REVIEW ARTICLE

A systematic review examining blood flow restriction in combination with isokinetic resistance exercise

John J. Welsh, Drew M. Robinson, Scott J. Dankel

Objectives: Many studies have examined the efficacy of blood flow restriction (BFR) applied during isotonic muscle actions, but its application with isokinetic exercise has been less explored and was the purpose of this systematic review.
Design: Systematic Review.
Methods: The online databases of Pubmed, Scopus, and Web of Science were searched on May 16, 2023 using the following search: "blood flow restriction OR kaatsu OR occlusion AND isokinetic." To be included in this review, the manuscripts had to incorporate human participants, involve the use of BFR during isokinetic exercise, and be written in English. Given limited studies comparing the same exercise completed with and without BFR, a quantitative meta-analysis was not completed.
Results: Twenty-one studies met the inclusion criteria, most of which incorporated concentric isokinetic contractions at 30% of peak torque using 40-60% of arterial occlusion pressure. Acutely, the addition of BFR did not appear to increase heart rate, blood pressure, muscle swelling, blood flow, or delayed onset muscle soreness, but it did increase markers of muscle activation. Chronically, the addition of BFR did not appear to enhance muscle hypertrophy, but augmentations in muscle strength depended on the speed and type of contraction.
Conclusion: The use of BFR during isokinetic exercise does not appear as effective when compared to isotonic exercise. Future studies may wish to examine different intensities and speeds of isokinetic exercises to determine its potential efficacy.
(***Journal of Trainology*** **2024;13(1):3-11)**

Key words: ■ kaatsu ■ muscle size ■ occlusion training ■ resistance exercise ■ strength

INTRODUCTION

Blood flow restriction (BFR) involves the use of elastic wraps or inflatable cuffs to reduce arterial inflow and occlude venous return from the distal musculature. The application of BFR has been shown to increase muscle size and strength when combined with low intensity aerobic exercise,[1,2] but is most commonly used in conjunction with low load resistance exercise where it has been shown to increase muscle size,[3,4] strength,[4] and physical function[5]. The adaptations occurring in response to low load exercise with BFR appear similar to that of higher load resistance exercise.[3] As such, the use of BFR may be particularly appealing for those who have difficulty lifting heavier loads such as older adults,[6] individuals with neurological diseases,[7] or those recovering from injuries[8].

Isokinetic exercises are unique in that there is no set force/torque required to complete each repetition. This allows for more adaptability when performing/administering exercise as there is no clear failure point that is reached, and each repetition can be performed maximally even as fatigue ensues. The ability to perform repeated maximal contractions using an isokinetic dynamometer may be why muscle adaptations are sometimes greater than that of isotonic exercise.[9] Similar to that of BFR, isokinetic exercise is commonly employed in rehabilitation settings to limit injury risk,[10] but there are notable differences between isokinetic and isotonic exercise that may alter how the BFR stimulus works.

Applying BFR during low load resistance exercise increases muscle activation as assessed by electromyography (EMG) amplitude[4] and inorganic phosphate splitting.[11] This has led to the hypothesis that metabolites trapped within the exercising musculature induce fatigue, which subsequently requires a greater number of active muscle fibers to make up for the loss of force production.[12] If this is indeed the mechanism, the efficacy of BFR applied during isokinetic exercise may depend on the relative force/torque applied, such that BFR may be useful for submaximal but not maximal exercise. While this would appear to be the case during isotonic exercise,[13] isokinetic exercises often do not require eccentric muscle actions. This may alter hemodynamics and allow for an increased reperfusion of blood flow between repetitions given the lack of eccentrically induced compression of skeletal muscle on the vasculature. Another major difference exists, in that, enhancing fatigue during high load isokinetic contractions will not reduce the number of repetitions that can be completed since the lever arm moves at a set speed without

Received March 14, 2024; accepted May 15, 2024
From the Department of Health and Exercise Science, Exercise Physiology Laboratory, Rowan University, Glassboro, NJ, USA (J.J.W., D.M.R., S.J.D.)
Communicated by Takashi Abe, Ph.D.
Correspondence to: Scott Justin Dankel, PhD. 201 Mullica Hill Rd; Glassboro, NJ 08028; James Hall Room 1044
Email: dankel47@rowan.edu
Journal of Trainology **2024;13(1):3-11 ©2024 The Active Aging Research Center http://trainology.org**

the need to generate a specified amount of force. Therefore, individuals can continue exercising even when they are extremely fatigued, which differs from isotonic exercise, where the number of repetitions will be reduced since the required force cannot be generated. Therefore, applying BFR during isokinetic contractions may allow for individuals to complete the same number of repetitions, albeit in a more fatigued state.

While BFR may be able to augment adaptations, it is also likely to increase participant discomfort and ratings of perceived exertion (RPE) relative to the same protocol completed without BFR.[14] Fewer studies have examined if discomfort and RPE would still be augmented by the addition of BFR when the contractions are performed in conjunction with isokinetic exercise. This is an important consideration as perceptual responses to exercise may be good predictors of exercise adherence. Furthermore, cardiovascular responses to exercise with and without BFR may provide insight into whether the use of BFR is safe for individuals with cardiovascular complications. Therefore, the purpose of this systematic review was to examine studies implementing BFR during isokinetic exercise to determine how it impacts both acute responses and chronic adaptations.

METHODS

The online databases of PubMed, Scopus, and Web of Science were searched on May 16, 2023 using the following search: "blood flow restriction OR kaatsu OR occlusion AND isokinetic." No filters or limits were used for the searches. A flow chart showing the number of articles scanned and reasons for exclusion are shown in Figure 1. To be included in this review, the manuscripts had to incorporate human participants, involve the use of BFR during isokinetic exercise, and be written in English. The references of the included studies were then searched for additional manuscripts meeting the search criteria. Each of the three authors worked independently to manually screen all articles without the use of any screening software. Once the first screening was completed, all three authors met to discuss which full articles should be obtained. If there were any disagreements, the full article was obtained and included in the second screening stage. Each of the three authors then evaluated the full manuscripts independently and met again after the second screening stage to discuss which articles met the inclusion criteria. Once the articles were obtained, SJD collected the data and created the tables. JJW and DMR then reviewed the tables for accuracy. While the primary outcomes of interest were changes in muscle size and strength, all the dependent variables assessed were included in this review. We also included information on the study design including the sample size, sex, age, training status, exercise mode, and application of blood flow restriction. Given the limited number of studies comparing the same exercise completed with and without BFR, a quantitative meta-analysis was not completed.

RESULTS

A total of 21 studies met the inclusion criteria.[15-35] A description of the methods of each of the included studies are shown in Table 1. Notably, the sample sizes ranged anywhere from 6[16] to 60 individuals[27,34]. The majority of the included studies assessed either knee extension[15,16,25-28,30,32-35] or elbow flexion[17-24,31] exercises, with one study assessing plantar and dorsiflexion[29]. The speeds of isokinetic contractions included 30°/sec,[16,25,26] 45°/sec,[15] 60°/sec,[27,28,34] 90°/sec,[32,33,35] 120°/sec,[17-24,30,31] and 300°/sec[33]. Studies incorporated either concentric,[16,18,19,21,22,24,28-31,35] eccentric,[15,25-27,34] or both concentric and eccentric[17,20,23] muscle actions. Most of the studies incorporated submaximal contractions at 30% of peak eccentric, con-

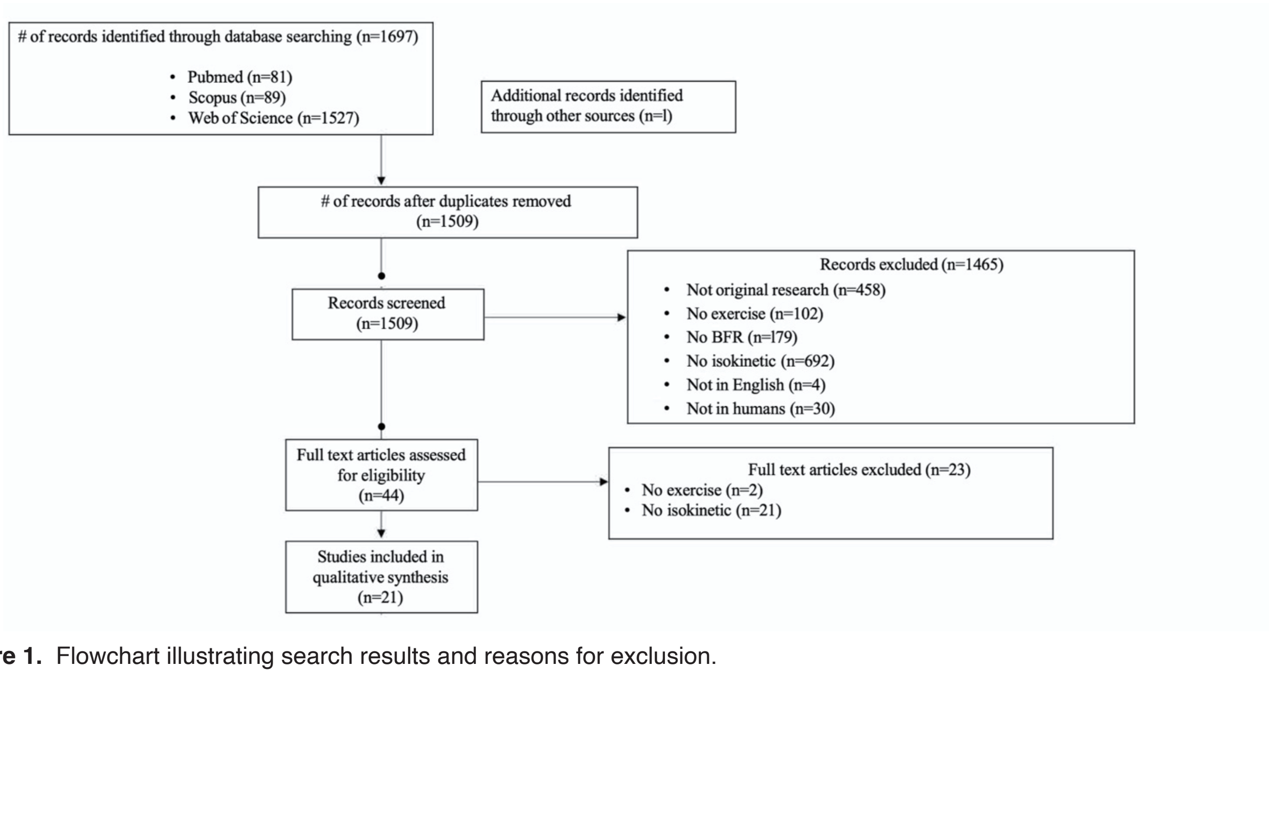

Figure 1. Flowchart illustrating search results and reasons for exclusion.

Table 1. Overview of Included Studies

Reference	Population	Torque	Blood Flow Restriction	Exercise Protocol
(15)	16 untrained males (mean age = 26)	30% of isometric peak torque.	13 cm cuff inflated to 90 - 100 mmHg which remained inflated for the whole protocol.	4 sets of eccentric knee extension exercises at 45°/sec were completed on a Cybex, but the repetitions are unknown. Individuals completed either: 1) eccentric exercise alone (n=6), or 2) eccentric exercise with BFR (n=10).
(16)	6 males (age not reported)	As close to 50% of maximum 1RM.	8.5 cm cuff was inflated to 100 mmHg. Cuff was inflated continuously throughout the protocol.	Knee extensions at 30°/sec were completed on a Biodex System 3. Exercises involved 10 repetitions per set with 90 seconds of rest in between. Everyone completed 1) exercise to volitional failure without BFR, 2) exercise to volitional failure with BFR, and 3) repetition matched protocol without BFR.
(22)	20 untrained females (mean age = 22)	30% of eccentric or concentric peak torque.	3 cm wide cuff inflated to 40% AOP which remained inflated for the duration of the exercises.	Concentric elbow flexion and extension exercises at 120°/sec were completed on a Cybex 6000. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. Everyone completed: 1) Low load BFR, and 2) Low load without BFR.
(23)	25 untrained females (mean age = 21.7)	30% of eccentric or concentric peak torque.	3 cm wide cuff inflated to 40% AOP which remained inflated for the duration of the exercises.	Either eccentric or concentric elbow flexion exercises at 120°/sec were completed on a Cybex 6000. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. 6 training session over the course of 2 weeks (3x/wk). Individuals completed either 1) eccentric only exercises (n=12), or concentric only exercises (n=13).
(17)	36 untrained females (mean age = 22)	30% of eccentric or concentric peak torque	3 cm wide cuff inflated to 40% AOP which remained inflated for the duration of the exercises.	Either eccentric or concentric elbow flexion exercises at 120°/sec were completed on a Cybex 6000. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. 13 training sessions over 5 weeks. Individuals completed either: 1) eccentric only exercises (n=12), 2) concentric only exercises (n=13), or 3) non-exercised Control (n=12).
(18)	30 untrained females (mean age = 22)	30% of eccentric or concentric peak torque.	40% AOP which remained inflated for the duration of the exercises.	Concentric elbow flexion exercises at 120°/sec were completed on a Cybex 6000. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. 13 training sessions over 5 weeks. Individuals completed either: 1) resistance training with BFR (n=10), 2) resistance training without BFR (n=10), or 3) non-exercise control (n=10).
(20)	36 untrained females (mean age = 21.7)	30% of eccentric or concentric peak torque	3 cm wide cuff inflated to 40% AOP which remained inflated for the duration of the exercises	Either eccentric or concentric elbow flexion exercises at 120°/sec were completed on a Cybex 6000. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. 12 training sessions over 4 weeks. Individuals completed either: 1) eccentric exercise with BFR (n=12), 2) concentric exercise with BFR (n=12), or 3) non-exercised control (n=12).
(21)	12 untrained women (mean age = 22.1)	30% of concentric peak torque	3 cm wide cuff inflated to 40% AOP which remained inflated for the duration of the exercises.	Concentric elbow flexions at 120°/sec were completed on a Cybex 6000. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. Completed 12 sessions over 4 weeks.
(19)	20 untrained females (mean age = 22)	30% of eccentric or concentric peak torque	3 cm wide cuff inflated to 40% AOP which remained inflated for the duration of the exercises	Concentric elbow flexion and extension exercises at 120°/sec were completed on a Cybex 6000. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. Completed 12 training sessions over 4 weeks. Individuals completed either: 1) concentric exercise with BFR (n=10), or 2) non-exercised control (n=10).
(24)	20 untrained females (mean age = 21)	30% of eccentric or concentric peak torque	40% AOP which remained inflated for the duration of the exercises.	Concentric elbow flexion exercises at 120°/sec were completed on a Biodex Systems 3. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. Completed 7 training sessions over 2 weeks. Individuals completed either: 1) concentric exercise with BFR (n=10), or 2) concentric exercise without BFR (n=10).
(25)	24 individuals (mean age = 22.8)	30% of eccentric peak torque	6 cm wide cuff inflated to 130% of systolic blood pressure and remained inflated for the duration of the exercises.	Eccentric knee extension exercises at 30°/sec were completed on a Biodex Systems 2. 4 sets of 30-15-15-15 each separated by 60 seconds of rest. Individuals completed either: 1) eccentric exercise with BFR (n=?), 2) eccentric exercise without BFR (n=?), or 3) non-exercised control (n=?).

(26)	17 individuals (mean age = 24)	30% of eccentric peak torque	6 cm wide cuff inflated to 130% of systolic blood pressure and remained inflated for the duration of the exercises.	Eccentric knee extension exercises at 30°/sec were completed on a Biodex Systems 2. 4 sets of 30-15-15-15 each separated by 60 seconds of rest. Individuals completed either: 1) concentric exercise with BFR and concentric exercises without BFR (n=?), or 2) eccentric exercise with BFR and eccentric exercise without BFR (n=?).
(27)	60 males (mean age = 24)	40% or 80% of eccentric peak torque.	18 cm cuff inflated to 40% AOP which remained inflated for the duration of the exercises.	Eccentric knee extension exercises at 60°/sec were completed on a Biodex Systems 3. 4 sets of 6 repetitions with 60 seconds rest between sets. Individuals completed either: 1) high load (80%) eccentric exercise without BFR (n=15), 2) high load (80%) eccentric exercise with BFR (n=16), 3) low load (40%) eccentric exercise without BFR (n=14), or 4) low load (40%) eccentric exercise with BFR (n=15).
(28)	9 males (mean age = 21)	30% of concentric peak torque	17 cm cuff inflated to 60% AOP which remained inflated for the duration of the exercise.	Concentric knee extension exercises at 60°/sec were completed on a Cybex. 4 sets of 30-15-15-15 each separated by 30 seconds of rest. Everyone completed both: 1) concentric exercise with BFR, and 2) concentric exercise without BFR.
(29)	10 individuals (mean age = 27)	Maximal	220 - 280 mmHg for complete occlusion.	Plantar and dorsiflexion exercises were completed on a Biodex System 3. One set to failure was performed. In experiment 1 everyone completed: 1) plantar flexion at 60°/s with BFR, 2) dorsiflexion at 120°/s with BFR, 3) dorsiflexion at 120°/s and plantar flexion at 60°/s with BFR, 4) 10 minutes of arterial occlusion without exercise. In experiment 2 everyone completed both of the following: 1) dorsiflexion at 60°/s with BFR, and 2) dorsiflexion at 120°/s with BFR.
(30)	30 untrained females (mean age = 22)	30% of maximal isometric strength	11 cm cuff inflated to 60% AOP which remained inflated for the whole protocol.	Concentric and eccentric knee extension exercises were completed at 120°/sec on a Biodex System 3. 4 sets with 30 s rest between sets. Everyone completed both protocols, 1 per each leg separated by 15 minutes of rest: 1) 30-15-15-15, and 2) 4 sets to failure.
(31)	30 untrained females (mean age = 22)	30% peak torque	3 cm wide cuff inflated to 40% AOP which remained inflated for the duration of the exercises.	Concentric elbow flexion and elbow extension exercises were completed at 120°/sec on a Biodex System 3. 4 sets of 30-15-15-15 with 30 seconds rest between sets. Everyone completed: 1) exercise with BFR (n=10), 2) exercise without BFR (n=10), 3) non-exercise control (n=10).
(32)	14 trained women (mean age = 21)	30% of peak isometric torque	12 cm wide cuff inflated to 60% AOP which remained inflated for the duration of the exercises.	Concentric knee extension exercises at 90°/sec on a Biodex dynamometer. 4 sets of 30-15-15-15. Everyone completed: 1) isotonic exercise with BFR, 2) isokinetic exercise with BFR.
(33)	21 male track and field athletes (mean age = 19.9)	Appears to be maximal but not clear.	200 mmHg.	Performed 3 sets of knee extensions and flexions with 60 seconds rest between sets. Completed 10 training sessions over 3 weeks. Exercises were completed at either 90 or 300°/sec on a Biodex System 3. Individuals completed either: 1) high speed 300°/sec with BFR (n=6), 2) high speed 300°/sec without BFR (n=6), 3) slow speed 90°/sec with BFR (n=4), 4) slow speed 90°/sec without BFR (n=5).
(34)	60 untrained males (mean age = 24)	40% or 80% of eccentric peak torque	18 cm cuff inflated to 40% AOP which remained inflated for the duration of the exercises.	Performed 18 sessions over 6 weeks of eccentric knee extension exercises at 60°/sec on a Biodex System 3 at. Completed 4-5 sets of 6-10 repetitions with 60 seconds rest between sets. Individuals completed either: 1) high load eccentric exercise (80%) with BFR (n=16), 2) high load eccentric exercise (80%) without BFR (n=15), 3) low load eccentric exercise (40%) with BFR (n=15), 4) low load eccentric exercise (40%) without BFR (n=14).
(35)	15 males and females (mean age = 23.2)	Maximal	Traditional BFR was inflated to 50% AOP. Practical BFR involved a 5 cm band stretched to 50% of the original length and overlapped by 50% of the width. BFR remained inflated for the duration of the exercises.	Performed 3 sets of 20 leg extension and flexion exercises. 30 seconds rest between sets. 90°/sec on a Human Norm dynamometer. Everyone completed: 1) BFR using an inflatable cuff, 2) practical BFR, 3) control performing the same exercise without BFR.

AOP = arterial occlusion pressure; BFR = blood flow restriction centric, or isometric torque[15,17-26,28,30-32] while other studies used submaximal torques of either 40%,[34] 50%,[16] or 80%[34] of maximum. Three studies incorporated maximal isokinetic contractions.[29,33,35] Many different blood flow restriction pressures were used, with the most common incorporating relative pressures of 40% to 60% of arterial occlusion pressure.[17-24,27,28,30-32,34,35] The primary findings of each study are shown in Table 2 and are summarized by dependent variables in the subsequent subheadings.

Ratings of Perceived Exertion

While two studies found that the addition of BFR did not increase RPE over the same protocol completed without BFR,[15,24] one study observed that the addition of BFR did increased RPE[16]. Another study compared BFR in conjunction with either isotonic or isokinetic exercises noting no differences between exercises.[32]

Table 2. Primary Findings of Included Studies

Reference	Primary Findings
(15)	There were no differences in any of the outcome variables when compared to the control group.
(16)	1) BFR increased RPE over the same protocol without BFR. 2) BFR reduced the number of repetitions that could be completed. 3) BFR increased total hemoglobin and deoxygenated hemoglobin in the VMO. It also decreased the amount of saturated hemoglobin when compared to both other conditions.
(22)	Muscle thickness, echo-intensity, and blood flow all increased but there were no differences between BFR and non-BFR.
(23)	Isometric strength increased by the end of the protocol. There were no changes in isometric strength, perceived soreness, pain pressure threshold, joint angle, or echo-intensity.
(17)	Muscle strength increased for eccentric BFR only. Muscle activation was increased for both eccentric and concentric. There were no changes in muscle size.
(18)	Isokinetic concentric torque increased greater in resistance training with BFR as compared to resistance training alone. There were similar increases in isometric strength and muscle size.
(20)	Both eccentric and concentric BFR increased muscle size and strength. There were no changes in neuromuscular outcomes and no changes in the control group.
(21)	There was an increase in muscle mass and a decrease in EMG amplitude to torque ratio. There was no change in MMG to torque ratio.
(19)	Low load BFR increased both muscle size and strength.
(24)	RPE and fatigue increased similarly for both groups across sets. Strength increased to a similar extent for both groups.
(25)	No difference in DOMS between exercise with and without BFR. The addition of BFR augmented muscle activation and increased total and deoxyhemoglobin.
(26)	The addition of BFR augmented muscle activation and increased deoxyhemoglobin during both eccentric and concentric exercises. BFR only augmented total hemoglobin during eccentric.
(27)	There were no differences in autonomic or cardiovascular outcomes with the addition of BFR.
(28)	There were no differential changes between the BFR and non-BFR trials for any of the outcome variables.
(29)	Experiment 1: Peak leg blood flow was greater in response to plantar flexion or plantar + dorsiflexion as compared to just dorsiflexion. BFR in the absence of exercise increased blood flow more than dorsiflexion with BFR. Mean arterial pressure increased similarly in all exercise conditions greater than BFR without exercise. Leg vascular conductance was greater in response to plantar flexion, plantar flexion + dorsiflexion, and BFR without exercise when compared to dorsiflexion. Time to failure differed between each of the protocols with plantar flexion longest, dorsiflexion next, and plantar + dorsiflexion resulting in quickest time to failure. There were no differences in torque or mean arterial pressure during the exercises. Experiment 2: No differences were present between the 60°/s and 120°/s conditions.
(30)	No changes in range of motion, pain pressure threshold, or circumference. Muscle soreness and isometric strength increased to a similar extent in response to both protocols.
(31)	No changes in range of motion, peak power, or soreness. Pain pressure threshold increased in response to exercise with BFR but this did not differ from the non BFR condition.
(32)	There were greater decreases in isometric strength (fatigue) and EMG mean power frequency because of the isotonic exercise. Muscle thickness and RPE increased similarly for both conditions.
(33)	BFR augmented strength for high velocity but not slow velocity. No increases in muscle mass were observed.
(34)	High load produced greater torque than low load, BFR did not enhance strength. (Values in appendix 1A).
(35)	Heart rate increased to a similar extent across all 3 conditions. Traditional BFR did not significantly reduce average power per rep over the protocol, but the practical BFR condition did. There were no differences between the practical and traditional BFR in power output.

Heart Rate

Two of the included studies examined heart rate responses to the same protocols performed with and without BFR noting no differences between conditions.[15,35]

Blood Pressure

One study noted that exercise with BFR increased mean arterial pressure, but this was not compared to the same exercise without BFR.[29] Two other studies noted no differences between systolic, diastolic, or mean arterial pressure when comparing the same exercises completed with or without BFR.[15,27]

Blood Oxygen Saturation

One study found no differences in oxygen saturation comparing the same protocol with and without BFR.[15] Similar findings were present in another study noting no differences in oxygen saturation between low load exercise with BFR, low load exercise without BFR, and high load exercise.[27] Other studies noted that BFR increased total deoxyhemoglobin,[16,25,26] and total hemoglobin,[16] while decreasing saturated hemoglobin compared to the same exercise completed without BFR[16]. Of these studies, one noted that BFR only augmented total hemoglobin during eccentric exercises, but not concentric exercises with BFR.[26]

Delayed Onset Muscle Soreness

One study found no increases in markers of muscle damage in response to eccentric or concentric exercises completed with BFR.[23] Four other studies found no differences in markers of muscle damage when comparing exercises completed either with or without BFR.[22,25,30,31]

Fatigue

One study found that BFR reduced the number of repetitions that could be completed compared to the same exercise without BFR.[16] Another study found that practical BFR, but not traditional BFR, resulted in greater fatigue in comparison to the same exercise without BFR.[35] Others found that torque decreased to a similar extent after completing low load exercise with and without BFR.[24,25] Lastly, one study observed greater decreases in isometric strength and EMG mean power frequency in response to isotonic exercise with BFR as compared to isokinetic exercise with BFR.[32]

Markers of Muscle Activation

Two studies found that the addition of BFR augmented muscle activation when compared to either concentric[26] or eccentric[25,26] exercises completed without BFR. Two other studies examined changes in EMG amplitude during a maximal contraction completed before and after 4-weeks of training noting no changes in response to eccentric or concentric training.[17,20]

Autonomic Function

Only one study examined autonomic function noting no differences in heart rate variability between low load exercise with BFR, low load exercise without BFR, and high load exercise.[27]

Blood Flow and Endothelial Function

One study found that exercise with BFR increased blood flow, but not to a greater extent than the same exercise without BFR.[22] Another study compared exercise with BFR to BFR in the absence of exercise, finding no difference in vascular conductance.[29] One last study found that BFR did not enhance, but rather blunted, markers of endothelial integrity.[28]

Muscle Swelling

One study found that muscle swelling increased, but to the same extent as exercise completed without BFR.[22] Another study compared muscle swelling in response to isokinetic and isotonic exercises completed under BFR noting no differences between conditions.[32]

Muscle Hypertrophy

One study found no increases in muscle size in response to either eccentric or concentric elbow flexion exercise under BFR.[17] Similar findings were observed as both fast and slow speed isokinetic contractions performed under BFR did not increase muscle size.[33] Another study found conflicting results in that muscle size increased in response to both eccentric[20] and concentric[19-21] exercise with BFR, but there was no comparison to the same exercises completed without BFR. Finally, one study found that, while exercise with BFR did increase muscle size, this increase was not greater than the same exercise completed without BFR.[18]

Muscle Strength

Three studies found that performing concentric[19,20,23] or eccentric[20,23] exercises with BFR increased strength, but this was not compared to the same exercise completed without BFR. Another study found that eccentric, but not concentric exercise with BFR increased strength, but this was also not compared to the same exercise without BFR.[17] Two studies found that training with BFR increased strength, but the addition of BFR was unable to provide greater strength gains compared to the same exercise completed without BFR.[24,34] Other studies found that adding BFR enhanced concentric, but not isometric torque, when compared to the same exercises completed without BFR.[18] Lastly, one study found that BFR was able to augment strength during faster, but not slower contractions completed without BFR.[33]

DISCUSSION

The primary findings of the present review demonstrate that the addition of BFR to isokinetic resistance exercise appears to have less of an impact on both acute and chronic measures as compared to isotonic exercise. Specifically, there is a lack of strong support for the use of BFR in conjunction with isokinetic resistance exercise as it relates to increasing muscle size and strength. The primary limitation of this review involves the lack of studies incorporating control groups comparing the same exercises completed without BFR. Thus, these studies cannot tease out the additive effect of BFR beyond completing the exercise itself. An overview of each of the dependent variables in the included studies follows.

It is not clear as to why 2 of the 3 included studies observed that the addition of BFR did not increase RPE,[15,24] particularly given a fixed number of repetitions were completed as opposed to exercising to task failure[36]. The inability of BFR to increase RPE during isokinetic exercise may be related to a smaller activation of group III/IV afferents relative to isotonic exercise, as activation of these afferents is linked to an increase in RPE.[37] This reduced afferent activation is plausible as BFR did not exacerbate fatigue in two of the included studies.[24,25] This is of importance as the accumulation of metabolites (i.e. hydrogen ions) that activate group III/IV afferents also contribute to local and central fatigue.[38]

Both of the studies assessing markers of muscle activation during exercise found that BFR increased muscle activation,[25,26] despite not increasing muscle fatigue[25]. This is an interesting finding but may be related to how fatigue was measured. BFR did not increase fatigue as assessed by changes in maximal isometric torque before and after exercise,[24,25] but did increase fatigue assessed by the number of repetitions until task failure[16]. Thus, the inability to detect fatigue may be related to the amount of time present between the completion of exercise and the post-exercise strength test, as the restoration of phosphocreatine occurs rapidly[39] and would occur immediately upon cuff deflation as hydrogen ions are removed and oxygen availability increases[40]. The increased deoxyhemoglobin concentrations[16,25,26] would support the reduced ability to restore phosphocreatine during exercise, as this process relies on aerobic respiration[39]. Thus, it is possible that fatigue was greater in response to exercise with BFR, but a rapid recovery was made before completion of the post-exercise isometric test used to assess fatigue.

Only one of the included studies tested whether the addition of BFR could enhance muscle growth, reporting no added benefit of BFR.[18] This is supported by an acute study detailing no difference in the magnitude of muscle swelling (an acute marker used to infer about hypertrophic potential) occurring during isokinetic exercise with or without BFR.[22] The inability of BFR to enhance muscle hypertrophy is interesting given the increased muscle activation noted previously. One would assume that a greater muscle activation would result in the mechanotransduction cascade occurring in a greater number of muscle fibers, and thus greater overall muscle growth. If BFR enhances muscle hypertrophy via increasing muscle activation, this hypothesis could be tested via isokinetic exercises employing maximal contractions. If BFR can augment muscle hypertrophy during maximal contractions, this must be working through a mechanism independent of augmenting muscle activation, as muscle activation would be already near maximal and unable to be enhanced. While this provides an avenue for future study, it should be mentioned that only one of the included studies assessed the magnitude of muscle growth occurring in the same exercise completed with and without BFR. This points to the importance of including a control group, as the only way to decipher the efficacy of adding BFR is to compare the results to the same training intervention completed without BFR. Thus, other studies finding increases in muscle growth[19-21] may have just been testing the efficacy of isokinetic exercise and not BFR per se.

Similar to that of muscle size, many of the included studies did not compare strength gains between the same training intervention completed with and without BFR.[17,19,20,23] When examining those studies including control groups, two found no difference,[24,34] and others found that it was dependent on the speed[33] or type[18] of contraction employed during the strength test. One study noted that the addition of BFR did not enhance muscle growth, but did increase muscle strength, particularly during faster contraction speeds.[33] This dissociation between the change in muscle size and muscle strength has been noted previously,[41] and indicates that BFR may be enhancing muscle strength through adaptations to the central nervous system and/or peripheral skeletal muscle adaptations independent of muscle growth[42]. While the exact mechanisms are speculative, the included studies demonstrate that BFR does not appear to enhance maximal muscle fiber activation.[17,20]

Collectively the included studies would suggest that the addition of BFR to isokinetic exercise does not propose any additive risks for individuals with cardiovascular complications. While isokinetic exercise with BFR did increase blood pressure,[29] this was likely due to the exercise itself, as other studies noted no further increase in blood pressure[15,27] or heart rate[15,35] due to the addition of BFR. These would corroborate the findings of studies using BFR in conjunction with isotonic exercise.[43] While one study noted the addition of BFR blunted acute markers of endothelial function,[28] another found no difference in vascular conductance[29]. Chronic training studies employing isotonic exercise have found beneficial effects of BFR on enhancing vascular function[44] indicating that acute markers of vascular health may not necessarily manifest into chronic adaptations. The idea that BFR did not increase markers of muscle damage[22,23,25,30,31] further provides support for its safety and feasibility.

CONCLUSION

The addition of BFR to isokinetic resistance exercise does not appear to exacerbate RPE, blood pressure, heart rate, or markers of muscle damage. While apparently safe, the evidence supporting the efficacy of BFR in conjunction with isokinetic exercise is not as strong as that of isotonic exercise. Chronic changes in muscle size and strength may depend on the type and speed of contraction used during training, as well as the level of resistance. Future studies examining acute and chronic effects of BFR should incorporate control groups to tease out the influence of BFR from the exercise itself.

Acknowledgements: None

Disclosure Statement: The authors report no conflicts of interest

Funding: None

REFERENCES

1. Abe T, Kearns CF, 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* 2006; 100: 1460-1466.
2. Sakamaki M, Bemben MG, Abe T. Legs and trunk muscle hypertrophy following walk training with restricted leg muscle blood flow. *J Sports Sci Med* 2011; 10: 338-340.
3. Laurentino GC, Ugrinowitsch C, Roschel H et al. Strength training with blood flow restriction diminishes myostatin gene expression. *Med Sci Sports Exerc* 2012; 44: 406-412.
4. Takarada Y, Takazawa H, Sato Y et al. Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. *J Appl Physiol* 2000; 88: 2097-2106.
5. Clarkson MJ, May AK, Warmington SA. Chronic blood flow restriction exercise improves objective physical function: A systematic review. *Front Physiol* 2019; 10: 1058.
6. Lim ZX, Goh J. Effects of blood flow restriction (BFR) with resistance exercise on musculoskeletal health in older adults: a narrative review. *Eur Rev Aging Phys Act* 2022; 19: 15.
7. Freitas EDS, Miller RM, Heishman AD et al. The perceptual responses of individuals with multiple sclerosis to blood flow restriction versus traditional resistance exercise. *Physiol Behav* 2021; 229: 113219.
8. Charles D, White R, Reyes C et al. A systematic review of the effects of blood flow restriction training on quadriceps muscle atrophy and circumference post ACL reconstruction. *Int J Sports Phys Ther* 2020; 15: 882-891.
9. Vidmar MF, Baroni BM, Michelin AF et al. Isokinetic eccentric training is more effective than constant load eccentric training for quadriceps rehabilitation following anterior cruciate ligament reconstruction: a randomized controlled trial. *Braz J Phys Ther* 2020; 24: 424-432.
10. Cabri JMH, Clarys JP. Isokinetic exercise in rehabilitation. *Appl Ergon* 1991; 22: 295-298.
11. Suga T, Okita K, Morita N et al. Intramuscular metabolism during low-intensity resistance exercise with blood flow restriction. *J Appl Physiol* 2009; 106: 1119-1124.
12. Dankel SJ, Mattocks KT, Jessee MB et al. Do metabolites that are produced during resistance exercise enhance muscle hypertrophy? *Eur J Appl Physiol* 2017; 117: 2125-2135.
13. Dankel SJ, Buckner SL, Jessee MB et al. Can blood flow restriction augment muscle activation during high-load training? *Clin Physiol Func Imaging* 2018; 38: 291-295.
14. Jessee MB, Dankel SJ, Buckner SL et al. The cardiovascular and perceptual response to very low load blood flow restricted exercise. *Int J Sports Med* 2017; 38: 597-603.
15. Bazgir B, Rezazadeh Valojerdi M et al. Acute cardiovascular and hemodynamic responses to low intensity eccentric resistance exercise with blood flow restriction. *Asian J Sports Med* 2016; 7: e38458.
16. Ganesan G, Cotter JA, Reuland W et al. Effect of blood flow restriction on tissue oxygenation during knee extension. *Med Sci Sports Exerc* 2015; 47: 185-193.
17. Hill EC. Eccentric, but not concentric blood flow restriction resistance training increases muscle strength in the untrained limb. *Phys Ther Sport* 2020; 43:1-7.
18. Hill EC, Housh TJ, Keller JL et al. Low-load blood flow restriction elicits greater concentric strength than non-blood flow restriction resistance training but similar isometric strength and muscle size. *Eur J Appl Physiol* 2020; 120: 425-441.
19. Hill EC, Housh TJ, Keller JL et al. Patterns of responses and time-course of changes in muscle size and strength during low-load blood flow restriction resistance training in women. *Eur J Appl Physiol* 2021; 121: 1473-1485.
20. Hill EC, Housh TJ, Keller JL et al. Early phase adaptations in muscle strength and hypertrophy as a result of low-intensity blood flow restriction resistance training. *Eur J Appl Physiol* 2018; 118: 1831-1843.
21. Hill EC, Housh TJ, Keller JL et al. The validity of the EMG and MMG techniques to examine muscle hypertrophy. *Physiol Meas* 2019; 40: 025009.
22. Hill EC, Housh TJ, Smith CM et al. Acute changes in muscle thickness, edema, and blood flow are not different between low-load blood flow restriction and non-blood flow restriction. *Clin Physiol Func Imaging* 2021; 41: 452-460.
23. Hill EC, Housh TJ, Smith CM et al. Eccentric and concentric blood flow restriction resistance training on indices of delayed onset muscle soreness in untrained women. *Eur J Appl Physiol* 2019; 119: 2363-2373.
24. Keller JL, Hill EC, Housh TJ et al. The acute and early phase effects of blood flow restriction training on ratings of perceived exertion, performance fatigability, and muscular strength in women. *Isokinetics Exerc Sci* 2021; 29: 39-48.
25. Lauver JD, Cayot TE, Rotarius T et al. The effect of eccentric exercise with blood flow restriction on neuromuscular activation, microvascular oxygenation, and the repeated bout effect. *Eur J Appl Physiol* 2017; 117: 1005-1015.
26. Lauver JD, Cayot TE, Rotarius TR et al. Acute neuromuscular and microvascular responses to concentric and eccentric exercises with blood flow restriction. *J Strength Cond Res* 2020; 34: 2725-2733.
27. Lemos LK, Teixeira Filho CAT et al. Autonomic and cardiovascular responses on post-eccentric exercise recovery with blood flow restriction at different loads: Randomized controlled trial. *Eur J Integr Med* 2022; 53: 102148.
28. Montgomery R, Paterson A, Williamson C et al. Blood flow restriction exercise attenuates the exercise-induced endothelial progenitor cell response in healthy, young men. *Front Physiol* 2019; 10: 447.
29. Polichnowski AJ, Heyer EK, Ng AV. Effect of active muscle mass during ischemic exercise on peak lower leg vascular conductance. *J Appl Physiol* 2005; 98: 765-771.
30. Proppe CE, Aldeghi TM, Rivera PM et al. 75-repetition versus sets to failure of blood flow restriction exercise on indices of muscle damage in women. *Eur J Sport Sci* 2023; 23: 1993-2001.
31. Proppe CE, Rivera PM, Hill EC et al. The effects of blood flow restriction resistance training on indices of delayed onset muscle soreness and peak power. Isokinetics *Exerc Sci* 2022; 30: 167-175.
32. Rivera PM, Proppe CE, Gonzalez-Rojas D et al. Effects of load matched isokinetic versus isotonic blood flow restricted exercise on neuromuscular and muscle function. *Eur J Sport Sci* 2023; 23: 1629-1637.
33. Sakuraba K, Ishikawa T. Effect of isokinetic resistance training under a condition of restricted blood flow with pressure. *J Orthop Sci* 2009; 14: 631-639.
34. Santos IF, Lemos LK, Biral TM et al. Relationship between heart rate variability and performance in eccentric training with blood flow restriction. *Clin Physiol Func Imaging*. 2022; 42: 333-347.
35. Winchester LJ, Blake MT, Fleming AR et al. Hemodynamic responses to resistance exercise with blood flow restriction using a practical method versus a traditional cuff-inflation system. *Int J Environ Res Public Health* 2022; 19: 11548.
36. de Queiros VS, Rolnick N, Dos Santos ÍK et al. Acute effect of resistance training with blood flow restriction on perceptual responses: A systematic review and meta-analysis. *Sports Health* 2023; 15: 673-688.
37. Broxterman RM, Hureau TJ, Layec G et al. Influence of group III/IV muscle afferents on small muscle mass exercise performance: a bioenergetics perspective. *J Physiol* 2018; 596: 2301-2314.
38. Amann M, Sidhu SK, Weavil JC et al. Autonomic responses to exercise: group III/IV muscle afferents and fatigue. *Auton Neurosci* 2015; 188: 19-23.
39. Forbes SC, Paganini AT, Slade JM et al. Phosphocreatine recovery kinetics following low- and high-intensity exercise in human triceps surae and rat

posterior hindlimb muscles. *Am J Physiol Regul Integr Comp Physiol* 2009; 296: R161-R170.

40. Sahlin K, Harris RC, Hultman E. Resynthesis of creatine phosphate in human muscle after exercise in relation to intramuscular pH and availability of oxygen. *Scand J Clin Lab Invest* 1979; 39: 551-558.
41. Loenneke JP, Buckner SL, Dankel SJ et al. Exercise-induced changes in muscle size do not contribute to exercise-induced changes in muscle strength. *Sports Med* 2019; 49: 987-991.
42. Dankel SJ, Kang M, Abe T et al. Resistance training induced changes in strength and specific force at the fiber and whole muscle level: a meta-analysis. *Eur J Appl Physiol* 2019; 119: 265-278.
43. Pinto RR, Polito MD. Haemodynamic responses during resistance exercise with blood flow restriction in hypertensive subjects. *Clin Physiol Funct Imaging* 2016; 36: 407-413.
44. Mouser JG, Mattocks KT, Buckner SL et al. High-pressure blood flow restriction with very low load resistance training results in peripheral vascular adaptations similar to heavy resistance training. *Physiol Meas* 2019; 40: 035003.