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Blood Flow Restriction Training for Athletes

CME

A Systematic Review

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Background: Blood flow restriction (BFR) is a novel technique involving the use of a cuff/tourniquet system positioned around the proximal end of an extremity to maintain arterial flow while restricting venous return.

Purpose: To analyze the available literature regarding the use of BFR to supplement traditional resistance training in healthy athletes.

Study Design: Systematic review.

Methods: A systematic review was performed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. From November to December 2018, studies that examined the effects of BFR training in athletes were identified using PubMed and OVID Medline. Reference lists from selected articles were analyzed for additional studies. The inclusion criteria for full article review were randomized studies with control groups that implemented BFR training into athletes' resistance training workouts. Case reports and review studies were excluded. The following data were extracted: patient demographics, study design, training protocol, occlusive cuff location/pressure, maximum strength improvements, muscle size measurements, markers of sports performance (eg, sprint time, agility tests, and jump measurements), and other study-specific markers (eg, electromyography, muscular torque, and muscular endurance).

Results: The initial search identified 237 articles. After removal of duplicates and screening of titles, abstracts, and full articles, 10 studies were identified that met the inclusion criteria. Seven of 9 (78%) studies found a significant increase in strength associated with use of BFR training as compared with control; 4 of 8 (50%) noted significant increases in muscle size associated with BFR training; and 3 of 4 (75%) reported significant improvements in sport-specific measurements in the groups that used BFR training. Occlusive cuff pressure varied across studies, from 110 to 240 mm HG.

Conclusion: The literature appears to support that BFR can lead to improvements in strength, muscle size, and markers of sports performance in healthy athletes. Combining traditional resistance training with BFR may allow athletes to maximize athletic performance and remain in good health. Additional studies should be conducted to find an optimal occlusive pressure to maximize training improvements.

Registration: CRD42019118025 (PROSPERO).

Keywords: blood flow restriction training; athletes; exercise; occlusion training

Blood flow restriction (BFR) training has garnered increased attention in recent years because of the potential for individuals to achieve an increased degree of muscle burden and physiologic change at a lower level of resistance training. BFR training involves the use of a cuff or tourniquet system positioned circumferentially around the proximal end of an extremity and inflated to a predetermined pressure (studies range from 110 to 240 mm Hg) in an attempt to maintain arterial flow while restricting venous return.[25] This technique is believed to have originated in the 1970s with Dr Yoshiaki Soto's Kaatsu resistance training; however, it was not until 1998 that the first study was published on BFR training.[5,25] By occluding venous outflow from the extremity, the resulting anaerobic environment promotes muscle hypertrophy through cell signaling and hormonal changes similar to what is seen at higher-intensity training with more resistance.[5] Recent studies have proposed alternatives to the traditional setup, including using Kaatsu bands and hook-and-loop resistance bands. These devices provide similar venous occlusion but at individualized perceived resistance rather than a predetermined pressurized level.[14,15,24,29]

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Traditional resistance training has long been viewed as the primary method for increasing strength and muscle size in athletes.[3,7] The American College of Sports Medicine recommends performing resistance training at 70% of an individual's concentric 1-repetition maximum (1RM) to improve muscular strength and hypertrophy.[3] Several techniques—including low-volume, high-intensity work or endurance-style training regimens—have proven effective for athletes looking to improve strength and performance.[2] By contrast, it has been suggested that with the use of BFR, resistance training at 20% to 50% 1RM can result in muscle hypertrophy similar to that of traditional strength training protocols.[28,32] Despite this, a limited number of studies have examined if and how BFR can be implemented as part of a traditional training regimen to enhance gains in strength and performance.[23]

It remains unclear how BFR elicits cellular responses to increase recovery and promote muscle hypertrophy.[13] Several hypotheses have been proposed, including that the cellular mechanism is related to metabolic stress,[20] elevated muscle fiber recruitment,[30,31] or other metabolic signaling mechanisms leading to increased muscle development through the enhanced production of growth hormone or the accumulation of metabolites, causing muscle cell swelling.[12,21,26] BFR has been used during physical therapy to aid in the recovery of elderly patients after knee arthroscopy or more complex knee surgery, such as anterior cruciate ligament reconstruction.[5,19] BFR has also been utilized to treat patients with knee osteoarthritis.[6] For patients undergoing nonoperative and postoperative rehabilitation, regaining strength by training at high loads is not often feasible; thus, many orthopaedic surgeons and physical therapists have begun incorporating BFR therapy to facilitate improvements in strength.[9,28]

There is a paucity of literature about the use of BFR among well-trained athletes and whether BFR training can elicit similar responses to those seen in athletes who follow more traditional resistance training protocols. The purpose of this systematic review was to analyze the available literature regarding the use of BFR to supplement resistance training in healthy athletes.

METHODS

The review was reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Additionally, it was registered through PROSPERO online (CRD42019118025). No meta-analysis was undertaken for the included studies, given the heterogeneity of treatment techniques employed. The conclusions were based on small sample sizes and may have been underpowered. However, the samples were composed of high-level athletes (collegiate, semiprofessional, or professional) with adequate monitoring and proper tracking of data.

Literature Search

From November 1 to December 31, 2018, an online literature search was performed using PubMed and OVID Medline. A computerized search using the following search terms was conducted: "Blood flow restriction" OR "Blood flow occlusion" OR "Kaatsu" OR "vascular occlusion" OR "Ischemia" OR "restricted blood flow" OR "occlusion training" AND "athlete" OR "student athlete" OR "elite athlete."

Selection Criteria

Studies were considered for inclusion if they were peer-reviewed articles that (1) examined BFR training in athletes; (2) implemented BFR training into an anaerobic/resistance workout regimen whereby athletes perform high-intensity movements for short bouts to promote strength, endurance, or power; (3) were randomized or matched experimental studies; (4) included a comparison between treatment and control groups; and (5) were English-language publications. This review excluded studies that (1) did not use BFR as a primary training regimen; (2) used BFR in conjunction with aerobic/cardiovascular training; (3) were case studies, systematic reviews, or opinion-based editorials; or (4) were not English-language publications.

Study Selection

The relevant titles and abstracts of the articles identified during the search were reviewed to determine if they met inclusion criteria. Duplicates were removed, titles and abstracts were screened, and full texts were read for inclusion assessment. References of the relevant articles were reviewed for related studies. Two coauthors (R.J.W. and S.M.B.) independently performed the literature search and identified articles that met the inclusion and exclusion criteria. Our senior author (M.K.M.) served as a third reviewer in the case of any discrepancies. Included studies were evaluated for their level of evidence in accordance with the Oxford Centre for Evidence-Based Medicine (Table 1).[8]

Data Extraction

The following data were extracted: athlete demographics, study design, number of training sessions, training protocol

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TABLE 1
Studies Included in the Systematic Review:
Training Protocols, Changes in Muscle Strength, Markers of Sports Performance, and Muscle Size[a]

First Author: LOE[b]	Cohort of Athletes	Training Protocol	Training Duration and Frequency	Cuff Location and Pressure, mm Hg	Strength Improvements	Markers of Sports Performance	Muscle Size Changes
Abe[1]: 1	Male collegiate track and field athletes (n = 15)	Squats and leg curls: 3s × 15r at 20% 1RM	8 d, 2 sessions/d	Most proximal part of thigh, 160-240	Significantly increased 1RM leg press in BFR vs control group	Significantly improved 30-m and 10-m sprint time in BFR vs control group	Significantly improved thigh muscle thickness in BFR vs control group measured via ultrasound; significantly improved muscle-bone CSA in BFR vs control group measured via anthropometry
Cook[4]: 1	Male semiprofessional rugby players (n = 20)	Bench press, leg squat, and pull-ups: 5s × 5r performed at 70% 1RM	3 wk, 3 sessions/wk	Proximal part of thigh, 180	Significantly improved 1RM squat and bench press	Significantly improved maximal sprint time and countermovement jump power	NA
Lowery[14]: 1	Male collegiate weight lifters (n = 20)	Bicep curls: 3s × 30r at 20% 1RM	4 wk, 2 sessions/wk	Proximal part of upper extremity; elastic practical BFR bands were strapped to 6 or 7/10 perceived pressure	NA	NA	No significant difference between groups in muscle thickness improvements via ultrasound measurement
Luebbers[15]: 2	Male collegiate football players (n = 62)	Bench press and squat: 4s × 30-20-20-20r at 20% 1RM	7 wk, 4 sessions/wk; BFR sessions came after normal strength training program workouts (4 total groups)	Proximal part of upper extremity (bench press) and thigh (squat); elastic practical BFR bands used and pulled to 7.6 cm	High-intensity training with additional low-load BFR resulted in significant 1RM squat improvements between groups but not in 1RM bench press	NA	No significant differences in chest, arm, or leg girths across groups
Manimmanakorn[16]: 1	Female netball athletes (n = 30)	Bilateral knee flexion and extension: 3s to failure at 20% 1RM	5 wk, 3 sessions/wk	Proximal part of thigh, 160-230	Improved flexor and extensor muscle strength vs control groups	Improved muscular endurance, 5-m sprint, 10-m sprint, 505 agility test, vertical jump test, and 20-m shuttle run test vs control group	Improved flexor and extensor muscle CSA vs control group via MRI
Neto[18]: 1	Male jiu-jitsu fighters (n = 12)	Squats: warm-up set of 10-15r at 20% 1RM, then 1s to failure at 80% 1RM	8 d, 1 session/d	Proximal part of thigh, 110	No significant differences in isometric strength via surface EMG muscle firing[c]	NA	NA
Sakuraba[22]: 2	Male track and field university athletes (n = 21)	Isokinetic knee flexion and extensions: 3s × 10r	4 wk, 2 sessions/wk	Proximal part of thigh, 110	BFR training with high- or low-intensity training improved isokinetic muscle strength but greater improvements with high intensity	NA	No significant change in CSA across groups measured via MRI
Scott[24]: 2	Male semiprofessional soccer players (n = 21)	Low-load squats 3/wk	5 wk of normal resistance training regimen with additional BFR training regimen	Proximal part of thigh; elastic practical BFR bands were strapped to 7/10 perceived pressure	No significant improvement in BFR vs control group for the 3RM squat test	No significant improvement in BFR vs control group for countermovement jump or sprint performance	No significant differences in muscle architecture were found via ultrasonography
Takarada[27]: 2	Male elite rugby team (n = 17)	Isokinetic bilateral knee extensions: 4s to failure	8 wk, 2 sessions/wk	Proximal part of thigh, 196	BFR group showed significant improvements in isometric and isokinetic muscular strength	NA	CSA of knee extensors increased significantly in BFR group via MRI vs before BFR training; no significant changes in knee flexors[d,e]

(continued)

TABLE 1
(continued)

First Author: LOE[b]	Cohort of Athletes	Training Protocol	Training Duration and Frequency	Cuff Location and Pressure, mm Hg	Strength Improvements	Markers of Sports Performance	Muscle Size Changes
Yamanaka[29]: 1	Male collegiate football players (n = 32)	Bench press and squat: 4s × 30-20-20-20r at 20% 1RM	4 wk, 3 sessions/wk after normal training	Proximal part of upper extremity and thigh; hook-and-loop practical BFR bands were used and tightened to restrict arterial flow but not venous return	1RM bench press and squat significantly improved in BFR vs control group	NA	Upper chest, lower chest, and upper left arm girths were significantly improved via a standardized muscle girth measurement protocol

[a]1RM, 1-repetition maximum; 3RM, 3-repetition maximum; BFR, blood flow restriction; CSA, cross-sectional area; EMG, electromyography; LOE, level of evidence; MRI, magnetic resonance imaging; NA, not applicable; r, repetitions; s, sets.
[b]Oxford Centre for Evidence-Based Medicine LOE: 1, randomized controlled trial; 2, matched controlled study.
[c]Other findings: similar reductions in torque after maximal voluntary isometric contraction in BFR and control groups postexercise attributed to fatigue (measured by surface EMG).
[d]Did not measure muscle size changes in control group.
[e]Other findings: BFR group had significant improvements in knee extension torque and muscular endurance.

(eg, exercises, sets, repetitions), cuff location, cuff pressure, maximum strength improvements, markers of sports performance, muscle size measurements (imaging or manual measurements), and other study-specific measured markers.

RESULTS

Search Strategy and Criteria

The results of the search strategy and criteria are shown in Figure 1. The database search identified 237 articles. After removal of duplicates and review of titles and abstracts, 21 studies remained. These were read in their entirety and assessed for inclusion eligibility. Nine studies met inclusion criteria. A search of the reference lists of the included studies identified 1 additional article, leaving 10 studies for this review. An overview of the studies and their outcome measures is summarized in Table 1.

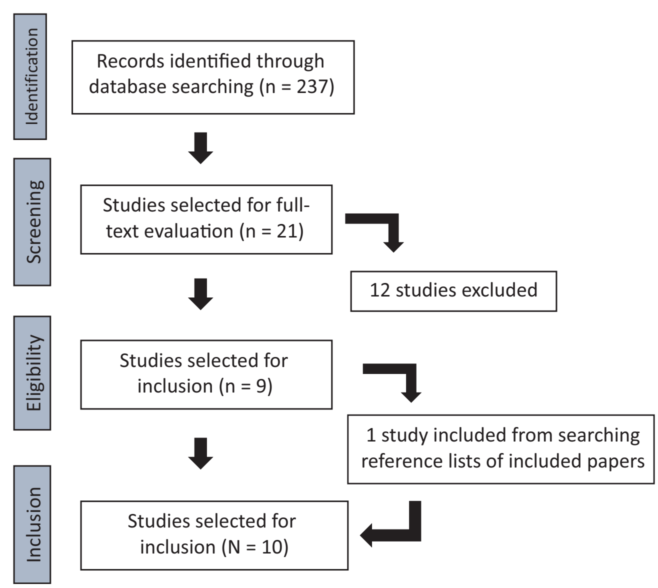

Figure 1. Flowchart using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines presents the search procedure and study selection.

Outcome Measures

Clinical Population. The 10 studies in the systematic review included a total of 250 athletes (220 male, 30 female) from various sports, including track and field,[1,22] rugby,[4,27] American football,[15,29] weightlifting,[14] netball,[16] jiu-jitsu fighting,[18] and soccer.[24] The participating athletes ranged in age from 19.8 to 25.9 years.

Training Intervention Methods. Table 1 details the BFR training protocols from each study. Abe et al[1] and Neto et al[18] conducted the shortest BFR protocols, lasting 8 days, while the protocol described by Takarada et al[27] lasted 8 weeks. Studies ranged in frequency of sessions from 1 per day[18] to 4 sessions per week.[15] BFR was combined with varying intensities of training, ranging from 20% 1RM[1,14-16,29] to 80% 1RM.[18] Additionally, BFR training was performed after regularly scheduled training sessions[15,24] and on lower body muscle groups only,[1,16,18,22,24,27] upper body muscle groups only,[14] or both.[4,15,29] Occlusive cuff pressure ranged from 110 to 240 mm Hg across studies. Additionally, some studies used a more practical BFR approach,[14,15,24,29] which is an elastic or hook-and-loop band device that can be tightened to a perceived resistance. In each of the 10 studies, the cuff or elastic band was placed at the most proximal portion of the extremity being trained to occlude venous return.

Physical Measures. Three categories measuring sports performance outcomes were examined in this study: strength improvements, sport-specific markers for performance, and changes in muscle size. These outcomes varied depending on the sport and targeted muscle group or extremity.

Strength. In many studies, muscle strength was assessed via isotonic 1RM tests for the squat[1,4,15,29] and bench press.[4,29] Other studies used isokinetic[22,27] or isometric testing[18,27] to examine muscle strength improvements. Of 10 studies, 9 (90%) reported strength improvements:

7[1,4,15,16,22,27,29] (78%; n = 197/230) found a significant increase ($P < .05$) in strength associated with the use of BFR training as compared with control groups that did not use BFR in at least 1 body group, and 2[18,24] (22%; n = 33/230) cited no significant improvements in strength as compared with a control group.

Cook et al[4] performed BFR training on the upper and lower body and reported significant improvements in the squat ($P < .01$) and bench press ($P < .01$). Conversely, Luebbers et al[15] indicated significant improvements in the squat ($P < .05$) but not the bench press in the BFR training group versus the control group. Neto et al[18] examined surface electromyography in male jiu-jitsu athletes for 8 days to compare muscle strength and maximum isometric torque in the quadriceps after incorporating a BFR protocol for squats. The BFR training and control groups demonstrated similar but not statistically significant ($P < .05$) reductions in isometric strength and torque. This study measured the reductions in isometric strength and torque as measurements of fatigue (greater strength reductions in progressive sets = greater fatigue) over the course of the 8-day protocol. Takarada et al[27] showed significant improvements in knee extension torque ($P < .05$) after BFR training as compared with the control group in their 8-week protocol.

Markers of Sports Performance. Studies that measured markers of sports performance utilized the following tests: sprint testing,[1,4,16,24] countermovement jump power,[4,24] muscular endurance,[16] 505 agility test,[16] vertical jump test,[16] and 20-m shuttle run test.[16] Three of 4 (75%; n = 65/86) studies demonstrated a significant improvement ($P < .05$) in the groups that used BFR training for at least 1 of these 6 metrics.[1,4,16] One of 4 (25%; n = 21/86) studies found no significant difference in any sports performance metric when comparing the use of BFR with a control group.[24] Scott et al[24] reported no significant improvements among male semiprofessional soccer players in countermovement jumps or sprint performance in a 5-week traditional resistance training regimen with added BFR workouts. Some studies were mixed in terms of which sports performance tests were statistically significant between the BFR and control groups. Abe et al[1] documented significantly improved 10- and 30-m sprint times ($P < .05$) but no significance in any jump tests in this cohort of male collegiate track and field athletes using BFR training.

Muscle Size. Muscle size improvements were examined via ultrasound muscle thickness,[1,14] muscle-bone anthropometry,[1] standardized muscle girth measurement protocol,[15,29] magnetic resonance imaging cross-sectional area (CSA),[16,22,27] and ultrasonography.[24] In terms of muscle size changes, 8 of the 10 (80%) studies reported results: 4 studies (50%; n = 94/218) noted significant increases in muscle size associated with BFR training,[1,16,27,29] whereas 4 (50%; n = 124/218) reported no significant differences in muscle mass in groups using BFR versus control.[14,15,22,24] Among male elite rugby players who performed BFR training on their legs, Takarada et al[27] found significant increases in CSA of the quadriceps ($P = .02$) before and after BFR by using magnetic resonance imaging. This study did not include a control group for the muscle size portion. Sakuraba and Ishikawa[22] used magnetic resonance imaging to measure femoral CSA in their cohort of male university track and field athletes and indicated no significant differences between the BFR and control groups. Future studies should seek to clarify the effect of BFR training on muscle size.

DISCUSSION

BFR training has become popular because of the potential for participants to achieve similar or greater strength and performance gains with lower levels of resistance. BFR has various uses, including incorporation into training regimens for high-level athletes or postoperative rehabilitation for patients with limited activity and weightbearing. Given the ability of BFR to stimulate gains at a submaximal load, athletes can incorporate this treatment at the end of a workout to achieve more muscle development.[23] Additionally, BFR training could be used in athletes who are susceptible to injuries or who cannot tolerate the traditional sets and repetitions of 60% to 75% 1RM.[23] This systematic review demonstrated that BFR training could lead to significant improvements in muscle strength, markers of sports performance, and muscle size. Presently, there is substantial variability with regard to the proposed frequency and durations of BFR training. Additionally, variations exist among the protocols for this type of training with regard to cuff size, cuff pressure, and frequency of training, which can lead to differing results among athletes. This makes it challenging to draw conclusions regarding which sports and athletes can most benefit from BFR training.

To date, 1 review has included solely athletes in the cohort.[23] Scott et al[23] (n = 228) concluded that muscular development is possible in well-trained athletes after low-load resistance BFR training but the neural stimulus is different as compared with traditional high-load regimens. The study also found that traditional high-load resistance training combined with low-load BFR training would provide maximal results for athletes. Other systematic reviews have looked at strength and muscular development but not specifically in athletes. In 2018, Lixandrao et al[11] performed a systematic review to examine the effects of BFR training in a population that included a broad spectrum of ages and with low-load resistance as compared with high-load resistance training. The authors found that there were greater muscle strength gains in the group using high-load exercise over BFR training. They also demonstrated that muscle size growth was similar in the high-load and BFR groups.[11] In the rehabilitation setting, Hughes et al[9] concluded that low-load BFR training could provide a more effective approach to low-load resistance training in a broad population undergoing clinical musculoskeletal rehabilitation.

The studies included in our systematic review demonstrated mixed results in terms of whether BFR can be used alone or in combination with regularly scheduled training programs. Scott et al[24] found that 5 weeks of traditional resistance training combined with BFR versus resistance training alone led to no difference in strength, muscle size, and sports performance testing results in 21 semiprofessional soccer players. Conversely, Yamanaka et al[29] found a significant improvement in 1RM of bench press and squat in 32

Division I football players using BFR training in comparison with a control group undergoing normal training over the course of 4 weeks. Luebbers et al[15] also evaluated the use of BFR in football players and found a significant increase in 1RM of squat but not bench press. The study also found no significant difference in muscle size changes.

Clinical Implications and Safety

The potential applications of BFR training are vast and include individualized training protocols for athletes as well as postoperative rehabilitation regimens. Additionally, patient or athlete selection remains a potential concern as well as an area for further investigation. Minniti et al[17] recently published a review of the safety of BFR training in patients with musculoskeletal disorders. The authors concluded that BFR training is relatively safe in patients with knee disorders, but more research is needed for other musculoskeletal conditions. Additionally, there are some relative contraindications to BFR therapy that could increase the risk of blood clotting, such as vascular disease, obesity, diabetes, sickle cell trait or disease, severe hypertension, cancer, and history of deep venous thrombosis.[5] Thus far, BFR training has been shown to be relatively safe, with very few complications reported and no apparent increased risk for clotting. Iversen and Rostad[10] reported 1 case of ischemic exercise–induced rhabdomyolysis, although this is the only known report. In our included studies, there were no reports of adverse events attributed to the use of BFR. However, research has been limited in this area, and further study has the potential to influence guidelines to help avoid complications associated with the use of BFR.

Limitations

This systematic review has several limitations. First, there is substantial variability with the implementation of BFR training. The training protocols in the studies varied drastically in their frequency, duration, and exercise regimens. This makes comparing results challenging in that athletes respond differently when they undergo different-style workouts. Second, only 10 studies met our inclusion criteria. It is possible that searching other databases would have identified more studies. Third, it is not possible to blind athletes in terms of whether they are training with or without BFR. This could affect the results, as the athletes may have worked harder in the BFR group, given the novel nature of the training. Naturally, athletes perform differently on different days and on the basis of the environment and a variety of internal and external variables. This creates inherent variability in the results of the BFR group when compared with those of the control group. Fourth, the cuff pressure during training varied considerably among the BFR protocols identified. Currently, there is no established range for cuff pressure that is necessary to obtain optimal vascular restriction or produce improvement in strength and hypertrophy. Finally, 4 studies[14,15,24,29] used practical BFR, whereas 6[1,4,16,18,22,27] used the traditional inflatable tourniquet method. There is currently not enough evidence in the literature to determine whether there is an advantage of one technique over the other. Overall, we believe that the evidence is of relatively high quality (levels 1 and 2) with regard to BFR as a topic; however, the applicability of the evidence is again limited, secondary to the heterogeneity of the application of BFR techniques, monitoring, and measurement of performance.

CONCLUSION

This systematic review demonstrated that BFR training has the potential to increase strength and performance when incorporated as part of resistance workout regimens for healthy athletes. Current literature supports the improvement of strength and sports performance with BFR training. However, there is variability in terms of whether BFR can lead to increased muscle size. Further investigation is needed to determine the overall efficacy of BFR training and its benefits in conjunction with a resistance training regimen for athletes. Future studies should also seek to define the ideal duration and frequency of training, number of repetitions, and cuff pressure needed to obtain the greatest benefit from BFR. Finally, it will be important to investigate how molecular biomarkers of muscle change in the athletic population undergoing BFR training.

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REFERENCES

1. Abe T, Kawamoto K, Yasuda T, Kearns CF, Midorikawa T, 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*. 2005;1(1):19-23.
2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. Lippincott Williams & Wilkins; 2000.
3. American College of Sports Medicine position stand: progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2009;41(3):687-708.
4. Cook CJ, Kilduff LP, Beaven CM. Improving strength and power in trained athletes with 3 weeks of occlusion training. *Int J Sports Physiol Perform*. 2014;9(1):166-172.

5. DePhillipo NN, Kennedy MI, Aman ZS, Bernhardson AS, O'Brien LT, LaPrade RF. The role of blood flow restriction therapy following knee surgery: expert opinion. *Arthroscopy*. 2018;34(8):2506-2510.
6. Ferraz RB, Gualano B, Rodrigues R, et al. Benefits of resistance training with blood flow restriction in knee osteoarthritis. *Med Sci Sports Exerc*. 2018;50(5):897-905.
7. Hass CJ, Feigenbaum MS, Franklin BA. Prescription of resistance training for healthy populations. *Sports Med*. 2001;31(14):953-964.
8. Howick J, Chalmers I, Glasziou P, et al. The Oxford levels of evidence 2. Published 2011. https://www.cebm.net/index.aspx?o=5653
9. Hughes L, Paton B, Rosenblatt B, Gissane C, Patterson SD. Blood flow restriction training in clinical musculoskeletal rehabilitation: a systematic review and meta-analysis. *Br J Sports Med*. 2017;51(13): 1003-1011.
10. Iversen E, Rostad V. Low-load ischemic exercise-induced rhabdomyolysis. *Clin J Sport Med*. 2010;20(3):218-219.
11. Lixandrao ME, Ugrinowitsch C, Berton R, et al. Magnitude of muscle strength and mass adaptations between high-load resistance training versus low-load resistance training associated with blood-flow restriction: a systematic review and meta-analysis. *Sports Med*. 2018;48(2):361-378.
12. Loenneke JP, Fahs CA, Rossow LM, Abe T, Bemben MG. The anabolic benefits of venous blood flow restriction training may be induced by muscle cell swelling. *Med Hypotheses*. 2012;78(1):151-154.
13. Loenneke JP, Wilson GJ, Wilson JM. A mechanistic approach to blood flow occlusion. *Int J Sports Med*. 2010;31(1):1-4.
14. Lowery RP, Joy JM, Loenneke JP, et al. Practical blood flow restriction training increases muscle hypertrophy during a periodized resistance training programme. *Clin Physiol Funct Imaging*. 2014;34(4): 317-321.
15. Luebbers PE, Fry AC, Kriley LM, Butler MS. The effects of a 7-week practical blood flow restriction program on well-trained collegiate athletes. *J Strength Cond Res*. 2014;28(8):2270-2280.
16. Manimmanakorn A, Hamlin MJ, Ross JJ, Taylor R, Manimmanakorn N. Effects of low-load resistance training combined with blood flow restriction or hypoxia on muscle function and performance in netball athletes. *J Sci Med Sport*. 2013;16(4):337-342.
17. Minniti MC, Statkevich AP, Kelly RL, et al. The safety of blood flow restriction training as a therapeutic intervention for patients with musculoskeletal disorders: a systematic review. *Am J Sports Med*. 2020;48(7):1773-1785.
18. Neto GR, Santos HH, Sousa JB, et al. Effects of high-intensity blood flow restriction exercise on muscle fatigue. *J Hum Kinet*. 2014;41:163-172.
19. Ohta H, Kurosawa H, Ikeda H, Iwase Y, Satou N, Nakamura S. Low-load resistance muscular training with moderate restriction of blood flow after anterior cruciate ligament reconstruction. *Acta Orthop Scand*. 2003;74(1):62-68.
20. Pearson SJ, Hussain SR. A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. *Sports Med*. 2015;45(2):187-200.
21. Reeves GV, Kraemer RR, Hollander DB, et al. Comparison of hormone responses following light resistance exercise with partial vascular occlusion and moderately difficult resistance exercise without occlusion. *J Appl Physiol (1985)*. 2006;101(6):1616-1622.
22. Sakuraba K, Ishikawa T. Effect of isokinetic resistance training under a condition of restricted blood flow with pressure. *J Orthop Sci*. 2009;14(5):631-639.
23. Scott BR, Loenneke JP, Slattery KM, Dascombe BJ. Blood flow restricted exercise for athletes: a review of available evidence. *J Sci Med Sport*. 2016;19(5):360-367.
24. Scott BR, Peiffer JJ, Goods PSR. The effects of supplementary low-load blood flow restriction training on morphological and performance-based adaptations in team sport athletes. *J Strength Cond Res*. 2017;31(8):2147-2154.
25. Shinohara M, Kouzaki M, Yoshihisa T, Fukunaga T. Efficacy of tourniquet ischemia for strength training with low resistance. *Eur J Appl Physiol Occup Physiol*. 1998;77(1-2):189-191.
26. Takarada Y, Nakamura Y, Aruga S, Onda T, Miyazaki S, Ishii N. Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *J Appl Physiol (1985)*. 2000;-88(1):61-65.
27. Takarada Y, Sato Y, Ishii N. Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *Eur J Appl Physiol*. 2002;86(4):308-314.
28. Wernbom M, Augustsson J, Raastad T. Ischemic strength training: a low-load alternative to heavy resistance exercise? *Scand J Med Sci Sports*. 2008;18(4):401-416.
29. Yamanaka T, Farley RS, Caputo JL. Occlusion training increases muscular strength in Division IA football players. *J Strength Cond Res*. 2012;26(9):2523-2529.
30. Yasuda T, Brechue WF, Fujita T, Shirakawa J, Sato Y, Abe T. Muscle activation during low-intensity muscle contractions with restricted blood flow. *J Sports Sci*. 2009;27(5):479-489.
31. Yasuda T, Loenneke JP, Ogasawara R, Abe T. Influence of continuous or intermittent blood flow restriction on muscle activation during low-intensity multiple sets of resistance exercise. *Acta Physiol Hung*. 2013;100(4):419-426.
32. Yasuda T, Ogasawara R, Sakamaki M, Ozaki H, Sato Y, Abe T. Combined effects of low-intensity blood flow restriction training and high-intensity resistance training on muscle strength and size. *Eur J Appl Physiol*. 2011;111(10):2525-2533.

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