Blood flow restriction plyometric training and muscle power in untrained adults

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Summary

Introduction: Anaerobic training with blood flow restriction stimulates the gain of strength and muscle mass. It is efficient in low weekly training load modalities. It has not been elucidated whether flow-restricted training modalities can influence muscle power, nor their usefulness in plyometric training. Power development is a key indicator of human health and functional integrity.
Objective: To test the effect of low-load plyometric training with or without blood flow restriction on muscle power gains measured by vertical jumps in healthy, untrained male individuals.
Material and method: A quasi-experimental study was carried out in 18 healthy adult men with no previous strength training. They were divided into two groups, one group performed two weekly sessions for four weeks of plyometric exercises with partial blood flow restriction, ERF group (n = 9; 22.77 ± 5.11 years) and another with conventional plyometric exercises, EC group (n = 9; 21.66 ± 4.21 years). Prior to group distribution, an anthropometric characterization was performed. Before and after the training protocol, maximum strength (leg press 1RM), muscle power (Squat Jump and Counter Movement Jump) of the lower limbs, thigh circumference and thigh crease were measured.
Results: The comparison of means of previous anthropometric characteristics showed no differences between the groups. On average, power and relative power increased significantly in both groups (*P*-value <0.05). Compared to the EC group, the mean of the ERF group was significantly higher in the indicators of the jump test without counter movement (*P*-value <0.05). Strength and thigh circumference only increased significantly in the ERF group.
Conclusion: The plyometric training program with flow restriction showed greater adaptations in power, strength, and muscle growth than the conventional plyometric training.

Key words:
Plyometric exercise. Strength training. Blood flow restriction training. Physical training. Sports medicine.

Entrenamiento pliométrico con restricción del flujo sanguíneo y potencia muscular de adultos no entrenados

Resumen

Introducción: El entrenamiento con restricción del flujo sanguíneo (ERF) estimula la ganancia de fuerza y masa muscular. Es eficiente en modalidades de baja carga semanal de entrenamiento. No se ha dilucidado el entrenamiento con restricción de flujo puedan tener influencia en la potencia muscular, tampoco su utilidad en el entrenamiento pliométrico. El desarrollo de la potencia es un indicador clave de salud y funcionalidad del ser humano.
Objetivo: Comprobar el efecto del entrenamiento pliométrico de baja carga con o sin restricción del flujo sanguíneo en la ganancia de potencia muscular medida a través de saltos verticales de individuos varones, sanos y no entrenados.
Material y método: Se plantea un estudio cuasiexperimental, en 18 hombres adultos sanos sin entrenamiento de la fuerza previo. Fueron divididos en dos grupos, un grupo realizó dos sesiones semanales por cuatro semanas de ejercicios pliométricos con restricción de flujo, grupo ERF (n = 9; 22,77 ± 5,11 años) y otro con ejercicios pliométricos convencionales, grupo EC (n = 9; 21,66 ± 4,21 años). Previa a la distribución en grupos se realizó una caracterización antropométrica. Antes y después de protocolo de entrenamiento fueron medidas la fuerza máxima (*leg press* – 1 repetición máxima), la potencia muscular (*Squat Jump* y *Counter Movement Jump*), el perímetro y pliegue del muslo.
Resultados: La comparación de medias de características antropométricas previa no mostró diferencias entre los grupos. En promedio, la potencia y potencia relativa aumentó de forma significativa en ambos grupos (P-valor <0,05). En comparación al grupo EC, la media del grupo ERF fue significativamente mayor en los indicadores la prueba de salto sin contra movimiento (P-valor <0,05). La fuerza y el perímetro del muslo solo aumentó de forma significativa en el grupo ERF.
Conclusión: El programa de entrenamiento pliométrico con restricción parcial de flujo mostró mayores adaptaciones en la potencia, fuerza y crecimiento muscular que el grupo sin restricción.

Palabras clave:
Ejercicios pliométricos. Entrenamiento de la fuerza. Entrenamiento con restricción del flujo sanguíneo. Entrenamiento físico. Medicina del deporte.

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Introduction

Current scientific evidence has shown that blood flow restriction training stimulates strength gain, hypertrophy and muscle activation, and that is has even been effective when used with low load training[1]. In healthy populations, resistance training at controlled speed and with restricted blood flow rapidly increases muscle mass and strength gain[1,2]. These phenomena are considered to be related to higher metabolite concentrations, increased growth hormone release, enhanced activation of mTOR cell signalling, greater neuromuscular recruitment and reduced myostatin mRNA expression[3]. However, it is not yet clear whether forms of blood flow restriction training can influence another indicator of muscle integrity and function, power.

Muscle power is the result of the relationship between strength and movement execution speed, which is highly important for health, functional capacity[4] and athletic performance[5]. In this context, plyometric training has been widely used as the most versatile and practical strategy to develop this aspect of the musculoskeletal system[6]. In addition to being inherently related to strength gain, muscle power affects adaptations in the elastic elements of the musculoskeletal system, such as tendons, fascia and connective tissue, and the subsequent relationship with the stretch-shortening cycle (SSC). Insufficient evidence linking blood flow restriction training combined with specific types of plyometric training has hindered adaptations in muscle power[7].

The literature shows that low speed, high load training is recommended for muscle hypertrophy while high speed, low load training is indicated to increase muscle power[8,9]. Some authors have questioned these recommendations due to ambiguous results in relation to performance increases after short-term strength and power protocols, finding similar results in both. Some studies have also described increases in the rate of force development and improvements in jump height with both training regimes[10,11].

Previous studies support the thesis of greater muscle hypertrophy after strength training. In power training, however, increases in the motor unit discharge rate and improvements in SSC are found, chiefly when body position specificity, as there is in jumping, is involved[12,13]. Accordingly, it seems that both factors are important to increase muscle power.

Considering that blood flow restriction can lead to functional and morphological adaptations even with low training loads, and contextualising plyometric training as an effective strategy for developing muscle power, the main objective of this study is to verify the effect of plyometric training models with and without blood flow restriction on muscle power gain measured through vertical jumps performed by healthy, untrained male individuals.

Materials and method

A quasi-experimental study was proposed because the groups were not organised at random. The aim was to analyse the adaptations and functional responses caused by a plyometric training regime prescribed in 8 sessions over four weeks in two groups of healthy young adult men, one of which completed the sessions with cuffs partially restricting blood flow to the lower limbs.

Subjects

As a result of exposure and public invitation on social networks, 23 young men presented themselves as volunteers at the bodybuilding laboratory of *Universidade Regional Integrada do Alto Uruguay y das Missões* (Brazil), where the procedures involved in this study were carried out[5]. were excluded because they had painful symptoms and musculoskeletal disorders in the lower limbs. The remaining 18 subjects met the inclusion criteria, which included having a low level of physical activity, not having participated in training programmes for at least 3 months and having no significant systemic diseases.

Procedures

The participants were first subjected to an anthropometric assessment and performed a one-repetition maximum (1RM) test to assess maximum dynamic force, and two vertical jump tests on a contact mat to measure jump height. They were then divided into two groups: a blood flow restriction plyometric training group (BFRT n = 9) and a conventional plyometric training group (CT n = 9). After the draw, the participants started the training protocol with two sessions per week for 4 weeks. After competing the training protocols, the participants returned to the laboratory to repeat the tests. All the tests were conducted by the same tester, who was unaware of the purpose and distribution of the groups, and used the same procedures before the training protocols and after 4 weeks of training.

Anthropometric measurements: the measurements were taken using a calliper (Mitutoyo 0.1 mm precision - Cescorf), scales with coupled stadiometer (Welmy, 200 kg capacity, 0.1 kg and 0.005 m precision) and, for circumferences, a tape measure (Cescorf- Porto Alegre Brazil). The marks and measuring techniques followed the standards of *The International Society for the Advancement of Kinanthropometry* (ISAK). The measurements of body mass (kg), height (cm), front thigh skinfold (mm), and mean thigh circumference (cm) were verified.

Power tests: the participants became familiar with the movement required by warming up with 8 vertical jumps of variable heights, with a rest of two minutes before the tests started. The protocol first consisted of *Counter Movement Jumps* (CMJ), jumps without the aid of the upper limbs, the participants keeping their hands on their hips and their trunks upright. They did three maximum vertical jumps with a 10-second interval between attempts and following the verbal orders given. After 2 minutes of recovery and the same number of attempts, the participants did a *Squat Jump* (SJ), which consisted of a maximum vertical jump starting with their knees bent to a right angle, without any counter movement in the lower limbs and without the help of the upper limbs, keeping their hands on their hips from the starting position until completion of the jump[14]. The jumps were performed on a contact mat (Jump System 1.0®, CEFISE, SP/Brazil).

1RM test: a 1RM leg press test was performed bilaterally on a variable loading leg press (Taurus, Brazil). Prior to the test, the participants completed a five-minute general warm-up at 5 km/h on an ergometer. After the general warm-up, they took up position on the leg press (Taurus, Brazil). Each participant then completed a specific warm-up consisting of two sets of eight repetitions with loads which the participants estimated required moderate effort. During the warm-up, the participants had to fully extend their knees and repetition was only assessed when the participants were able to reach the range limiter when in front of the equipment. After the specific warm-up, the participants had a 3-minute break before starting the maximum test.

The maximum test consisted of obtaining the greatest load it was possible to lift in a complete cycle (flexion and extension of the knees). When the participant was able to do more than one repetition, the load was readjusted based on Lombard correction coefficients[15]. The participants had a 5-minute break between attempts. If more than four attempts were needed to determine the 1-RM value, the test was interrupted and performed 48 hours later. Each participant was familiarised with the test before the maximum test. The execution speed of each repetition was guided by a metronome.

Training protocol

The training sessions were identical for both groups in terms of structure and content. The participants initially did a 5-minute warm-up on a treadmill and then completed the main phase, which involved plyometric exercises with 30 seconds of rest between sets and 2 minutes between exercises. Finally, the subjects performed low intensity activities which included walking and breathing exercises for a further 5 minutes to warm down. A weekly progression was proposed based on an increase in the difficulty and volume of plyometric exercises in the main phase. Table 1 shows the structure of the sessions and the progression strategy. The approximate duration of the sessions was 30 minutes in weeks 1 and 2, and 35 minutes in weeks 3 and 4. A 45-cm plyo box was used for those exercises for which one was necessary.

Vascular restriction protocol

To determine partial vascular occlusion or restriction in the lower limbs, the participants in the BFRT group adopted the supine position and remained at absolute rest for 20 minutes prior to each session. Their resting blood pressure was then measured and used to calculate cuff fixation for partial limb occlusion (Scientific Pro -WCS 2020). The pressure used was 20 mmHg above resting systolic blood pressure, thereby ensuring that limb occlusion was partial, particularly impeding venous return. The exercises were carried out with the lower limbs occluded, even during recovery intervals. The methodology used included constant inspection of the limbs and monitoring of the subjects' degree of comfort[16].

Table 1. General structure of the main phase of the training programme sessions for the groups studied in the 4 weeks of training.

Week/Sessions (intensity)	Exercise	Sets	Repetitions
Week 1 / Sessions 1-2 (Low)	*Squat jump* *Split squat jump* *Cycled split squat jump*	2	10
Week 2 / Sessions 3-4 (Low to moderate)	*Split squat jump* *Pike jump* *Double leg tuck jump*	2	10
Week 3 / Sessions 5-6 (Moderate)	*Pike jump* *Double leg tuck jump* *Double leg zigzag hop* *Double leg hop*	3	10
Week 4 / Sessions 7-8 (High)	*Double leg zigzag hop* *Double leg hop* *In-depth jump* (45 cm) *Box jump* (45 cm)	3	10

Statistics

The data were presented as means with their corresponding standard deviation. The Shapiro Wilk test was used to verify the normality of the data. A paired Student's t-test was used for the comparisons of the variables at the pre- and post-training moments The independent Student's t-test was used to compare these variables between groups. The computer program used was IBM SPSS 20.0.

Ethical considerations

This study was approved by the Research Ethics Committee of Centro Universitario Metodista IPA, under decision number 1,475,648 and followed all the recommendations of decision 466/12 of the National Health Council of Brazil. The Helsinki Declaration regulating ethical principles for research studies involving human subjects with prior informed consent was also taken into account.

Results

The data of all the variables are presented as means and standard deviation. The initial characterisation of the population studied showed that the mean age of the subjects was 22.22 ± 4.58 years and their BMI was 23.92 ± 3.40. The random distribution of subjects in two study groups showed no differences in any of the characteristics shown in Table 2.

According to the results of the SJ test shown in Figure 1, significant differences were found in the mean values of pre- and post-training power both in the BFRT group (1,610.7 ± 407.3 *vs.* 3,590 ± 553.1 W, Δ138.55%; *P* <0.001) and in the CT group (1,803.6 ± 371.2 *vs.* 2,942.2 ± 335.1 W, Δ68.51%; *P* <0.001). The mean values before and after the relative power training programme for both groups (BFRT: 22.6 ± 2.9 *vs.*48.7 ± 4.9 W/kg, Δ118.67%; CT: 24.6 ± 3.7 *vs.* 42.7 ± 1.2 W/kg Δ76.86%) and jump height (BFRT: 26.1 ± 6.9 *vs.* 34.3 ± 2.3 cm, Δ41.49%; CT: 26.2 ± 2.5 *vs.* 30.5 ± 1.3 cm, Δ17.20%) were statistically different (*P*-value <0.01). Regarding the comparison between groups, a statistical difference (*P*-value <0.01) was found after the training programme in favour of the BFRT group, the mean observed in this group being higher in power, relative power and jump height.

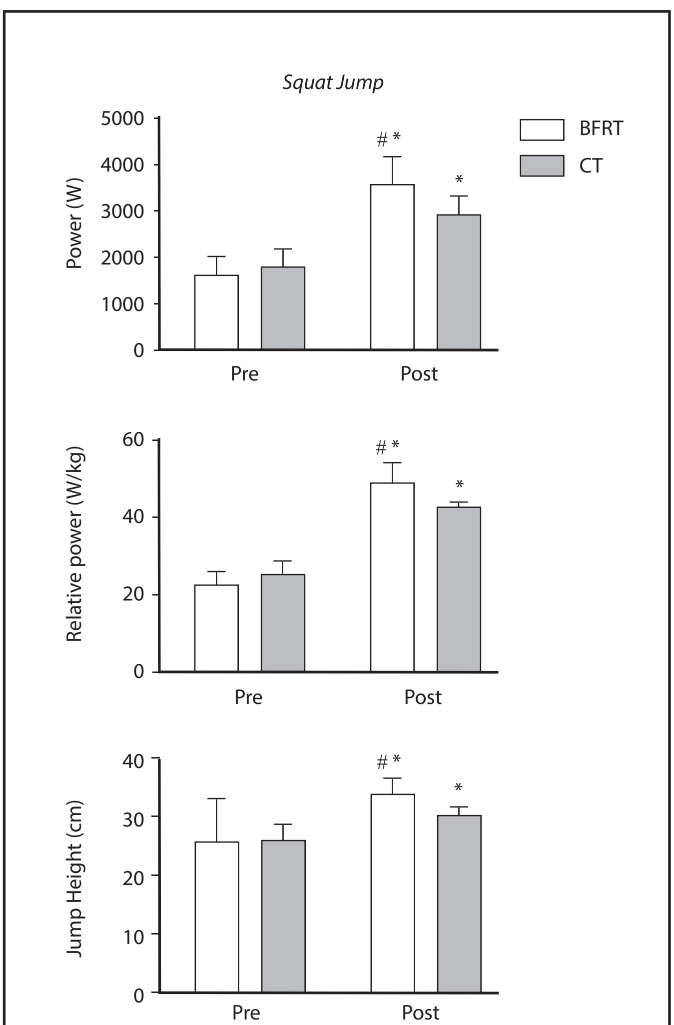
Table 2. Comparison of means of the general characteristics of the population according to the groups formed and studied.

Characteristic	BFRT	CT	*P*-value
Age (years)	22.77 ± 5.11	21.66 ± 4.21	0.621
Weight (kg)	72.77 ± 10.52	74.00 ± 13.20	0.830
Height (m)	1.72 ± 0.06	1.77 ± 0.07	0.165
BMI (kg/m²)	24.34 ± 2.99	23.511 ± 3.90	0.620

BMI: body mass index.

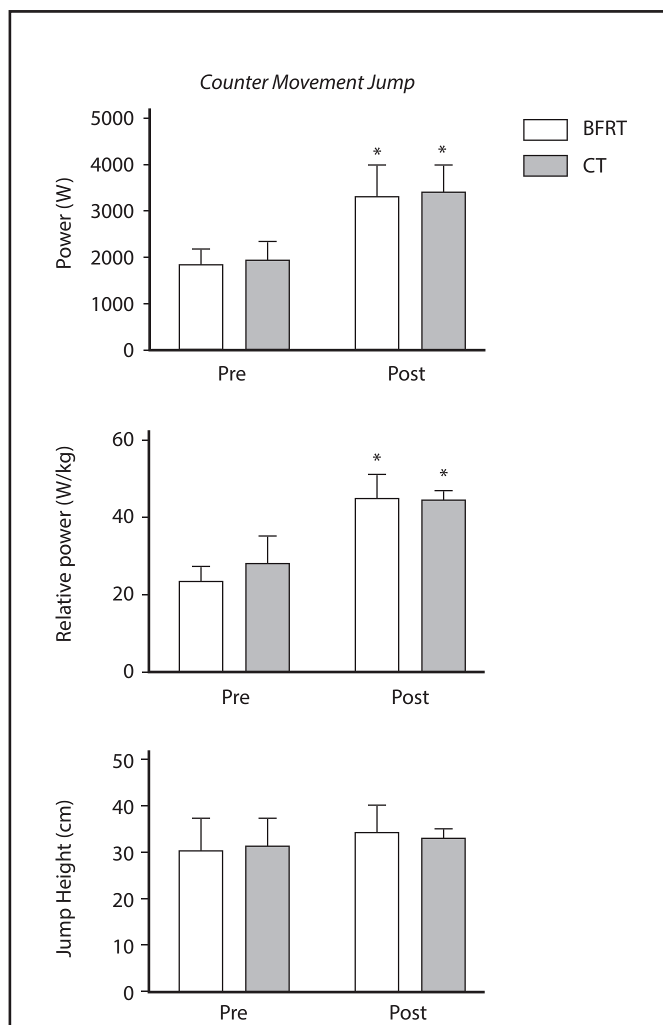
As Figure 2 shows, significant differences (*P*-value <0.001) were found in the CMJ test results between the pre- and post-training moments of both groups, both in power (BFRT: 1,830,6 ± 391.6 *vs.* 3,355.6

Figure 1. Pre- and post-training comparison of mean values of power, relative power and jump height according to the results of the SJ test in the groups studied.



*P-value <0.05 between pre- and post-training; #P-value <0.05 between groups.

Figure 2. Pre- and post-training comparison of mean values of power, relative power and jump height according to the results of the CMJ test in the groups studied.



*P-value <0.05 between pre- and post-training; #P-value <0.05 between groups.

Table 3. Comparison of intra- and inter-group means of anthropometric and lower limb strength measurements before and after the training programme.

Measurement	Pre	Post	Δ%	Intra-group *P*-value	Inter-group *P*-value	
					Pre	Post
1RM leg press (kg)						
BFRT	259.66 ± 86.38	381.33 ± 62.02	54.72	0.003	0.887	0.007
CT	254.11 ± 76.63	300.33 ± 50.46	26.40	0.150		
Thigh circumference (cm)						
BFRT	52.77 ± 4.60	57.88 ± 4.13	9.83	0.024	0.465	0.009
CT	51.00 ± 5.45	51.22 ± 5.35	0.46	0.931		
Thigh skinfold (mm)						
BFRT	9.69 ± 1.40	7.55 ± 1.42	-22.22	0.005	0.112	0.005
CT	11.88 ± 3.65	11.44 ± 3.39	-3.37	0.792		

RM: repetition maximum.

± 672.2 W, Δ86.47%; CT: 1,973 ± 347 *vs.* 3,414.4 ± 651.2 W, Δ75.00%) and relative power (BFRT: 24.8 ± 2.5 *vs.* 45.9 ± 4.2 W/kg, Δ86.21%; CT: 28.8 ± 6.9 *vs.* 45.1 ± 1.2 W/kg). Although there was an increase, the jump height did not show statistical differences in the mean variations before and after the training programme in the groups (BFRT: 31.02 ± 6.7 *vs.* 34.90 ± 5.1 cm, Δ14.80%; CT: 31.74 ± 6.1 *vs.* 33.70 ± 1.56, Δ9.80%). No significant differences were found when comparing the groups.

The results of the strength assessment and the specific anthropometric characteristics considered in the study are shown in Table 3. The 1RM leg press test showed significant differences between the pre- and post-training moments in the BFRT group and differences with the CT group in the final results (*P*-value <0.01). Finally, only the BFRT group showed statistically significant variations in thigh circumference and skinfold, differing from the results of the CT group in the post-training measurements (*P*-value <0.01).

Discussion

The results of this study show that, compared to the subjects who followed a conventional low load plyometric training programme, the previously untrained individuals who did the training sessions with partial blood flow restriction showed greater adaptations in power, strength and muscle mass. Although scientific evidence has previously supported the beneficial effects of blood flow restriction resistance training with increased peaks in strength and muscle mass at low loads[1,3,8,10], evidence supporting adaptations in power and functional indicators such as jump height is limited.

Previous findings with similar methodological approaches have shown, in general, results which contradict those of this study. In this vein, Horiuchi *et al.* reported in their study that subjects who did four weeks of training with traditional jumps improved jump performance and muscle power to a greater extent than those who trained with flow restriction[17]. However, although they analysed the responses in untrained subjects, it should be noted that their methodology involved high occlusion pressures for the training (200 mmHg), inducing total flow restriction. At present, high levels of vascular occlusion for strength training are not usually associated with adaptive advantages and, consequently, limited gains in power and jump height[18].

Our study shows that the BFRT group registered greater gain in relative power and that their jump height improved to a greater extent in the SJ test. This finding is interesting because, although all the indicators of the stretch-shortening cycle test, CMJ, improved, no differences with the results of the group without flow restriction, including jump height, were observed. Previous reports have shown that blood flow restriction training can lead to significant improvements in the functional and elastic properties of the musculoskeletal system, optimising the stretch-shortening cycle, which, in turn, leads to greater acute responses in power and vertical counter movement jump height[19].

In individuals with prior training, evidence supports blood flow restriction methods with significant adaptations in muscle power. Recently, Sun *et al.* showed that, in 4 weeks, a low load, squat-based exercise programme with varying levels of vascular restriction improved vertical jump performance in female football players[20]. Along the same lines, Yang *et al.* described the effectiveness of low load blood flow restriction training in gymnasts. They compared a ten-week training programme based on low intensity resistance exercises with blood flow restriction to conventional high intensity resistance training without flow restriction, the two groups displaying similar adaptations in strength, power and jump height at the end of the study[21]. Although they did not apply specifically plyometric or jump-based exercise protocols, these studies concluded that the effects of blood flow resistance training were potentially safe in improving muscle power as a result of neuromuscular and morphological plasticity.

The improved strength of the BFRT group observed in the present study is not a new finding. However, it should be noted that the plyometric training programme involving vascular occlusion was, in proportion, more effective than conventional training. There is a strong relationship between strength, muscle power and jump performance. Previous studies have reported that improved jump performance is proportional to the contractile capabilities of muscle tissue and the rate of force development in the lower limbs[22]. In parallel, morphological adaptations lead to improvements in the elastic properties of the tissue which benefit jump execution and, consequently, improvements in power[23]. As this study has found, therefore, the physiological conditions stimulated by blood flow restriction methods act as a catalyst in such a way that, with a low weekly training load, there is a greater potential for morphological adaptation, which is consistent with the development of maximum strength.

The strength gain measured by 1RM leg press tests is not necessarily a factor which ensures adaptations in power and jump height[24,25], which is why the authors recommend that, as is well known in sports science, training must be specifically managed in order to improve the required performance indicators, such as jump height, maximum strength or muscle mass.

Finally, the authors regard the simple methodological design of this study as a strength beyond the barriers of quasi-experimental or pre-experimental studies, especially those related to controlling all the factors which could influence the subjects' adaptive potential at a physiological level over the limited training period or could also directly affect the collection of information when applying the tests. The limited number of subjects involved in the groups could also be considered a limitation. However, the authors were as methodologically rigorous as possible when executing the different procedures, calling on assistance from first-rate academics and experts to ensure the quality of the data obtained.

In conclusion, the results of this research suggest that both weekly low load blood flow restriction plyometric training and conventional training can prove effective when it comes to improving power, jumping capability and muscle strength in untrained healthy men, although the effect on subjects who trained with blood flow restriction was statistically greater. These findings are consistent with approaches which make use of partial flow restriction to obtain great benefits with low training loads in short training periods.

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Conflict of interest

The authors declare that they are not subject to any type of conflict of interest.

Bibliography

1. Bobes Álvarez C, Issa-Khozouz Santamaría P, Fernández-Matías R, Pecos-Martín D, Achalandabaso-Ochoa A, Fernández-Carnero, *et al*. Comparison of blood flow restriction training versus non-occlusive training in patients with anterior cruciate ligament reconstruction or knee osteoarthritis: a systematic review. *J Clin Med*. 2020;10:68.
2. Beato M, Bianchi M, Coratella G, Merlini M, Drust B. Effects of plyometric and directional training on speed and jump performance in elite youth soccer players. *J Strength Cond Res.* 2018;32:289-96.
3. Yamanaka T, Farley RS, Caputo JL. Occlusion training increases muscular strength in division IA football players. *J Strength Cond Res.* 2012;26:2523-9.
4. Rebolledo-Cobos R, Silva-Correa C, Juliao-Castillo J, Polo-Gallardo R, Suarez-Landazabal O. Functional implications of strength training on older adults: a literature review. *Arch Med Deporte.* 2017;34:31-9.
5. Morris SJ, Oliver JL, Pedley JS, Haff GG, Lloyd RS. Comparison of weightlifting, traditional resistance training and plyometrics on strength, power and speed: a systematic review with meta-analysis. *Sports Med*. 2022;52:1533-54.
6. Layne AS, Larkin-Kaiser K, Gavin-MacNeil R, Sandesara B, Dirain M, Bufford WT, *et al.* Effects of blood-flow restriction on biomarkers of myogenesis in response to resistance exercise. *Appl Physiol Nutr Metab*. 2017;42:89-92.
7. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol* (1985). 2002;93:1318-26.
8. Lopez P, Radaelli R, Taaffe DR, Newton UR, Galvão AD, Trajano GS, *et al.* Resistance training load effects on muscle hypertrophy and strength gain: systematic review and network meta-analysis. *Med Sci Sports Exerc*. 2021;53:1206-16.
9. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc.* 2004;36:674-88.
10. Rodrigo-Mallorca D, Loaiza-Betancur AF, Monteagudo P, Blasco-Lafarga C, Chulvi-Medrano I. Resistance training with blood flow restriction compared to traditional resistance training on strength and muscle mass in non-active older adults: a systematic review and meta-analysis. *Int J Environ Res Public Health*. 2021;18:11441.
11. Hosseini-Kakhak SA, Kianigul M, Haghighi AH, Nooghabi MJ, Scott BR. Performing soccer-specific training with blood flow restriction enhances physical capacities in youth soccer players. *J Strength Cond Res.* 2022;36:1972-7.
12. Del-Vecchio A, Casolo A, Negro F, Scorcelletti M, Bazzucchi L, Enoka R, *et al.* The increase in muscle force after 4 weeks of strength training is mediated by adaptations in motor unit recruitment and rate coding. *J Physiol.* 2019;597:1873-87.
13. Van-Roie E, Walker S, Van-Driessche S, Delabastita T, Vanwanseele B, Delecluse C. An age-adapted plyometric exercise program improves dynamic strength, jump performance and functional capacity in older men either similarly or more than traditional resistance training. *PLoS One.* 2020;15:e0237921.
14. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. *Eur J Appl Physiol Occup Physiol.* 1983;50;273-82.
15. Verdijk L, van Loon L, Meijer K, Savelberg H. One-repetition maximum strength test represents a valid means to assess leg strength in vivo in humans, *J Sports Sci.* 2009;27:59-68.
16. Goldfarb AH, Garten RS, Chee PD, Reeves VG, Hollander BD, *et al.* Effects of endurance exercise on blood glutathione and plasma protein carbonyl status: influence of partial vascular occlusion. *Eur J Appl Physiol.* 2008;104:813-9.
17. Patterson SD, Hughes L, Warmington S, burr J, Scott SB, Owens J, *et al*. Blood Flow Restriction Exercise: Considerations of Methodology, Application, and Safety. *Front Physiol.* 2019;10:533.
18. Doma K, Leicht AS, Boullosa D, Woods CT. Lunge exercises with blood-flow restriction induces post-activation potentiation and improves vertical jump performance. *Eur J Appl Physiol.* 2020;120:687-95.
19. Horiuchi M, Endo J, Sato T, Okita K. Jump training with blood flow restriction has no effect on jump performance. *Biol Sport*. 2018;35:343-8.
20. Sun D, Yang T. Semi-squat exercises with varying levels of arterial occlusion pressure during blood flow restriction training induce a post-activation performance enhancement and improve vertical height jump in female football players. *J Sports Sci Med.* 2023;22:212-25.
21. Yang S, Zhang P, Sevilla-Sanchez M, Zhou D, Cao J, He J, Gao B, *et al*. Low-load blood flow restriction squat as conditioning activity within a contrast training sequence in high-level preadolescent trampoline gymnasts. *Front Physiol.* 2022;13:852693.

22. Bruhn S, Kullmann N, Gollhofer A. The effects of a sensorimotor training and a strength training on postural stabilisation, maximum isometric contraction and jump performance. *Int J Sports Med*. 2004;25:56-60.

23. Maffiuletti NA, Cometti G, Amiridis IG, Martin A, Pousson M, Chatard JC. The effects of electromyostimulation training and basketball practice on muscle strength and jumping ability. *Int J Sports Med*. 2000;21:437-43.

24. Fatouros I, Jamurtas A, Leontsini D, Taxildaris K, Aggelousis N, Kostopoulos N. Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *J Strength Cond Res.* 2000;14:470-6.

25. Ferri A, Scaglioni G, Pousson M, Capodaglio P, Van-Hoecke J, Narici MV. Strength and power changes of the human plantar flexors and knee extensors in response to resistance training in old age. *Acta Physiol Scand.* 2003;177:69-78.