Occlusion Training Increases Muscular Strength in Division IA Football Players

Tetsuo Yamanaka, Richard S. Farley, and Jennifer L. Caputo

Department of Health and Human Performance, Middle Tennessee State University, Murfreesboro, Tennessee

Abstract

Yamanaka, T, Farley, RS, and Caputo, JL. Occlusion training increases muscular strength in division IA football players. *J Strength Cond Res* 26(9): 2523–2529, 2012—The purpose of this study was to investigate the effectiveness of 4 weeks of low-intensity resistance training with blood-flow occlusion on upper and lower body muscular hypertrophy and muscular strength in National Collegiate Athletic Association Division IA football players. There were 32 subjects (average age 19.2 ± 1.8 years) who were randomized to an occlusion group or control group. The athletes performed 4 sets of bench press and squat in the following manner with or without occlusion: 30 repetitions of 20% predetermined 1 repetition maximum (1RM), followed by 3 sets of 20 repetitions at 20% 1RM. Each set was separated by 45 seconds. The training duration was 3 times per week, after the completion of regular off-season strength training. Data collected included health history, resting blood pressure, pretraining and posttraining bench press and squat 1RM, upper and lower chest girths, upper and lower arm girths, thigh girth, height, and body mass. The increases in bench press and squat 1RM (7.0 and 8.0%, respectively), upper and lower chest girths (3 and 3%, respectively), and left upper arm girth were significantly greater in the experiment group ($p < 0.05$). Occlusion training could provide additional benefits to traditional strength training to improve muscular hypertrophy and muscular strength in collegiate athletes.

Key Words KAATSU, hypertrophy, athletes

Introduction

Low-intensity resistance training with blood-flow restriction (BFR), called KAATSU in Japan, is known to facilitate an increase in muscular hypertrophy and muscular strength among various populations (1–3,6–9,13,17,18,20,22,24–29). Since its development in the 1960s, BFR training has progressively become an attractive training method used across several Japanese populations (23). The first study that featured the impact of BFR training on muscle hypertrophy in untrained adults was reported by Takarada et al. (28). This study revealed an acute effect of low-intensity BFR training on human growth hormone secretion in a healthy sample, which resulted in significant strength gains and muscle hypertrophy. The available literature now clearly demonstrates promising results of BFR training in healthy, untrained individuals (1,3,9,13,18,25,28,29). For instance, BFR training has been shown to have positive effects among populations with lower extremity orthopedic conditions (7,22). In addition, subsequent studies by Abe et al. (2) and Takarada et al. (27) showed the effectiveness of low-to-moderate intensity (i.e., 20–50% 1 repetition maximum [1RM]) resistance training accompanied by vascular occlusion in athletic populations.

The unique aspect of BFR training is that it involves the application of elastic belts on the most proximal portion of upper and lower extremities (24). With respect to pressure settings of vascular occlusion, Sumide et al. (25) reported that 50–100 mm Hg of pressure was adequate to produce muscle hypertrophy and strength gains. Traditionally, KAATSU training uses a KAATSU-specified training band (Kaatsu-Master, Sato Sports Plaza Ltd., Tokyo, Japan), which is an airbag-contained belt that is connected to an electric pressure control system to allow monitoring of the restriction pressure (28). Contrary to the traditional method, however, Loenneke and Pujol (17) have suggested that it can be substituted for the KAATSU band.

Pertaining to the physiological adaptations in response to occlusion training, human growth hormone is known to play an important role in producing neuroendocrine changes resulting in muscle hypertrophy (15). Release of human growth hormone is closely related to exercise intensity and is released in greater amounts with higher intensity exercise (15). Interestingly, despite the lower intensity, it has been reported that BFR training produces similar or greater growth hormone levels compared with 70–85% 1RM with no restriction (20,24). Although BFR training produces greater muscle hypertrophy and growth hormone secretion at lower exercise loads, it results in less muscle damage than that produced in higher intensity exercise with no vascular restriction (1,9). Indicators of muscle damage (i.e., creatine

Address correspondence to Tetsuo Yamanaka, yamanaka.tetsuo@gmail.com.

26(9)/2523–2529

Journal of Strength and Conditioning Research

kinase, myoglobin, and interleukin-6) have been shown to remain unchanged during BFR training (1,9). Therefore, BFR training may be performed on a daily basis and be used as a strengthening exercise not only for physically active population but also for physically challenged populations, such as the elderly and those undergoing rehabilitation (7,21,22).

The current recommendation for muscular hypertrophy exercise includes high-intensity resistance training that consists of 70–80% of 1RM performed 2–3 times per week (15). As mentioned, relatively less intense BFR training, on the other hand, has been reported to produce greater muscular hypertrophy and muscular strength outcomes as compared with traditional high-intensity resistance training (1–3,6–9,13,17,18,20,22,24–29). In terms of training intensity, Cook et al. (6) reported that 20% 1RM was the most effective intensity for BFR training in the general population, because it resulted in a significantly higher rate of muscle fatigue than did the traditional high-intensity (i.e., 80% 1RM) exercise. Additionally, Abe et al. (2) employed BFR training at 20% 1RM for 8 days in an athletic sample and demonstrated improvements in participants' sprint performance.

The available literature clearly demonstrates that there are many positive effects of BFR training. However, there is minimal research in athletic populations to support the use of the current recommendations for BFR training. If shown to be effective in increasing muscular strength and muscular hypertrophy, then BFR training could supplement traditional strength training in collegiate athletes. Therefore, the purpose of this study was to investigate the effectiveness of 4 weeks of BFR training on muscular hypertrophy and muscular strength in National Collegiate Athletic Association (NCAA) Division IA collegiate football players. The study was conducted in the real-life setting, and the outcome measures were applied measures of muscular strength and hypertrophy. It was hypothesized that BFR training would result in greater muscular strength and muscular hypertrophy than that in the same training regimen without BFR.

Methods

Experimental Approach to the Problem

This study was a between-group, pretest-posttest design with a training intervention. The NCAA Division IA football players were randomized into intervention (n = 16) and control (n = 16) groups. Dependent variables included upper and lower body girths, bench press and squat maximal lifts, height, and body mass. In addition to regular off-season football strength training program, all the subjects performed 4 sets of bench press and squat, 3 times a week for 4 weeks. The intervention group performed these exercises with occlusion, whereas the control group performed the same exercises without occlusion. After the 4-week intervention, both groups were tested at posttraining on all preliminary measures. The experiment was conducted during off-season football training.

Subjects

The subjects were NCAA Division IA football athletes (n = 32; average age of 19.2 ± 1.8 years) attending a university in the southeastern U.S. Inclusion criteria were as follows: (a) at least 5 years of experience in resistance training; (b) possessing high levels of upper and lower body strength (i.e., 93.2 and 94.4 percentile, respectively) (5); and (c) no medical conditions as stated on a self-report health questionnaire. All the subjects were free of high blood pressure and circulatory problems to avoid complications because of the hemodynamic alterations caused by BFR (21). Also, based on average strength measures, muscular strength was similar in both groups before the training sessions. The subjects were training regularly 5 $d \cdot wk^{-1}$ in the off-season football strength training program during this study. To ensure methodological validity, each subject was assigned a consistent time to train by the strength and conditioning staff throughout the intervention period. The study was approved by the Ethics Committee for Human Experiments at the university. All the subjects were informed of the experimental procedures and the purpose of the study and completed written informed consent before data collection.

Procedures

All the subjects took part in a pretest session in which resting blood pressure, girth measures (upper and lower chest, upper and lower arm, and thigh), height, body mass, and 1RM of bench press and squat were measured. The same measurements were taken at a posttest session 2 days after the completion of the training sessions. The pretraining and posttraining girths were measured before 1RM measurements with a Gulick tape measure. Chest girths were measured with the subjects standing in a neutral position with the feet shoulder width apart. The arms were slightly abducted to allow the investigator to put the tape measure around the chest. After the tape was positioned, the arms were lowered to a neutral position. Upper chest girth was measured around the upper latissimus dorsi and below the armpits. Lower chest girth was measured at nipple level. Both chest girths were measured at the end of a normal expiration. Upper arm girth was measured with the subjects standing with arms hanging relaxed at the sides with palms facing the thighs, and the measurement was taken at the midpoint between the acromion and the olecranon processes. Forearm girth was measured with subjects standing with arms slightly away from the body and palms facing front at the maximal circumference. Thigh girth was measured while standing, foot on a bench, with the knee and hip flexed 90°. The measurement was taken at the midpoint between the most proximal thigh, the intersection of the inguinal crease and anterior midline of the thigh, and the proximal border of the patella. All girths were measured twice and were averaged. If the 2 measurements were not within 5 mm, a third measure was taken (5).

To assess muscular strength, the bench press measurement was conducted first, followed by the squat measurement. The

Table 1. Physical characteristics of the subjects.*

	Experimental group		Control group	
	Pretraining	Posttraining	Pretraining	Posttraining
Height (cm)	181.8 (1.2)	181.7 (1.2)	181.1 (1.9)	181.2 (1.8)
Body mass (kg)	91.3 (2.4)	91.5 (2.4)	89.7 (2.9)	89.6 (2.7)

*No significant changes in the height or body mass in either control or experimental group. Values are mean (*SEM*).

subjects performed 10 repetitions of bench press at 40% estimated 1RM as a warm-up. After a 1-minute rest, the subjects performed 5 repetitions at 60% estimated 1RM. All the subjects the performed the first 1RM attempt at an estimated 1RM. The subjects had 3- to 5-minute rest between 1RM attempts, and 5 lb was added after the successful completion of each lift. The 1RM was determined when the participant successfully completed an exercise with the heaviest barbell throughout the full range of motion (10). The workloads for the experimental sessions were determined from the 1RM. The subjects were closely monitored by a certified strength and conditioning specialist for appropriate lifting form.

The exercise protocol was 1 set of 30 repetitions of each exercise at 20% predetermined 1RM followed by 3 sets of 20 repetitions with each set separated by a 45-second rest period. After bench press, the subjects performed squats in the same manner. The pace of the concentric and eccentric phases of motion was guided by a metronome during the exercise sessions, with the eccentric phase lasting twice as long (i.e., 80 $b \cdot min^{-1}$) as the concentric phase. The training sessions took place at the same time for each subject, 3 times a week (i.e., Monday, Wednesday, and Friday), for 4 weeks after the completion of regular off-season football strength training. The experimental group participated in training sessions with BFR after the completion of regular strength training, whereas the control group performed the same additional exercise regimen as the experiment group but without BFR. The control group was asked not to participate in any BFR training activities throughout the duration of the study. The primary investigator was present at each training session to monitor compliance and ensure proper performance.

Restriction of muscular blood flow was accomplished by wrapping elastic bands with Velcro on the most proximal portion of both upper and lower extremities during the BFR training sessions. The elastic bands (5 cm × 55 cm for upper body, 5 cm × 90 cm for lower body) were marked every 0.5 in.. The bands were applied to restrict the brachial artery on both upper arms and the femoral artery on both lower extremities. The bands were initially applied without tension, pulled to overlap 2 in., and secured so the magnitude of occlusion was equivalent across the subjects. The restriction was maintained for the entire exercise session, including the rest periods. The bands

Table 2. Pretest and posttest measurements of strength and girth measures by group.

	Experimental group						Control group					
	Pretraining			Posttraining			Pretraining			Posttraining		
	M	*SD*	*SEM*	*M*	*SD*	*SEM*	*M*	*SD*	*SEM*	*M*	*SD*	*SEM*
Bench press (kg)	128.6	16.5	4.1	137.9*	17.1	4.3	115.7	14.7	3.7	119.8*	16.2	4.0
Squat (kg)	157.3	20.2	5.1	171.4*	22.4	5.6	149.4	23.0	5.8	156.6*	24.3	6.1
Upper chest (cm)	108.5	6.2	1.5	112.3*	5.8	1.5	108.1	5.6	1.4	109.1*	5.1	1.3
Lower chest (cm)	99.8	5.0	1.2	102.3*	4.4	1.1	99.9	5.3	1.3	101.1*	5.2	1.3
Right upper arm (cm)	35.3	2.8	0.7	36.7*	2.8	0.7	33.4	2.6	0.7	34.8*	2.5	0.6
Left upper arm (cm)	35.3	2.7	0.7	36.1*	2.6	0.7	33.4	2.9	0.7	34.9*	2.7	0.7
Right lower arm (cm)	30.9	1.5	0.4	31.7*	1.5	0.4	30.3	1.3	0.3	31.4*	1.6	0.4
Left lower arm (cm)	30.7	1.8	0.5	31.4*	1.7	0.4	29.8	1.6	0.4	30.8*	1.8	0.4
Right thigh (cm)	56.8	4.4	1.1	58.0*	4.6	1.1	55.6	4.6	1.2	56.3*	4.5	1.1
Left thigh (cm)	56.2	4.6	1.1	57.3*	4.2	1.0	55.1	4.3	1.1	55.7*	4.6	1.2

*Significant change from pretest to posttest, $P < 0.05$.

Table 3. Pretest to posttest increases (kilograms) and percent changes in strength.*

	Experimental group				Control group				Eeffect size	Intraclass correlation coefficient
	M	*SD*	*SEM*	% Change	*M*	*SD*	*SEM*	% Change		
Bench press	9.3*	3.4	1.0	7.0*	4.1	4.2	0.9	3.2	1.2	0.983 ± (0.965–0.992)
Squat	14.0*	3.8	1.3	8.0*	7.2	5.3	1.1	4.9	1.3	0.984 ± (0.968–0.992)

*Significant difference between groups, $P < 0.05$.

were applied on the upper extremities first, and the pressure was released immediately after completion of the upper body exercise. The bands were then applied to the lower extremities for the lower body exercise, and the pressure was released immediately after completion of the lower body exercise.

Statistical Analyses

Dependent *t*-tests were employed for each training group to examine the differences in muscular strength and girth measurements between pretraining and posttraining. To create difference-improvement scores as a method to evaluate the research hypothesis, pretest values were subtracted from posttest values for all measures (i.e., upper-lower chest girths, upper-lower arm girths, thigh girth, height, body mass, and 1RM of bench press and squat). Independent sample *t*-tests were employed to determine significant differences in the amount of changes from pretest to posttest between the BFR training group and the control group. Statistical significance was established at an alpha level of 0.05. All data analyses were conducted using the Statistical Package for Social Sciences (SPSS; Chicago, IL, USA) version 17.0.

Results

A total of 32 individuals volunteered to participate in this study. The subjects were randomly divided into 2 groups; experiment group ($n = 16$) or control group ($n = 16$). The change in body mass was not significantly different in the experimental group as compared with that in the control group, $t(1, 30) = -0.827$, $p > 0.05$, and there was no change in height, $t(1, 30) = -0.397$, $p > 0.05$ (Table 1). There were significant changes within each group for all muscular strength and girth measures, $p > 0.05$ (Table 2).

The change in 1RM in bench press was significantly greater in the experimental group than in the control group, $t(1, 30) = -3.859$, $p < 0.05$. Likewise, the change in 1RM in squat was significantly greater in the experimental group as compared with that in the control group, $t(1, 30) = 4.193$, $p < 0.05$ (Table 3).

The change in the girth of the upper chest was significantly greater in the experimental group than in the control group, $t(1, 30) = -5.102$, $p < 0.05$. Additionally, the change in the girth of the lower chest was significantly greater in the experimental group as compared with that in the control group, $t(1, 30) = -2.574$, $p < 0.05$ (Table 4).

Table 4. Differences in girth measures (centimeters) from pretest to posttest.*

	Experimental group			Control group			Effect size	Intraclass correlation coefficient
	M	*SD*	*SEM*	*M*	*SD*	*SEM*		
Upper chest	3.7*	1.6	0.4	1.0	1.4	0.4	1.9	0.967 ± (0.932–0.984)
Lower chest	2.6*	1.4	0.4	1.2	1.5	0.4	0.9	0.973 ± (0.944–0.987)
Right upper arm	1.3	0.9	0.2	1.4	0.9	0.2	−0.1	0.976 ± (0.951–0.988)
Left upper arm	0.8*	0.6	0.2	1.5	1.0	0.3	−0.7	0.975 ± (0.949–0.988)
Right lower arm	0.8	0.5	0.1	1.1	0.5	0.1	−0.5	0.967 ± (0.932–0.984)
Left lower arm	0.7	0.6	0.1	1.0	0.6	0.1	−0.5	0.971 ± (0.942–0.986)
Right thigh	1.3	1.1	0.3	0.8	1.0	0.3	0.5	0.986 ± (0.971–0.993)
Left thigh	1.0	1.4	0.3	0.7	1.1	0.3	0.4	0.981 ± (0.960–0.991)

*Significant difference between groups, $P < 0.05$.

The change in girth of the right upper arm was not significantly greater in the experimental group than in the control group, $t(1, 30) = 0.204$, $p > 0.05$. The change in the girth of the left upper arm was significantly greater in the experimental group as compared with that in the control group, $t(1, 30) = 2.385$, $p < 0.05$. The change in the girth of the right lower arm was not significantly greater in the experimental group than in the control group, $t(1, 30) = 1.338$, $p > 0.05$. Likewise, the change in the girth of the left lower arm was not significantly greater in the experimental group as compared with that in the control group, $t(1, 30) = 1.379$, $p > 0.05$ (Table 4).

The change in the girth of the right thigh was not significantly greater in the experimental group than in the control group, $t(1, 30) = -1.328$, $p > 0.05$. Further, the change in the girth of the left thigh girth was not significantly greater in the experimental group as compared with that in the control group, $t(1, 30) = -0.870$, $p > 0.05$ (Table 4).

Discussion

The purpose of this study was to investigate the effectiveness of 4 weeks of BFR training on muscular hypertrophy and muscular strength in NCAA Division IA collegiate football players. All the 32 subjects completed the study. This study was novel in that the subjects were more physically active than were most previous research samples (1,3,6–9,12–16,18,20–22,24–26,28,29). Moreover, the sample size of this study was greater than that of previous studies, which generally consisted of <20 subjects (1–3,8,9,14,18,20–22,24,26,27,29).

This study demonstrated that low-intensity resistance exercise (20% 1RM) combined with BFR resulted in greater muscular hypertrophy and significantly greater ($p < 0.05$) increases in muscular strength, whereas there were no significant changes in height and body mass, as compared with the control group (Table1). In terms of strength gains, the average percent increase in bench press was 7.0% in the BFR training group, which was significantly greater than the 3.2% increase in the control group (Table 3). Likewise, the 8.0% increase in the squat 1RM, on average, in the BFR training group was significantly greater than the 4.9% increase in the control group (Table 3). Therefore, although both groups showed significant changes after the 4-week period, the BFR training group had significantly greater ($p < 0.05$) increases in muscular strength. Because the subjects in this study were trained football players who had already achieved a high level of muscular strength, low-intensity (i.e., 20% 1RM) resistance training would not normally have produced muscular strength gains. The significant increases in strength and girth measurements in the control group are attributed to the regular off-season strength training program. This may indicate that short-term BFR training is effective in increasing strength among the athletic population when combined with high-intensity training.

The strength gains observed in this study were consistent with those reported by several researchers (1,3,9,18,25,27,28). Although previous studies had examined gains in muscular strength by measuring maximum voluntary contraction, isokinetic torque, 1RM, or a combination of those, muscular strength was assessed in this study through bench press and squat 1RM. More specifically, Yasuda et al. (29) who employed BFR training within the general population demonstrated higher EMG activity in the involved muscle group during low-intensity (i.e., 30% 1RM) bench press with vascular restriction. In addition, they indicated that the BFR training led to a hypoxic and acidic environment (29), resulting in lactic acid accumulation, which inhibits muscular contraction and recruitment of additional fast-twitch motor units to maintain force production (28). The additional fast-twitch fiber recruitment as a result of BFR training would be one of the factors that could potentially induce higher muscular strength. In fact, Takarada et al. (28) investigated integrated electromyogram (iEMG) activity to determine muscle fiber recruitment during BFR training and reported that there was almost equal iEMG activity between lower intensity BFR training and traditional high-intensity exercise. This finding could explain the underlying mechanism of the strength gains that occurred in our study.

In addition, increases in upper and lower chest girths were also observed, which revealed muscular hypertrophy (Table 1). Although the subjects in this study were trained athletes and had already achieved muscular hypertrophy in the chest area, greater muscular hypertrophy was observed in the chest girths of the subjects who were in the experimental group as compared with those in the control group. Interestingly, Yasuda et al. (29) showed that BFR bench press training significantly increased muscle activity, not only in the blood-flow restricted muscle (i.e., triceps brachii) but also the blood-flow nonrestricted muscle (i.e., pectoralis major). During bench press, the chest and triceps muscles are the primary muscles activated. Additionally, Yasuda et al. (29) documented elevated muscular activity in the pectoralis major muscle during the BFR training. It has been reported that BFR training induces acute changes in the redistribution of cutaneous blood circulation, resulting in greater girths (16). Although blood-flow redistribution after the BFR training could have increased the girth measures in our study, posttest measures were conducted 2 days after the last training session; thus, blood-flow changes were less likely to impact the observed outcomes.

To further extend our understanding of muscular hypertrophy because of BFR training, Madarame et al. (18) documented a crosstransfer effect as a result of BFR training. A crosstransfer effect occurs when muscular hypertrophy is seen not only in the trained limb but also in the untrained limb when combined with contralateral resistance training. In the study of Madarame et al. (18), adding lower extremity BFR training after regular upper extremity exercise induced greater hypertrophy in the upper extremity. Similarly, the subjects in this study performed squats immediately after bench press. Thus, the crosstransfer effect could also have played an important role in producing the observed hypertrophy of the chest in this study.

An interesting and novel finding of this study was that the 4 weeks of BFR training produced significant increases in chest girths but not in arm or thigh girths. This is contrary to the findings of previous research that has demonstrated significant changes in girths in all extremities after BFR training (1–3,6–9,13,17,18,20,22,24–29). Possible explanations for this difference may be (a) the variation in the type of subjects; (b) the number of exposures to BFR training; and (c) the types of exercise performed.

With respect to the variation in sample populations, the subjects in most previous studies that displayed hypertrophy with BFR training were healthy, untrained individuals (1,3,9,13,18,22,25,28,29), whereas this study examined physically trained individuals. For instance, the subjects in the study of Fujita et al. (9) were novice lifters. In terms of the number of training exposures, Takarada et al. (27) and Abe et al. (2) documented increases in muscular hypertrophy in both upper and lower extremities after a greater number of BFR training exposures. Specifically, the length of BFR training in the study of Takarada et al. (27) was 8 weeks with a total of 16 exposures to BFR training and in the study of Abe et al. (2), the training period was 8 days, providing a total exposure of 16 sessions of BFR training. In contrast, the training period of this study was 4 weeks with 12 exposures to BFR training, indicating that the number of exposure may not have been sufficient to produce hypertrophy in the upper and lower extremities as a result of the present intervention. Fujita et al. (9) documented significant hypertrophy in the quadriceps muscles after the same number of exposures to BFR training as in this study, yet, it is important to note that the subjects in the study of Fujita et al. (9) were from the nonathletic population.

Another possible explanation as to why there were significant changes in chest girths, but not in arm and thigh girths, might have been the differences in the type of exercises and exercise regimen performed in this study. In most previous studies, the subjects performed either biceps curls or knee extension and flexion, whereas the subjects in this study performed bench press and squat. Although increases in chest girths were observed in this study, another arm exercise may have been needed to observe muscular hypertrophy in the upper extremities in these trained athletes. Similarly, another lower extremity exercise could be added to enhance muscular hypertrophy in highly trained athletes.

The exercise protocol for BFR training in this study was 1 set of 30 repetitions of 20% predetermined 1RM, then 3 sets of 20 with each set separated by a 45-second rest period, which was consistent with that in several studies. All the subjects were able to complete all repetitions in this study, and according to brief conversations with the subjects after the training sessions, the number of repetitions was not sufficient for them to reach exhaustion. In fact, the BFR training study with elite rugby players by Takarada et al. (27) consisted of exercises until failure. The subjects in this study were trained athletes; therefore, the conventional BFR training regimen could have been modified by increasing the number of repetitions to perhaps produce greater increases in strength and girth measurements.

Lastly, the lack of significance in arm and thigh girths in this study may be because of the regular strength training that preceded each BFR training session. No other studies have been conducted to investigate the effectiveness of BFR training combined with regular high-intensity strength training. Therefore, the inclusion of regular strength training might have affected the results of BFR training in this study.

Several limitations did exist in this study. The first limitation was the number of exposures to BFR training. This study involved only 12 exposures to BFR training over a 4-week period, which was fewer than the previous studies (1–3,7,9,11,18,22,27,28). Additionally, there was no follow-up testing to see whether or not the observed increases in muscular strength and hypertrophy after BFR training were sustained. Further studies are warranted to observe the long-term effect of BFR training in trained athletes. As stated earlier, our results suggest that BFR training to failure be applied in future studies to maximize muscular hypertrophy and strength gains in trained athletes.

Another limitation of the study was that body water and body fat percentage were not measured. Specifically, body water and body fat measures can differentiate the changes in girth measures caused by increased protein synthesis from those caused by alterations in intercellular fluid levels and loss of body fat. True muscular hypertrophy is typically assessed using magnetic resonance imaging to assure that the girth measurements are not influenced by subcutaneous adipose tissue or intercellular fluid. In addition, even though the timing of the training sessions and tests were controlled, nutrition intake and hydration levels were not controlled. Although the magnitude of occlusion was controlled by following the same procedure across the subjects, pressure levels were not digitally measured due to the lack of an appropriate pressure control device. Lastly, the subjects of BFR training studies, including this study, have been limited to male subjects. Further research should encompass a variety of population to set recommendations to modify the traditional BFR training regimen.

In summary, BFR training in this study resulted in increased muscular strength and muscular hypertrophy among NCAA Division IA football players. However, future research is needed to reveal the potential advantages of BFR training in trained athletes.

Practical Applications

The results of this study indicated that 4 weeks of occlusion training for bench press and squat can significantly improve muscular strength and muscular hypertrophy in NCAA

Division IA collegiate football players when added to a traditional strengthening program. Although BFR training in this study showed improvements in measured outcomes, BFR training to failure along with multiple exercises per muscle group may produce greater outcomes in physically trained individuals. Occlusion training, therefore, can be used as a supplementary workout to regular strength and conditioning sessions during the off-season training period.

References

1. Abe, T, Beekley, MD, Hinata, S, Koizumi, K, and Sato, Y. Day-to-day change in muscle strength and MRI-measured skeletal muscle size during 7 days KAATSU resistance training: A case study. *Int J KAATSU Train Res* 1: 71–76, 2005.
2. Abe, T, Kawamoto, T, Yasuda, C, Kreans, CF, Midorikawa, T, and Sato, Y. Eight days KAATSU-resistance training improved sprint but not jump performance in collegiate male track and field athletes. *Int J KAATSU Train Res* 1: 19–23, 2005.
3. Abe, T, Kearns, CF, and Sato, Y. Muscle size and strength are increased following walk training with restricted venous blood flow from the leg muscle, Kaatsu-walk training. *J Appl Physiol* 100: 1460–1466, 2006.
4. American College of Sports Medicine. New program internationalizes health and fitness research, 2008. Available at: http://www.acsm.org/AM/Template.cfm?Section=Home & TEMPLATE=/CM/ContentDisplay.cfm& CONTENTID=11532. Accessed July 15, 2009.
5. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription* (8th ed.). Philadelphia, PA: Lippincott Williams & Wilkins, 2009. pp. 65–66.
6. Cook, SB, Clark, BC, and Plouts-Snyder, LL. Effects of exercise load and blood-flow restriction on skeletal muscle function. *Med Sci Sports Exerc* 39: 1708–1713, 2007.
7. Fujino, H, Sata, S, and Sata, M. Effect of resistance training with partial vascular occlusion after anterior cruciate ligament reconstruction. *J Jpn Soc Clin Sports Med* 8: 247–251, 2000.
8. Fujita, S, Abe, T, Drummond, MJ, Cadenas, JG, Dreyer, HC, Sato, Y, Volpi, E, and Rasmussen, BB. Blood flow restriction during low-intensity resistance exercise increases S6K1 phosphorylation and muscle protein synthesis. *J Appl Physiol* 103: 903–910, 2007.
9. Fujita, T, Brechue, WF, Kurita, K, Sato, Y, and Abe, T. Increased muscle volume and strength following six days of low-intensity resistance training with restricted muscle blood flow. *Int J KAATSU Train Res* 4: 1–8, 2008.
10. Heyward, VH. Assessing muscular fitness. In: *Advanced Fitness Assessment and Exercise Prescription.* M.S. Bahrke, A.S. Ewing, L. Alexander, M. Eckstein, and J. Engman, eds. Champaign, IL: Human Kinetics, 2006. pp. 122–123.
11. Hubal, MJ, Gordish-Dressman, H, Thompson, PD, Brice, TB, Hoffman, EP, Angelopoulos, TJ, Gordon, PM, Moyna, NM, Pescatello, LS, Visich, PS, Zoeller, RF, Seip, RL, and Clarkson, PM. Variability in muscle size and strength gain after unilateral resistance training. *Med Sci Sports Exerc* 37: 964–972, 2005.
12. Iida, H, Takano, H, Meguro, K, Asada, K, Oomura, H, Morita, T, Kurano, M, Sakagami, F, Uno, K, Hirose, K, Nagata, T, Takenaka, K, Suzuki, F, Hirata, Y, Furuichi, T, Eto, F, Nagai, R, Sato, Y, and Nakajima, T. Hemodynamic and autonomic nervous responses to the restriction of femoral blood flow by KAATSU. *Int J KAATSU Train Res* 1: 57–64, 2005.
13. Ishii, N, Madarame, H, Odagiri, K, Nagamura, M, and Shinoda, K. Circuit training without external load induces hypertrophy in lower-limb muscles when combined with moderate venous occlusion. *Int J KAATSU Train Res* 1: 24–28, 2005.
14. Karabulut, M, Cramer, JT, Ryan, ED, Anderson, RL, Hull, HR, Sato, Y, Abe T, and Bemben, MG. Effects of KAATSU on muscular function during isometric exercise. *Int J KAATSU Train Res* 2: 19–28, 2006.
15. Kraemer, WJ, Adams, K, Cafarelli, E, Dudley, GA, Dooly, C, Feigenbaum, MS, Fleck, SJ, Franklin, B, Fry, AC, Hoffman, JR, Newton, RU, Potteiger, J, Stone, MH, Ratamess, NA, and Triplett-McBride, T. Progression models for resistance training in healthy adults. *Med Sci Sports Exerc* 34: 364–380, 2002.
16. Kusuhara, K, Fujita, T, Yasuda, T, Nakajima, T, Sato, Y, Miyagi, Y, Murakami, Y, and Abe, T. Effect of knee extension exercise with KAATSU on forehead cutaneous blood flow in healthy young and middle-aged women. *Int J KAATSU Train Res* 2: 29–34, 2006.
17. Loenneke, JP and Pujol, TJ. The use of occlusion training to produce muscle hypertrophy. *Strength Conditioning J* 31: 77–84, 2009.
18. Madarame, H, Neya, M, Ochi, E, Nakazato, K, Sato, Y, and Ishii, N. Cross-transfer effects of resistance training with blood flow restriction. *Med Sci Sports Exerc* 40: 258–263, 2008.
19. Peterson, MD, Rhea, MR, and Alvar, BA. Maximizing strength development in athletes: A meta-analysis to determine the dose-response relationship. *J Strength Conditioning Res* 18: 377–382, 2004.
20. Reevs, GV, Kraemer, RR, Hollander, BD, Clavier, J, Thomas, C, Francois, M, and Castracane, VD. Comparison of hormone responses following light resistance exercise with partial vascular occlusion and moderately difficult resistance exercise without occlusion. *J Appl Physiol* 101: 1616–1622, 2006.
21. Sakamaki, M, Fujita, S, Sato, Y, Bemben, MG, and Abe, T. Blood pressure response to slow walking combined with KAATSU in the elderly. *Int J KAATSU Train Res* 4: 17–20, 2008.
22. Sata, S. KAATSU training for patella tendinitis patient. *Int J KAATSU Train Res* 1: 29–32, 2005.
23. Sato, Y. The history and future of KAATSU training. *Int J KAATSU Train Res* 1: 1–5, 2005.
24. Sato, Y, Yoshitomi, A, and Abe, T. Acute growth hormone response to low-intensity KAATSU resistance exercise: Comparison between arm and leg. *Int J KAATSU Train Res* 1: 45–50, 2005.
25. Sumide, T, Sakuraba, K, Sawaki, K, Ohmura, H, and Tamura, Y. Effect of resistance exercise training combined with relatively low vascular occlusion. *J Sci Med Sports* 12: 107–112, 2009.
26. Takano, H, Morita, T, Iida, H, Kato, M, Uno, K, Hirose, K, Matsumoto, A, Takenaka, K, Hirata, Y, Furuichi, T, Eto, F, Nagai, R, Sato, Y, and Nakajima, T. Effects of low-intensity "KAATSU" resistance exercise on hemodynamic and growth hormone responses. *Int J KAATSU Train Res* 1: 13–18, 2005.
27. Takarada, Y, Sato, Y, and Ishii, N. Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *Eur J Appl Physiol* 86: 308–314, 2002.
28. Takarada, Y, Takazawa, H, Sato, Y, Takebayashi, S, Tanaka, Y, and Ishii, N. Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. *J Appl Physiol* 88: 2097–2106, 2000.
29. Yasuda, T, Fujita, T, Miyagi, Y, Kubota, Y, Sato, Y, Nakajima, M, Bemben MG, and Abe T. Electromyographic responses of arm and chest muscle during bench press exercise with and without KAATSU. *Int J KAATSU Train Res* 2: 15–18, 2006.