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Review

Chronic hemodynamic adaptations induced by resistance training with and without blood flow restriction in adults: A systematic review and meta-analysis

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A R T I C L E I N F O

Keywords:
Strength training
Blood flow restriction
Blood pressure
Chronic effect

A B S T R A C T

The purposes of this systematic review and meta-analysis of peer-reviewed literature were to examine the chronic effects of resistance training with blood flow restriction (RT-BFR) on hemodynamics, and to compare these adaptations to those induced by traditional resistance training (TRT) programs in adults (PROSPERO: Registry: CRD42022339510). A literature search was conducted across PubMed, Sports Discus, Scielo, and Web of Science databases. Two independent reviewers extracted study characteristics and blood pressure measures. Risk of bias (The Cochrane risk of bias tool for randomized controlled trials [RoB-2]), and the certainty of the evidence (Grading of Recommendations, Assessment, Development, and Evaluation [GRADE]) were used. A total of eight studies met the inclusion criteria for systolic (SBP), diastolic (DBP), and mean arterial pressure (MAP). Regarding the comparison of RT-BFR *vs.* non-exercise, no significant differences favoring the exercise group were observed ($p > 0.05$). However, when compared to TRT, RT-BFR elicited additional improvements on DBP (−3.35; 95%*CI* -6.00 to −0.71; $I^2 = 14\%$; $z = -2.48$, $p = 0.01$), and on MAP (−3.96; 95%*CI* -7.94 to 0.02; $I^2 = 43\%$; $z = -1.95$, $p = 0.05$). Results indicate that RT-BFR may elicit a decrease in DBP in comparison with TRT, but the lack of data addressing this topic makes any conclusion speculative. Future research on this topic is warranted.

1. Introduction

Resistance training (RT) with blood flow restriction (BFR) is defined as strength training with intentional reduction of blood flow to the exercising muscles. Partial or complete occlusion of blood flow is caused by placing an external tourniquet, blood pressure cuff, or training band proximally to the exercised muscle.[1] Compared to traditional resistance training (TRT) without blood flow restriction, in RT-BFR, exercise intensity and volume are reduced,[2] not overcoming 40% of the one-repetition maximum (1 RM).[3]

Despite some controversial data,[4] available scientific literature has shown that RT-BFR seems to induce similar morphological and functional adaptations to those induced by TRT with moderate to high loads.[5,6] Therefore, because the exercise intensity is lower and the benefits in terms of physical fitness are still present, RT-BFR is gaining interest amongst clinical populations, who are less able to exercise at high intensities.[7] For example, experimental protocols have already been applied to older adults with osteoarticular conditions,[8] and to people living with human immunodeficiency virus.[9] As a result, some people are of the opinion that RT-BFR is a risk-free alternative to TRT because of its positive chronic muscle adaptations and lower osteoarticular repercussions.[3]

Besides muscle adaptations, acute and chronic hemodynamic responses induced by RT-BFR and cardiovascular safety arouse the interest of the scientific community.[10] Muscle contraction at low blood flow elevates metabolic stress, diminishes venous return, exacerbates sympathetic activity, and increases peripheral vascular resistance, which together acutely raises blood pressure and heart rate.[11] These acute hemodynamic responses seem to return to baseline values following 5–10

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Abbreviation list

BFR	Blood flow restriction
RT-BFR	Resistance training with blood flow restriction
BRF1	Continuous blood flow restriction
BFR2	Intermittent blood flow restriction
1 RM	One-repetition maximum
TRT	Traditional resistance training
TRT1	Just traditional resistance training
TRT2	Moderate traditional resistance training
RCTs	Randomized control trial studies
CG	Control group
F	Frequency
I	Intensity
T	Time
T'	Type
Reps	Repetition
Sec	Seconds
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SE	Standard error
SD	Standard deviation
n	Sample size
MD	Mean difference
95%*CI*	95% Confidence interval
Z-value	Overall effects
RoB-2	The Cochrane risk of bias tool for randomized controlled trials
GRADE	The certainty of the evidence for each outcome was assessed using the Grading of Recommendations, Assessment, Development, and Evaluation
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
MAP	Mean arterial pressure
♀	Female
♂	Male
*	Hypertensive
→	No significant change
↓	Significant reduction

min after the end of the exercise session.[3] In terms of chronic hemodynamic effects of RT-BFR, the large variability of BFR (compression intensity and duration, for example),[3] of the exercise protocols (exercises, intensity, and volume),[3] and of the participants' characteristics, make comparability between studies difficult. In addition, the comparison of the hemodynamic effects induced by RT-BFR in comparison with TRT and non-training conditions are unusual, and require further research.

Therefore, this study aims to conduct a systematic review and meta-analysis of randomized control studies (RCTs) investigating the chronic effects of RT-BFR on hemodynamics parameters (blood pressure) and to compare RT-BFR *vs.* TRT and control group (CG) in adults.

2. Methods

2.1. Study design and protocol registration

This systematic review and meta-analysis were guided according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline,[12] and the protocol was registered in PROSPERO (registration number CRD42022339510).

2.2. Eligibility criteria

Studies were eligible if they (i) were RCTs; (ii) with adults (≥18 years old); (iii) comparing an experimental group receiving a structured RT-BFR exercise training; (iv) *vs.* a control group (CG) (that did not receive any exercise training) or a TRT group, meaning strength training without blood flow occlusion; (v) assessing peripheral blood pressure; and (vii) were written in English, Spanish or Portuguese. We excluded literature reviews, letters to the editor, abstracts published in conference proceedings, studies that assessed the acute effects of a single exercise session, studies involving people with chronic health conditions, and animal model studies. For identification of the studies, the relevant electronic databases PubMed/MEDLINE®, SPORTDiscus®, Scielo®, and Web of Science® were searched.

2.3. Search strategy

The search was conducted independently by the researchers using the following search string for all databases: "blood flow restriction" OR "blood flow occlusion" OR "vascular occlusion" OR "Kaatsu training" AND "blood pressure". To ensure that the union of the search terms was included in the results, the operator 'OR' was for synonyms, and the operator 'AND' was to connect these terms. Relevant studies from the reference list of included studies (snowball technique) were also screened. Only studies published between January 2000 and December 2021 were searched, and the last search was conducted on the September 8, 2022 to ensure that the whole body of evidence was collected. See Supplementary Table 1.

2.4. Study selection, data extraction, and synthesis

Initially, a single author screened the titles and discarded all duplicates. Subsequently, two reviewers (AR and GB) have independently screened all studies according to eligibility criteria through the examination of titles and abstracts. Whenever there were discrepancies between reviewers, citations were checked by two senior investigators (LB and CS). The program Mendeley Desktop (1.19.18) was used to store all studies from the mentioned electronic databases and to examine titles and abstracts of studies. Data were extracted from the included studies. Data from Cezar et al. (2016), Fahs et al. (2012), and Ozaki et al. (2013) were transformed from standard error (*SE*) into standard deviation (*SD*) using the following formula:[13]

$$SD = SE^* \sqrt{n}$$

2.5. Methodological quality of assessment

The Cochrane risk of bias tool for randomized controlled trials (RoB-2)[14] was used to assess the risk of bias. Bias assessment that composes RoB-2 domains was rated as low risk, some concerns, or high risk. Two authors (AR and GB) independently reviewed the study's quality, and disagreements were solved through discussion with a third author (LB).

2.6. Strength of the body of evidence assessment

The certainty of the evidence for each outcome was assessed using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach. GRADE encompasses 5 categories: risk of bias, inconsistency, indirectness, imprecision, and publication bias, and is classified as high, moderate, low, or extremely low.[15]

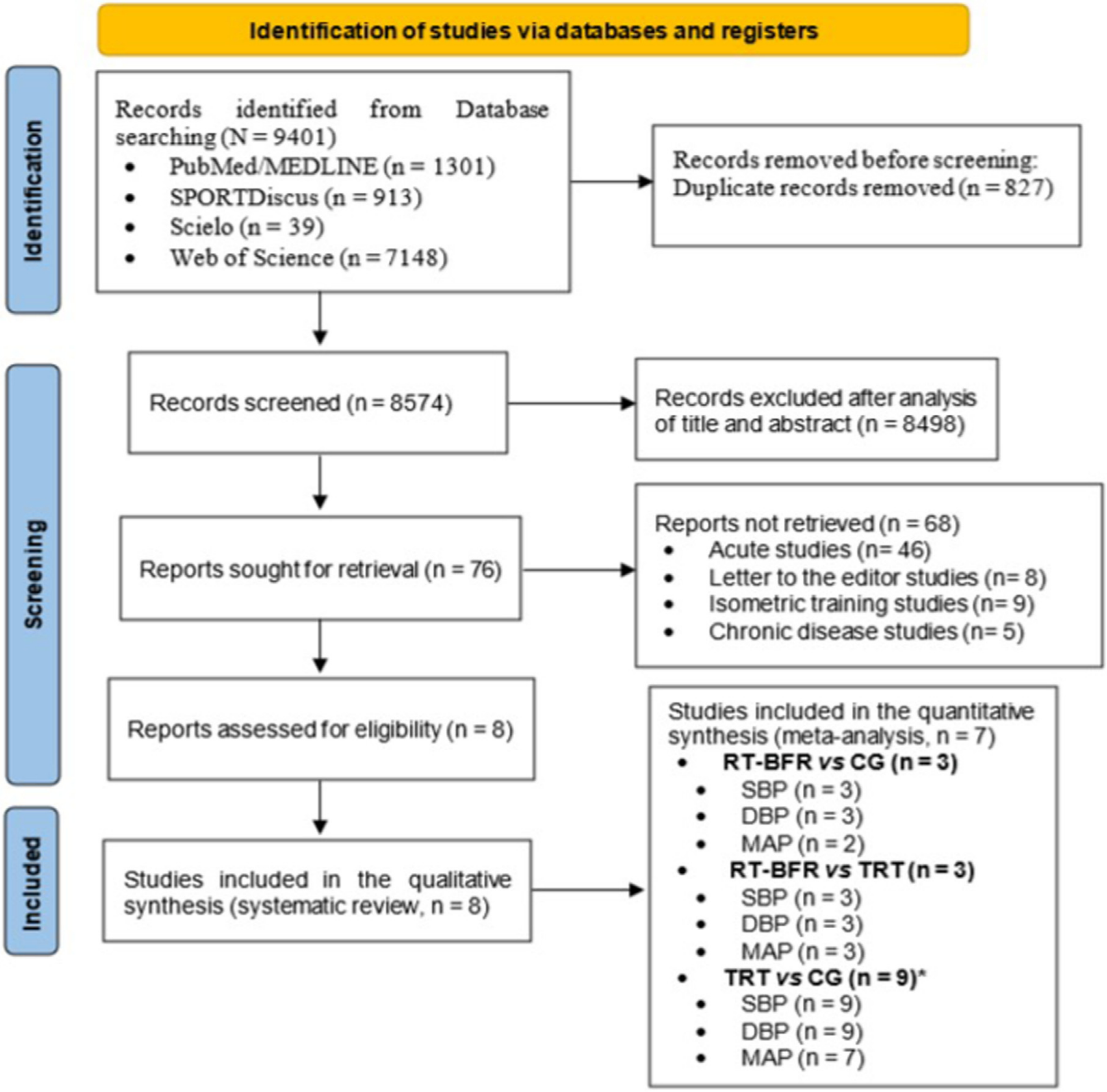

Fig. 1. Flow diagram indicating the number of studies retrieved in the literature search, and the final number of studies included in the meta-analysis. Abbreviations: RT-BFR, resistance training with blood flow restriction; CG, control group; TRT, traditional resistance training.
Note: * Some studies have more than one group and then are counted and defined as a new study.

2.7. Statistical analysis

A random-effects model was performed for each outcome selected. Pooled effect sizes (*ES*) were presented as unstandardized mean difference (*MD*) with a 95% confidence interval (95%*CI*). The primary analysis was conducted to explore the effects of BFR *vs*. CG on blood pressure, and as a secondary analysis, we also compared the exercise intervention type effects BFR *vs*. TRT on blood pressure. Sensitivity analyses were conducted to detect if any study was responsible for a large proportion of heterogeneity (I^2), which was assessed and qualitatively considered not important if $I^2 = 0\%–40\%$, moderate if $I^2 = 30\%–60\%$, substantial if $I^2 = 50\%–90\%$, and considerable if $I^2 = 75\%–100\%$.[13] Because outcome analyses had less than 10 studies included, the publication bias through visual funnel plot inspection and according to Egger's linear regression method test was not performed.[16] The package "meta" (version 4.11–0) for the R statistical software (version 4.1.0) was used.[17] Overall effects (*z*-value) were considered statistically significant at p-value < 0.05.

3. Results

3.1. Study selection and sample characteristics

A total of 9 401 references were examined. After removing duplicates, 8 574 articles were pre-selected for analysis of inclusion eligibility. From those, 8 498 were excluded after being screened for titles and abstracts. Following a thorough review of the 76 articles, 68 were removed based on the previously stated criteria. The inclusion criteria were met by 8 studies. Fig. 1 depicts the flow diagram of the studies included in this systematic review and meta-analysis. The selected studies were performed in Brazil,[18,19] China,[20] Japan,[21–23] and the United States of America.[24,25] Seven[18,20–25] of them were written in English and 1 in Portuguese,[19] and were published between 2012 and 2021.

The selected studies encompassed a total of 204 participants (133 men and 71 women), aged between 21 and 71 years old. Four studies included exclusively men,[19–21,25] 1 exclusively women,[18] and 3 studies were based on both sexes.[22–24] Five studies[19–21,24,25] included young adults, and 3 older adults.[18,22,23] In terms of blood pressure, 181

Table 1
Main features of the included studies.

Study	Participants			Study Protocols				Main findings Group * Time Interactions
	RT-BFR	TRT	Control	BFR characteristics	RT-BFR	TRT	Control	
Cezar et al. (2016)[18]	$n = 8$, ♀* 63.75 ± 11.58 years	$n = 8$, ♀* 59 ± 13.03 years	$n = 7$ ♀* 57.3 ± 8.17 years	Medial portion of both arms; sphygmomanometers (Erkamater™ E300, Germany); 70% of resting SBP; Continuously from the beginning to the end of the last set.	**F**: 2 sessions per week **I**: 3 sets, 30% of 1RM; 30 s intervals between sets **T**: 8 weeks **T**: Resistance training – 1 exercise (wrist flexion)	**F**: 2 sessions per week **I**: 3 sets, 80% of 1RM; 30 s intervals between sets **T**: 8 weeks **T**: Resistance training – 1 exercise (wrist flexion)	No structured physical exercise program	SBP changes: ↓ RT-BFR ≻ →TRT ($p < 0.05$); ↓ RT-BFR ≻ → CG (p < 0.05) DBP changes: ↓ RT-BFR ≻ →TRT ($p < 0.05$); ↓ RT-BFR ≻ → CG ($p < 0.05$) MAP changes: ↓ RT-BFR ≻ → TRT ($p < 0.05$); ↓ RT-BFR ≻ → CG ($p < 0.05$)
Early et al. (2020)[24]	$n = 11$ 24 ± 4 years	$n = 10$ 23 ± 3 years	$n = 10$ 23 ± 3 years	Relatively narrow (5.5 cm wide arms/7 cm wide legs), elastic, pneumatic band (BStrong training SystemsTM); placed on both upper arms and both upper thigh; inflated to 250 mmHg for upper body or 350 mmHg for lower body; bands not deflated between training	F: 2–3 sessions per week I: 3 sets of 30 reps, 30% 1 RM; 30–60 s rest between sets and 2–3 min rest between exercises; progression to a maximum of 50% 1 RM T: 8 weeks T': Resistance training – 5 exercises (Arm Extension; Arm Curl; Leg Extension; Leg Curl; Heel Raise)	**F**: 2–3 sessions per week for 8 weeks **I**: 3 sets of 10 reps, 60% 1 RM; 2–3 min rest between exercises; progression every 2 weeks by 10% 1 RM **T**: 8 weeks **T**: Resistance training – 5 exercises (Arm Extension; Arm Curl; Leg Extension; Leg Curl; Heel Raise)	Maintain their current exercise and physical activity levels	Data not shown. SBP ($p = 0.44$) and DBP ($p = 0.46$) similar between groups.
Fahs et al. (2012)[25]	$n = 10$ ♂ 21 ± 0 years	**TRT1** $n = 12$ ♂ 21 ± 1 years **TRT2** $n = 9$ ♂ 21 ± 1 years	$n = 15$ ♂ 23 ± 1 years	Elastic cuffs (50 mm width, KAATSU Master; Sato Sports Plaza, Japan) around both thighs; cuffs applied with an initial pressure of 40–60 mmHg. Cuff pressure started at 160 mmHg for the first 2 weeks, increased to 180 mmHg for weeks 3/4 and increased to 200 mmHg for weeks 5/6; cuff pressure was released upon completion of the 2 lower body exercises.	**F**: 3 sessions per week **I**: 3 sets of 10 reps, 50% of 1RM (upper body); 1 set of 30 reps + 3 sets of 15 reps, 20% of 1 RM (lower body); 1 min rest periods **T**: 6 weeks **T**: Resistance training – 6 exercises (lat pulldown, seated shoulder press, elbow extension and elbow flexion, knee extension and knee flexion)	**TRT1:** **F**: 3 sessions per week **I**: 3 sets of 10 reps, 50% of 1 RM (upper body)/70% of 1 RM (lower body); 1 min rest periods **T**: 6 weeks **T**: Resistance training – 6 exercises (lat pulldown, seated shoulder press, elbow extension and elbow flexion, knee extension and knee flexion) **TRT2:** **F**: 3 sessions per week **I**: 3 sets of 10 reps, 50% of 1RM (upper body); 3 sets of 15 reps, 45% of 1RM (lower body); 1 min rest periods **T**: 6 weeks **T**: Resistance training – 6 exercises (lat pulldown, seated shoulder press, elbow extension and elbow flexion, knee extension and knee flexion)	Not assessed	SBP changes: → High TRT ≻ → Moderate TRT ≻ → RT-BFR ≻ → CG ($p > 0.05$) DBP changes: → High TRT ≻ → Moderate TRT ≻ ↓ LI-BFR ≻ → CG ($p < 0.05$) MAP changes: → High TRT ≻ → Moderate TRT ≻ → LI-BFR ≻ → CG ($p > 0.05$)
Ozaki et al. (2013)[21]	$n = 10$ ♂ 23 ± 0 years	$n = 9$ ♂ 24 ± 1 years	Not assessed	Three (3 cm) wide elastic cuffs (Kaatsu-Master system, Sato Sports Plaza, Japan) at proximal region of both arms; external cuff pressure (80–130 mmHg) selected based on resting blood pressure; cuffs used at 100 mmHg and then pressure was increased by 10 mmHg until 160 mmHg; cuffs released after session	**F**: 3 sessions per week **I**: 1 set of 30 reps + 3 sets of 15 reps, 30% 1 RM; 30 s rest between sets **T**: 6 weeks **T**: Resistance training – 1 exercise (free-weight flat bench press)	**F**: 3 sessions per week **I**: 3 sets of 10 reps, 75% 1 RM for TRT; 2–3 min rest between sets for TRT **T**: 6 weeks **T**: Resistance training – 1 exercise (free-weight flat bench press)	Not assessed	SBP changes: → RT-BFR ≻ →TRT ($p > 0.05$); → RT-BFR ≻ → CG ($p > 0.05$) DBP changes: → RT-BFR ≻ →TRT ($p > 0.05$); → RT-BFR ≻ → CG ($p > 0.05$)
							Not assessed	

(continued on next page)

Table 1 (*continued*)

Study	Participants			Study Protocols				Main findings Group * Time Interactions
	RT-BFR	TRT	Control	BFR characteristics	RT-BFR	TRT	Control	
Silva et al. (2018)[19]	**BFR1** $n = 9$ ♂ 26.1 ± 5 years **BFR2** $n = 8$ ♂ 23.8 ± 5.6 years	$n = 8$ ♂ 22.2 ± 3.5 years	Not assessed	Sphygmomanometer (tourniquet in extremities - Riester) for the upper limb (width 60 mm; length 470 mm) fixed in the axillary region; cuff pressure used was 80% for RT-BFR in the resting state; RT-Intermittent BFR group had a cuff deflated between sets; RT-continuous BFR group: cuff kept inflated between sets but deflated at the end of each exercise.	**F**: 2 sessions per week **I**: 4 sets of 15 reps, 20% 1 RM; 30 s rest between sets and 1 min between exercises **T**: Resistance training – 4 exercises (Bench Press, Pull Over, Triceps and Biceps Pulley) **T:** 6 weeks	**F**: 2 sessions per week **I**: 4 sets of 15 reps, 20% 1 RM; 30 s rest between sets and 1 min between exercises **T**: Resistance training – 4 exercises (Bench Press, Pull Over, Triceps and Biceps Pulley) **T**: 6 weeks		SBP changes: → RT-Continuous BFR ≻ → RT-Intermittent BFR ≻ → TRT ($p = 0.855$) DBP changes: → RT-Continuous BFR ≻ → RT-Intermittent BFR ≻ → TRT ($p = 0.802$) MAP changes: → RT-Continuous BFR ≻ → RT-Intermittent BFR ≻ → TRT ($p = 0.816$)
Tomohiro Yasuda et al. (2015)[23]	$n = 9$ 71.8 ± 6.2 years	$n = 8$ 68 ± 5.1 years	Not assessed	Pneumatic cuffs (30-mm width, KAATSU Master, Sato Sports Plaza, Japan) around the proximal portion of both arms; first day of training, the cuffs inflated to 120 mmHg then increased by 10–20 mmHg at each subsequent session until 270 mm Hg was reached; cuffs remained for the 2 exercises, including rest periods between sets and exercises	**F**: 2 sessions per week **I**: 4 sets of 75 repetitions (30, 15, 15, 15) with heavy elastic band (Green) for men and thin elastic (Yellow) for women; 30-s rest between sets and 90-s rest between exercises **T**: 12 weeks **T**: Resistance training – 2 exercises (bilateral arm curl and triceps press down)	**F**: 2 sessions per week **I**: 4 sets of 75 repetitions (30, 15, 15, 15) with heavy elastic band (Green) for men and thin elastic (Yellow) for women; 30-s rest between sets and 90-s rest between exercises **T**: 12 weeks **T**: Resistance training – 2 exercises (bilateral arm curl and triceps press down)	Not assessed	SBP changes: → RT-BFR ≻ → TRT ($p > 0.05$); → RT-BFR ≻ → CG ($p > 0.05$) DBP changes: → RT-BFR ≻ → TRT ($p > 0.05$); → RT-BFR ≻ → CG ($p > 0.05$)
Yasuda et al. (2014)[22]	$n = 9$ 71 ± 7 years	Not assessed	$n = 10$ 68 ± 6 years	Elastic pressure cuff (50 mm width, KAATSU Master, Sato Sports Plaza, Japan) at proximal portion of both legs; cuff was set at 120 mmHg at beginning; pressure increased 10–20 mmHg at each training session until reach approximately 270 mmHg; cuffs were remained for the exercises, including rest periods	**F**: 2 sessions per week **I**: 4 sets of 75 reps (30, 20, 15, and 10, respectively), 20%/30% of 1 RM; 30 s rest between sets and 90 s rest between exercises **T**: 12 weeks **T**: Resistance training – 2 exercises (Leg Extension and Leg Press)	Not assessed	Continued their daily physical activity	SBP changes: ↓ RT-BFR ≻ → CG ($p < 0.05$) DBP changes: → RT-BFR ≻ → CG ($p > 0.05$)

Note. BFR: blood flow Restriction training; TRT: traditional resistance training; CG: control group; F: frequency; I: intensity; T: time; T': type; reps: repetition; s: seconds; 1 RM: 1-maximum repetition; SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure.
Symbols: ♀ female; ♂ male; * Hypertensive; → no significant change; ↓ significant reduction.
TRT types: **TRT1:** just TRT; **TRT2**: moderate TRT.
BFR types: **BRF1:** continuous BFR; **BRF2**: intermittent BFR.

participants (from 7 studies)[19–25] were normotensive, and 23 (from in 1 study)[18] had hypertension or were under anti-hypertensive therapy. Among all individuals, 90 were involved in RT-BFR, 72 in TRT, and 42 in CG. The intervention duration varied from 6,[19,21,25] 8,[18,20,24] and 12 weeks.[22,23] With the exception of 1 study,[20] in which participants exercised 5 times per week, all interventions had a training frequency of 2–3 times per week.

Regarding the kind of compression equipment, studies used elastic cuffs,[21,22,25] pneumatic cuffs,[22,23] and sphygmomanometers.[18–20] The anatomical region under compression was the most proximal portion of 1 arm only,[20] both arms,[18,19,21,23] both legs and arms,[24] or both legs.[22,25] The intensity of compression was determined based on participants' resting systolic blood pressure (SBP), and ranged from 65%,[20] 70%,[18] and 80% of it.[19] Alternatively, some have determined the intensity of compression in absolute pressures of 100–160 mmHg,[21] 120–270 mmHg,[22,23] 160–200 mmHg,[25] 250 mmHg for upper body, and 350 mmHg for lower body.[24] Seven studies[18,20–25] did not remove BFR cuffs during the training sessions, and 1 study[19] released the cuffs during intervals between sets. The RT-BFR intensity ranged from 20%[19,22,25] to 30% of 1 RM.[18,20–22,24] One study[23] applied elastic bands as external load (thick elastic for men and thin for women), and thus it did not provide information about maximal strength and exercise intensity. With the exception of the study mentioned above,[23] all others have used weight machines and free weights to impose external load.

Regarding the types of study arms, there was 1 study containing RT-BFR and CG (meaning not exercise treatment) groups,[22] 4 studies with RT-BFR and TRT groups,[19–21,23] and 3 studies with RT-BFR, TRT and CG groups.[18,24,25] In terms of TRT exercise intensity, studies applied high,[18,21,24,25] moderate,[25] and low[19,20,23] intensities. All the studies reported SBP and diastolic blood pressure (DBP), and 4 reported mean arterial pressure (MAP).[18–20,25] One study[24] did not provide post-intervention SBP, DBP, and MAP results, and was therefore only included in the qualitative synthesis. Table 1 summarizes the full description of the included studies.

3.2. Methodological quality assessment

The RoB-2 assessment is given in Fig. 2. Five studies[19–21,23,25] were

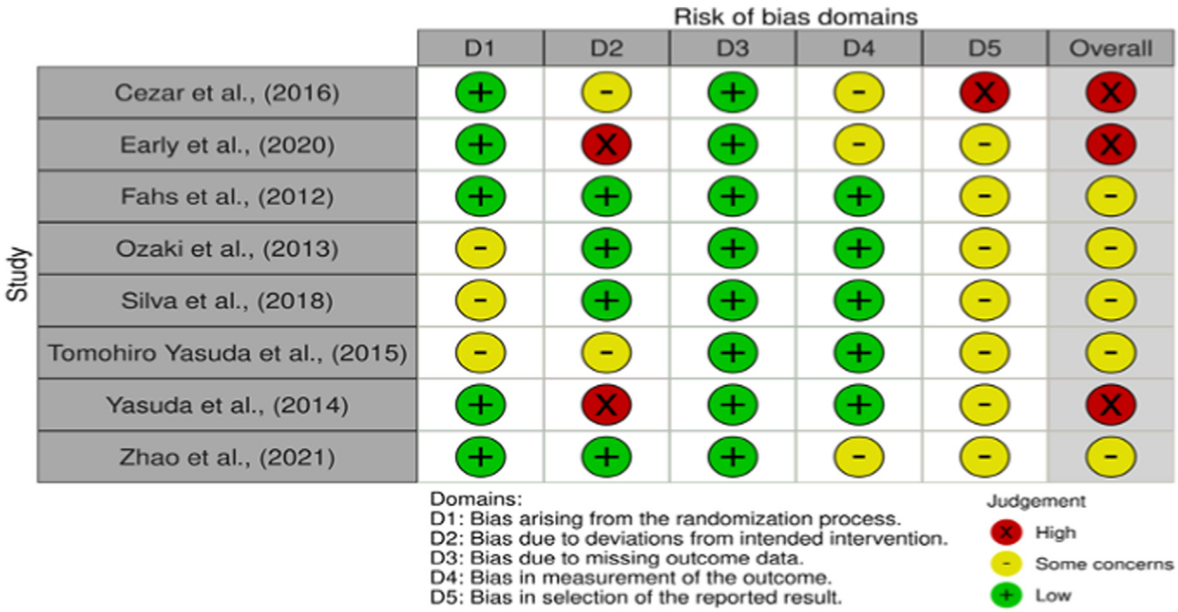

Fig. 2. Effects of RT-BFR *vs.* CG on blood pressure.
Notes. *SD*, standard deviation; *MD*, mean difference; RT-BFR, resistance training with blood flow restriction; CG, control group *$Z(p)$ test for overall effect and p-value < 0.05.

rated as having some concerns of bias due to bias from the randomization process, deviations from the intended intervention, bias in the measurement of the outcome, and bias in the selection of the reported results. Three studies[18,22,24] were rated as high risk of bias due to deviations from the intended intervention and bias in the selection of the reported result.

3.3. Meta-analysis

3.3.1. Effects of RT-BFR training on blood pressure

Fig. 3 shows the analysis of RT-BFR *vs.* CG, and indicates that for any of the outcomes assessed, the pooled results of RT-BFR have not provided additional benefits on SBP ($p = 0.10$), DBP ($p = 0.10$), and MAP ($p = 0.09$). However, the analysis showed a favorable tendency for the RT-BFR group.

3.3.2. Effects of TRT vs. CG on blood pressure

The analysis showed that TRT has not induced significant changes in SBP ($p = 0.72$), DBP ($p = 0.93$), and MAP ($p = 0.80$) when compared to the CG, Supplementary Fig. S2.

3.3.3. Comparison between RT-BFR vs. TRT on blood pressure

The analysis indicates that there was no significant effect observed on SBP ($p = 0.35$). However, despite the lack of significant results, the analysis suggests a favorable effect of RT-BFR interventions. Notably, RT-BFR interventions provided additional benefits in terms of DBP ($p = 0.01$) and MAP ($p = 0.05$) when compared to TRT. These results are consistent with the findings depicted in Fig. 4.

3.3.4. Certainty of evidence

Table 2 presents certainty levels of evidence using the GRADE approach. For RT-BFR *vs.* CG, SBP and MAP comparisons show low certainty based on 3 RCTs (59 participants) and 2 RCTs (40 participants), respectively. However, DBP analysis reveals moderate certainty with 3 RCTs (59 participants). Comparing TRT *vs.* CG, moderate certainty is seen for SBP, DBP, and MAP, all from 3 RCTs (66 participants). RT-BFR *vs.* TRT shows moderate certainty for SBP and DBP from 9 RCTs (158 participants) and for MAP from 7 RCTs (122 participants).

3.3.5. Sensitivity analysis

Sensitivity analyses are in Supplementary Figs. S3 and S4. The heterogeneity in the comparison of RT-BFR and CG was mainly caused by the study of Cezar et al.[18] because the participants were hypertensive. In the analysis of RT-BFR *vs.* TR, the studies that most contributed to heterogeneity were Cezar et al.,[18] and Yasuda et al.,.[23] The removal of these studies from the analysis decreases the I^2 values as follows:

a) RT-BFR *vs.* CG: The I^2 decreased from 54% to 0% on SBP, and 22% to 0% on DBP from.
b) RT-BFR *vs.* TRT: The I^2 decreased from 26% to 5% on SBP, from 14% to 0% on DBP, and from 43% to 0% on MAP.

4. Discussion

The present systematic review and meta-analysis provide a synthesis of the evidence suggesting that RT-BFR showed a non-significant tendency to chronically reduce SBP, DBP, and MAP compared to non-exercise conditions in apparently healthy adults. In addition, results comparing RT-BFR and TRT showed an additive effect of RT-BFR on DBP and MAP, which was supported by a moderate certainty of evidence.

Despite the large number of studies demonstrating the acute effects of RT-BFR on hemodynamic parameters, there is still a lack of research examining the chronic effects of RT-BFR on blood pressure. Additionally, there is a lack of studies comparing the effects of both exercise approaches (RT-BFR and TRT) on hemodynamics. Our main results highlighted that in adults, RT-BFR induced a non-significant trend toward reducing SBP, DBP, and MAP compared to non-exercise conditions, which is somehow consistent with the current available scientific literature.[26] The reduction of resting SBP and DBP induced by repeated bouts of exercise (TRT, combined or aerobic) depends on the blood pressure profile of each subject, with greater reductions observed in those with higher values of SBP and DBP.[26] Our results revealed a non-significant trend of reduction in blood pressure profile results, which could be partly attributed to the characteristics of our sample. It is important to highlight that of the eight studies included, seven were based on normotensive individuals, while only one[18] included participants with hypertension. These results somehow reflected the synthesis of the certainty of the evidence, in which the findings were classified as low to SBP

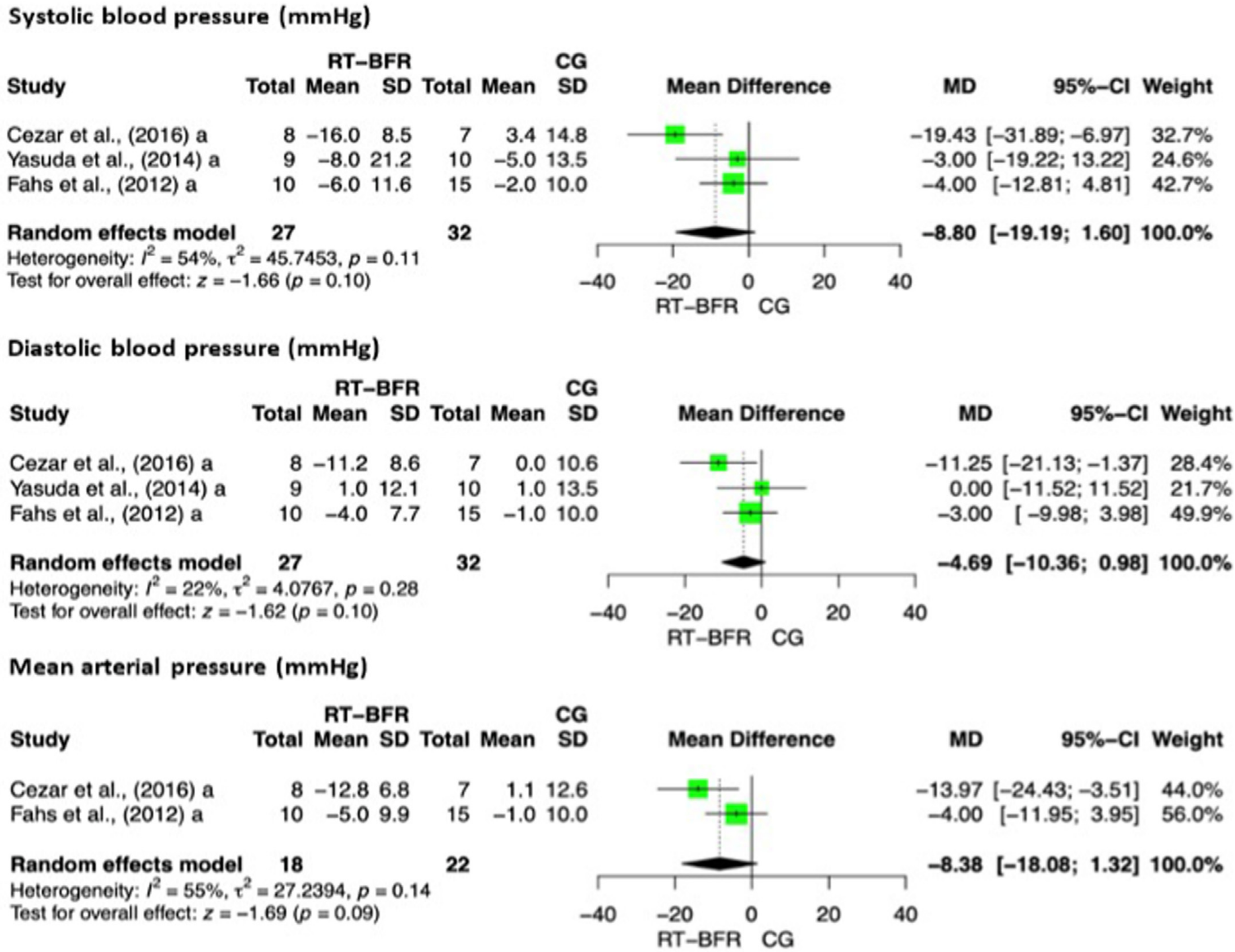

Fig. 3. Comparison between RT-BFR and TRT on blood pressure.
Notes. *SD*, standard deviation; *MD*, mean difference; RT-BFR, resistance training with blood flow restriction; TRT, traditional restriction training. *$Z(p)$ test for overall effect and p-value $<$ 0.05.

and MAP, and as moderate to DBP. Attempting to explain the results found in the comparison between RT-BFR and non-exercise (CG), we performed an analysis confronting TRT and CG, and the results agree with the previous analysis, possibly due to the sample characteristics of the included studies (mainly normotensive participants). Contrary to what was found on the analysis of RT-BFR *vs.* CG, the TRT *vs.* CG showed a moderate certainty of the evidence even with a low number of pooled studies. Therefore, it is necessary to ascertain the effects of RT-BFR on hemodynamic parameters within specific blood pressure groups of patients. The potential chronic effects of RT-BFR on blood pressure can be attributed to several physiological mechanisms, including improved endothelial function, increased nitric oxide production, activation of muscle metaboreflex, muscle hypertrophy, increased metabolic demand, and hormonal adaptation.[27] It is important to note that although these mechanisms have been proposed previously, the exact physiological processes underlying the chronic effects of RT-BFR on blood pressure are not yet fully understood and additional research is needed to understand and validate them.

We also compared RT-BFR and TRT, with results showing an additive effect of RT-BFR on DBP and MAP, which was supported by a moderate certainty of the evidence. A possible explanation for this positive RT-BFR result is the fact that after the release of blood vessels from compression, the reperfusion of blood flow to the muscular capillaries induces the release of endothelium-dependent vasodilator substances, such as nitric oxide, resulting in vasodilatation and decreased peripheral vascular resistance, which can chronically reduce DBP and MBP.[28,29]

Sensitivity results showed a variation range from 0% to 40%. Those analyses with a moderate to high I^2 were submitted to sensitivity analysis to produce the most accurate possible evidence synthesis. At most, we were able to find one study that included people who had hypertension.[18] Removing this study, the I^2 decreased, but as was previously indicated, RT-BFR was not superior to CG or TRT in changing the outcomes of interest.

We hypothesized that people who regularly underwent RT-BFR would have lower blood pressure values compared to those who did not practice regular physical activity. This hypothesis was based on the expected chronic effect of RT-BFR in reducing peripheral arterial resistance,[30] improving arterial stiffness,[30] and increasing nitric oxide.[29] Nonetheless, we failed to prove our hypothesis, and this can be explained, at least in part, by the huge methodological variations among the included studies.

The limitations of this meta-analysis are associated with the heterogeneity of participants across studies (such as age, baseline blood pressure profiles, and sex), insufficient description and variability of exercise training protocols, and variability in BFR protocols, including anatomical region of compression, intensity, duration of compression, and used

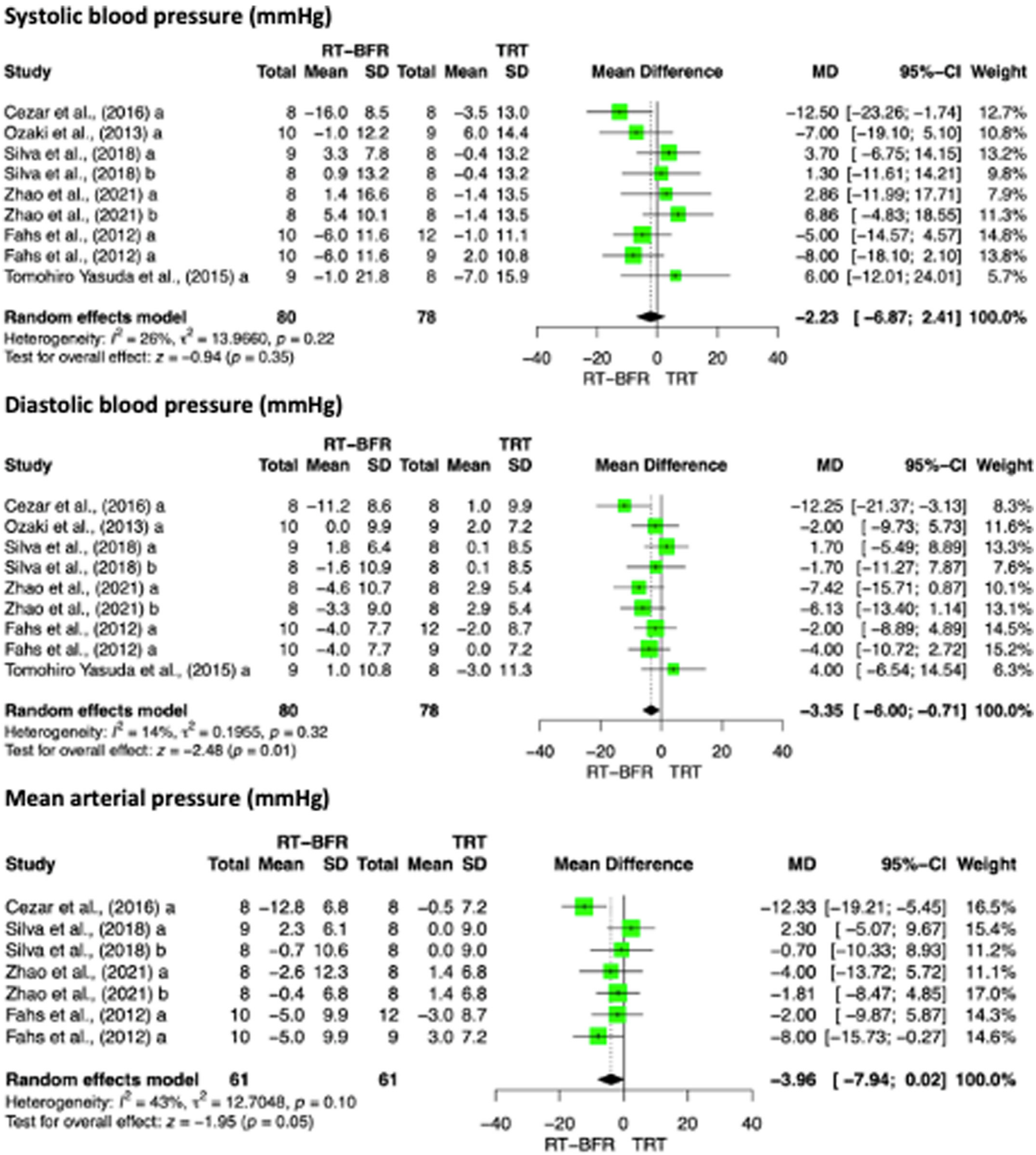

Fig. 4. Comparison between RT-BFR and TRT on blood pressure.
Notes. *SD*, standard deviation; *MD*, mean difference; RT-BFR, resistance training with blood flow restriction; TRT, traditional restriction training. **Z*(*p*) test for overall effect and *p*-value < 0.05.

devices. These factors restricted our ability to conduct additional sensitivity analyses. Furthermore, in many studies, hemodynamic variables were not the primary outcome and there were cases in which post-intervention hemodynamic results were not reported. Overall, this meta-analysis underscores the need for further randomized controlled research on this topic.

One of the major strengths of this study is that it is the first to conduct a certainty of evidence analysis using controlled metadata alone. Additionally, sensitivity analysis was performed, and the RoB-2 instrument, considered the most appropriate for bias analysis, was used. These approaches helped identify the studies that contributed most to the heterogeneity.

Table 2
Summary of findings. Certainty of evidence.

Outcomes[a]	Studies[b]	Certainty assessment					№ of patients		Absolute effect (95% *CI*)	Certainty
		Risk of bias[c]	Inconsistency[h]	Indirectness	Imprecision[i]	Other considerations	CO 1	CO 2		
RT-BFR vs CG										
SBP (mm Hg)	3 RCTs	serious[c]	not serious[h]	not serious	not serious	none	27	32	*SMD* **-0.58** (−1.29 to −0.13)	⊕⊕◯◯ LOW
DBP (mm Hg)	3 RCTs	serious[c]	not serious	not serious	not serious	none	27	32	*SMD* **-0.38** (−0.91 to 0.14)	⊕⊕⊕◯ MODERATE
MAP (mm Hg)	2 RCTs	Serious[d]	not serious[h]	not serious	not serious	none	18	22	*SMD* **-0.76** (−1.67 to 0.14)	⊕⊕◯◯ LOW
TRT vs CG										
SBP (mm Hg)	3 RCTs	Serious[e]	not serious	not serious	not serious	none	29	37	*SMD* **0.06** (−0.43 to 0.56)	⊕⊕⊕◯ MODERATE
DBP (mm Hg)	3 RCTs	serious[e]	not serious	not serious	not serious	none	29	37	*SMD* **0.02** (−0.47 to 0.51)	⊕⊕⊕◯ MODERATE
MAP (mm Hg)	3 RCTs	serious[e]	not serious	not serious	not serious	none	29	37	*SMD* **-0.36** (−0.47 to 0.52)	⊕⊕⊕◯ MODERATE
RT-BFR vs CG										
SBP (mm Hg)	9 RCTs	Serious[f]	not serious	not serious	not serious	none	80	78	*SMD* **-0.14** (−0.48 to 0.20)	⊕⊕⊕◯ MODERATE
DBP (mm Hg)	9 RCTs	serious[f]	not serious	not serious	not serious	none	80	78	*SMD* **-0.34** (−0.66 to −0.02)	⊕⊕⊕◯ MODERATE
MAP (mm Hg)	7 RCTs	serious[3d]	not serious	not serious	not serious	none	61	61	*SMD* **-0.39** (−0.79 to 0.01)	⊕⊕⊕◯ MODERATE

Abbreviations: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; *CI* = confidence interval; RCT = randomized controlled trial; CO1 = comparator 1; CO2 = comparator 2; *SMD* = standard mean difference.

GRADE Working Group grades of evidence.

High certainty: The current evidence provides a very good indication of the likely effect, and the likelihood that the actual effect will be substantially different is low.

Moderate certainty: The current evidence provides a good indication of the likely effect, and the likelihood that the actual effect of the treatment will not be substantially different is moderate.

Low certainty: The current evidence provides some indication of the likely effect, but the likelihood that the actual effect will be substantially different is high.

Very low certainty: The current evidence does not provide a reliable indication of the likely effect, and the likelihood that the actual effect will be substantially different is very high.

[a] Hemodynamics outcomes.

[b] Number of studies included in the analyses. Some studies presented more than two groups.

[c] Two studies in the overall risk of bias assessment for all RCT indicated “High risk of bias” and one study in the overall risk of bias assessment indicated as “some concerns” (Rob 2 tool).

[d] One study in the overall risk of bias assessment for all RCT indicated “High risk of bias” and one study in the overall risk of bias assessment indicated as “some concerns” (Rob 2 tool).

[e] One study in the overall risk of bias assessment for all RCT indicated “High risk of bias” and one study in the overall risk of bias assessment indicated as “some concerns” (Rob 2 tool).

[f] One study in the overall risk of bias assessment for all RCT indicated “High risk of bias” and 8 studies in the overall risk of bias assessment indicated as “some concerns” (Rob 2 tool).

[g] One study in the overall risk of bias assessment for all RCT indicated “High risk of bias” and 6 studies in the overall risk of bias assessment indicated as “some concerns” (Rob 2 tool).

[h] Presences of moderate between-study heterogeneity (I^2 ≥50%) observed in the meta-analysis.

[i] All the studies presented adequate sample size according to power calculation for meta-analysis.

5. Conclusion

Our findings suggest that, compared to non-exercise conditions, RT-BFR in apparently healthy adults may not lead to significant chronic hemodynamic adaptations. However, when comparing RT-BFR to TRT, there is some evidence to suggest that RT-BFR may result in a reduction in DBP and MAP. It is important to note that the limited availability of data on this specific comparison makes it uncertain to draw definitive conclusions. Therefore, further research investigating the effects of RT-BFR *vs.* TRT on hemodynamic variables are needed. Additional studies are needed to provide more robust evidence and a clearer understanding of the potential benefits and considerations of RT-BFR concerning hemodynamic adaptations.

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Authors’ contributions

AR, GB, CS, and LB participated in the study design. AR and GB were responsible for selecting studies and conducting the risk of bias assessment. AR and GB were responsible for data extraction, the process was supervised by CS and LB. GB was responsible for the data analysis. AR drafted the manuscript. GB, CS, and LB drafted and critically revised the manuscript. All authors read and approved the manuscript.

Submission statement

The manuscript has not been published and is not under consideration for publication elsewhere.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhs.2023.09.006.

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