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Review

Effects of Training with Blood Flow Restriction on Muscular Strength: A Systematic Review and Meta-Analysis

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ABSTRACT

International Journal of Exercise Science 15(3): 1563-1577, 2022. The purpose of this study was to analyze how blood flow restriction (BFR) training influences muscular strength through a systematic review and meta-analysis. The review was conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analyses guidelines. The following databases were used to conduct the research: Academic Search Complete, Medline, Web of Science, SPORT-Discus, HealthSource: Consumer, and HealthSource: Nursing. The following search limitations were included in this study: full-text articles investigating the effects of BFR training on muscular strength, published in a peer-reviewed academic journal, and published in the English language. Out of 327 articles, 25 were eligible to be included in this study. Comprehensive meta-analysis v.3 software was used to run statistics of the collected data from each study. The results showed that BFR training positively affects muscular strength. However, no group difference was found by gender, duration, workload, and cuff type/pressure in current data. This study provides additional information that can be used in future studies to obtain optimum strength results during BFR training.

KEY WORDS: Musculoskeletal, cuff pressure, gender, duration, workload

INTRODUCTION

A current commodity in the kinesiology world today is the addition of blood flow restriction (BFR) to exercise training to improve muscular strength and mass (hypertrophy). BFR training was first utilized in Japan by Doctor Yoshiaki Sato in the 1970s (21). Sato came up with the idea while he was sitting in a traditional Japanese posture when he suddenly realized that the blood flow is restricted to his calves and his feet giving him the same burning sensation he experienced during exercise. After this revelation, Sato began experimenting to replicate the physiological conditions he experienced, to produce similar results to exercising at high volumes. Once Sato's theory demonstrated positive results, he trademarked this form of training as KAATSU training, a Japanese term meaning "additional pressure" (21). Since Sato's initial theory, BFR training has become more refined and intricate. When combined with a form of exercise training, the contraction of the muscles under the conditions of low blood flow causes an elevation in metabolic stress that emphasizes activity in the sympathetic nervous system (41). While BFR is being used around the world today, it has yet to be perfected. Improving this training technique could significantly reduce the amount of recovery time needed for individuals recovering from injury, improve strength gains, and possibly provide safer approaches to BFR training (13). This begs the question of how much further BFR training can be refined if more research is conducted. The study of the pathways of muscle protein synthesis in BFR training is important, in that they provide insight into different possibilities for promoting muscle growth in special populations (16, 37). In the last 40 years alone blood flow restriction has seen a breakthrough in both practice and equipment used, which has turned it into the trending method of training it is today.

When training with BFR, different variables such as type of cuff and pressure can be used and applied to different training regimens. The availability of numerous variables for this training method paves the way for further research into the application of BFR in training regimens to be conducted. Ranging from the type of cuff and pressure used in training, to the placement of the cuff on an upper or lower extremity; researchers can compare factors such as cuff width, age of training subjects, device type, and training durations (40). BFR training can conveniently be used on either the upper or lower extremities. Whether an individual is focusing on recovering from an injury to a certain body part or training for a sporting event, the ability to train with BFR either lower or upper extremities provides numerous opportunities and advantages including further improving strength gains and faster recovery from the previous exercise (3,11). When combined with BFR, resistance training at lower loads has demonstrated exaggerated results in maximizing muscular strength (18). There are various mechanisms of BFR training proposed. These may include increases in hormonal concentrations, increases in intracellular signaling pathways for muscle protein synthesis such as the mTOR pathway, and increases in satellite cell activity (19). However, it appears that the exact mechanisms behind favorable adaptations to BFR training have yet to be discovered. As the popularity of BFR training increases in clinical, athletic, and personal settings, it will be interesting to see what the future holds for this training method in terms of new devices, commercialization, and training methods.

An understudied variable in BFR training is gender. In BFR literature, there is a vast underrepresentation of young and older women in comparison to their male counterparts (8). With this underrepresentation of women in BFR literature, it is difficult to determine and analyze the effects that BFR training has on skeletal muscle in women as compared to men. Each variable associated with BFR may or may not have a greater impact on the anticipated results of BFR training (strength gain and hypertrophy) (45). Even if a variable indicates insignificance to the results, the research behind it still provides insight into the BFR training for future researchers. For example, most training regimens associated with BFR consist of resistance exercise, however, several studies have emerged that analyze aerobic training with BFR (7,14). This information may be useful since it is providing more insight into other forms of exercises that will produce sought-out results when combined with BFR training. Since the use of BFR is becoming more common in a variety of settings from rehabilitation to use in professional sports, different modes and variables of this form of exercise must be analyzed and compared to appropriately and effectively use the technology that has been presented. With contradictory findings, the duration of training with BFR should be further analyzed, to accurately achieve the appropriate amount of time needed to increase muscular strength with BFR.

The purpose of this systematic review and meta-analysis is to analyze and assess which variables encompass a more favorable impact on the effects of BFR training. The moderator variables that will be analyzed in this review include gender, duration, workload, exercise mode, cuff type, and cuff pressure. Further research into the variables may help further refine the use of BFR as a method for increasing skeletal muscle strength. As research into BFR training is growing, so is the number of practitioners utilizing this training method (38). Therefore, investigations pertaining to the types of cuffs used and pressure applied during BFR training are pertinent to implementing research-based standards for BFR training that are both safe and effective.

METHODS

Participants

This systematic review and meta-analysis follow the guidelines provided in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (35). A literature search was conducted by two independent researchers (KG & KK) to identify relevant studies for the data collection. The databases used in the search included: Academic Search Complete, Medline, Web of Science, SPORT-Discus, HealthSource: Consumer, and HealthSource: Nursing. The search string was conducted in two sections with the use of the keywords "blood flow restriction" and "strength." The operator 'AND' was used to connect the two sections. Database restrictions included articles published in the English language, peer-reviewed articles, articles published in an academic journal or periodical, and articles containing human subjects. This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (36).

The research was conducted independently by each of the researchers following the same string for all databases "blood flow restriction" AND strength. Researchers continuously stayed in contact to ensure the same number of results were yielded in the databases. Once the same number of results were obtained, the studies were divided evenly between both researchers to screen. The title and abstract were analyzed for each study and exported into a file folder if the information provided was deemed relevant to the study. From the 327 records screened, 293 were excluded for either being irrelevant to the study or not having the appropriate information needed to be applicable to the study. The number of studies that were excluded from the review was recorded in the appropriate spaces provided in the PRISMA flow diagram in Figure 1. Studies were then further analyzed for the removal of duplicates.

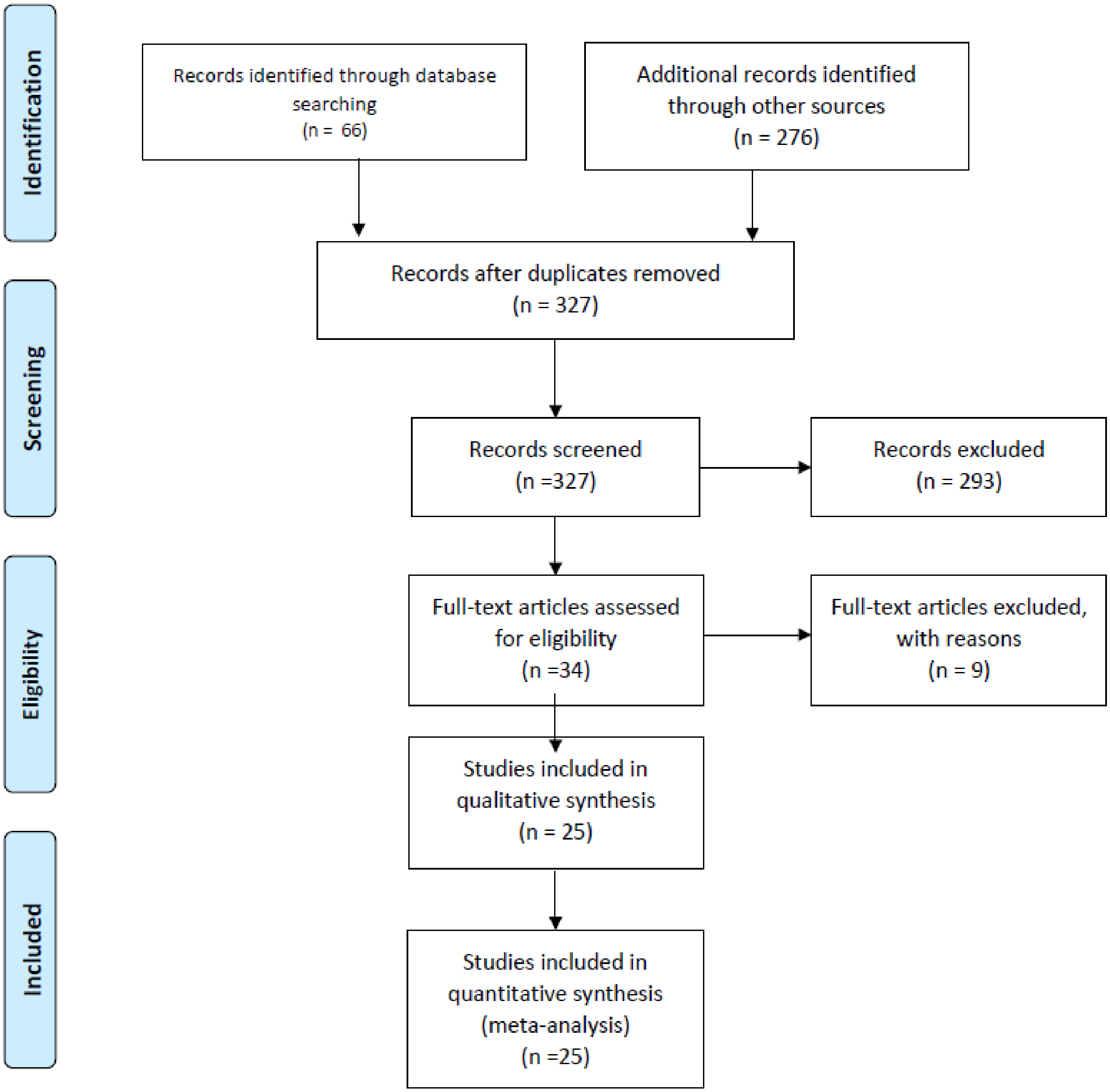

Figure 1. Flowchart indicating the number of studies used in this review

Inclusion and Exclusion Criteria
The full text of each study was screened based on inclusion and exclusion criteria. The inclusion and exclusion criteria for this study were as follows: (1) Sample consisted of healthy young individuals (< 60 years); (2) assessment of muscular strength in the included in the study with the inclusion of both pre-test and post-test measurements; (3) study must state the gender of sample being tested; (4) article states which form of training is being assessed (e.g., resistance, aerobic, or both).

Study Records
Data for the source of the study, author(s), subject type, age of subjects, gender, duration of experiment, controls, height, body weight, exercise type (aerobic, resistance, or both), exercise mode, strength measurements, and conclusion were obtained independently by two researchers. Any concerns in the studies were resolved through a face-to-face discussion. The data from the selected studies were extracted and inputted into a Microsoft Excel spreadsheet created for this data collection.

Data Extraction and Coding
Multiple characteristics were extracted from each of the included studies: study information (author, year), the gender of participants, study duration, exercise mode, cuff type (automatic or manual), cuff pressure, and quantitative outcomes (Pre-1RM, Post-1 RM). The extracted data was recorded into a Microsoft Excel table. Table 1 displays the data previously listed in each study that was evaluated.

Assessment of Methodological Quality
The methodological quality of included studies was assessed using a modified version of Downs and Black's checklist (12, 25). This checklist provides an overall score based on 27 criteria across four major categories including reporting, external validity, internal validity, and study power (25). The maximum score of the assessment was 28 where the higher score represents the higher methodological quality.

Independent reviewers assessed 25 studies and the scores were cross-checked. The discrepancies of the scores were discussed and solved by consensus. The average score was 19.16 (SD=1.72), indicating the included studies were fairly robust: (a) reporting (7.96 of 11), (b) external validity (2.12 of 3), (c) internal validity (8.16 of 13), and (d) study power (0.92 of 1).

Table 1. Characteristics of included studies

Authors/Citation	Age	Size	Gender	Length	Control	Workload	Exercise	Cuff Type	Cuff Pressure
Barcelos et al. (2015)	< 30 yrs.	10	Male	8 wks.	High/low load	20, 50% 1RM 1, 3 rep.	Unilateral knee extension	Pneumatic cuff	120-200
Bowman et al. (2019)	≤ 30 yrs.	26	Mixed	6 wks.	High/low load BFR	30% 1RM	Straight leg raise, Side-lying hip abduction, long arc quad extension, standing hamstring curl	Delfi Personalized Tourniquet System	80% AOP
Clark et al. (2011)	≤ 30 yrs.	9	Mixed	4 wks.	Res w/BFR, HLE	30, 80% HLE 1RM	Knee extension	Pneumatic cuff	N/A
Conceicao (2018)	< 30 yrs.	10	Male	8 wks.	RT, ET, ET-BFR	70%1RM, 40, 70%VO2r	Leg press	Pressure cuff	95
Dankel et al. (2016)	< 30 yrs.	13	Mixed	8 wks.	BFR	70%1RM	Elbow flexion	Nylon cuff	70%
95Denadai et al. (2017)	≤ 30 yrs.	6	Mixed	8 wks.	BFR training	30% 1RM	Knee flexion	Pressure cuff	144
Hill et al. (2018)	21.1 yrs.	12	Female	5 wks.	BFR	30% ECC peak torque	Elbow flexion	KAATSU master cuff	> 30
JBC et al. (2017)	≤ 30 yrs.	8~11	Mixed	6 wks.	High/low intensity HI w/ LI-BFR	30~33 % 1RM	Knee extension	Pressure cuff	129.83, 141.56
Jensen et al. (2016)	20-50 yrs.	18	Males	20 days	BFR	N/A	Aerobic training	Liquid cool compression cuff	60
Jessee et al. (2018)	< 35 yrs.	46	Mixed	8 wks.	High/low load BFR	15% 1RM	Knee extension	Pressure cuff	0%, 40% AOP
Kim et al. (2016)	≤ 35 yrs.	9	Male	10 wks.	High/low load BFR	30% 1RM	Elbow flexion	Nylon pressure cuff	72
Kim et al. (2017)	< 30 yrs.	10	Male	6 wks.	VI, LI-BFR	30, 60-70%HRR	Cycle ergometer	Elastic cuff	106-189
Ladlow et al. (2018)	≤ 30 yrs.	14	Male	3 wks.	LL-BFR Resistance training	30% 1RM	Leg press	Pressure cuff	124
Laurentino et al. (2015)	< 30 yrs.	11	Male	12 wks.	BFR + N, 5 cm	20%1RM	Elbow flexion	Pressure cuff	50–300
Madarame et al. (2007)	10.5 ~ 25.8 yrs.	7~8	Male	10 wks.	BFR	30, 30-40% 1RM	Knee extension Horizontal squat	Pressure belt KAATSU air cuff	160-220 200-250
Martin-Hernandez et-al. (2013)	20.3 ~ 21.1 yrs.	8~10	Male	5 wks.	LI-BFR, HIT	20% 1RM	Knee extension	Pneumatic cuff	110
May et al. (2018)	22.6 yrs.	12	Male	8 wks.	BFR	30% 1RM	Knee flexion	ATS 3000 tourniquet system	122
Oliveria et al. (2016)	≤ 30 yrs.	7~10	Mixed	6 wks.	LIT, HIT, BFR	30, 60, 102% Pmax	Cycle ergometer	Pressure cuff	140
Pope et al. (2015)	≤ 30 yrs.	5~7	Male	4 wks.	BFR	50% 1RM	Elbow flexion	Aneroid Sphygmomano meters	90-100
Sugiarto et al. (2015)	33.3 yrs.	6	Male	5 wks.	HIRT, LIRT BFR	30, 70%1RM	Bicep curl	Sphygmomano meters	50
Yamanaka et al. (2012)	≤ 30 yrs.	16	Male	4 wks.	BFR	20% 1 RM	Squat	Elastic bands	N/A
Yasuda et al. (2012)	22 yrs.	10	Male	6 wks.	ECC-BFR	30%-40% 1RM	Elbow flexion	KAATSU master cuff	100-160

Statistical Analysis

The overall effect size (ES) of the effect of blood flow restriction on skeletal muscle strength was examined using a meta-analysis with a random-effects model. Cohen's d, which is a method used to interpret the standardized differences between two means, was used to determine effect size: small (ES = 0.2); medium (ES = 0.5); and large (ES = 0.8) effects (6).

$$\text{Cohen's } d\ (ES_{sm}) = = \frac{\bar{X}_{G1-}\ \bar{X}_{G2}}{S_p} \text{ where } S_p = \sqrt{\frac{(N_{G1}-1)S^2{}_{G1} + (N_{G2}-1)S^2{}_{G2}}{(N_{G1}-1)+(N_{G2}-1)}}$$

Descriptive analyses were conducted using the Comprehensive Meta-Analysis version 3 software program (6).

RESULTS

Publication Bias

A visual inspection of a funnel plot (Figure 2) was used in order to verify any publication bias. The funnel plot was created using Comprehensive Meta-Analysis version 3 software program (6). The results showed that studies were symmetrical distributed indicating absence of bias.

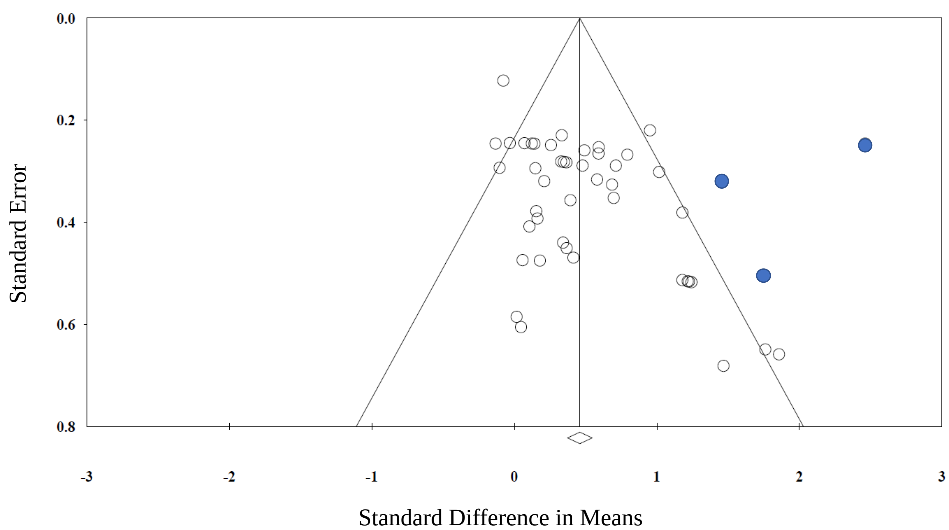

Figure 2. Funnel Plot of Standard Error by Std. diff in means

Overall Effect Size

The results from the study indicated that blood flow restriction (BFR) training had positive effects on skeletal muscle strength. Utilizing a random effects model, it was interpreted that the overall effect size (Cohen's d) was .558 (95% CI = .385, .731) which yielded a medium effect. As seen in figure 2, three BFR training studies had large effects on muscle strength among studies. The z-score for the random-effects model was 6.32 and the p-value was less than .001. Heterogeneity between studies demonstrated significance [Cochran's Q = 163.71; $df(Q)$ = 46; p-value < .001; I^2=71.90]. Figure 3 shows the standardized mean differences for effect size (ES) values, 95% CI and forest plot for all included studies.

Study name	Statistics for each study		
	Std diff in means	Lower limit	Upper limit
Barcelos et al. (2015)a	1.225	0.213	2.237
Barcelos et al. (2015)b	1.179	0.173	2.185
Barcelos et al. (2015)c	1.243	0.229	2.258
Barcelos et al. (2015)d	1.217	0.206	2.228
Bowman et al. (2019)	0.686	0.046	1.326
Clark et al. (2011)a	0.713	0.146	1.280
Clark et al. (2011)b	1.180	0.433	1.927
Conceicao et al. (2018)a	1.017	0.425	1.608
Conceicao et al. (2018)b	0.072	-0.409	0.552
Conceicao (2018)c	0.142	-0.341	0.624
Dankel et al. (2016)	0.163	-0.607	0.933
Denadai et al. (2017)	1.468	0.132	2.804
Hill et al. (2018)a	0.333	-0.117	0.784
Hill et al. (2018)b	1.451	0.823	2.079
JBC et al. (2017)a	0.793	0.269	1.318
JBC et al. (2017)b	0.591	0.071	1.112
JBC et al. (2017)c	0.479	-0.088	1.046
JBC et al. (2017)d	0.366	-0.188	0.920
Jenson et al. (2016)	0.952	0.521	1.384
Jessee et al. (2018)a	2.462	1.980	2.943
Jessee et al. (2018)b	-0.077	-0.317	0.163
Kim et al. (2016)a	0.368	-0.516	1.252
Kim et al. (2016)b	0.342	-0.520	1.205
Kim et al. (2017)a	1.761	0.488	3.034
Kim et al. (2017)b	1.857	0.566	3.149
Ladlow et al (2018)	0.154	-0.587	0.896
Lourentino et al. (2015)	0.592	0.096	1.089
Madaramae et al. (2007)a	0.329	-0.222	0.880
Madaramae et al. (2007)b	0.148	-0.429	0.725
Madaramae et al. (2011)a	0.581	-0.039	1.202
Madaramae et al. (2011)b	0.348	-0.205	0.901
Martin-Hernandez et al. (2013)a	0.180	-0.752	1.111
Martin-Hernandez et al. (2013)b	0.058	-0.872	0.988
Martin-Hernandez et al. (2013)c	0.415	-0.505	1.335
May et al. (2018)	0.107	-0.694	0.907
Oliveira et al. (2016)a	-0.031	-0.511	0.449
Oliveira et al. (2016)b	0.492	-0.016	1.000
Oliveira et al. (2016)c	-0.103	-0.678	0.473
Oliveira et al. (2016)d	-0.131	-0.613	0.351
Pope et al. (2015)a	0.016	-1.131	1.164
Pope et al. (2015)b	0.047	-1.140	1.234
Sugiarto et al. (2017)a	0.698	0.007	1.389
Sugiarto et al. (2017)b	1.748	0.763	2.734
Sugiarto et al. (2017)c	0.210	-0.416	0.837
Yamanaka et al. (2012)	0.394	-0.306	1.094
Yasuda et al. (2012)a	0.123	-0.359	0.605
Yasuda et al. (2012)c	0.258	-0.230	0.746
	0.558	0.385	0.731

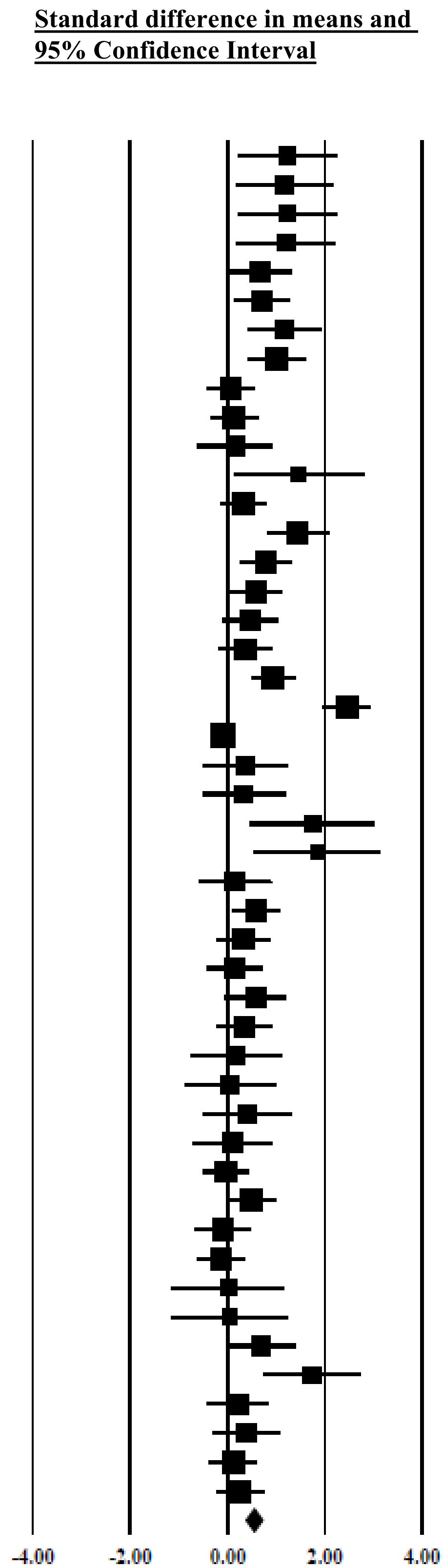

Figure 3. Standardized mean differences for effect size (ES) values

Moderator Analysis

Table 2 displays the results of the moderator analysis. These statistics include ES, 95% CI, and Cochran's *Q* statistic for each of the moderator variables. The moderator analyses were performed in order to observe the effect of gender, duration, workload, mode, cuff type and cuff pressure on overall weighted mean ES. The study indicated that there was no significant group difference by group. However, some group had significant effect on the outcome while some do not have a significant effect on the outcome depend on the group categorization. Based off the results of the moderator variables it was determined that the following groups have relatively larger impact on muscular strength than other groups: gender-females (ES = .851, *p*-value = .037), duration of more than 8 weeks (ES = .632, *p*-value=.008), workload of 60%-80% (ES=.794, *p*-value = .000), lower body exercise mode (ES = .610, *p*-value = .000), automatic cuff type (ES = .649. *p*-value = .001), and cuff pressure of more than 150 mmHG (ES = .810, *p*-value = .001).

Table 2. Effect sizes by moderator variables in the meta-analysis

Moderator variables		*N*	ES	95% CI		*p*-value	Q_b
				Lower	Upper		
Gender	Male	30	.566	.335	.797	.000	.620
	Female	2	.851	.052	1.649	.037	
	Mixed	15	.511	.216	.805	.001	
Durations	< 4 wks.	2	.608	-.024	1.419	.142	.131
	4-8 wks.	38	.544	.347	.740	.000	
	> 8wks.	7	.632	.168	1.095	.008	
Workload	< 40%	27	.513	.290	.735	.000	3.182
	40-60%	9	.366	-.031	.763	.071	
	> 60%	10	.794	.423	1.164	.000	
Mode	Upper body	19	.457	.178	.736	.001	1.226
	Lower body	27	.610	.380	.841	.000	
	Both	1	.952	-.115	2.019	.080	
Cut type	Manual	22	.591	.320	.863	.000	.636
	Automatic	9	.649	.270	1.029	.001	
	NA	16	.465	.161	.769	.003	
Cut Pressure	< 50 mmHG	2	.851	.049	1.653	.038	1.953
	50-150 mmHG	21	.467	.202	.733	.001	
	> 150 mmHG	7	.810	.313	1.307	.001	

DISCUSSION

The purpose of this study was to review the literature and utilize the meta-analytical model in order to determine differences in moderator variables and how they affect the implementation of BFR in increasing skeletal muscle strength. The data collected indicated that 1) BFR interventions displayed positive effects on skeletal muscle strength; 2) Moderator analyses indicated that some individual variables had a significant effect on the overall outcome.

Publication Bias: Publication bias for this analysis was determined using a funnel plot. A funnel plot is a means of testing for publication bias using asymmetry (17). As can be seen in Figure 2, the x-axis represents the standard difference in means, and the y-axis represents standard error. Studies consisting of larger populations that contain higher power, or placed towards the top of the pyramid, and studies containing smaller populations are placed toward the bottom of the inverted funnel. In order for a funnel plot to be symmetrical, the x-intercept should be close to zero. The x-intercept on Figure 2 falls around 0.5 indicating that there is no publication bias in this study.

Effect Size: The overall effect size obtained from this meta-analysis indicates that training with BFR has a significant effect on increasing skeletal muscle strength in the studies that were reviewed. The results depicted in this study are consistent with other research that has investigated the effects of BFR training on muscular strength. Results from a meta-analysis conducted by Slysz et al. (41). are also indicative of increases in muscular strength with BFR implementation. Oliveira et al (10). analyzed functional gains differences between four groups: high intensity training (HIT) with BFR, HIT without BFR, low-intensity training (LIT) with BFR and LIT without BFR. Both HIT groups in the study were only able to increase aerobic performance, however the LIT with BFR group demonstrated increases in both aerobic performance and muscular strength (10). The findings of this meta-analysis provide further support to the claim that BFR training does in fact have a medium impact on muscular strength.

Gender: Once the moderator analysis of gender was conducted, studies including females indicated the highest ES (.851) over studies with only males and studies including males and females. The combined group had the lowest ES (.511). However, there were only two studies that included a female only group; therefore, the results may have been skewed. Further analysis should be conducted on the muscular adaptations of BFR training in females. As mentioned in the literature review by Counts et al (8)., women are underrepresented in research pertaining to BFR training. The effect sizes of the male and combined groups are .566 and .511respectively. In the meta-analysis mentioned previously, the effect sizes were .42 and .26, and it was explained that this was a result of females in the group being a "buffer" (27). Although male-only groups both indicated a higher ES, the two groups in this study did not indicate as great a difference in ES as the values in the other meta-analysis (27). Based on these findings, it may be plausible that women are not as much as a "buffer" when it comes to muscular adaptations from BFR training as previously explained. Further research should be conducted to compare and contrast the differences in muscular adaptations of males and females when training with BFR. Further research into the variables may provide insight into present research.

Duration: Exercise duration was analyzed in three subgroups: 1) < 4 weeks 2) 4-8 weeks and 3) > 8 weeks. Results indicated that the studies with the largest ES on muscular strength were those with durations greater than eight weeks (ES = .632). The results are consistent with those of Loenneke et al. (27). As mentioned above, their investigation indicated that muscular strength did not significantly increase until the 10-week time point; which may indicate that neural adaptations may not occur until much later in a training program (27). If those indications are accurate, then studies of durations of < 8 weeks are not accurately depicting the strength benefits that blood flow restriction is producing.

Workload: The effects of workload were also analyzed in this study, comparing very low loads (15%-40% 1RM), low-moderate loads (40%-60% 1RM) and high loads (60%-80% 1RM). Based on the moderator analyses, studies that used high loads contained the largest ES (.794). Under normal conditions, 70% of 1RM has been deemed necessary in order to increase muscular strength (47). These findings may infer that when implementing BFR into a training regimen using high loads that are ~70% 1 RM, maximum strength gains may be able to be achieved. Further analysis into this factor should be analyzed, such as a comparing high load with BFR implementation versus regular high load resistance training to determine the difference in strength gains between the two variables.

Mode: In the moderator analyses for mode, studies that used upper body training methods, lower body training methods, or both were included. Based on the results, it appears that studies that utilized both training methods appeared to have the largest ES (.952). However, this may be due to the fact that there was only one study investigating both upper and lower body strength with BFR implementation. If this is the case, then lower body exercises seem to indicate the larger effect size (.610) versus upper body training. These results may prove beneficial to individuals who have injured a certain extremity or are interested in strengthening one or more of their extremities.

Cuff Type: Over the history of BFR training, the equipment behind it has greatly improved. From tire tubes and rubber bands to manual air cuffs, and finally automatic cuffs that are used today. The effects of both manual and automatic cuffs were explored in this analysis. From the results, it can be inferred that automatic cuffs have the greater effects on BFR training and strength due to the larger effect size obtained from the analysis (.649). The use of automatic cuffs allows for an accurate measurement of an individual's arterial occlusion pressure (AOP) which in turn allows for a precise calculation of the percent of blood flow being restricted from an extremity. Whereas, with a manual cuff, most studies use a set pressure throughout the course of the study. This may cause some inaccuracies in results since each person has a different arterial occlusion pressure. Not only are automatic cuffs more effective due to the enhanced technology behind them, but they also provide a safer approach to BFR training (34).

Cuff Pressure: In relation to cuff type, the effects of cuff pressure on muscular strength with BFR implementation were also analyzed. Through the analysis, it was found that cuff pressure of < 50 mmHG had the greatest ES (.851), however this is probably subsequent to only two studies that used pressures of < 50 mmHG. Aside from studies with pressures of < 50 mmHG, the collected data indicated that studies that included pressures of > 200 mmHG also exhibited a large effect size on the outcome (.810). Both groups both having a relatively large ES may be an indicator that the absolute pressure for increasing muscular strength may not have to be as high as some believe. These results are consistent with other studies that have found that higher cuff pressures are no more effective at increasing intramuscular metabolites than moderate pressure, especially if one is utilizing a wide cuff. Other studies have also found that using too high of a pressure during BFR training may actually prevent optimum results by occluding all blood flow to the extremity (34). Not only could results be inhibited by too much pressure, but as mentioned above by McEwen et al. (34), too much pressure could also be dangerous to individuals participating in BFR training (34). These findings may be useful in creating standard methods to safely and efficiently utilize and study BFR training.

Conclusion: This meta-analysis offers information into the overall impact of numerous training variables on blood flow restriction training's effect on skeletal muscle strength. The meta-analysis contained 25 studies that met the inclusion criteria, allowing for recommendations to be made from the observed results and patterns of the different variables. This study presents information that may be valuable in future studies to reap maximum strength gain through blood flow restriction training. From the information observed, it can be concluded that using an automatic cuff presents a better response to strength gain than a manual cuff. It was also found that higher workloads have a high impact on strength when combined with BFR. Furthermore, more longitudinal studies should be conducted in order to study the long-term effects of BFR on muscular strength. Longitudinal studies will also provide more insight into the pattern of strength gains with BFR training.

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