Type IIx fibres are fast-twitch, develop large tension, are highly fatigable, and are recruited to satisfy this higher contractile demand. As such, it is traditionally expected that only with HRST can significant numbers of larger motor units be recruited, and therefore, HRST is required to induce the greatest increases in whole muscle strength and hypertrophy given that type II muscle fibres have the greatest capacity for adaptation to increase strength and hypertrophy.
However, during LVO where muscle is subjected to potentially hypoxic/ischemic conditions, as a result of the blood flow restriction with vascular occlusion, it would seem that Hennemans’ size principle no longer governs recruitment. Instead, much earlier or preferential recruitment of larger motor units (and type IIa and IIX muscle fibres) has been shown to occur despite a low-intensity of contraction (14). The reason for this is not known but has been suggested to be related to the large oxygen requirement of small motor units being unable to be satisfied during LVO, which therefore, results in much earlier supplemental recruitment of larger motor units that are more capable of anaerobic/glycolytic metabolism (14). Previous studies using integrated electromyography (iEMG) have investigated changes in electrical activity during muscular contractions with occlusion, which may reflect changes in motor unit recruitment and firing frequency. In the study by Takarada et al. (5) LVO (~40% 1 RM; 110 mmHg) and HRST (80% 1 RM) showed similar iEMG activity during single arm curl exercises despite the significantly different loads between each group. However, when the effects of LVO were compared to exercise at the same intensity without occlusion it was observed that the level of iEMG activity gradually increased across 4 sets of exercise in both groups but was significantly higher in the LVO group suggesting greater motor unit recruitment across the set (27). Further evidence to support the effect of altered recruitment during LVO is supplied in one study where it was reported that following 2 weeks of LVO type II fibre size increased by 25% (20). While there is an obvious need to investigate the direct changes in motor unit control patterns during training, these data suggest that the combination of low oxygen and fatigue during LVO may affect both the recruitment pattern of motor units and their firing frequency (4). This not only allows for the muscle to maintain a given level of force, but is also one of the factors that promote increases in strength and hypertrophy.

Acute changes in anabolic hormones such as hGH following HRST have been suggested to be important for skeletal muscle growth (28) given that hGH provides an acute stimulus for muscle protein synthesis (29). During HRST the high forces of contraction effectively occludes blood flow to active muscle, which is then released during relaxation. As a result, the muscle environment is often hypoxic, but also metabolites such as lactate accumulate to create an acidic intramuscular environment. This is important because the release of hGH may be stimulated by an increase in lactate and changes in acid-base balance (29). The release of hGH was thought only to be associated with HRST given that the high-intensity and volume of the exercise is thought necessary for release (30), and that limited release of hGH is observed following sub-maximal loading (31, 32). However, recent evidence suggests that LVO also increases circulating hGH following exercise (15-17) that is typically higher than the increase seen following traditional HRST (28, 31, 33). For example, LVO (four sets of leg extension to volitional fatigue) at 20% 1 RM increased hGH approximately 100 times above baseline values (15). Similarly, five sets of knee extension exercise with occlusion at 20% 1 RM to volitional fatigue increased hGH 290 fold above resting levels (17). This increase in hGH was 1.7 times greater than a typical HRST program (28), indicating that LVO can produce strong endocrine responses even at low intensities.

The acute and chronic responses to LVO are summarised in Figure 2. These acute responses to LVO such as a higher degree of type IIa and IIX muscle fibre recruitment and stimulation of hGH secretion are somewhat well characterised, in addition to the chronic adaptations of hypertrophy and increased strength. However, these chronic adaptations are a result of the persistent and/or repeated activation of subsequent downstream molecular pathways within muscle that ultimately result in elevated protein synthesis. These molecular pathways are comparatively less well understood, and for LVO further investigation of these mechanisms and their components is needed. These include more extensive examination of insulin-like growth factor 1 (IGF-1) secretion (15), production of reactive oxygen species (ROS), nitric oxide and heat shock protein-72 (HSP-72) (34), activation of the rapamycin (mTOR) pathway (35), and muscle myostatin gene expression (34). Even though no relationship between LVO-induced muscle growth and these intracellular targets has been established, it is unlikely that the gains in strength and hypertrophy are caused by one single mechanism, but more likely depend on a number of local and systemic growth factors that work together to result in a net gain in muscle protein synthesis and cell growth. These are not a focus of this review.
APPLICABLE POPULATIONS

In Japan LVO is common in sports and exercise including; combat sports, marathon, bodybuilding, aerobics, swimming, boxing, and in team sports such as rugby, soccer, and basketball (36). Recent evidence suggests that this method of training is gaining awareness on a global scale. While published LVO studies support its effectiveness at increasing muscle strength and size in untrained adult populations, to date, only two studies have investigated the effects of LVO on exercise performance in athletic populations (8, 9). In a study by Abe et al. (8) college track and field athletes (sprinters and jumpers) combined their regular sprint/jump training with LVO which consisted of twice daily squat and leg curl exercises for 8 consecutive days (20% 1 RM, 3 sets of 15 repetitions, 30 second rest periods between sets). A specially designed elastic cuff was placed around the proximal portion of both thighs and inflated to a maximum pressure of ~240 mmHg. The restriction of blood flow was maintained throughout the exercise session including rest periods and then released immediately upon completion of the session (approximately 15 minutes). Following training, muscle CSA and strength increased by 4.5% and 10%, respectively, which is consistent with previously published data for untrained populations. The hypertrophy and strength gains induced by LVO resulted in an improved 30 metre sprint time, in particular over the first 10 metres. But LVO was not sufficient to improve jumping performance. In another study, elite rugby players trained twice per week for eight weeks (9). Training consisted of four sets of knee extension exercise at 50% 1 RM to volitional fatigue (each set was separated by 30 seconds rest). Occlusion was applied in a similar manner to that of Abe et al. (8) (described above), with a mean occlusion pressure of ~200 mmHg throughout the training period which lasted approximately 10 minutes. Isokinetic strength (14%), quadriceps CSA (12%) and muscle endurance (50 repeated contractions) increased following training, whereas no significant changes were observed in LRST without occlusion.

It seems LVO may be a more efficient training method compared with traditional HRST that is currently the prescription of choice, with additional benefits such as a more rapid increase in strength and hypertrophy while avoiding overtraining due to the low-loads and minimal muscle damage. However, future research should attempt to measure the benefits of LVO in athletes and the effects on exercise performance, as this data is limited.

Another factor important for athletic performance is recovery from injury in order to return to training as quickly as possible, without compromising safety. While the majority of vascular occlusion studies have been conducted in healthy populations, Takarada et al. (38) evaluated the effects of occlusion (without training) for reducing the loss of muscle mass and strength following ACL reconstruction. Sessions were conducted twice daily for 12 days and consisted of five repetitions of vascular occlusion for 5 minutes separated by 3 minutes to allow for reperfusion. While the injured knee was kept immobilized via a knee brace, a pneumatic occlusion cuff was applied to the proximal portion of the thigh (100 mm below the hip joint) of the injured leg at a mean maximal pressure of 238 ± 8 mmHg. The decrease in CSA of the knee extensors and flexors without occlusion was 20.7% and 11.3%, respectively, which was...
significantly larger than the 9.4% and 9.2% observed in the occlusion group (38). Even when much lower occlusion pressures have been used (50 mmHg), a mild preventative effect on muscle atrophy and weakness is observed (39). Based on these findings, occlusion alone may reduce atrophy associated with inactivity or when combined with LRST may rapidly increase hypertrophy and strength in trained populations.

While LVO may have important and useful implications for healthy, trained individuals, and also for rehabilitation from musculoskeletal injuries, populations with limited strength-training capacities such as the elderly may also benefit. In elderly populations, the ability to improve muscular strength is important to maintain and/or improve quality of life. However, HRST poses a risk to health given the greater susceptibility to injury in this population, especially when typically sedentary (40). Recent evidence suggests that occlusion training is effective in improving muscle strength and functional ability tests, and in preventing sarcopenia (5, 11). In one study, women aged 47-67 completed LVO consisting of bicep curl exercise twice a week for 16 weeks. Bicep CSA and strength increased to the same extent as those that completed HRST, whereas no change was found following LRST without occlusion (5). Alternatively, Abe et al. (11) had participants aged 60-78 perform low intensity walk training five times a week for six weeks. Isometric (12%) and isokinetic (7-16%) strength, leg muscle size (5.8%), as well as performance in functional ability tests increased significantly in the occlusion group only.

Although there is evidence to suggest that occlusion alone, or when combined with LRST can be a more effective and beneficial method to promote strength and hypertrophy for the above populations, it is quite conceivable that LVO would also benefit clinical populations that have limited strength training capacities such as conditions that affect the functional capacity of skeletal muscle (i.e. cardiomyopathies, diabetes and certain neuromuscular conditions).

**EXERCISE PRESCRIPTION**

The development of one or more typical LVO protocols is necessary given that low-intensity exercise is most often prescribed for populations that are primarily sedentary, or where exercise has important implications such as in clinical populations, and will be discussed (see Practical Application). Despite some years of research, no critical analysis has been performed on the available literature, or through systematic research studies to determine the most appropriate protocols for LVO. Therefore, below is a review of literature that may contribute to forming prescription guidelines for LVO by providing support for the greatest benefit to strength and hypertrophy, while avoiding potential safety risks when using LVO that are particularly pertinent to clinical or primarily sedentary populations.

**Occlusion variables**

To initially apply the occlusion pressure, it may be common practice to set the pressure to the approximate mean blood pressure of the participant. Prior to exercise a ‘warm up’ occlusion process that is thought to stimulate peripheral and central circulation of the blood takes place. To do this, an initial low-level occlusion pressure is selected for 30 seconds then released. Following this, pressure is increased by 10-20 mmHg and held for 30 seconds before being released by 10 seconds between occlusive stimulations. This process is continued until the final selected occlusion pressure is set for each day. The final occlusion pressure applied to the limbs during LVO is generally higher than resting systolic blood pressure (up to 150 mmHg) (3, 15, 26, 27, 37, 41). However, low-level occlusion (50 mmHg) that may allow for some circulatory inflow to exercising muscle has also been used (5, 12, 41, 42). Alternatively, supramaximal occlusion pressures (200-300 mmHg) have also been used, which are likely to fully restrict muscle blood flow given that such pressures are greater than typical systolic pressures and/or mean arterial pressures observed during heavy exercise (8, 11, 16, 20). However, the relative safety of these high pressures is unknown and are important to understand more fully. One particular study compared the effect of different occlusion pressures during LRST over 8 weeks (41). Subjects were randomly allocated to occlusion pressures of either 50 mmHg (below resting diastolic pressure), 150 mmHg (above resting systolic pressure) or with a supramaximal occlusion pressure of 250 mmHg. Following training, each group showed a similar significant increase in strength. However, of note though, subjects in the supramaximal occlusion group complained of discomfort and numbness in their legs during the occlusion training, which should be of particular interest when considering implementing occlusion training (41).

The duration of application of occlusion used previously is also quite variable. The continuous application of the occlusion pressure throughout an entire set of exercises/contractions appears to be more common (5, 8, 12, 15, 20, 26, 41), however, pressure applied intermittently during each set has also been used, and this likely allows some reperfusion of muscle between sets (3, 8, 14, 16). Typically, the occlusion stimulus is only sustained for a short period (<15 min) due to the nature of the strength training exercise.
Intensity and volume of training
Intensity or load is generally regarded as the most important variable in the prescription of strength training. Typically, the intensity of the exercise in LVO studies has ranged from 20-50% 1 RM. During HRST, the high degree of muscle tension that is produced effectively occludes blood flow to the exercising limb. As such, no beneficial adaptations to strength and hypertrophy are seen when HRST is combined with occlusion compared to HRST alone (3).

During LVO, three to five sets of each exercise are completed to volitional fatigue, with rest periods between sets as short as 30 seconds, and no longer than 1 minute in length (43). Also, because training at such low intensities produces minimal muscle damage and less recovery time is needed (20), it is not uncommon for training to be conducted twice daily (9, 20, 25, 44).

Modes of training
As previously discussed, the majority of the literature investigating occlusion during exercise training has focussed on resistance training. However, occlusion training has also been used with different modes of exercise to investigate the response to training, and the adaptation of skeletal muscle. For example, Abe and colleagues have produced several papers investigating the effect of occlusion during walk training (9-11). Briefly, continuous occlusion (160-240 mmHg) was applied to the proximal portion of both thighs for five sets of 2-minute bouts interspersed with 1-minute rest periods. The first of these studies consisted of twice daily training for 3 weeks, and resulted in a 4-7% increase in thigh muscle CSA, and a 7.4% and 8.3% increase in 1 RM leg press and leg curl strength, respectively (9). When the same training protocol was undertaken but the volume was reduced by half (once daily training over 3 weeks), the increase in strength following occlusion walk training were similar, but the change in muscle CSA was approximately half that reported for twice daily training (10). Of particular interest, no changes in strength or hypertrophy were found in the control-walk groups (9-11).

Using another approach, subjects performed a body weight circuit-training program with restriction to the proximal portions of both the upper and lower limbs for 8 weeks (12). No change in thigh muscle CSA was observed in the control subjects training without occlusion, whereas the occlusion-training group increased thigh muscle CSA by 3%. Based on these findings, while the combination of occlusion with different modes of training programs may increase strength and hypertrophy, further research is needed to support these claims and to clarify the magnitude of gains from LVO in all types of exercise training.

Possible risks
Although LVO has been shown to promote strength and hypertrophy, optimal methods for its application have not yet been identified, and therefore, the practicality and safety of its use should be of some concern. Absolute occlusion of both the venous and arterial circulations may induce some degree of injury (such as damage to blood vessels), however, the relatively short duration (<15 min) of occlusion during exercise in most studies would seem unlikely to result in any deleterious chronic effects. However, it has been reported in some studies that the use of high occlusion pressures (>180 mmHg) are associated with slight discomfort and a dull pain (45), and side effects such as reduced peripheral sensation, dizziness and fainting have also occurred during training (41, 44). In a recent survey of 105 facilities in Japan where LVO is being undertaken, the most frequent side effects were subcutaneous haemorrhage and temporary numbness, where 13.1% and 1.3% of users reported incidents, respectively. Other more serious side effects included venous thrombosis, pulmonary embolism, and cerebral anaemia (all with an incident rate less than 1%) (36). In summary, evidence suggests that the practical use of vascular occlusion training is safe, however more research is needed in regards to acute and chronic responses following LVO, particularly in populations that have reduced functional capacity.

PRACTICAL APPLICATION
Presently, the research literature suggests LVO is an effective way to increase maximal strength and muscle size in untrained adult populations. However, this research is relatively sparse and quite recent. As such, further research is required in order to determine the most appropriate training variables (frequency, intensity, and volume) for suitable training protocols. Table 1 outlines three typical LVO protocols used in research that should be followed if the coach or athlete wishes to implement an LVO training program. Although medical supervision is not required and LVO is generally considered to be safe in healthy populations, given that blood flow is restricted it is important to note that the occlusion should only be applied for a brief period (<15 min) to avoid any chronic deleterious effects.
Table 1 - Examples of typical LVO training programs.

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<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td>KAATSU Master</td>
<td>Hokanson E20 Rapid Cuff Inflator</td>
<td>KAATSU Master</td>
</tr>
<tr>
<td><strong>Occlusion pressure</strong></td>
<td>Training day 1: • Begin at 30 mmHg • Progressively inflate to 100 mmHg. Subsequent training days: • Inflate 10 mmHg higher each day until 160 mmHg (day 7)</td>
<td>Occlusion set at 30% above resting systolic blood pressure</td>
<td>Training day 1: • Begin at 120 mmHg • Progressively inflate to 160 mmHg. Subsequent training days: • Inflate 10 mmHg higher each day until 230 mmHg (day 8)</td>
</tr>
<tr>
<td><strong>Occlusion time</strong></td>
<td>Maximum of 15 min Continuous application (even during rest)</td>
<td>Continuous application (even during rest)</td>
<td>Occlusion maintained for the entire exercise session (14 min)</td>
</tr>
<tr>
<td><strong>Cuff placement</strong></td>
<td>Most proximal portion of both arms</td>
<td>Most proximal portion of both thighs</td>
<td>Most proximal portion of both thighs</td>
</tr>
<tr>
<td><strong>Training protocol</strong></td>
<td>Free weight flat bench press</td>
<td>Bi-lateral knee extension</td>
<td>Walking on a motor-driven treadmill</td>
</tr>
<tr>
<td><strong>Intensity</strong></td>
<td>30% 1 RM</td>
<td>30% 1 RM</td>
<td>50 m/min</td>
</tr>
<tr>
<td><strong>Sets x reps</strong></td>
<td>1 x 30, followed by 3 x 15</td>
<td>3 x volitional fatigue (30-50)</td>
<td>5 x 2 min</td>
</tr>
<tr>
<td><strong>Rest period</strong></td>
<td>30 s</td>
<td>90 s</td>
<td>1 min</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>3 d/wk. for 6 wks.</td>
<td>3 d/wk. for 4 wks.</td>
<td>Twice daily, 6 d/wk. for 3 wk.</td>
</tr>
<tr>
<td><strong>Training adaptation</strong></td>
<td>1 RM bench press increased 8.7%</td>
<td>MVC increased ~8%</td>
<td>1 RM leg press and leg curl increased 8-10%</td>
</tr>
<tr>
<td><strong>Hypertrophy</strong></td>
<td>Triceps brachii CSA increased 4.9%, Pectoralis major CSA increased 8.3%</td>
<td>Did not measure</td>
<td>Thigh CSA increased 4-7%</td>
</tr>
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**CONCLUSION**

Previous research suggests that in order to maximise hypertrophy and gain strength, HRST programs should be undertaken. However, recent evidence suggests that the increase in both strength and hypertrophy following LVO is similar, or even greater than traditional HRST. A typical training program should include loads corresponding to 20-50% 1 RM. In addition; partial occlusion pressures ranging from 50 mmHg to 150 mmHg should be applied continuously throughout an exercise session that is comprised of 3 to 4 sets of 15 or more repetitions. As such, LVO would appear to have important implications, and be well suited to populations with a limited strength-training capacity such as the elderly, patients in early rehabilitation following injury, or where muscle atrophy and weakness occur due to the effects of inactivity or disease.

While the mechanisms responsible for adaptations to strength and hypertrophy following LVO are not well understood, the acute responses such as preferential recruitment of type II fibres and the stimulated secretion of hGH following training appear to be the most likely contributing factors driving the longer term gains in strength and hypertrophy with continuous training.

With the use of LVO being relatively recent outside Japan, further independent research is necessary to fully ascertain the safety and benefits to populations in which LVO would appear quite suitable. Therefore, LVO should be used with caution by all users given the potential for the restricted blood flow to illicit long-lasting chronic tissue damage, but especially in “at risk” groups such as clinical and elderly populations. However, for athletes that require rapid gains in strength and hypertrophy for a specific even or following injury, and without the risk of overtraining given the low loads used produce minimal muscle damage and require minimal recovery, LVO would appear to be a suitable effective alternative for these athletes.
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