Original Research

Does Beta-Alanine Supplementation Potentiate Muscle Performance Following 6 Weeks of Blood Flow Restriction or Traditional Resistance Training?

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ABSTRACT

International Journal of Exercise Science 16(2): 999-1011, 2023. We aimed to compare the effects of beta-alanine on Traditional Resistance Training (TRAD) or Blood Flow Restriction Training (BFR). Methods: 19 subjects were randomly allocated to a Placebo (*n* = 10) or beta-alanine (*n* = 9) group. Subjects from both groups were trained unilaterally (unilateral arm curl) for six weeks, and each arm was trained using a different paradigm (BFR or TRAD). One repetition maximum (1RM) test measurements were performed before and after the strength training program. Work output was accessed as the total weight lifted (repetitions × weight lifted × sets) for the entire strength training program. Results: 1RM or total weight lifted was not increased by beta-alanine supplementation. However, the TRAD-trained arm showed a significantly increased 1RM and total weight lifted compared to the BFR arm (*p* < 0.05). Conclusion: We conclude that in the short-term (6 weeks) and following the current experimental conditions, beta-alanine does not benefit BFR or TRAD in terms of total weight lifted (volume of training) or maximal strength (1RM).

KEY WORDS: Resistance training, pre-workout, performance

INTRODUCTION

The strength and hypertrophy gain are important adaptations induced by resistance training (RT) that translate to clinically meaningful outcomes in various populations, including athletes, older adults, and the rehabilitation population. Traditionally, the American College of Sports Medicine recommends RT with intensities over 70% of the one repetition maximum (1RM) to optimize strength and hypertrophic adaptations (1). However, while high intensities (i.e., > 85% 1RM) appear necessary to maximize strength adaptations in trained populations, heavy loading may not be appropriate for populations with chronic health problems or individuals with injuries (1).

Blood flow restriction (BFR) resistance training has been recognized as a low-load resistance training method capable of producing increases in muscle strength, sometimes comparable to traditional resistance training (TRAD), mainly when repetitions to failure are performed (5, 14). The main difference between the BFR and other low-load methods is using an inflatable cuff in the exercised limb, which occludes blood flow and generates increased muscle hypoxia (17, 27). Consequently, early muscle fatigue occurs, increasing the recruitment of higher threshold motor neurons (type II muscle fibers) and the production of H^+ ions, muscle metabolites, and growth factors associated with increased muscle strength and muscle mass (25, 32, 33).

As described by Hultman & Sahlin (10), during dynamic exercise, the majority of H^+ ion buffering is shared between blood (extracellular) and intramuscular buffers (10). Contrariwise, when the exercise is isometric, blood circulation is locally occluded (11), reducing the efficacy of the bicarbonate system and increasing intracellular buffering dependence (28). Since venous outflow is also robustly reduced during BFR conditions (24), intramuscular buffers like carnosine, part of the first line of defense against H^+ ions, predominate (6). Compared to bicarbonate, carnosine has a higher pKa (3) and is considered the most relied upon for H^+ buffering during anaerobic conditions (16). Notably, by supplementing beta-alanine, the intramuscular carnosine reservoir can be robustly increased, thereby enhancing intramuscular H^+ ion buffering and attenuating acidosis during submaximal exercise (2). Buffering H^+ ions may enhance muscle performance (9, 23, 20), and such increased muscle performance may benefit resistance training muscle adaptations, including skeletal muscle hypertrophy (31).

In a recent study, our group demonstrated that creatine supplementation in association with BFR substantially increased muscle performance (i.e., exercise volume of training – VLT) (31), probably via enhanced ATP resynthesis and H^+ buffering mechanisms (26). Furthermore, considering that beta-alanine supplementation via increased carnosine content has a greater potential to increase muscle buffering capacity against the H^+ ions produced during BFR than creatine (29), a possibility exists that beta-alanine can be equally or even more ergogenic for BFR than creatine, thus benefiting BFR muscle adaptations (31).

For this purpose, we investigate the role of beta-alanine supplementation for six weeks by employing a previously described within-subject unilateral elbow flexion RT program (31) on

exercise volume and maximal strength. As a control, we compared beta-alanine effects on BFR against a TRAD paradigm, as previous studies have demonstrated its positive effects following this paradigm (9, 23, 20). If beta-alanine could increase muscle performance during BFR training, this supplement would be prescribed in association with BFR to enhance muscle adaptations to this exercise model.

METHODS

Participants
Only male subjects participated in this study. Of the 35 men who participated in the first screening, twenty-six men untrained in RT met all the inclusion criteria, agreeing to participate in the study protocol. However, seven participants dropped out during the study due to personal problems ($n = 7$). As a result, only 19 healthy untrained male undergraduate students at the Federal University of Maranhão completed all stages of the study. This study was approved by the Research Ethics Committee (CAAE: 91094318.7.0000.5087), and all research was conducted according to the Declaration of Helsinki. All subjects read and signed an informed consent form. This study was conducted by the ethical standards of the International Journal of Exercise Science (22). The inclusion criteria for the study were: 1) male subjects between 18 to 30 years of age, 2) had not been involved in regimented RT in the previous six months, 3) had not used any dietary supplement or ergogenic drug for at least two years before the study and 4) did not smoke or drink alcohol within proximity (at least one week) of testing visits. Figure 1 presents the flowchart of participant recruitment. All subjects read and signed an informed consent form.
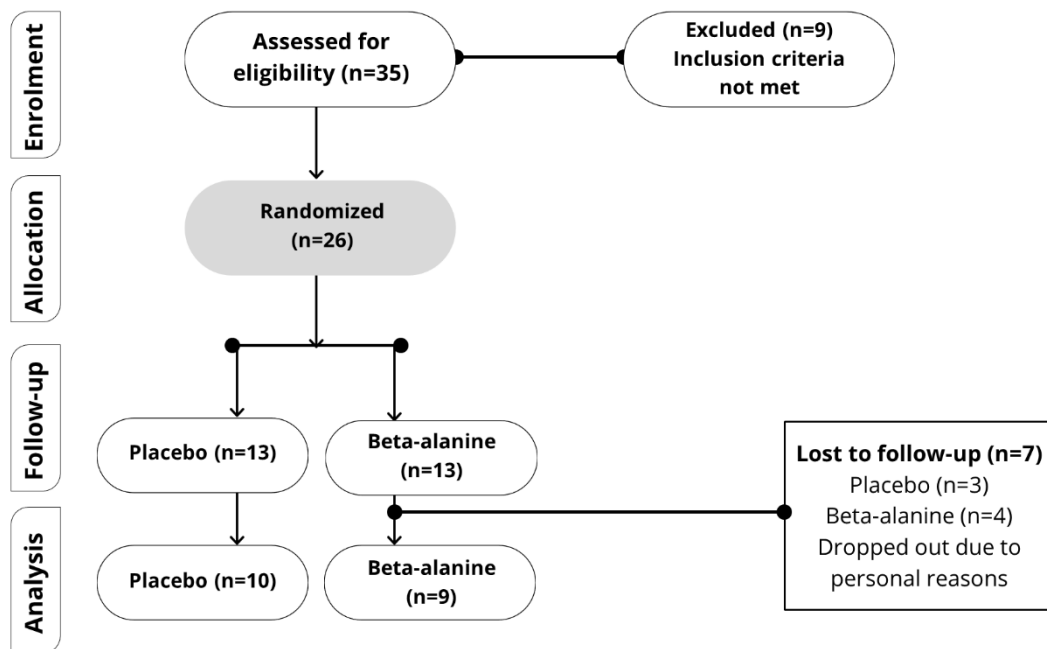

Figure 1. CONSORT Flowchart.

Protocol
This study used a randomized, double-blind, and placebo-controlled design. The subjects and researchers were only aware of the supplement subjects consumed at the end of the study. The researcher not directly involved in the data collection generated the random allocation sequence using an Excel program (Microsoft, USA) to ensure blinding. Participants were pair-matched based on initial arm circumference and strength levels and then randomly assigned to one of two treatment groups: Placebo or beta-alanine. Each arm was randomly assigned to either a blood flow restriction (BFR) or traditional (TRAD) resistance training condition. Participants were assessed for anthropometric measures and arterial pressure occlusion (AOP) on the first visit. During the second visit, participants performed a one-repetition maximum test (1 RM). Training occurred for six weeks, with each arm being trained twice weekly on separate days, and each particular training session was separated by 72 hours. The total number of repetitions performed was recorded for each set, and the total weight lifted was calculated. The experimental design is illustrated in Figure 2.
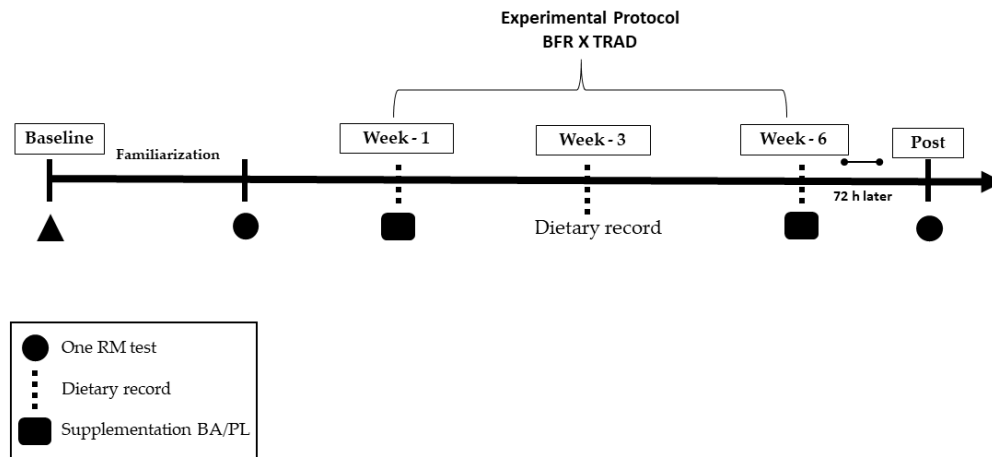

Figure 2. Experimental design.

Anthropometrics: Initially, body mass was measured using an electronic scale (Filizzola PL 50, Filizzola Ltda., Brazil), with a precision of 0.1 kg, and height was measured on a fixed stadiometer (Sanny, São Paulo, Brazil) with an accuracy of 0.1 cm and a length of 2.20 m.

Food Intake: All participants recorded food intake via three-day food diaries consisting of one weekend and two weekdays. All food intakes were analyzed for total kilocalorie and macronutrient intakes averaged for the three days at baseline and after the intervention. Food diaries were analyzed using NutWin version 1.5 [Nutrition Support Program, Federal University of São Paulo, São Paulo, Brazil, 2002].

Determination of Arterial Occlusion Pressure (AOP)*:* The 6 cm wide (Nylon) model (JPJ, Brazil) used the cuff to determine the total occlusion pressure. To determine AOP, the cuff was placed near the glenohumeral joint. The pulse was initially detected using a portable Doppler probe (ME 163 DMEGA, DV 610V), positioned on the radial artery, subsequently inflated to 50 mmHg

with a manual sphygmomanometer (MISSOURI, Brazil) following the same protocol as Loenneke et al. (18). The re-test of the intraclass correlation coefficients of these procedures proved to be reliable (ICC = 0.91).

Maximal Strength Test (1 Repetition Maximum Test): To determine the 1RM value of unilateral elbow flexion, subjects followed the test protocol according to the study by Yasuda et al. (35). During the test, participants had their heels and back resting on the wall and feet separated by shoulder width to ensure positional standardization.

Beta-alanine or Placebo Supplementation: The subject's intake of beta-alanine (99.9% pure beta-alanine; CarnoSyn, NAI, San Marcos, California, USA) or a placebo (dextrose, Neonutri, Poços de Caldas, Minas Gerais, Brazil) for six weeks. Both the placebo and beta-alanine were powdered and packed in gastro-resistant capsules (hydroxypropyl methylcellulose, Dr. Caps, Capsugel, Puebla, Puebla, Mexico), identical in appearance (i.e., 188 white, opaque, and size 00), which were produced in the laboratory using a manual capsule filling machine (Ideal, Arujá, São Paulo, Brazil). In addition, the subjects consumed six slow-release gel capsules containing 800 mg of beta-alanine per day (split between three doses per day) (7), totalizing 4.8 g/day.

Resistance Training Protocol: Initially, the subjects were introduced to the laboratory, after which they were instructed on the exercise to be performed in the study. They were then familiarized with the BFR and TRAD biceps curl exercises. The training protocol was randomly selected for each subject's arm, each arm was trained twice weekly, and each separate protocol was performed on non-consecutive days (i.e., BFR: Monday and Thursday, and; TRAD: Tuesday and Friday), as shown in Figure 3. Subjects were instructed to perform each repetition starting with a fully extended elbow, flexing at the elbow to full flexion, and then returning to full arm extension (21). A metronome controlled the repetition time, with 2 seconds for concentric and 2 seconds for eccentric. The training program consisted of two progressive three-week phases: first to the third week, for BFR, the subjects performed one set of 30 repetitions and two sets of 15 repetitions with 30% of 1RM and 30 seconds of rest; For TRAD, three sets of 10 to 12 repetitions with 70% of 1RM and 120 seconds of rest were performed. After three weeks, from the fortieth to sixtieth week of training, the BFR arm performed one set of 30 repetitions and 3 sets of 15 repetitions with 30% of 1RM and 30 seconds of rest; and for TRAD, four sets of 10 to 12 repetitions with 70% of 1RM and 120 seconds of rest. Following the 3rd week, the 1RM was reassessed, and the load used in weeks four through six were calculated based on the updated 1RM. For BFR, the subjects were equipped with a cuff to be placed near the glenohumeral joint and then inflated to a pressure corresponding to 50% of the AOP of the arm blood flow. The occlusion pressure was maintained across all sets and rest and removed after the last set of exercises. For TRAD, the intensity was controlled by the zone of repetition, and subjects needed to complete movement failure with no more than 12 and not less than 10 repetitions. For BFR, sets were conducted to concentric movement failure, and the training load was adjusted session after session to maintain the prescribed repetition count (5). These protocols were described in detail elsewhere (31). Below, Table 1 shows how the training sessions were carried out.

Table 1. BFR x TRAD training protocol

Exercise: BFR	Days (Monday and Thursday) (series x reps)	Cadence	AOP	Rest	Intens/ (1RM)
1- BC (1 to 3 weeks)	3 x 30-15-15	4 s (2/2 con/exc)	50%	30 s	30%
2- BC (4 to 6 weeks)	4 x 30-15-15-15	4 s (2/2 con/exc)	50%	30 s	30%
Exercise: TRAD	Days (Tuesday and Friday) (series x reps)	Cadence		Rest	Intens/ (1RM)
1- BC (1 to 3 weeks)	3 x 10 a 12 RM	4 s (2/2 con/exc)		120 s	70%
2- BC (4 to 6 weeks)	4 x 10 a 12 RM	4 s (2/2 con/exc)		120 s	70%

Note: Training protocol with blood flow restriction (BFR); Traditional resistance training protocol (TRAD); BC – Biceps Curl; AOP – Arterial Occlusion Pressure; Intens/ – Intensity; 1RM – One Repetition Maximum; reps – repetitions; RM – maximum repetitions; 2/2 con/exc – 2 seconds concentric / 2 seconds eccentric; s – seconds.
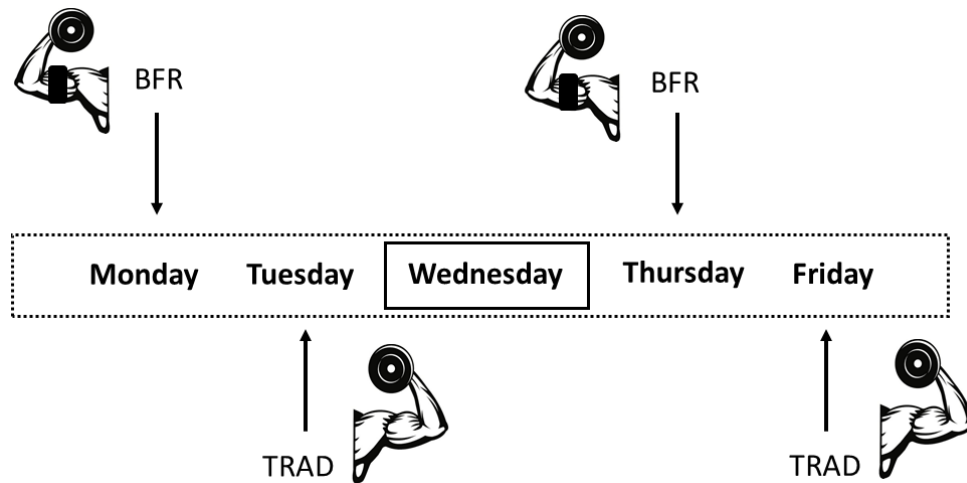

Figure 3. Training Division.
Note: BFR = blood flow restriction - Training Monday and Thursday; TRAD = traditional resistance training - Training Tuesday and Friday; Wednesday rest.

Statistical Analysis

The estimated sphericity was verified according to Mauchly's *W* test, and the Greenhouse-Geisser correction was used when necessary. A 2 x 12 (group x time) repeated measures analysis of variance with the Bonferroni adjustment for multiple comparisons was used to compare the total weight lifted in each training session between groups. A 2 x 3 (group x time) repeated measures analysis of variance with the Bonferroni adjustment for multiple comparisons was used to compare placebo and beta-alanine on the dietary intake and macronutrient distribution (baseline, after three and six weeks of training). A mixed factorial ANOVA was used to analyze 1RM for the longitudinal analysis. The supplementation group (placebo vs. beta-alanine) was included as the between-subject factor, and time (baseline and post-testing) and training condition (BFR vs. TRAD) were used as the within-subject factors. The interactions analyzed

were time x training condition, training condition x group, and time x training condition x group. If a significant training interaction was found, percent changes were calculated and compared with a one-way ANOVA. Effect sizes for the ANOVA were calculated using partial eta squared (η^2). Effect sizes (Cohen's) were calculated as the mean pre-post change divided by the pooled pretest standard deviation and defined as small, medium, and large for 0.20, 0.50, and 0.80, respectively. The data were analyzed using Statsoft Statistic software (version 10). Data are presented as mean and standard deviation (SD). The statistician was blinded to both groups during data analyses.

RESULTS

Table 2 shows the general characteristics of the sample. There were no significant differences between any variables at baseline. There were also no statistically significant differences between groups for dietary intake (kcal), carbohydrates, proteins, or fats expressed as grams or relative to body mass at any time and total kilocalories (Table 3. *Supplementary material*). The AOP for the Placebo group was 146 ± 11.7 mmHg and 150 ± 14.9 mmHg for the beta-alanine group. The pressure corresponding to 50% of the AOP used during the training program was 73 ± 5.9 mmHg for Placebo and 75 ± 7.4 mmHg for beta-alanine.

Table 2. General characteristics of the placebo and beta-alanine groups.

Variable	Placebo (*n* = 10)	Beta-alanine (*n* = 9)
Age (y)	22.6 ± 3.1	21.9 ± 2.8
Height (cm)	176.5 ± 3.5	173.3 ± 6.8
Weight (kg)	67.4 ± 6.1	74.0 ± 9.8

Note: Data are presented as mean +/- SD

Table 3. Comparison between placebo and beta-alanine on the macronutrient distribution.

Variable	Group	Week-1	Week-3	Week-6	Time x Group
CHO (g/kg/weight)	Placebo	4.3 ± 1.8	4.0 ± 2.3	3.9 ± 1.5	0.695
	Beta	4.1 ± 1.1	4.1 ± 0.9	4.1 ± 1.4	
PRO (g/kg/weight)	Placebo	1.9 ± 0.6	1.8 ± 0.5	1.9 ± 0.5	0.272
	Beta	1.4 ± 0.4	1.6 ± 0.5	1.7 ± 0.5	
LIP (g/kg/weight)	Placebo	0.9 ± 0.4	0.9 ± 0.3	0.9 ± 0.4	0.288
	Beta	0.8 ± 0.3	1.0 ± 0.4	0.9 ± 0.4	

Note: CHO = carbohydrate; PRO = protein; LIP = lipids.

Figure 4 compares placebo and beta-alanine on the total weight lifted (A), total weight lifted in each training session (B), and maximum strength (C).
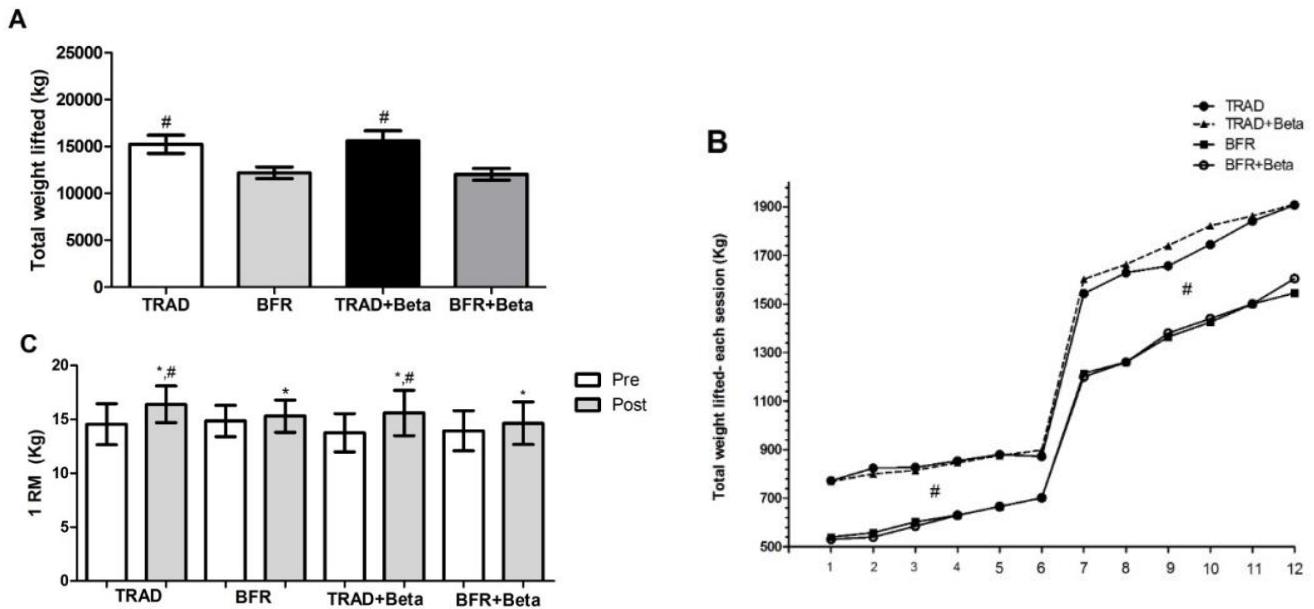
Figure 4. Comparison between placebo and beta-alanine. (A): Total weight lifted; (B): Total weight lifted in each training session. In (B): Adding one exercise set for both paradigms in the middle of the resistance training was made to assure muscle adaptations according to reference (31). (C): Maximum strength. Data are presented as mean +/- SD. (B) **Note**: BFR = blood flow restriction; BFR+Beta = blood flow restriction plus beta-alanine; TRAD = traditional resistance training; TRAD+Beta = traditional resistance training plus beta-alanine; *= statistically significant differences between Pre and Post-intervention; # = statistically significant differences between TRAD and BFR conditions. (Figure 4A), the statistical difference for TRAD in both groups (Placebo and beta-alanine, p = 0.001), no statistical difference for beta-alanine (p > 0.05). (Figure 4B), significant increases for TRAD (p < 0.05). (Figure 4C), significantly greater strength increases in TRAD compared to BFR (p < 0.001), with no significant interaction between groups and conditions with beta-alanine (p = 0.669). Data are presented as mean +/- SD.

There was a significant difference in total training volume (number of series x load x number of repetitions), between BFR and TRAD (Figure 4A), with significantly more weight for TRAD in both groups investigated (represented in absolute values, Placebo: BFR = 12.185 ± 1.965 vs. TRAD = 15.230 ± 3.061 kg, p = 0.001). However, for Beta-alanine (BFR = 12.336 ± 1.798 vs. TRAD = 15.823 ± 3.514 kg, p = 0.001), there were no treatment group x training condition interactions (p > 0.05). When analyzing the total weight lifted in each session of training, that is, the total weight that the subjects carried out during each exercise session, there were statistically significant differences between the BFR and TRAD in all training sessions, with greater increases for the TRAD condition (p < 0.05) compared to the BFR (Figure 4B). However, there were no treatment group x training condition x time interactions. For maximum strength (Figure 4C), there was a significant increase across time (F = 57.426, p < 0.001, η^2 = 0.77) with significantly higher strength increases in the TRAD compared to BFR (p < 0.001). However, there was no significant treatment group x training condition x time interactions (F = 0.189, p = 0.669). Effect sizes for 1 RM were BFR (d = 0.19), BFR+Beta-alanine (d = 0.30), TRAD (d = 0.78), and TRAD+Beta-alanine (d = 0.78).

DISCUSSION

This was the first study to investigate the effects of 6 weeks of beta-alanine supplementation on muscle performance during blood flow-restricted resistance training in healthy men. The main findings of the present study were that TRAD induced greater increases in strength and VLT compared to BFR. However, beta-alanine supplementation did not influence 1 RM strength adaptations to BFR or TRAD, nor did beta-alanine influence the volume of work performed. Based on these results, we reject our initial hypothesis that possibly increasing carnosine levels via beta-alanine supplementation would transitorily buffer the inhibitory muscle contraction, H^+ ions, thus increasing muscle BFR performance (i.e., maximal strength or tonnage). Increased muscle load induced by supplements with buffering properties, such as creatine, has been shown to augment muscle adaptations to BFR (31). However, in the present study, BFR performance-enhancing properties were not seen with beta-alanine supplementation under our experimental conditions.

It was hypothesized that beta-alanine supplementation would enhance the strength outcomes associated with RT, possibly via diminishing the formation of H^+ ions associated with muscle fatigue (16). The BFR and TRAD protocols used in this study were selected because they met the exercise criteria suggested by Trexler et al. (34), whereby beta-alanine supplementation may exert ergogenic effects. However, no additional benefits for muscle performance were found between supplementation groups in the current investigation. The effects of beta-alanine on strength performance following RT are somewhat ambiguous (34). Some studies have shown improvements in resistance exercise repetitions to fatigue (23, 20) and exercise volume (19), while others have reported no differences compared to placebo (13, 12).

Regarding maximal strength, beta-alanine combined with creatine monohydrate supplementation resulted in greater 1 RMs than creatine monohydrate or placebo alone. Still, the effects of beta-alanine versus placebo were not measured (15). In addition, Lowery et al. (19) observed increased bench press strength with a pre-workout multi-ingredient performance supplement containing 2.8g of a blend composed of micronized creatine monohydrate, beta-alanine, and creational-o-phosphate on which individual concentrations of each ingredient were not revealed. However, even considering that the blend was 100% pure beta-alanine, the supra-cited dose is still considered low, and the synergistic effects of beta-alanine with the other ingredients such as beetroot extract, caffeine, glucuronolactone, and green tea extract, among many others, may have influenced in the observed gains of performance in this study.

In a previous study (31), we observed the association of creatine supplementation with BFR-increased exercise volume and repetitions to failure at 30% 1RM, compared to BFR non-supplementing subjects. Interestingly, in both studies (creatine and the current study), BFR training was equalized to the number of repetitions and sets; however, only in the creatine study was an ergogenic effect observed for BFR. Thus, even matching exercise conditions and samples (i.e., young, untrained subjects from the same region of Brazil), beta-alanine was ineffective in enhancing VLT. However, it should be emphasized that other strength manifestations, such as

repetitions to failure at 30%, were not measured, and the possibility exists that beta-alanine could increase such performance.

It should be stressed, however, that the exercise herein employed was the unilateral arm curl, a small muscle compared to the lower limb quadriceps, where several studies demonstrated the benefits of beta-alanine supplementation. Furthermore, although the exercise volume employed was compatible with the arm flexor muscles, this is generally reduced compared to the larger quadriceps, where most beta-alanine effects were seen. In addition, our sample was composed of untrained individuals, lifting initial low loads compared to their training counterparts but compatible with their training state. In this regard, a recent study demonstrated the benefits of beta-alanine supplementation on VLT in trained subjects, who could squat 1.25x and 1x total body mass in the back squat and bench press exercises, respectively (4). In this case, the increased stress may have impacted muscle adaptations induced by beta-alanine supplementation, but future studies will be addressed to solve this question.

Last, our supplementation schedule started at the same time as the resistance exercise protocol. Considering that increases in muscle carnosine are dose- and time-dependent, our mild dose supplementation schedule (4.8g/day) may have delayed increasing muscle carnosine. In this respect, according to a prediction equation proposed by Spelnikov & Harris (30), when supplementing with a beta-alanine dose similar to ours, a subject would expect to achieve lower carnosine levels when compared to the observed when supplementing with 6.4g/day. On the other hand, the total beta-alanine dose consumed per subject in our study was 201.6 g of beta-alanine over six weeks. This is according to the beta-alanine threshold (179 g for total ingestion) for performance improvements proposed by Hobson et al. (8).

In conclusion, our findings demonstrate that six weeks of TRAD induced greater increases in strength and VLT compared to BFR. Furthermore, these results suggest that beta-alanine supplementation following the present dose and time schedule does not enhance exercise volume when combined with upper body BFR or TRAD training. Six weeks of BFR training with moderate occlusion pressure (50% arterial occlusion) or TRAD training associated with beta-alanine does not enhance total work or 1RM strength. Future studies employing longer periods of training/supplementation are necessary to explore this issue in depth, and studies performed on the larger, lower body muscles, such as the knee extensors, are advised.

ACKNOWLEDGEMENTS

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