Practical blood flow restriction training increases muscle hypertrophy during a periodized resistance training programme

Ryan P. Lowery[1], Jordan M. Joy[1], Jeremy P. Loenneke[2], Eduardo O. de Souza[3], Marco Machado[4,5], Joshua E. Dudeck[1] and Jacob M. Wilson[1]

[1]Department of Health Sciences and Human Performance, The University of Tampa, Tampa, FL, [2]Department of Health and Exercise Science, University of Oklahoma, Norman, OK USA, [3]Laboratory of Neuromuscular Adaptations to Strength Training, School of Physical Education and Sport, University of São Paulo, São Paulo, [4]Laboratory of Human Movement Studies, Universitary Foundation of Itaperuna, and [5]Laboratory of Physiology and Biokinetics, Iguaçu University Campus V, Itaperuna, Brazil

Correspondence
Jacob M. Wilson, Department of Health Science and Human Performance, The University of Tampa, 401 W. Kennedy Blvd, Tampa, FL 33606, USA
E-mail: jmwilson@ut.edu

Accepted for publication
Received 30 June 2013;
accepted 11 October 2013

Key words
hypertrophy; low intensity; occlusion; periodization

Summary

Background: Resistance training in combination with practical blood flow restriction (pBFR) is thought to stimulate muscle hypertrophy by increasing muscle activation and muscle swelling. Most previous studies used the KAATSU device; however, little long-term research has been completed using pBFR.

Objective: To investigate the effects of pBFR on muscle hypertrophy.

Methods: Twenty college-aged male participants with a minimum of 1 year of resistance training experience were recruited for this study. Our study consisted of a randomized, crossover protocol consisting of individuals either using pBFR for the elbow flexors during the first 4 weeks (BFR-HI) or the second 4 weeks (HI-BFR) of an 8-week resistance training programme. Direct ultrasound-determined bicep muscle thickness was assessed collectively at baseline and at the end of weeks 4 and 8.

Results: There were no differences in muscle thickness between groups at baseline ($P = 0{\cdot}52$). There were time ($P<0{\cdot}01$, $ES = 0{\cdot}99$) but no condition by time effects ($P = 0{\cdot}58$, $ES = 0{\cdot}80$) for muscle thickness in which the combined values of both groups increased on average from week 0 ($3{\cdot}66 \pm 0{\cdot}06$) to week 4 ($3{\cdot}95 \pm 0{\cdot}05$) to week 8 ($4{\cdot}11 \pm 0{\cdot}07$). However, both the BFR-HI and HI-BFR increased significantly from baseline to week 4 (6·9% and 8·6%, $P<0{\cdot}01$) and from weeks 4 to 8 (4·1%, 4·0%, $P<0{\cdot}01$), respectively.

Conclusion: The results of this study suggest that pBFR can stimulate muscle hypertrophy to the same degree to that of high-intensity resistance training.

Introduction

Resistance training (RT) has been widely recognized as an effective stimulus for increasing skeletal muscle size and strength (American College of Sports Medicine position stand, 2009). Traditionally, the American College of Sports Medicine (ACSM) recommends resistance training using intensities >70% 1 rep maximum (RM) as it seems to elicit the greatest increases in skeletal muscle size and strength (American College of Sports Medicine position stand, 2009). More recently, low-intensity RT in combination with blood flow restriction (LI-BFR) has been shown to increase muscle size and strength using only 20–30% of an individual's 1 RM (Takarada *et al.*, 2004; Madarame *et al.*, 2008; Karabulut *et al.*, 2010). In addition, LI-BFR training seems to be an effective, safe alternative to training at higher intensities (Loenneke *et al.*, 2010b), which may have a potential for increased risk of injury and overreaching (Fry *et al.*, 1994). Although the mechanisms that underlie LI-BFR are not totally understood, three primary mechanisms have been proposed. Loenneke *et al.* (2012a) recently suggested that cell swelling may occur through blood pooling, an accumulation of metabolites and reactive hyperaemia. Cellular swelling is thought to activate an intrinsic volume sensor, which may lead to the stimulation of various anabolic-signalling pathways (Fujita *et al.*, 2007; Fry *et al.*, 2010; Loenneke *et al.*, 2012a). Research also demonstrates that LI-BFR resistance training increases metabolic stress (Suga *et al.*, 2010), thus leading to greater increases in growth factors, epinephrine and norepinephrine (Goto et al., 2005). In addition, the accumulation of metabolites can increase muscle fibre recruitment through the stimulation of group III and group IV afferents (Yasuda et al., 2010). It is postulated that this may increase fast-twitch fibre recruitment by inhibiting smaller alpha motor neurons, which ultimately supplies slow-twitch fibres (Loenneke et al., 2012b).

The purpose of LI-BFR training is to fully occlude venous, but not arterial blood flow (Loenneke et al., 2012a). LI-BFR resistance training involves applying a wrapping device, typically a pneumatic restriction cuff, proximal to the muscle being trained (Cook et al., 2007; Fahs et al., 2011; Rossow et al., 2011). Another possibility is to use a KAATSU device; however, this may not be a practical approach for most populations due to cost and accessibility. Recently, because of its accessibility and relative cost-effectiveness, practical blood flow restriction training has been a rising topic in our field. Loenneke & Pujol (2009); Loenneke et al. (2010a, 2011) were the first to propose pBFR training to induce positive changes in skeletal muscle. Specifically, these researchers applied knee wraps proximally around participants' thighs until they were snug, but the wraps did not cause pain on the participants (Loenneke et al., 2010a, 2011, 2012b). Recently, we quantified the tightness of the wrap to only elicit venous occlusion, while not fully occluding the artery (Wilson et al., 2013). In addition, our findings showed that pBFR applied during the leg press exercise was able to induce greater increases in the proposed acute determinants of muscle hypertrophy than a control condition. However, to our knowledge, only one other study has used pBFR in combination with a regular RT regimen (Yamanaka et al., 2012). Therefore, the purpose of this study was to investigate the effects of LI-pBFR as a training regimen on muscle hypertrophy as compared to traditional high-intensity (HI) training regimen.

Methods

Experimental approach to the problem

Our study consisted of a randomized, crossover protocol consisting of individuals either restricting blood flow to the biceps brachii during the first 4 weeks (BFR-HI) or the second 4 weeks (HI-BFR) of an 8-week RT programme. The 8-week training regimen consisted of training the biceps twice per week on Mondays and Fridays (Fig. 1). Overall total volume (sets × repetitions × mass lifted was controlled throughout the 8 weeks in both training regiments. Two weeks prior to the study, subjects recorded their diets so that we had a baseline average daily intake for each individual. Direct ultrasound-determined muscle thickness of the biceps brachii muscle was assessed collectively at the end of weeks 0, 4 and 8 from a blinded researcher. Every subject was able to complete the protocol without any injuries or non-compliance. During each testing session, participants wore the same clothing worn on the first testing day to avoid any carryover effects.

Monday	**Friday**
Hypertrophy	*Strength*
Leg press	Leg press
Leg extension	Bench press
Leg curl	Leg extension
Pullups	Close grip bench press
Bent over row	BFR bicep curls *
Shoulder press	
Bench press	
Dumbell incline bench press	
Close grip bench press	
Tricep cable extension	
BFR bicep curls *	

Figure 1 Workout protocol.

Subjects

Twenty college-aged male participants aged 23 ± 5 years (body mass 76·2 ± 12·3 kg, height 175·6 cm ± 4·8) with a minimum of 1 year of RT training experience were recruited for this study. All participants were thoroughly informed of the purpose, nature, practical details and possible risks associated with the experiment, as well as the right to terminate participation at will, before they gave their voluntary informed consent to participate. The study was approved by the University's Institutional Review Board. The IRB Approval Submission ID was 11–38 and was overseen by the members of the University of Tampa's Ethics Committee.

Condition procedures

Prior to testing, subjects' 10-RM was measured. This value was then converted to a 1-RM for load prescription (prescribed percentage of 1-RM that they would be using). Successful repetitions were defined as the subject could successfully curl the bar and weight without any moving of the elbow and while maintaining a straight back throughout the lift. For bicep curls in combination with pBFR, the subjects' arms were wrapped at a perceived pressure of 6–7 of 10 with knee wraps as utilized by our former study (Wilson et al., 2013) (Elite FTS, London, Ohio; 76 mm wide). For non-pBFR bicep curls, subjects' arms were wrapped at a perceived pressure of 0 of 10 with knee wraps to control for any confounds. During the first week of pBFR, subjects performed three sets of thirty repetitions with 30% of their calculated 1 RM. To control for total volume, the non-pBFR subjects performed three sets of curls at one-half of the repetitions and two times the load of their pBFR weeks for each week. For instance, if a pBFR individual did 30 repetitions at 30% of their 1 RM on their first set, the non-pBFR condition performed 15 repetitions at 60% of their 1 RM for their first set.

Muscle thickness of each participant on their dominant arm was determined via the ultrasound by measuring the total distance of the long and short head of the biceps brachii as well as the fascia between the two muscles located midway between the head of the humerus and lateral epicondyle

(General Electric Medical Systems, Milwaukee, WI, USA). The muscle thickness was assessed at baseline and after weeks 4 and 8. To ensure accuracy, we took three measurements per subject and recorded the average. All three values were within 0·10 cm variation by a blinded researcher. Reliability of muscle thickness assessments was 0·98.

Diet control

Two weeks prior to and throughout the study, subjects were placed on a diet consisting of 25% protein, 50% carbohydrates and 25% fat by a registered dietician who specialized in sport nutrition. Subjects met as a group with the dietician, and they were given individual meal plans at the beginning of the study. Diet counselling was continued on an individual basis throughout the study. Following every resistance training session, all subjects were given 24 g of hydrolysed whey protein (Dymatize Iso 100).

Statistical analysis

Repeated measures analysis of variance was run to assess group, time and group by time interactions. Whenever a significant F-value was obtained, a *post hoc* test with Tukey adjustment was performed for multiple comparisons. The significant level was set at $P<0{\cdot}05$. Statistica (StatSoft®, Tulsa, OK, USA) was used for all statistical analysis.

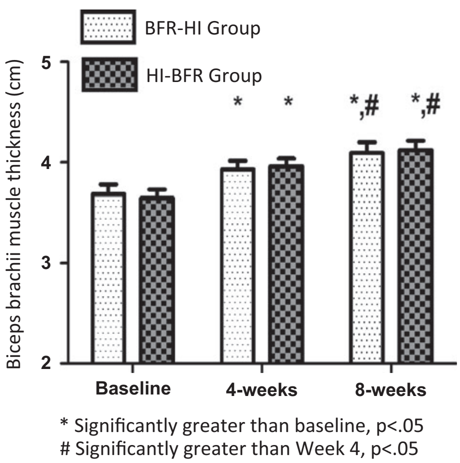

Figure 2 Muscle thickness weeks 0, 4, and 8 in both BFR-HI and HI-BFR. *Significantly greater than baseline, $P<0{\cdot}05$ #significantly greater than week 4, $P<0{\cdot}05$.

Results

There were no differences between groups at baseline ($P = 0{\cdot}52$). There were time ($P<0{\cdot}01$, ES = 0·99) but no condition by time effects ($P = 0{\cdot}58$, ES = 0·80) for muscle thickness in which the combined values of both groups increased on average from week 0 ($3{\cdot}66 \pm 0{\cdot}06$) to week 4 ($3{\cdot}95 \pm 0{\cdot}05$) to week 8 ($4{\cdot}11 \pm 0{\cdot}07$). However, both the BFR-HI and HI-BFR increased significantly from baseline to week 4 (6·9% and 8·6%, $P<0{\cdot}01$) and from weeks 4 to week 8 (4·1%, 4·0%, $P<0{\cdot}01$), respectively (Figs 2 and 3).

Discussion

The purpose of this study was to investigate the effects of LI-pBFR as a training regimen on muscle hypertrophy when used in combination with a periodized resistance training programme. The primary findings of this research were that LI-pBFR resulted in similar hypertrophy gains as high-intensity training, regardless of which was performed first (BFR-HI or HI-BFR).

According to Haussinger *et al.* (1990), cell swelling shifts protein balance towards anabolism and thus induces hypertrophy. More recently, Loenneke *et al.*, (2012a) postulated that LI-BFR results in increased water content of the muscle cells, which induces a cascade of anabolic intracellular signalling to occur. This postulation is supported in part by Fry *et al.* (2010) who observed greater increases in muscle size (measured by circumference) with LI-BFR compared with low-intensity resistance exercise without BFR. The authors suggested that this acute swelling might mechanistically explain part of the increase in muscle protein synthesis observed following LI-BFR (Fujita *et al.*, 2007; Fry *et al.*, 2010; Gundermann *et al.*, 2012). We previously showed that LI-pBFR resulted in an acute increase in muscle swelling and size following a resistance exercise bout (Wilson *et al.*, 2013). However, to our knowledge, this is the first study to look chronically at changes in muscle size compared with high-intensity training. Previous studies have

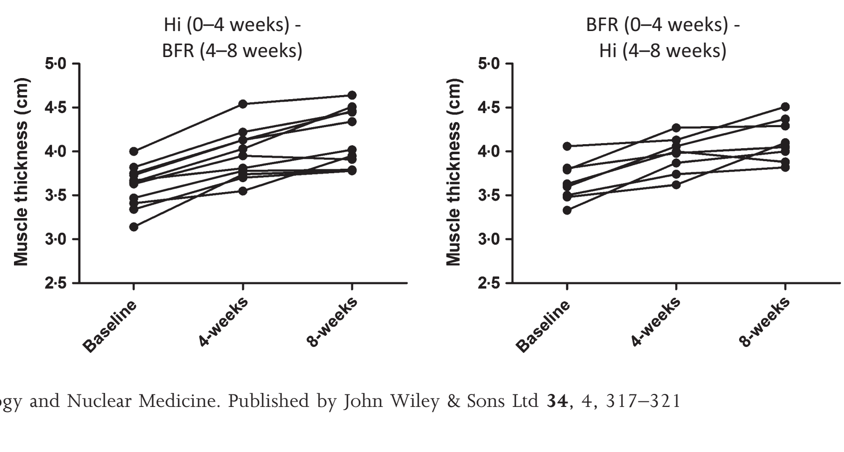

Figure 3 Individual data for muscle thickness weeks 0, 4, and 8 in both BFR-HI and HI-BFR.

shown that high-intensity training alone results in increases in hypertrophy (Felsing *et al.*, 1992). Nevertheless, our data demonstrate for the first time that LI-pBFR results in similar hypertrophy gains as a volume matched, high-intensity exercise bout. In addition, our results suggest that regardless of the order instituted, LI-pBFR can be utilized in combination with high-intensity resistance training in a linear periodized fashion. One important limitation to this study is that we did not assess 1 rep maximum strength for the bicep curl prior to the beginning of the study. Therefore, future research should invest strength variables such as 1 repetition maximum when comparing traditional training to blood flow-restricted training.

Practical applications

Our results suggest LI-pBFR can increase muscle hypertrophy to the same degree as that of high-intensity training. Athletes and strength practitioners can use LI-pBFR in combination with their training programmes to elicit muscle hypertrophy without the muscle damage incurred by heavier weight. Future research should investigate the long-term effects of pBFR on muscle strength and hypertrophy as compared to less practical laboratory methods of BFR.

Acknowledgments

There was no financial support for this project.

Author contributions

All authors contributed to study design, data collection and manuscript preparation.

Conflict of interest

The authors declare no conflict of interest.

References

American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* (2009); **41**: 687–708.

Cook SB, Clark BC, Ploutz-Snyder LL. Effects of exercise load and blood-flow restriction on skeletal muscle function. *Med Sci Sports Exerc* (2007); **39**: 1708–1713.

Fahs CA, Rossow LM, Seo DI, Loenneke JP, Sherk VD, Kim E, Bemben DA, Bemben MG. Effect of different types of resistance exercise on arterial compliance and calf blood flow. *Eur J Appl Physiol* (2011); **111**: 2969–2975.

Felsing NE, Brasel JA, Cooper DM. Effect of low and high intensity exercise on circulating growth hormone in men. *J Clin Endocrinol Metab* (1992); **75**: 157–162.

Fry AC, Kraemer WJ, Van Borselen F, Lynch JM, Triplett NT, Koziris LP, Fleck SJ. Catecholamine responses to short-term high-intensity resistance exercise overtraining. *J Appl Physiol* (1994); **77**: 941–946.

Fry CS, Glynn EL, Drummond MJ, Timmerman KL, Fujita S, Abe T, Dhanani S, Volpi E, Rasmussen BB. Blood flow restriction exercise stimulates mTORC1 signaling and muscle protein synthesis in older men. *J Appl Physiol* (2010); **108**: 1199–1209.

Fujita S, Abe T, Drummond MJ, Cadenas JG, Dreyer HC, Sato Y, Volpi E, Rasmussen BB. Blood flow restriction during low-intensity resistance exercise increases S6K1 phosphorylation and muscle protein synthesis. *J Appl Physiol* (2007); **103**: 903–910.

Goto K, Ishii N, Kizuka T, Takamatsu K. The impact of metabolic stress on hormonal responses and muscular adaptations. *Med Sci Sports Exerc* (2005); **37**: 955–963.

Gundermann DM, Fry CS, Dickinson JM, Walker DK, Timmerman KL, Drummond MJ, Volpi E, Rasmussen BB. Reactive hyperemia is not responsible for stimulating muscle protein synthesis following blood flow restriction exercise. *J Appl Physiol* (2012); **112**: 1520–1528.

Haussinger D, Hallbrucker C, vom Dahl S, Lang F, Gerok W. Cell swelling inhibits proteolysis in perfused rat liver. *Biochem J* (1990); **272**: 239–242.

Karabulut M, Abe T, Sato Y, Bemben MG. The effects of low-intensity resistance training with vascular restriction on leg muscle strength in older men. *Eur J Appl Physiol* (2010); **108**: 147–155.

Loenneke JP, Pujol TJ. The use of occlusion training to produce muscle hypertrophy. *Strength Cond J* (2009); **31**: 77–84.

Loenneke JP, Kearney ML, Thrower AD, Collins S, Pujol TJ. The acute response of practical occlusion in the knee extensors. *J Strength Cond Res* (2010a); **24**: 2831–2834.

Loenneke JP, Wilson GJ, Wilson JM. A mechanistic approach to blood flow occlusion. *Int J Sports Med* (2010b); **31**: 1–4.

Loenneke JP, Balapur A, Thrower AD, Barnes JT, Pujol TJ. The perceptual responses to occluded exercise. *Int J Sports Med* (2011); **32**: 181–184.

Loenneke JP, Fahs CA, Rossow LM, Abe T, Bemben MG. The anabolic benefits of venous blood flow restriction training may be induced by muscle cell swelling. *Med Hypotheses* (2012a); **78**: 151–154.

Loenneke JP, Thrower AD, Balapur A, Barnes JT, Pujol TJ. Blood flow-restricted walking does not result in an accumulation of metabolites. *Clin Physiol Funct Imaging* (2012b); **32**: 80–82.

Madarame H, Neya M, Ochi E, Nakazato K, Sato Y, Ishii N. Cross-transfer effects of resistance training with blood flow restriction. *Med Sci Sports Exerc* (2008); **40**: 258–263.

Rossow LM, Fahs CA, Sherk VD, Seo DI, Bemben DA, Bemben MG. The effect of acute blood-flow-restricted resistance exercise on postexercise blood pressure. *Clin Physiol Funct Imaging* (2011); **31**: 429–434.

Suga T, Okita K, Morita N, Yokota T, Hirabayashi K, Horiuchi M, Takada S, Omokawa M, Kinugawa S, Tsutsui H. Dose effect on intramuscular metabolic stress during low-intensity resistance exercise with blood flow restriction. *J Appl Physiol* (2010); **108**: 1563–1567.

Takarada Y, Tsuruta T, Ishii N. Cooperative effects of exercise and occlusive stimuli on muscular function in low-intensity resistance exercise with moderate vascular occlusion. *Jpn J Physiol* (2004); **54**: 585–592.

Wilson JM, Lowery RP, Joy JM, Loenneke JP, Walters JA, Amsden CE. Practical blood flow restriction training increases acute determinants of hypertrophy without increasing indices of muscle damage. *J Strength Cond Res* (2013). In Press.

Yamanaka T, Farley RS, Caputo JL. Occlusion training increases muscular strength in division IA football players. *J Strength Cond Res* (2012); **26**: 2523–2529.

Yasuda T, Abe T, Brechue WF, Iida H, Takano H, Meguro K, Kurano M, Fujita S, Nakajima T. Venous blood gas and metabolite response to low-intensity muscle contractions with external limb compression. *Metabolism* (2010); **59**: 1510–1519.