Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Hemodynamic Effects of Low-Load Resistance Training Combined with Blood Flow Restriction (BFR) on Inflation Pressure (IP) Adaptations in Trained and Untrained Individuals

Janyeliton Alencar Oliveira
janyeliton@gmail.com
Federal University of Paraíba, UFPB
Antonio Filipe Pereira Caetano
Federal University of Paraíba, UFPB
Pedro Augusto Mariz Dantas
Federal University of Paraíba, UFPB
Karolina Sena Morais
Federal University of Paraíba, UFPB
Gilmário Batista Ricarte
Federal University of Paraíba, UFPB
Pedro Pinheiros Paes
Federal University of Pernambuco, UFPE
Maria do Socorro Cirilo Sousa
Federal University of Paraíba - UFPB, DEF – Postgraduate Block of Physiotherapy

Research Article

Keywords: Blood flow restriction therapy, blood pressure, hypertrophy, muscle performance

Posted Date: September 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10871694/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

This study compared the adaptive effects of insonation pressure (INP) across different blood flow restriction (BFR) fractions in trained and untrained individuals.

Methods

The sample of N = 46 participants underwent an 8-week intervention (3 sessions/week), performing squat and elbow flexion exercises with a load of 30% of 1RM, with different restriction fractions (60% and 40%) and low-load training. The groups were divided into TBFR60%, TBFR40%, TLLT, UBFR60%, UBFR40%, and ULLT. Muscle thickness and muscle tissue quality (biceps brachii and rectus femoris) were assessed at baseline, after 4 weeks (intermediate), and after 8 weeks (final).

Results

In the BB, TBFR40% demonstrated superior hypertrophic gains (Δ=0.60; p = 0.001) compared to TBFR60% (Δ=0.28; p = 0.025). All BFR groups exhibited a chronic reduction in baseline INP, indicating improved vascular compliance and endothelial efficiency. Positive correlations between MT and INP confirmed that muscle mass directly influences required restriction pressure.

Conclusion

Low-load BFR at 40% INP effectively induces hypertrophy and reduces peripheral vascular resistance in untrained individuals, whereas trained individuals may require tailored pressure loads. Because muscular and vascular adaptations occur dynamically, pressure prescription must be individualized and periodically adjusted throughout training.

INTRODUCTION

Skeletal muscle tissue exhibits complex physiological adaptive responses to stimuli imposed by traditional strength training (TST). These adaptations occur through anabolic stimuli that result in morphological and neuromuscular increments, such as an increase in the cross-sectional area (CSA) of muscle fibers (~ 15–20%) with interventions ranging from 8 to 12 weeks [1] and protein density [2]. For maximized benefits, TST recommendations suggest loads equal to or greater than 65% of the load achieved in the 1 repetition maximum (1RM) test, according to the American College of Sports Medicine [3].

For populations intolerant to the mechanical stress of high loads, such as the elderly and clinical groups, low-load strength training combined with blood flow restriction (LLST + BFR) emerges as a viable alternative. Scientifically validated, the technique allows for gains in strength and muscle hypertrophy using only 20 to 30% of 1RM [4]. The BFR technique is based on the application of external compression to occlude venous return and partially reduce arterial flow, establishing a hypoxic environment in the muscle tissue [5]. This scenario potentiates metabolic stress and induces preferential recruitment of fast-twitch fibers, simulating the effects of high loads with reduced weights [6].

One of the greatest challenges in applying BFR lies in determining the pressure load (PL) and selecting the ideal fractional restriction (FR). Historically, many protocols have used absolute pressures, being considered inconsistent due to biological individualities, since fixed pressure may not reduce flow to the same extent in different subjects. Current literature indicates that prescription should be based on Insonation Pressure (INP), for which clear criteria have not yet been adopted [7,8]. Although studies demonstrate that different FR can increase muscle strength and volume, gaps remain, such as, for example: the lack of parameters to adjust these PL through specific characteristics such as the level of physical conditioning, which is a key determinant of the adaptive capacity of trained and untrained individuals trained and untrained individuals have distinct metabolic and hemodynamic profiles, potentially altering the way the body responds to BFR-induced hypoxia. Its application can generate discrepant stimuli between an athlete and a sedentary subject.

Factors, such as the thickness and quality of the muscle tissue, which vary according to training level, directly influence the efficiency of mechanical compression. To date, few studies analyze different training level conditions, which is an essential factor in selecting the RF and percentages of BFR during LLST, allowing for differentiated periodization to optimize safety and effectiveness in each group.

Individualization training is key to the success of clinical and physical performance interventions. However, most research [1,5] does not prioritize methods for individualizing pressure stimulation and mechanics based on training history. This study is therefore justified by the need to fill this knowledge gap, analyzing the relationships between the degree of physical conditioning and the necessary adjustments in pressure stimulation [8,10]. By establishing individualized parameters, it ensures adequate pressure stimulus for trained and untrained individuals.

Therefore, the present study aimed to compare the adaptive effects of insonation pressure and muscle tissue quality under different blood flow restriction fractions in trained and untrained individuals.

METHODS

Experimental Design

This randomized, single-blind (assessor-blinded) clinical trial investigated the effects of an 8-week low-load resistance training program, with and without blood flow restriction (BFR), on muscle strength and body composition in young adults with varying training statuses. Conducted in João Pessoa, Brazil, between May and October 2025, the study received ethical approval from the UFPB Health Sciences Center (Protocol No. 7.040.114, CAAE No. 81519024.8.0000.5188) and was registered with the Brazilian Clinical Trials Registry (ReBEC: RBR-7y5vh9j). The investigation strictly adhered to the Declaration of Helsinki and the SPIRIT guidelines, and written informed consent was obtained from all participants prior to the initial assessments.

Participants were assigned using a factorial design, stratified by training status (trained vs. untrained). The experimental protocol consisted of low-load resistance training (LL-RT) under three different blood flow restriction (BFR) magnitudes (0%, 40%, and 60%). To track physiological adaptations, morphological, hemodynamic, and neuromuscular assessments were conducted at 3 time points: baseline (pre), mid-point (intermediate), and post-intervention. The training program comprised 24 sessions, performed 3 times per week, with a mandatory 48-hour recovery interval between sessions.

Participants and Eligibility Criteria

A total of 126 participants (aged 18–30 years) were recruited through digital advertisements. To ensure eligibility, individuals were required to present a normal Ankle-Brachial Index (ABI) (0.91–1.30), be cleared for exercise according to the Physical Activity Readiness Questionnaire (PAR-Q) and have no history of cardiorespiratory diseases or musculoskeletal injuries. Participant stratification was based on physical activity levels, assessed via the International Physical Activity Questionnaire (IPAQ) and one-repetition maximum (1RM) performance. A relative strength threshold (1RM/body mass) of 1.2 was established to differentiate groups: trained individuals were classified as G1 (> 1.2), while untrained individuals were classified as G2 (< 1.2). Study discontinuation criteria included the occurrence of subsequent injuries, excessive absenteeism, or withdrawal of consent.

Randomization and allocation

Participants were randomly assigned to one of the 3 study arms 60%, 40%, and BFR and no BFR in a 1:1:1 allocation ratio. This process occurred following the baseline 1RM assessment, utilizing a concealed sequence generated via *randomizer.org* by an independent researcher not involved in the intervention protocol. To ensure balanced group distribution, a stratified randomization approach was employed based on training status and baseline muscular strength. Due to the inherent nature of this non-pharmacological intervention, blinding of both investigators and participants was not feasible. Ultimately, 46 individuals completed the protocol, as detailed in the CONSORT flow diagram (Fig. 1). A priori, a power of 0.80 was adopted, considering a significance level of 5%, a correlation coefficient between measurements of 0.5, a non-sphericity correction of 1, and an effect size of 0.3, resulting in a minimum sample size of n = 54.

Assessments

Data collection was conducted at the Laboratory of Kinanthropometry and Human Performance (LABOCINE) and the multi-user facilities of the Graduate Program in Physical Education at the Federal University of Paraíba (PAPGEF/UFPB). Assessments were performed concurrently in groups of three participants, with everyone evaluated by specialized assessors designated for specific testing protocols, to ensure methodological rigor and minimize potential bias, participants were randomly assigned to their respective evaluators.

To verify the insonation pressure (INP) was determined following the protocol described by [9], using a handheld vascular Doppler (MedPeg® DV-2001; Ribeirão Preto, SP, Brazil) and pneumatic cuffs (Riester, Jungingen, Germany). Participants were acclimated in a supine position for 5 minutes, in accordance with the recommendations of [10]. For the upper limbs, the cuff was fixed at the bilateral axillary fold; the Doppler probe was then positioned over the radial artery at a 60^{o} angle to the longitudinal axis, and the cuff was inflated until the auscultatory signal was no longer detected. For the lower limbs, the cuffs were placed at the inguinal fold, with the Doppler probe positioned over either the posterior tibial or the dorsalis pedis artery, following the same procedures described for the upper limbs.

Arterial diameters were measured using an ultrasound system (Philips ClearVue 850, Eindhoven, Netherlands). For radial artery assessment, the right arm was slightly abducted with the elbow in slight flexion. A broadband linear transducer (L4-12t) was positioned over the distal aspect of the biceps brachii, approximately 3–5 cm proximal to the cubital fossa. For the common carotid artery, the participant's neck was rotated approximately 30^{o} contralaterally and the transducer was positioned over the vessel. In both measurements, B-mode ultrasound was used, with a sampling frequency of 10 Mhz e 12 seconds during, with the arterial diameter calculated by the equipment's own software. The measurements were performed by an experienced ultrasound evaluator.

Muscle thickness (MT) of the rectus femoris (RF) and biceps brachii (BB) were assessed using B-mode ultrasound (ClearVue 650, Philips, Eindhoven, Netherlands). For the RF measurement, participants were placed in a supine position with the right lower limb fully extended; the transducer was positioned at the midpoint between the greater trochanter of the femur and the lateral joint line of the knee. For the BB, with the right upper limb extended and relaxed, MT was measured at 50% of the distance between the acromion process of the scapula and the lateral epicondyle of the humerus, following the protocol described by [11].

Three consecutive measurements (mm) were performed for each site, following the procedures of [12]. A transducer with a 7.5 MHz frequency was positioned perpendicularly over the target muscles. Conductive gel was applied to ensure optimal acoustic coupling and minimize skin compression. For the RF and BB echo intensity, a quantitative grayscale analysis was conducted. A square Region of Interest (ROI), standardized at 1x1 cm, was used to delineate the muscle area. The mean echo intensity within the ROI was calculated using the histogram function of the ImageJ software (NIH, Bethesda, MD, USA), expressed on a scale ranging from 0 (black) to 255 (white) in arbitrary units (AU) [13].

All measurements were conducted at the PAPGEF laboratory facility by a single experienced sonographer to ensure consistency. For both muscle thickness and echo intensity, 3 consecutive measurements were obtained at three distinct time points: baseline (pre-intervention), mid-point (week 4), and post-intervention (week 8). The highest value among the three measurements was used for subsequent statistical analysis.

To minimize nutritional confounding factors, participants were instructed to maintain their habitual dietary intake throughout the study. Dietary compliance was monitored using a 24-hour dietary recall, which quantified all food and beverage consumption from the preceding day, following the methodology described by [14].

Training Intervention

The exercise protocol comprising the back squat (BS) and elbow flexion (EF) was preceded by a familiarization phase. The training prescription consisted of 4 sets of 15 repetitions at 30% of 1RM, with 30-second rest intervals between sets. In the BFR groups, restriction was maintained continuously throughout the sets and released only during the transition between different exercises. Training load and pressure were progressed at the mid-point of the intervention (week 5), based on updated 1RM and Insonation Pressure (INP) assessments. The program totaled 24 sessions over 8 weeks (thrice weekly), with each session lasting approximately 20 minutes. All sessions were conducted under the direct supervision of specialized professionals, maintaining a 2:1 participant-to-supervisor ratio to ensure protocol adherence and safety.

Statistical Analysis

Data was analyzed using the Statistical Package for the Social Sciences (SPSS, version 25.0; IBM Corp., Armonk, NY, USA). Initially, a preliminary exploratory analysis was conducted to screen for potential outliers and data entry errors. The normality of data distribution and the homogeneity of variances were assessed using the Shapiro-Wilk and Levene's tests, respectively. All data are presented as mean ± standard deviation (SD), and the significance level was set at $p < 0.05$.

Pearson's correlation coefficient (r) was employed to assess the relationship between hemodynamic variables and muscle thickness. The correlation coefficient (r) was interpreted according to the following classification: null (0.0), weak (0.01–0.30), moderate (0.31–0.60), strong (0.61–0.90), very strong (0.91–0.99), and perfect (1.0) [15].

As the data met the assumptions of normality, a one-way analysis of variance (ANOVA) one-way repeated measures: initial, 4 and 8 weeks) three-way (1 - INP two members; 2 - morphological factors e; 3 – groups) used to evaluate differences across the assessment periods.

To investigate training effects on the primary outcome variables—including INP in all four limbs, as well as muscle thickness (MT) and muscle quality/echo-intensity (MQ/EI) for the biceps brachii and rectus femoris comparisons were made between the experimental groups (TBFR60%, TBFR40%, TLLT, UBFR60%, UBFR40%, and ULLT). When a significant F-value was observed, the Bonferroni post hoc test was applied to identify specific differences between levels. All statistical analyses were conducted with significance set at $P \leq 0.05$.

Effect sizes (ES) were calculated to determine the magnitude of treatment effects across assessments [16]. The ES values were interpreted based on the specific thresholds for resistance training research as proposed by Rhea [16]. Additionally, percentage change (Δ) was utilized to quantify differences in dependent variables across all comparisons.

RESULTS

Ultimately, 46 volunteers completed the intervention protocol, representing a retention rate of 67.6%. Baseline comparative analyses revealed no statistically significant differences between the experimental groups regarding strength, morphological, hemodynamic, or muscle quality variables ($P > 0.05$), confirming sample homogeneity across all study arms at the start of the trial (Table 1).

Key findings demonstrated significant positive correlations ($p = 0.001$) between the muscle thickness (MT) of the biceps brachii and rectus femoris and all assessed INP variables right and left upper limbs, and right and left lower limbs.

Table 1
Descriptive characteristics (mean ± standard deviation) of morphological variables, body composition, hemodynamics and muscle tissue quality TBFR60%, TBFR40%, TLLT, UBFR60%, UBFR40%, ULLT

VARIABLES	TBFR60% (n = 10)	TBFR40% (n = 10)	TLLT (n = 7)	UBFR60% (n = 5)	UBFR40% (n = 9)	ULLT (n = 5)	P
Age (years)	22 ± 2,71	20,7 ± 1,33	22,29 ± 3,95	20 ± 2,51	20,00 ± 2,35	22,00 ± 2,12	0,001
RABI	0,97 ± 0,08	0,99 ± 0,57	0,97 ± 0,08	1,06 ± 0,17	0,91 ± 0,15	1,02 ± 0,13	0,029
LABI	1,00 ± 0,07	1,05 ± 0,13	1,04 ± 0,08	1,00 ± 0,15	0,99 ± 0,12	1,04 ± 0,89	0,004
Body Composition							
BM (kg)	73,26 ± 14,79	74,40 ± 12,76	66,03 ± 8,99	75,98 ± 13,91	64,54 ± 17,48	74,52 ± 26,57	0,031
BFP (%)	28,71 ± 7,09	32,72 ± 8,61	29,93 ± 9,90	38,74 ± 10,03	38,29 ± 5,67	42,64 ± 5,73	0,330*
MM (Kg)	48,69 ± 10,42	47,08 ± 11,23	43,19 ± 9,01	43,07 ± 9,65	36,78 ± 9,37	38,73 ± 10,18	0,008
Strength							
1RMS(Kg)	119,50 ± 27,73	107,80 ± 33,66	103,42 ± 19,52	73,20 ± 17,64	69,78 ± 17,70	67,80 ± 16,41	0,029
1RMEF (Kg)	31,40 ± 12,93	23,80 ± 13,28	23,14 ± 9,99	22,00 ± 16,91	11,33 ± 6,86	12,8 ± 3,03	0,004
Hemodynamics							
RULINP (mmHg)	152,5 ± 19,61	153,5 ± 24,5	144,29 ± 7,87	156,00 ± 19,49	141,11 ± 10,54	148,00 ± 40,87	0,001
RLLINP (mmHg)	152,0 ± 29,65	155,0 ± 26,35	145,71 ± 12,72	168,00 ± 19,24	135,56 ± 17,40	154,00 ± 56,39	0,001
Muscle Tissue Quality							
BBMT (cm)	2,36 ± 0,56	2,28 ± 0,66	1,99 ± 0,48	2,20 ± 0,71	1,77 ± 0,50	1,67 ± 0,50	0,650*
RFMT (cm)	1,82 ± 0,29	1,91 ± 0,27	1,93 ± 0,23	1,92 ± 0,27	1,95 ± 0,41	1,95 ± 0,21	0,892*
Vascular Lumen							
DAC (cm)	0,69 ± 0,09	0,68 ± 0,07	0,69 ± 0,07	0,69 ± 0,09	0,66 ± 0,11	0,69 ± 0,07	0,070*
DAR (cm)	0,37 ± 0,11	0,37 ± 0,07	0,30 ± 0,09	0,41 ± 0,11	0,33 ± 0,07	0,32 ± 0,16	0,180*

Legend: RABI - Right Ankle-Brachial Index; LABI - Left Ankle-Brachial Index; MM - Muscle Mass; 1RMSQ – 1 Repetition Maximum Squat; 1RMEF – 1 Repetition Maximum Elbow Flexion; RULINP - Right Upper Limb Insonation Pressure; RLLINP - Right Lower Limb Insonation Pressure; BBMT - Biceps Brachii Muscle Thickness; RFMT - Rectus Femoris Muscle Thickness; CAD: Carotid Artery Diameter; RAD - Radial Artery Diameter.

Regarding biceps brachii muscle quality (BB_MQ), a significant yet weak negative correlation was observed exclusively with the INP of the right lower limb (r = -0.212; p = 0.001). All other correlations involving muscle quality variables failed to reach statistical significance. Furthermore, no statistically relevant correlations were identified between arterial diameters and any of the assessed INP values.

Table 2
Correlation matrix between arterial occlusion pressure (AOP) across all limbs, muscle thickness (MT), muscle quality (MQ), and arterial diameters (carotid and radial)

Variable	INP_RUL	INP_LUL	INP_RLL	INP_LLL
	r p	*r p*	*r p*	*r p*
MT_BB	0,249** 0,001	0,335** 0,001	0,319** 0,001	0,385** 0,001
MT_RF	0,319** 0,001	0,371** 0,001	0,459** 0,001	0,448** 0,001
MQ_BB	0,009 0,880	0,003 0,956	-0,212** 0,001	-0,076 0,216
MQ_RF	0,002 0,974	-0,001 0,993	-0,040 0,514	-0,016 0,796
CAD	0,040 0,525	-0,005 0,938	0,048 0,444	0,030 0,639
RAD	-0,001 0,993	-0,003 0,958	0,030 0,631	0,090 0,156

Legend: Right upper limb insonation pressure: INP_RUL; Left upper limb insonation pressure: INP_LUL; Right lower limb insonation pressure: INP_RLL; Left lower limb insonation pressure: INP_LLL; Biceps brachii muscle thickness: MT_BB; Rectus femoris muscle thickness: MT_RF; Biceps brachii muscle tissue quality: MTQ_BB; Rectus femoris muscle tissue quality: MTQ_RF; Carotid artery diameter: D_CA; Radial artery diameter: D_RA.

Table 3 demonstrates that the intervention was effective in reducing INP, with distinct responses observed across the experimental groups. For the right upper limb INP, the ANOVA one way revealed a significant main effect of time ($F = 82.49$; $P < 0.001$), indicating a decrease in INP throughout the evaluation periods.

Post hoc comparisons for the TBFR60% group revealed significant INP reductions from baseline to the mid-point ($\Delta = 16.18$; $P = 0.001$) and post-intervention assessments ($\Delta = 18.78$; $P = 0.001$); however, no significant differences were observed between the mid-point and post-intervention stages ($\Delta = 2.59$; $P = 0.306$). The TBFR40% group showed significant decreases from baseline to mid-point ($\Delta = 12.40$; $P = 0.001$) and post-intervention ($\Delta = 14.51$; $P = 0.001$), a pattern mirrored by the TLLT group at the same time points ($\Delta = 11.56$; $P = 0.001$ and $\Delta = 14.39$; $P = 0.001$, respectively). Regarding the untrained groups, UBFR60% exhibited significant INP reductions at mid-point ($\Delta = 14.79$; $P = 0.001$) and post-intervention ($\Delta = 19.13$; $P = 0.001$). For the UBFR40% group, significant differences were found between baseline and post-intervention ($\Delta = 7.45$; $P = 0.042$) and between mid-point and post-intervention ($\Delta = 7.03$; $P = 0.001$). Finally, the ULLT group demonstrated significant reductions at the mid-point ($\Delta = 10.47$; $P = 0.022$) and post-intervention ($\Delta = 13.00$; $P = 0.005$). Similar trends in INP were observed across all other assessed limbs.

For the left upper limb INP ($F = 84.50$; $P < 0.001$), the TBFR60% group showed significant reductions from baseline to mid-point ($\Delta = 17.59$; $P = 0.001$) and post-intervention ($\Delta = 21.01$; $P = 0.001$). The TBFR40% group demonstrated significant differences from baseline to mid-point ($\Delta = 11.32$; $P = 0.001$), baseline to post-intervention ($\Delta = 19.98$; $P = 0.001$), and between the mid-point and post-intervention assessments ($\Delta = 8.66$; $P = 0.001$). For the TLLT group, a significant difference was observed only between baseline and post-intervention ($\Delta = 10.23$; $P = 0.027$).

Among the untrained groups, the UBFR60% group exhibited significant reductions at the mid-point ($\Delta = 19.04$; $P = 0.001$) and post-intervention ($\Delta = 20.73$; $P = 0.001$). Finally, the UBFR40% group showed significant differences from baseline to post-intervention ($\Delta = 15.93$; $P = 0.001$) and between the mid-point and post-intervention stages ($\Delta = 8.76$; $P = 0.001$).

For the lower right limb INP ($F = 56.64$; $P < 0.001$), the TBFR60% group showed significant reductions at the mid-point ($\Delta = 11.56$; $P = 0.006$) and post-intervention ($\Delta = 20.96$; $P = 0.001$). The TBFR40% group exhibited significant decreases from baseline to mid-point ($\Delta = 9.47$; $P = 0.031$), baseline to post-intervention ($\Delta = 17.14$; $P = 0.001$), and between the

mid-point and post-intervention assessments (Δ= 7.67; P = 0.002). For the TLLT group, significant reductions were observed at both the mid-point (Δ= 13.51; P = 0.007) and post-intervention (Δ= 17.59; P = 0.001).

Regarding the untrained groups, UBFR60% demonstrated significant INP reductions at mid-point (Δ= 21.73; P = 0.001) and post-intervention (Δ= 26.08; P = 0.001). In the UBFR40% group, a significant difference was found between the mid-point and post-intervention stages (Δ= 8.64; P = 0.001), while for the ULLT group, a significant decrease was observed between baseline and post-intervention (Δ= 19.41; P = 0.001).

Regarding the left lower limb INP in the group TBRF60% (F = 75.47; P < 0.001), exhibited significant reductions from baseline to the mid-point (Δ= 16.60; P = 0.001) and post-intervention (Δ= 22.38; P = 0.001), as well as a significant difference between the mid-point and post-intervention assessments (Δ= 5.78; P = 0.020). In the TBFR40% group, significant decreases were observed at the mid-point (Δ= 14.61; P = 0.001) and post-intervention (Δ= 31.05; P = 0.001), with a significant difference also found between the mid-point and post-intervention stages (Δ= 16.43; P = 0.001). The TLLT group demonstrated significant reductions at both the mid-point (Δ= 17.93; P = 0.001) and post-intervention (Δ= 23.66; P = 0.001).

Among the untrained groups, the UBFR40% group showed a significant reduction at the post-intervention assessment (Δ= 13.85; p = 0.008). Finally, the ULLT group presented significant decreases at the mid-point (Δ= 14.68; p = 0.038) and post-intervention (Δ= 22.70; p = 0.001), along with a significant difference between the mid-point and post-intervention stages (Δ= 8.03; p = 0.027).

Figure 2A illustrates the significant group-by-time interaction for RUL_INP among trained participants (F = 1.346; p = 0.007). Post-hoc analysis for the post-intervention assessment revealed that the TBFR40% group exhibited significantly lower values compared to both TBFR60% (Δ= 6.73; p = 0.043) and TLLT (Δ= 9.95; p = 0.001). In Fig. 2B, the interaction for LUL_INP is presented (F = 5.78; p = 0.001). At the mid-point assessment, significant differences were observed, with the TBFR40% group showing a marked reduction compared to TBFR60% (Δ= 8.87; p = 0.026) and TLLT (Δ= 12.02; p = 0.001).

Figure 2C illustrates the group-by-time interaction for RLL_INP (F = 1.251; p = 0.028). Post-hoc analysis revealed that the TBFR40% group exhibited significantly lower values compared to the TBFR60% group at the post-intervention assessment (Δ= 8.80; p = 0.003). Additionally, the TBFR40% group showed significantly lower INP than the TLLT group at both the mid-point (Δ= 14.67; p = 0.004) and post-intervention (Δ= 11.08; p = 0.001) time points. Regarding Fig. 2D, a significant interaction was found for LLL_INP (F = 3.00; p = 0.001). At the mid-point assessment, the TBFR40% group presented significantly lower values than the TBFR60% group (Δ= 14.22; p = 0.006). Furthermore, the TBFR40% group exhibited significantly lower INP compared to the TLLT group at both the mid-point (Δ= 18.93; p = 0.001) and post-intervention (Δ= 8.22; p = 0.018) assessments.

Table 3

Comparative data of hemodynamic insonation pressure variables between groups at pre-, intermediate, and post-intervention assessments: TBFR60% (n = 10), TBFR40% (n = 10), TTLT(n = 7), UBFR60% (n = 5), UBFR40% (n = 9), ULLT (n = 5)

Variables	**TBFR60% M (SE)**			**TBFR40% M (SE)**			**TTLT M (SE)**				
	Home	**Inter**	**Final**	**Home**	**Inter**	**Final**	**Home**	**Inter**	**Final**	**F**	**P**
INP_RUL	151,9 ± 2,8	135,7 ± 1,8*	133,2 ± 1,6*	154,4 ± 2,8	142,0 ± 1,8*	139,9 ± 1,6*	144,3 ± 3,3	132,8 ± 2,2*	129,9 ± 1,9*	82,49	0,001
INP_LUL	152,5 ± 3,1	134,9 ± 1,9*	131,5 ± 1,7*	154,9 ± 3,1	143,6 ± 1,9*	134,9 ± 1,6*#	139,2 ± 3,7	131,6 ± 2,3	129,0 ± 2,0*	84,50	0,001
INP_RLL	151,1 ± 3,7	139,5 ± 2,5*	130,1 ± 1,7*#	156,0 ± 3,6	146,6 ± 2,5*	138,9 ± 1,7*#	145,4 ± 4,3	131,9 ± 3,0*	127,8 ± 2,3*	56,64	0,001
INP_LLL	156,3 ± 4,4	139,7 ± 2,8*	134,0 ± 1,6*#	168,6 ± 4,3	154,0 ± 2,8*	137,6 ± 1,6*#	153,0 ± 5,2	135,0 ± 3,3*	129,3 ± 1,9*	75,47	0,001
Variables	**UBFR60% M (SE)**			**UBFR40% M (SE)**			**ULLT M (SE)**				
	Home	**Inter**	**Final**	**Home**	**Inter**	**Final**	**Home**	**Inter**	**Final**	**F**	**P**
INP_RUL	155,9 ± 3,9	141,1 ± 2,6*	136,8 ± 2,2*	141,3 ± 3,0	140,9 ± 2,0	133,9 ± 1,7*	148 ± 4,0	137,5 ± 2,7*	135 ± 2,3*	82,49	0,001
INP_LUL	156,7 ± 4,3	137,6 ± 2,7*	135,9 ± 2,3*	144,6 ± 3,3	137,6 ± 2,1	128,6 ± 2,3*	146 ± 4,5	137,9 ± 2,8	132,2 ± 2,4*#	84,50	0,001
INP_RLL	167,4 ± 5,1	145,7 ± 3,5*	141,3 ± 2,3*	135,9 ± 3,9	144,4 ± 2,7	135,5 ± 1,7#	154 ± 5,3	141,4 ± 3,7	134,6 ± 2,4*	56,64	0,001
INP_LLL	159,4 ± 6,1	148,1 ± 3,9	146,0 ± 2,2	147,7 ± 4,6	138,3 ± 3,0	133,9 ± 1,7*	158,0 ± 6,3	143,3 ± 4,1*	135,3 ± 2,3*#	75,47	0,001

Legend: IP_RUL: Insonation Pressure Right Upper Limb; IP_LUL: Insonation Pressure Left Upper Limb; IP_RLL: Insonation Pressure Right Lower Limb; IP_LLL: Insonation Pressure Left Lower Limb. *: difference vs. home assessment; #: difference vs. intermediate assessment.

Table 4
Comparative data of muscle thickness and muscle tissue quality variables between groups at pre-intervention, intermediate and post-intervention TBFR60% (n = 10), TBFR40% (n = 10), TLLT (n = 7), UBFR60% (n = 5), UBFR40% (n = 9), ULLT (n = 5)

Variables	**TBFR60% M (SE)**			**TBFR40% M (SE)**			**TLLT M (SE)**				
	Home	**Inter**	**Final**	**Home**	**Inter**	**Final**	**Home**	**Inter**	**Final**	**F**	**P**
MT_BB	2,18 ± 0,08	2,31 ± 0,09	2,46 ± 0,08*	1,97 ± 0,08	1,98 ± 0,09	2,56 ± 0,09*#	1,92 ± 0,10	2,03 ± 0,10	2,34 ± 0,12*#	30,47	0,001
MT_RF	1,88 ± 0,05	2,18 ± 0,06*	2,20 ± 0,08*	1,89 ± 0,05	2,15 ± 0,06*	2,42 ± 0,08*#	1,88 ± 0,06	2,04 ± 0,07	2,41 ± 0,09*#	52,62	0,001
MQ_BB	110,6 ± 8,32	32,3 ± 7,46	33,0 ± 4,64	251,9 ± 8,32	38,3 ± 7,46	35,2 ± 4,64#	146,4 ± 9,59	35,9 ± 8,92	34,12 ± 5,55	5,02	0,007
MQ_RF	166,8 ± 7,36	26,8 ± 8,08	26,2 ± 4,62	310,1 ± 7,36	28,6 ± 8,08	25,4 ± 4,62#	219,2 ± 8,80	27,8 ± 9,66	26,3 ± 5,53	11,02	0,001
Variables	**UBFR60% M (SE)**			**UBFR40% M (SE)**			**ULLT M (SE)**				
	Home	**Inter**	**Final**	**Home**	**Inter**	**Final**	**Home**	**Inter**	**Final**	**F**	**P**
MT_BB	2,20 ± 0,11	1,88 ± 0,12*	1,98 ± 0,11	1,92 ± 0,08	2,00 ± 0,09	2,31 ± 0,09*#	1,69 ± 0,11	2,31 ± 0,12*	2,43 ± 0,12*	30,47	0,001
MT_RF	1,91 ± 0,06	2,05 ± 0,08	2,08 ± 0,10	1,76 ± 0,05	2,14 ± 0,06*	2,16 ± 0,08*	1,85 ± 0,07	2,15 ± 0,08*	2,32 ± 0,11*	52,62	0,001
MQ_BB	338,8 ± 7,88	36,0 ± 9,97	35,1 ± 6,20	393,3 ± 61,4	36,9 ± 7,86*	34,3 ± 4,89*#	334,9 ± 82,3	34,5 ± 10,55	33,6 ± 6,56	5,02	0,007
MQ_RF	279,2 ± 9,84	26,6 ± 10,80	27,4 ± 6,18	463,9 ± 77,6	26,5 ± 8,52*	28,0 ± 4,87*#	284,9 ± 104	27,8 ± 11,4	26,6 ± 6,54	11,02	0,001

Legend: MT_BB: Muscle Thickness Biceps Brachii; MT_RF: Muscle Thickness Rectus Femoris. MTQ_BB: Muscle Quality Biceps Brachii; MTQ_RF: Muscle Quality Rectus Femoris. *: difference vs. home assessment; #: difference vs. intermediate assessment.

Table 4 presents the results for MT and MQ, demonstrating that the intervention was effective in enhancing both parameters. For biceps brachii muscle thickness (BB_MT), a significant main effect of time was observed ($F = 30.47$; $P < 0.001$), indicating a progressive increase in muscle thickness throughout the study. Similarly, rectus femoris muscle thickness (RF_MT) showed a significant time effect ($F = 52.62$; $P < 0.001$). Regarding muscle quality, significant main effects of time were found for both the BB ($F = 5.02$; $P = 0.007$) and the RF ($F = 11.02$; $P < 0.001$). These improvements were characterized by a significant reduction in muscle echo intensity, which reflects an overall enhancement in muscle tissue quality.

Regarding BB_MT, post-hoc analyses revealed specific significant improvements across the groups. Within the trained participants, the TBFR60% group showed a significant increase at the post-intervention assessment compared to baseline ($\Delta = 0.28$mm; $P = 0.025$). The TBFR40% group exhibited significant gains at post-intervention ($\Delta = 0.60$ mm; $P =$

0.001) and between the mid-point and post-intervention stages (Δ= 0.58 mm; P = 0.001). For the TLLT group, significant increases were observed at the mid-point (Δ= 0.42 mm; P = 0.003) and between the mid-point and post-intervention (Δ= 0.32 mm; P = 0.040). Among the untrained participants, the UBFR60% group showed a significant increase at the mid-point compared to baseline (Δ = 0.33 mm; P = 0.020). The UBFR40% group demonstrated significant increases from baseline to post-intervention (Δ= 0.39 mm; P = 0.002) and between the mid-point and post-intervention (Δ= 0.31 mm; P = 0.018). Finally, the ULLT group exhibited significant growth at both the mid-point (Δ= 0.62 mm; P = 0.001) and post-intervention (Δ= 0.73 mm; P = 0.001) assessments compared to baseline.

Regarding RF_MT, the TBFR60% group exhibited significant increases from baseline to mid-point (Δ= 0.30 mm; P = 0.001) and post-intervention (Δ= 0.32 mm; P = 0.001). For the TBFR40% group, significant gains were observed at the mid-point (Δ= 0.26 mm; P = 0.001), post-intervention (Δ= 0.54 mm; P = 0.001), and between the mid-point and post-intervention assessments (Δ= 0.28 mm; p = 0.010). The TLLT group demonstrated significant improvements at the post-intervention assessment (Δ= 0.53 mm; P = 0.001) and between the mid-point and post-intervention stages (Δ= 0.38 mm; P = 0.002). Among the untrained participants, the UBFR40% group showed significant growth at both the mid-point (Δ= 0.38 mm; P = 0.001) and post-intervention (Δ= 0.40 mm; P = 0.001) assessments. Finally, the ULLT group revealed significant increases at the mid-point (Δ= 0.30 mm; P = 0.006) and post-intervention (Δ= 0.47 mm; P = 0.006) compared to baseline.

Regarding BB_MQ, the TBFR40% group exhibited a significant improvement between the midpoint and post-intervention assessments (Δ= 3.10; P = 0.001). Similarly, the UBFR40% group demonstrated significant changes at the post-intervention assessment (Δ= 2.66; P = 0.003). For RF_MQ, the UBFR40% group showed a significant improvement in the mid-point assessment compared to baseline (Δ= 3.31; P = 0.001).

DISCUSSION

The study results demonstrate that the intervention was effective in increasing muscle thickness (MT) in both the biceps brachii (BB) and the rectus femoris (RF). Notably, the group trained at 40% (TBFR40%) exhibited a significantly greater increase in the biceps brachii compared to the 60% group. This finding suggests that lower restrictive pressures may be equally or even more effective than higher pressures. Furthermore, these results align with Clarkson et al. (2024), who indicated that different pressure systems elicit similar hypertrophic adaptations.

The untrained group demonstrated significant gains at the final assessment, regardless of the applied restriction fraction. According to Loenneke et al. (2025), low-load resistance training combined with blood flow restriction (LLRT + BFR) increases muscle volume, serving as a valuable tool for untrained individuals or those intolerant to high-load training, irrespective of the applied cuff pressure.

Regarding arterial occlusion pressure (AOP), termed insonation pressure (INP) in some studies a significant reduction was observed in the assessed limbs throughout the intervention. This decrease is consistent with the findings of Russo et al. (2023), who demonstrated that low-load blood flow restriction training (LLRT-BFR) can induce greater chronic reductions in systolic blood pressure compared to traditional resistance training (TRT).

While training induces chronic reductions in blood pressure, it acutely elicits cardiovascular stress. As described by Ji et al. (2025), BFR exercise significantly elevates local pressures during both active sets and rest intervals compared to non-BFR training, a mechanism primarily driven by the accumulation of metabolites.

Significant positive correlations were observed between muscle thickness and all INP variables for each limb. These findings corroborate the evidence presented by Cerqueira et al. (2021) and Loenneke et al. (2025), indicating that limbs with greater muscle thickness require higher occlusion pressures to cease blood flow.

However, as muscle thickness increases following longitudinal training, a pertinent question arises regarding the necessity of adjusting the applied pressure. As muscle thickness develops, INP dynamics also evolve, which underscores the importance of assessing INP as part of an individualized protocol throughout the training intervention, as discussed by Gray et al. (2023).

The observation that INP chronically decreases despite increases in muscle thickness suggests an enhancement in vascular efficiency and endothelial sensitivity (Emam et al., 2025). These positive vascular adaptations are supported by Mouser et al. (2019), who demonstrated that low-load BFR training utilizing high occlusion pressures elicits vascular adaptations comparable to those observed following high-load resistance training.

Current literature lacks a consensus regarding the necessity of progressively increasing pressure over several weeks of training. Evidence suggests that unnecessary increments in pressure loads may primarily increase participant discomfort and potential risk without providing additional physiological benefits.

Amorim et al. (2022) reinforces that BFR exercise is safe and does not impair arterial stiffness in older adults. Similarly, Rolnick et al. (2024) argues that BFR does not acutely increase central arterial stiffness to a greater extent than traditional resistance training (TRT), which underscores the safety of chronic protocols (Cohen et al., 2021).

While BFR increases heart rate and lactate levels, it may improve pulse wave velocity, suggesting long-term benefits for vascular function (Huang et al., 2025). Regarding safety considerations, the ABI underscores that BFR should be applied with caution due to potential sympathetic hyperactivity (Nascimento et al., 2020).

Research conducted by Zheng et al. (2023) suggests that INP is linked to enhanced arterial compliance and endothelial function. Furthermore, the authors note that while acute hemodynamic stress is significant, BFR training does not result in harmful increases in arterial stiffness, potentially promoting favorable long-term vascular remodeling.

An analysis of the hemodynamic responses to BFR exercise reveals that, despite marked acute cardiovascular strain, BFR training does not result in harmful increases in arterial stiffness. Conversely, this modality may elicit favorable chronic vascular remodeling (Silva et al., 2019).

The TRFS60% group exhibited a more significant chronic decline in AOP across all assessed limbs, corroborating the findings of Gray et al. (2023). By directly comparing 40% and 60% INP Gray and colleagues showed that the 60% threshold elicits superior physiological strain, characterized by elevated heart rate, higher RPE scores, and increased levels of perceived discomfort.

Elevated pressure loads (60% INP) represent a feasible prescription strategy, fostering more robust and rapid adaptations among trained individuals. Jacobs et al. (2023) emphasizes the importance of autoregulation and INP estimation, further validating the principle that individuals with greater muscle thickness require higher arterial occlusion pressures.

No significant differences were observed between the 40% and 60% groups in the untrained population. This indicates that for untrained individuals, 40% INP represents a superior strategy in terms of cost-benefit, as it yields comparable outcomes with mitigated cardiovascular strain and enhanced tolerance and adherence. These findings align with the conclusions of Suga et al. (2021) regarding perceived exertion and adherence. Furthermore, the robust hypertrophic gains observed in the 40% group promote greater training program compliance, a critical factor highlighted by Mattocks et al. (2019).

The reduction in INP over time may serve as an indicator of altered muscle oxygenation during and after exercise. According to Kojima et al. (2021), the chronic decline in INP likely reflects vascular development characterized by more

efficient oxygen delivery or a decrease in peripheral resistance. This mechanism could explain the observed increases in muscle thickness despite the reduction in the required absolute pressure load.

The present findings must be interpreted with caution, acknowledging certain methodological limitations. First, the study design did not allow for load blinding, which may have permitted psychological expectancy effects. Second, the reliance on 1RM testing might have been suboptimal for the untrained cohort due to their lack of technical mastery of the exercise. Third, physical activity assessment via the IPAQ is subject to inherent self-report bias; the use of accelerometers would have provided more objective data. Finally, the lack of standardized nutritional control remains a potential confounding factor that warrants consideration.

CONCLUSION

This study sought to evaluate the adaptive responses to varying BFR fractions in both trained and untrained cohorts. The results underscore the efficacy of BFR in eliciting muscle hypertrophy and favorable hemodynamic remodeling across a spectrum of physical conditioning levels. For untrained subjects, a 40% INP threshold demonstrated significant morphological efficacy, providing a strategic balance between muscle thickness accrual and reduced cardiovascular stress. In contrast, the 60% INP protocol led to a markedly sharp decline in arterial occlusion pressure among trained participants, highlighting the necessity for higher occlusive stimuli to optimize results in more conditioned individuals.

The chronic reduction in INP over an eight-week period, despite the increase in muscle thickness, indicates favorable vascular adaptations, potentially related to improvements in arterial compliance and endothelial function. This finding highlights the necessity of periodic INP reassessments to ensure the safety and precision of the training stimulus.

Declarations

Conflicts of interest

The authors declare no conflicts of interest.

Author Contribution

• JAO: Investigation, Writing - Original Draft, Formal analysis;• AFPC Investigation, Methodology, Validation;• KSM: Investigation, Resources. • PAMD: Investigation, Data Curation, Writing.• GBR: Review & Editing.• PPP: Review & Editing.• MSCS: Supervision, Conceptualization, Project administration, Review & Editing.

Acknowledgements:

This study received external funding from the Paraíba State Research Support Foundation (FAPESQ-PB).

References

1. Patterson SD, Hughes L, Warmington S et al (2019) Blood flow restriction exercise: considerations of methodology, application, and safety. Front Physiol 10:533
2. Cognetti DJ, Sheean AJ, Owens JG (2022) Blood Flow Restriction Therapy and Its Use for Rehabilitation and Return to Sport: Physiology, Application, and Guidelines for Implementation. Arthrosc Sports Med Rehabil 4(1).

10.1016/j.asmr.2021.09.025

3. ACSM (2009) American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. ;41(3)
4. Formiga MF, Fay R, Hutchinson S et al (2020) Effect of aerobic exercise training with and without blood flow restriction on aerobic capacity in health young adults: a systematic review with meta-analysis. Int J Sports Phys Ther 15(2). 10.26603/ijspt20200175
5. Loenneke JP, Hammert WB, Kataoka R, Yamada Y, Abe T (2025) Twenty-five years of blood flow restriction training: What we know, what we don't, and where to next? J Sports Sci 43(19). 10.1080/02640414.2025.2474329
6. Centner C, Wiegel P, Gollhofer A, König D (2019) Effects of blood flow restriction training on muscular strength and hypertrophy in older individuals: a systematic review and meta-analysis. Sports Med 49(1):95–108
7. Silva JCG, Domingos-Gomes JR, Freitas EDS et al (2021) Physiological and perceptual responses to aerobic exercise with and without blood flow restriction. J Strength Cond Res 35(9). 10.1519/JSC.0000000000003178
8. Mouser JG, Laurentino GC, Dankel SJ et al (2017) Blood flow in humans following low-load exercise with and without blood flow restriction. Appl Physiol Nutr Metab 42(11). 10.1139/apnm-2017-0102
9. Laurentino G, Ugrinowitsch C, Aihara AY et al (2008) Effects of strength training and vascular occlusion. Int J Sports Med 29(8). 10.1055/s-2007-989405
10. Neto GR, Silva JCG, Umbelino RKC et al (2018) Are there differences in auscultatory pulse in total blood flow restriction between positions, limbs and body segments? Revista Brasileira de Cineantropometria e Desempenho Humano 20(5). 10.5007/1980-0037.2018v20n5p381
11. Radaelli R, Neto ENW, Marques MFB, Pinto RS (2011) Espessura e qualidade musculares medidas a partir de ultrassonografia: Influência de diferentes locais de mensuração. Revista Brasileira de Cineantropometria e Desempenho Humano 13(2). 10.5007/1980-0037.2011v13n2p87
12. Souza H, Rocha T, Pessoa M et al (2014) Effects of inspiratory muscle training in elderly women on respiratory muscle strength, diaphragm thickness and mobility. Journals Gerontol - Ser Biol Sci Med Sci 69(12). 10.1093/gerona/glu182
13. Mendes P, Wickerson L, Helm D et al (2015) Skeletal muscle atrophy in advanced interstitial lung disease. Respirology 20(6). 10.1111/resp.12571
14. Fisberg RM, Marchioni DML, Colucci ACA (2009) Assessment of food consumption and nutrient intake in clinical practice. Arq Bras Endocrinol Metabol 53(5). 10.1590/s0004-27302009000500014
15. Araújo JP et al The acute effect of resistance exercise with blood flow restriction with hemodynamic variables on hypertensive subjects. J Hum Kinet (2014) ; 43(1). doi: 10.2478/v10078-012-0011-y
16. Rhea MR (2004) Determining the magnitude of treatment effects in strength training research through the use of the effect size. J Strength Cond Res 18(4). 10.1519/14403.1
17. Clarkson MJ, McMahon B, Warmington SA (2024) Comparing adaptations from blood flow restriction exercise training using regulated or unregulated pressure systems: A systematic review and meta-analysis. Clin Rehabil 38(11). 10.1177/02692155241271040
18. Russo A, Boppre G, Schmidt C, Bohn L (2023) Chronic hemodynamic adaptations induced by resistance training with and without blood flow restriction in adults: A systematic review and meta-analysis. Sports Med Health Sci 5(4). 10.1016/j.smhs.2023.09.006
19. Ji S, Franz A, Vicas M et al (2025) Arterial and Venous Pressure Dynamics in Blood Flow Restriction Versus Traditional Strength Training. Scand J Med Sci Sports 35(2). 10.1111/sms.70029
20. Cerqueira MS, Costa EC, Santos Oliveira R, Pereira R, Brito Vieira WH (2021) Blood Flow Restriction Training: To Adjust or Not Adjust the Cuff Pressure Over an Intervention Period? Front Physiol 12. 10.3389/fphys.2021.678407

21. Gray SM, Cuomo AM, Proppe CE, Traylor MK, Hill EC, Keller JL (2023) Effects of Sex and Cuff Pressure on Physiological Responses during Blood Flow Restriction Resistance Exercise in Young Adults. Med Sci Sports Exerc 55(5). 10.1249/MSS.0000000000003103
22. Emam MA, Elsayed A, Hortobágyi T, Amin WM, Malik S, Ali OI (2025) Exploring Blood Flow Restriction Exercise Protocols for Elderly Populations: A Scoping Review of Cuff Pressure, Frequency, and Duration for Muscle Strength, Hypertrophy, and Functional Abilities Outcomes. J Clin Med 14(12). 10.3390/jcm14124185
23. Mouser JG, Mattocks KT, Buckner SL et al (2019) High-pressure blood flow restriction with very low load resistance training results in peripheral vascular adaptations similar to heavy resistance training. Physiol Meas 40(3). 10.1088/1361-6579/ab0d2a
24. Amorim S, Gaspar AP, Degens H et al (2022) The Effect of a Single Bout of Resistance Exercise with Blood Flow Restriction on Arterial Stiffness in Older People with Slow Gait Speed: A Pilot Randomized Study. J Cardiovasc Dev Dis 9(3). 10.3390/jcdd9030085
25. Rolnick N, Licameli N, Moghaddam M et al (2023) Autoregulated and Non-Autoregulated Blood Flow Restriction on Acute Arterial Stiffness. Int J Sports Med 45(1). 10.1055/a-2152-0015
26. Cohen JN, Slysz JT, King TJ, Coates AM, King RT, Burr JF (2021) Blood flow restriction in the presence or absence of muscle contractions does not preserve vasculature structure and function following 14–days of limb immobilization. Eur J Appl Physiol 121(9). 10.1007/s00421-021-04715-3
27. Huang R, Ma Y, Yang Z et al (2025) Hemodynamic analysis of blood flow restriction training: a systematic review. BMC Sports Sci Med Rehabil 17(1). 10.1186/s13102-025-01084-8
28. Nascimento Dda, Petriz C, Prego B, de Souza L, Prestes SA (2020) Effects of blood flow restriction exercise on hemodynamic and cardiovascular response in hypertensive subjects: a systematic review. J Health Sci 22(1):61–71
29. Zheng X, Headley SAE, Maris SA, Smith DM (2023) Acute cardiovascular responses to unilateral bicep curls with blood flow restriction. J Exerc Sci Fit 21(2). 10.1016/j.jesf.2023.01.001
30. Jacobs E, Rolnick N, Wezenbeek E et al (2023) Investigating the autoregulation of applied blood flow restriction training pressures in healthy, physically active adults: An intervention study evaluating acute training responses and safety. Br J Sports Med 57(14). 10.1136/bjsports-2022-106069
31. Suga T, Dora K, Mok E et al (2021) Exercise adherence-related perceptual responses to low-load blood flow restriction resistance exercise in young adults: A pilot study. Physiol Rep 9(23). 10.14814/phy2.15122
32. Mattocks KT, Mouser JG, Jessee MB et al (2019) Perceptual changes to progressive resistance training with and without blood flow restriction. J Sports Sci 37(16). 10.1080/02640414.2019.1599315
33. Kojima C, Yamaguchi K, Ito H, Kasai N, Girard O, Goto K (2021) Acute Effect of Repeated Sprint Exercise With Blood Flow Restriction During Rest Periods on Muscle Oxygenation. Front Physiol 12. 10.3389/fphys.2021.665383

Figures

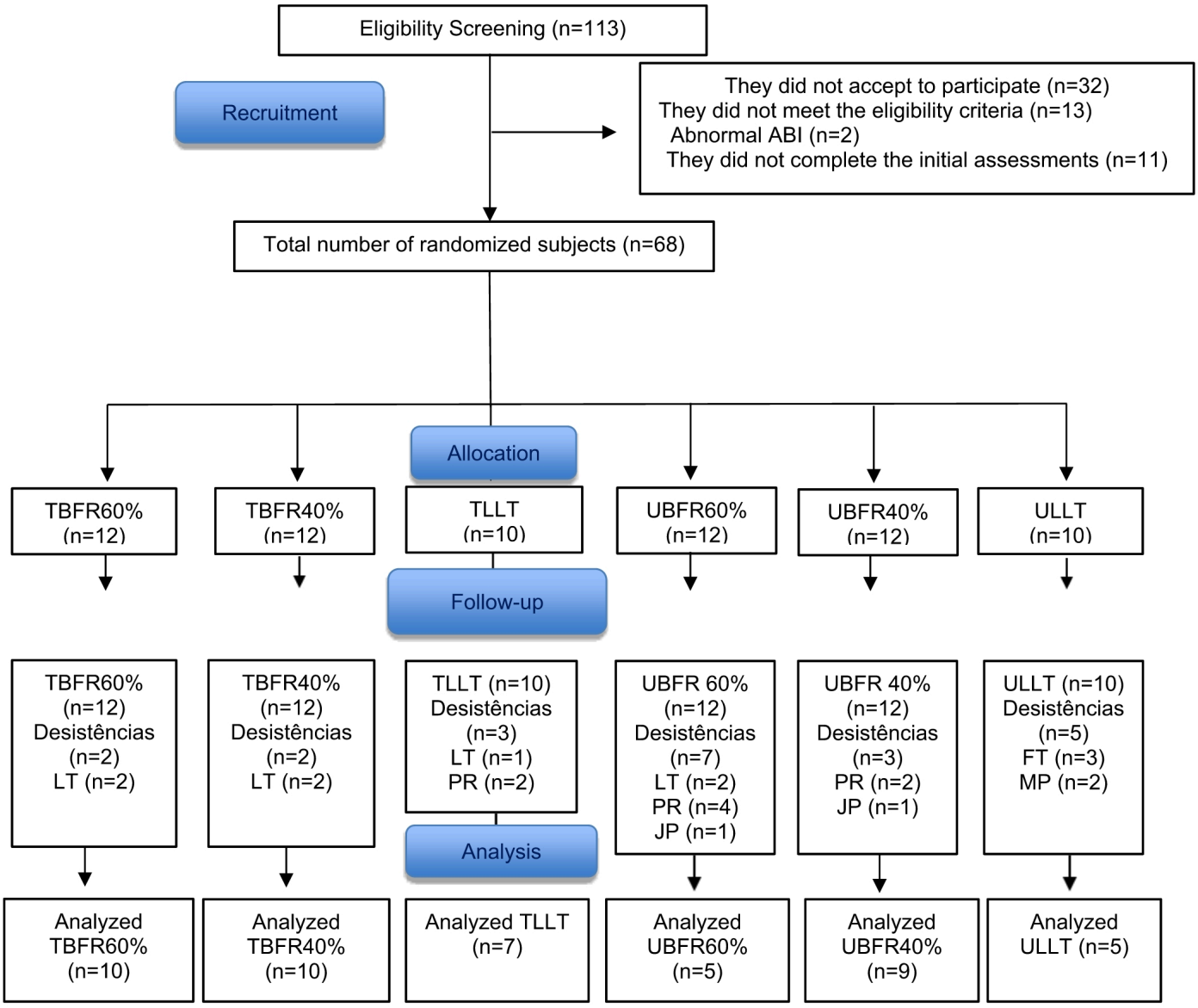


Figure 1

Flowchart of recruitment and sample loss for the study.

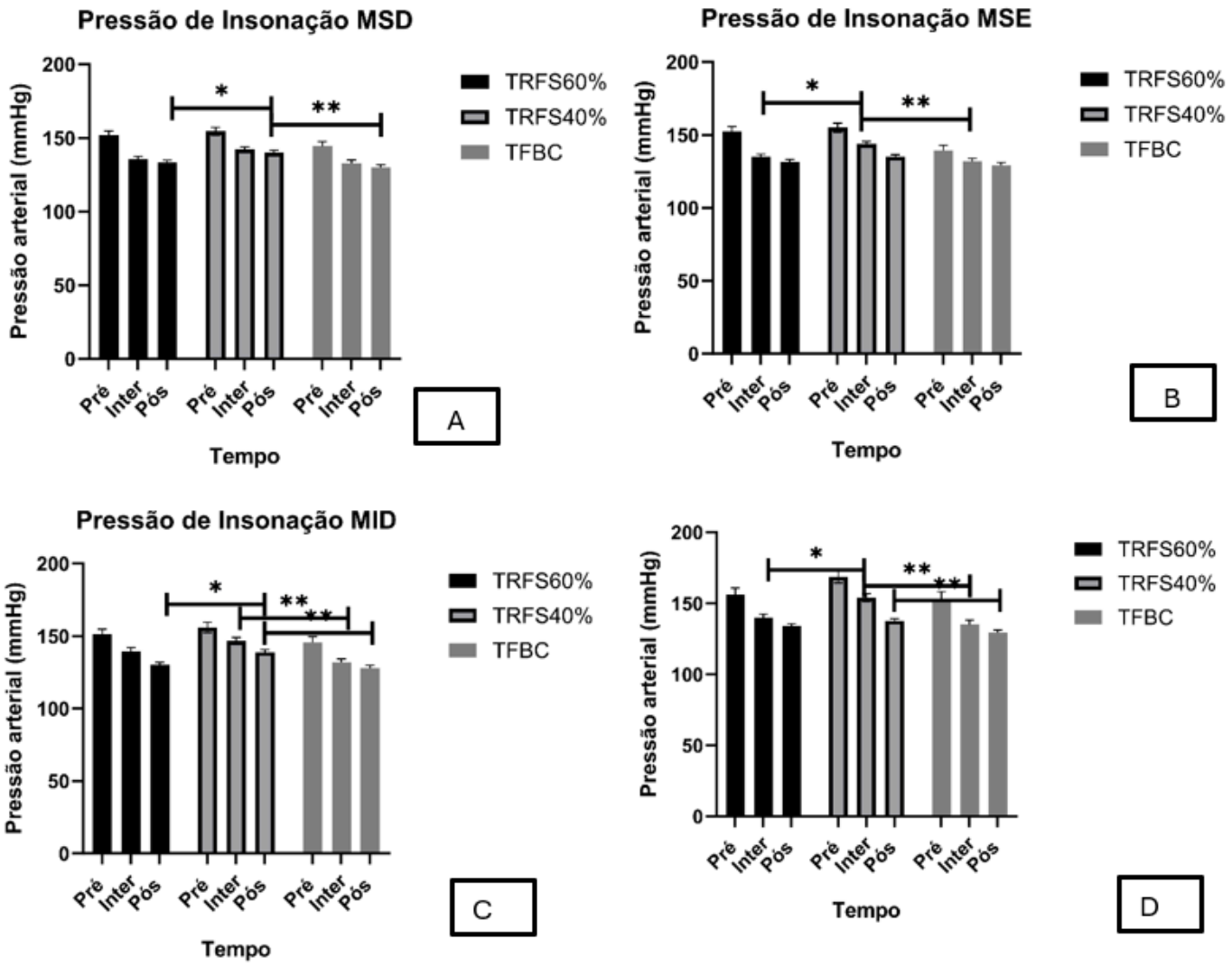


Figure 2

Comparative data of insonation pressure variables between groups at pre-intervention, intermediate and post-intervention assessments: TBFR60% (n=10), TBFR40% (n=10), TLLT (n=7).

Legend: RUL = Right Upper Limb; LUL= Left Upper Limb; RLL = Right Lower Limb; LLL = Left Lower Limb; TBFR60% = Trained Blood Flow Restriction 60%; TBFR40% = Trained Blood Flow Restriction 40%; TLLT = Trained Low-Load Training.