Effect of practical blood flow restriction training during bodyweight exercise on muscular strength, hypertrophy and function in adults: A randomised controlled trial

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Effect of practical blood flow restriction training during bodyweight exercise on muscular strength, hypertrophy and function in adults: A randomised controlled trial

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Background/Aims: *Practical blood flow restriction training (PBFRT) is a novel method of resistance exercise that has been proposed to increase muscular strength and hypertrophy at lower intensities than is currently recommended in guidelines for resistance training. This study aimed to investigate whether practical, inexpensive elastic wraps for PBFRT during a 6-week bodyweight resistance training programme increases lower limb muscular strength, hypertrophy and function.*

Methods: *This study was designed as a parallel, single-blind, randomised controlled trial. Young men and women were randomised to either the PBFRT (n=7; 2 males and 5 females) or control (n=5; 2 males and 3 females) group. The intervention was a single leg squat (SLS) bodyweight resistance exercise to fatigue, twice a week for 6 weeks. The PBFRT group performed the SLS exercise with an elastic wrap around their proximal thigh at a perceived tightness of 7/10, and the control group at a perceived tightness of 0/10. The following outcomes were then measured: knee extensor concentric, eccentric and isometric strength (dynamometer), thigh girth and single leg vertical jump height.*

Results: *There were no significant differences between groups (PBFRT and control) for all outcome measures assessed from baseline to post-intervention testing.*

Conclusion: *This study demonstrated that the use of PBFRT in conjunction with an SLS bodyweight resistance exercise was not effective at increasing lower limb muscular strength, hypertrophy and function.*

Key words: ■ Blood flow restriction training ■ Resistance exercise ■ Bodyweight exercise ■ Hypertrophy

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The American College of Sports Medicine (ACSM) recommends resistance training at 60% or more of one repetition maximum (1RM) to achieve significant gains in muscular strength and hypertrophy (Ratamess et al, 2009). Such resistance training loads could be detrimental for physically challenged populations, including the elderly and those undergoing post-surgical rehabilitation (Fujino et al, 2000; Takarada et al, 2000a; Sakamaki et al, 2008). Blood flow restriction training (BFRT) decreases blood flow to, while, more importantly, preventing blood from leaving the muscle (Loenneke et al, 2012a). A meta-analysis (Loenneke et al, 2012a) showed BFRT to increase muscular strength and hypertrophy at lower loads of 10–30% of 1RM, without safety concerns (Loenneke et al, 2011; Loenneke et al, 2014). It has been hypothesised that BFRT increases muscular strength and hypertrophy through a variety of mechanisms, including: metabolic accumulation (Takarada et al, 2000a; Kawada and Ishii, 2005; Takano et al, 2005; Gentil et al, 2006; Reeves et al, 2006; Kawada and Ishii, 2007); fast-twitch muscle fibre recruitment (Takarada et al, 2000a; 2000b), increased protein synthesis through the mammalian target of rapamycin pathway (Gentil et al, 2006); and cell swelling (Loenneke et al, 2012b).

Typically, BFRT research has used pneumatic wrapping devices, such as modified blood pressure cuffs to restrict blood flow (Loenneke et al, 2012a). However, these are not accessible or practical to use outside of a laboratory or clinical environment. The effectiveness of practical BFRT (PBFRT)—utilising inexpensive wraps to provide a practical blood flow restriction (PBFR) stimulus in order to elicit metabolic accumulation, muscular strength and hypertrophy—has been investigated (Yamanaka et al, 2012; Wilson et al, 2013; Lowery et al, 2014; Luebbers et al, 2014). Yamanaka et al (2012) and Luebbers et al (2014) found that PBFRT at 20% of 1RM using elastic wraps pulled tightly increased muscular strength (bench press and squat 1RM) and hypertrophy (chest girth) in collegiate athletes. However, both these studies performed PBFRT in combination with regular high-intensity repetition training (HIRT) and also failed to quantify how much blood flow restriction occurred.

Subjective perceived wrap tightness using elastic wraps has been shown to be a valid measure for causing venous occlusion similar to using pneumatic cuffs. Wilson et al (2013) found a moderate wrap tightness of 7/10 led to complete venous occlusion but not arterial in 12 participants using ultrasonography. Wilson et al (2013) also found that blood lactate, quadriceps electromyography activity and muscle cross-sectional area significantly increased after PBFRT (7/10 tightness) at 20% of 1RM ($p<0.05$). PBFRT at 30% of 1RM using this validated method (7/10 tightness) has also been shown to lead to similar hypertrophy increases as HIRT at 60% of 1RM on biceps brachii musculature in 20 resistance-trained participants (Lowery et al, 2014).

Current PBFRT research has been carried out in low-intensity (20–30% 1RM) resistance training (Yamanaka et al, 2012; Wilson et al, 2013; Lowery et al, 2014; Luebbers et al, 2014) and has used different methods for restricting blood flow. No PBFRT studies have been performed using bodyweight exercise alone to increase muscular strength, which is a common method of training in clinical settings and promoted in physical activity guidelines (Department of Health, 2004). BFRT meta-analytical data (Loenneke et al, 2012a) suggests that bodyweight exercise alone, performed with a blood flow restriction stimulus (pneumatic cuffs), produces significant increases in lower limb muscular strength and hypertrophy (Ishii et al, 2005; Abe et al, 2006; 2010). The 7/10 perceived wrap tightness PBFRT method has not been assessed for its effectiveness on lower limb strength changes and has not been investigated in females or during bodyweight resistance exercise alone. Hence, the purpose of this study was to assess the effectiveness of PBFRT during bodyweight exercise in increasing muscular strength, hypertrophy and function in adults.

METHODS

Study design

A parallel, single-blind, randomised controlled trial (RCT) comparing PBFRT (7/10 perceived wrap tightness) (n=7; 2 males and 5 females) with a control (0/10 perceived wrap tightness) (n=5; 2 males and 3 females) group on healthy adults performing bodyweight exercise twice a week for 6 weeks. The testing and training sessions took place at the Guy's Campus of King's College London (KCL) from May to July 2014. The study was approved by the KCL Research Ethics Subcommittee (BDM/13/14-94).

Participants

Participants were recruited by email, campus posters and word of mouth. Participants were included if they were healthy adults aged between 18 and 65 years and were excluded if they had a history of lower extremity surgery, traumatic injuries to the ankle, knee, hip, pelvis or lower back, a current musculoskeletal condition, high blood pressure or cardiovascular pathology (Sakamaki et al, 2008).

All participants were informed of the purpose of the study, the procedures and the potential risks involved before obtaining written consent. Participants had the right to withdraw at any time.

Procedures

Primary and secondary outcome variables were measured at baseline and post-intervention. After baseline testing all participants underwent bodyweight resistance training; two sessions per week for 6 weeks. Participants were randomised by one of the training researchers to either the PBFRT or control group (*Figure 1*).

Blinding

Both researchers testing outcome measures and one of the training researchers were blinded to group allocation.

Primary outcome variable

Isokinetic dynamometer

Knee extensor strength was assessed using the Kin-Com dynamometer (Chattecx Corporation, Tennessee, USA). The reliability of the Kin-Com dynamometer is reportedly high (Farrell and Richards, 1986; Sole et al, 2007), with intraclass correlation coefficients (ICC) of 0.99, 0.95 and

0.93 for lever function, force measurements and test-retest reliability of knee extensor peak torque measurements, respectively.

Concentric and eccentric peak torque was measured at an angular velocity of 60° per second between 0° and 90° of knee flexion. Isometric peak torque was measured after the concentric and eccentric contractions at 75° of knee flexion. Participants were positioned with the dynamometer resistance pad securely fastened approximately 2 cm above the participant's lateral malleolus. The lateral femoral condyle was aligned with the axis of rotation on the dynamometer. The gravity compensation function was performed and limb weighed according to the manufacturer's instructions.

Participants were instructed to perform a standardised warm up and familiarisation set of ten repetitions at approximately 50% of their maximum effort for the first eight repetitions and then maximally for the final two (Sole et al, 2007). Following 1 minute of rest, three maximal concentric and eccentric knee extensor contractions were performed at 60° per second. After 2 minutes of rest, participants were instructed to perform three maximal isometric contractions at 75° of knee flexion with reference to a predetermined zero according to the dynamometer (Phillips et al, 2000). Participants were instructed to push as hard as possible on the stationary lever arm for 5 seconds; 1 minute rest was given between each repetition. The largest peak torques of the concentric, eccentric and isometric contractions were used for statistical analysis (Phillips et al, 2000). The word 'push' was standardised and repeated to encourage maximal effort for all testing conditions. Each participant's right side was tested before their left.

Secondary outcome variables

Single leg vertical jump

Test-retest reliability for the single leg vertical jump (SLVJ) is 0.81–0.95 ICC (Hopper et al, 2002; Meylan et al, 2009). Each participant stood upright and reached as high as possible with both feet flat on the floor. The height was recorded from the tip of the middle finger of both upper extremities. The participant then performed a maximal effort SLVJ, attempting to make a mark with the tip of their chalked middle finger. All participants were allowed to perform a self-selected countermovement without stepping (Hopper et al, 2002; Meylan et al, 2009). Jump displacement was recorded as the difference between peak jump height and standing reach height (Swearingen et al, 2011).

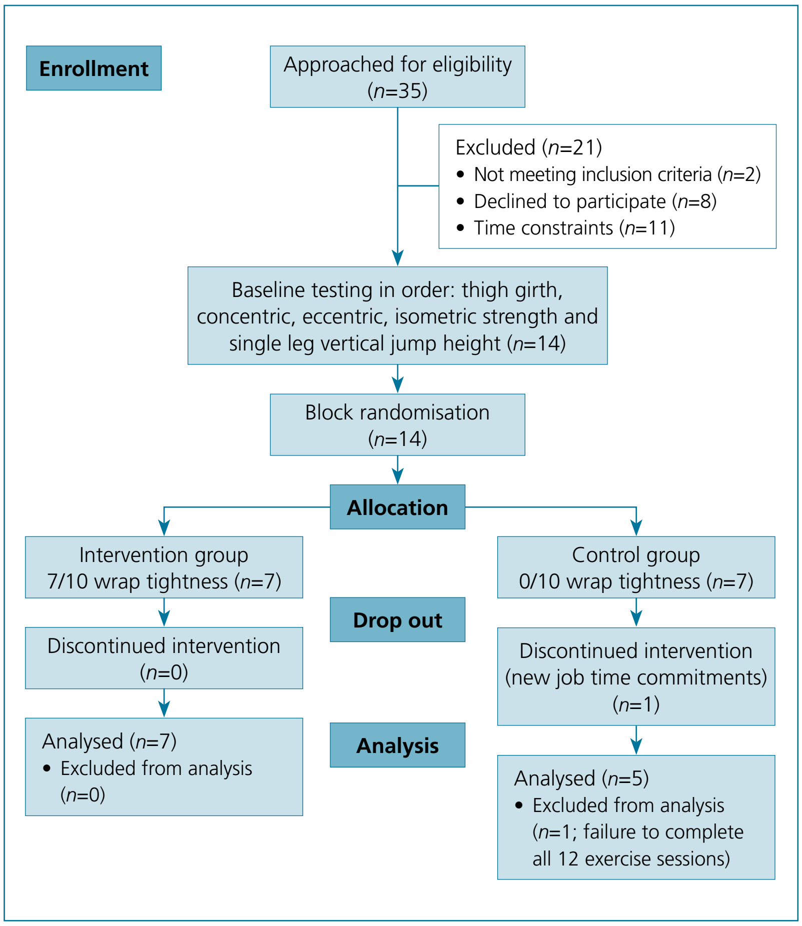

Figure 1. Participant flow diagram

To reduce errors associated with learning, each participant was allowed three practice jumps (Augustsson et al, 2006). A 1-minute rest period was given between practice and each of the three measured jumps to control fatigue (Swearingen et al, 2011). The highest point marked out of the three trials was used for statistical analysis (Swearingen et al, 2011). Each participant's right side was tested before their left.

Thigh girth

Thigh girth measurements have been shown to correlate with ultrasound readings for detecting significant improvements in knee extensor muscular hypertrophy in young adults (Weiss et al, 2000). Thigh girth was measured using a flexible tape measure, with each participant standing, foot on a bench, with the knee and hip flexed to 90°, measured by a goniometer (Knapik et al, 1996; Yamanaka et al, 2012). The measurement was taken by the same researcher on all participants at the midpoint between the anterior superior iliac spine and the base of the patella along the anterior midline of the thigh (Knapik et al, 1996; Yamanaka et al, 2012). All girths were measured twice and the mean was

Table 1. Single leg squat bodyweight resistance training protocol					
Week (sessions)	Angle of SLS (degrees)	Sets	Rest (minutes)	Repetitions each set	Speed (degrees per second)
1 (1–2)	75	3	1	Fatigue	60
2–3 (3–6)	75	4	1	Fatigue	60
4–6 (7–12)	90	4	1	Fatigue	60

SLS: single leg squat

calculated. If the two measurements were not within 5 mm, a third measurement was taken and the mean of the three measurements was used for analysis (ACSM, 2009). Test-retest reliability of measurements taken by the researcher within 1 minute of each other was 0.99 ICC (*n*=14).

Intervention protocol

Both groups performed the same single leg squat (SLS) bodyweight exercise. The exercise sessions were performed twice a week for 6 weeks and developed a priori. Training duration and frequency were selected from previous BFRT and PBFRT research supporting these parameters (Loenneke et al, 2012a; Yamanaka et al, 2012; Wilson et al, 2013; Lowery et al, 2014; Luebbers et al, 2014). The sessions were supervised by two of the researchers to control exercise technique. Participants were block-randomised into either the PBFRT or control group (Wilson et al, 2013). Participants were told that they should expect some level of discomfort and that the wrap (applied to the proximal aspect of their femur) should remain in place for the duration of the exercise, including the rest period between sets.

The SLS was chosen because it is functional and provides a stimulus to both lower limbs in isolation, minimising compensation from the contralateral limb (Beutler et al, 2002; Ayotte et al, 2007; Schoenfeld, 2010). It was performed to 75° during the first 3 weeks and then to 90° during the final 3 weeks (*Table 1*). The SLS exercise was standardised by each participant standing with the foot of the training leg 10 cm from a plinth. Standing upright on the training leg they performed a SLS to 75° or 90° of knee flexion, as measured using a goniometer (Clapper and Wolf, 1988) and defined as the point at which the participant touched the plinth behind them before rising back up to the start position. The SLS was performed in time with a metronome representing a concentric and eccentric contraction speed of 60° per second. Sets were performed to volitional fatigue with 1 minute rest between sets (Ratamess et al, 2009; Loenneke et al, 2012a).

Participants were allowed three errors before being discontinued from each set. Errors included the non-training leg touching the ground, touching the plinth for longer than a brief period and not keeping in time with the metronome.

The same protocol was used for both lower limbs. Repetitions performed during each set were recorded. The elastic wraps (Max Strength, Cheshire, UK) were 7.62 cm wide and 188 cm in length. Perceived wrap tightness of 7/10 at the proximal thigh was used in the PBFRT group. This method has been shown through ultrasonography to cause complete venous occlusion (Wilson et al, 2013). It has also been found to significantly increase blood lactate, quadriceps electromyography activity and muscle cross-sectional area when used during resistance training at 20–30% of 1RM (Wilson et al, 2013; Lowery et al, 2014). The wrap was applied by a training researcher and progressively tightened around the participant's proximal thigh until they felt a tightness of 7/10. Participants were told that a wrap tightness of 0/10 was deemed as no tightness and 10/10 as maximal tightness. The control group performed the same exercise with wraps at a perceived tightness of 0/10, which has been shown to produce no PBFR stimulus (Wilson et al, 2013).

Statistical analysis

Baseline values were subtracted from post-intervention values for all measures. Normally distributed data were analysed using independent t-tests and non-normally distributed data were analysed using the Mann–Whitney U test. Normality of data was assessed using the Shapiro–Wilk test. Statistical significance was set at $p<0.05$. All data analyses were conducted using SPSS version 22.

RESULTS

Twelve participants completed the 6-week (12 sessions) bodyweight resistance training intervention. One participant from the control group only completed 8 out of the 12 sessions and was excluded from the final analysis. There were no significant differences between groups for all baseline characteristics (*Table 2*). A significant difference was found in the PBFRT group for concentric peak torque with no other significant differences in either the PBFRT or control group at post-intervention testing (*Table 3*). There was no difference between the groups for all primary (*Table 4*) and secondary outcomes (*Table 5*) assessed from baseline to post-intervention. The success of outcome assessor and trainer blinding procedures for participant group allocation is shown in *Table 6*.

Table 2. Baseline characteristics

	PBFRT group (*n*=7)			Control group (*n*=5)			
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	***p***
Age (years)	26.0	4.0	11.0	24.8	0.9	5.0	0.69
Height (m)	168.0	9.3	26.0	171.2	4.5	25.0	0.58
Body mass (kg)	63.9	9.8	25.0	66.6	6.5	39.0	0.71
Concentric PT at 60°/sec (Nm)	83.2	28.1	81.4	112.0	21.3	112.5	0.22
Eccentric PT at 60°/sec (Nm)	127.0	25.4	74.9	152.1	30.3	151.4	0.39
Isometric PT (Nm)	101.5	17.7	48.1	131.1	33.9	172.0	0.34
SLVJ (cm)	30.9	8.4	22.9	33.2	4.8	28.1	0.68
Thigh girth (cm)	49.4	3.4	10.2	50.4	1.9	11.7	0.66

PBFRT: practical blood flow restriction training; PT: peak torque; SLVJ: single leg vertical jump

Table 3. Post-intervention testing

	PBFRT group (n=7)				Control group (*n*=5)			
	Mean	**SD**	**Range**	***p***	**Mean**	**SD**	**Range**	***p***
Concentric PT at 60°/sec (Nm)	91.0	31.5	6.9	0.01*	111.4	36.5	30.3	0.91
Eccentric PT at 60°/sec (Nm)	135.4	34.9	68.7	0.36	158.8	50.9	58.0	0.57
Isometric PT (Nm)	106.2	40.4	79.6	0.64	144.3	80.2	60.5	0.27
SLVJ (cm)	32.1	9.6	6.0	0.21	33.2	8.5	9.1	0.96
Thigh girth (cm)	49.7	3.6	2.6	0.36	51.0	3.4	2.3	0.16

*Significant change from baseline to post-intervention test ($p<0.05$)
PBFRT: practical blood flow restriction training; PT: peak torque; SLVJ: single leg vertical jump

Table 4. Change in primary strength outcome variables from baseline to post-intervention testing

	PBFRT group (*n*=7)			Control group (*n*=5)			
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	***p***
Concentric PT at 60°/sec (Nm)	8.0	6.6	36.4	–0.7	12.1	30.3	0.29*
Eccentric PT at 60°/sec (Nm)	11.1	23.9	67.2	6.7	24.4	58.0	0.90
Isometric PT (Nm)	6.3	27.2	78.7	13.3	23.2	60.5	0.29*

*Mann–Whitney U test significance level
PBFRT: practical blood flow restriction training; PT: peak torque

Table 5. Change in secondary outcome variables from baseline to post-intervention testing

	PBFRT group (*n*=7)			Control group (*n*=5)			
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	***p***
SLVJ (cm)	1.2	2.3	10.0	–0.1	3.60	9.1	0.47
Thigh Girth (cm)	0.5	0.8	2.6	0.6	0.82	2.3	0.55
Average reps per set	25.1	10.8	29.2	26.3	9.42	24.7	0.84
Discomfort change scores (NRS)	3.0	0.4	1.5	3.0	0.7	1.7	0.75

*Significant difference between groups ($p<0.05$)
NRS: numeric rating scale; PBFRT: practical blood flow restriction training

Table 6. Outcome of assessor and trainer blinding regarding participant group allocation

	Participant group allocation guess (blinding)		
Researcher	**PBFRT**	**Control**	**Correct (%)**
Outcome measure assessor	7	5	2/12 (16.7)
Outcome measure assessor	7	5	7/12 (58.3)
Training supervisor	7	5	7/12 (58.3)

PBFRT: practical blood flow restriction training

DISCUSSION

This study found that there was no difference in quadricep muscle strength, hypertrophy or function changes when comparing 6 weeks of PBFRT during bodyweight exercise and bodyweight exercise alone. This is the first study to assess lower limb muscular strength changes following PBFRT during bodyweight resistance exercise.

These findings contrast with meta-analytical data that found that strength was increased following BFRT during bodyweight exercise (Loenneke et al, 2012a). The studies included in this meta-analysis were Abe et al (2006), which compared the effects of BFRT (pneumatic cuffs) during walking at 50 m/minute in young men, and Abe et al (2010), which compared the effects of BFRT (pneumatic cuffs) during cycling at 40% of maximum oxygen uptake ($VO2_{max}$). Abe et al (2010) found that strength did not significantly increase in the BFRT group, while Abe et al (2006) found leg press, leg curl 1RM and knee extensor isometric strength significantly increased ($p<0.05$) in their BFRT group but not in the control. However, both studies did not report between group comparisons for strength improvements.

The findings of this study provide further contrast against previous research on PBFRT, which found significant improvements in strength (Yamanaka et al, 2012; Luebbers et al, 2014). It was not possible to provide a direct comparison of the results to other PBFRT studies due to different loads (20–30% of 1RM) being used in the other studies (Yamanaka et al, 2012; Wilson et al, 2013; Lowery et al, 2014; Luebbers et al, 2014). Yamanaka et al (2012) and Luebbers et al (2014) found that the squat 1RM value significantly increased after lower limb PBFRT at 20% of 1RM, compared with the same exercise and load without any blood flow resistance ($p<0.05$). A further finding by Yamanaka et al (2012) was that the 1RM bench press value significantly increased in the PBFRT group compared with the control group. Both Yamanaka et al (2012) and Luebbers et al (2014) did not describe any range of motion (ROM) used during their exercise interventions, and only Luebbers et al (2014) reported controlling the speed of their exercises. Greater ROM or slower speed performance during the exercises has been shown to affect strength gains due to varying times under tension (Burd et al, 2012).

Yamanaka et al (2012) and Luebbers et al (2014) also assessed muscular strength using changes in 1RM. In contrast, the present study used isokinetic dynamometry, which is considered the gold standard in assessing muscular strength and has been found to be more reliable and valid (Farrell and Richards, 1986; Knapik et al, 1996; Ly and Handelsman, 2002; Sole et al, 2007). None of the above mentioned studies provided a description of how randomisation blinding of outcome assessors occurred. Blinding is a critical methodological feature of RCTs that aims to prevent biased assessment of outcomes and ascertainment bias after randomisation (Karanicolas et al, 2010). The methodological flaws described above could have contributed to the contrasting results found in the present study.

The training durations of previous BFRT during bodyweight exercise (Ishii et al, 2005; Abe et al, 2006; 2010) and PBFRT research (Yamanaka et al, 2012; Luebbers et al, 2014) for assessing strength changes is under 8 weeks. It is proposed that there is a significant association between strength gains and weeks of training (Loenneke et al, 2012a). A meta-analysis of BFRT (Loenneke et al, 2012a) found that the greatest significant increases in muscular strength occurred after 10 weeks of training. It is possible, therefore, that the 6 weeks of training adopted in the current study is not a sufficient period to elicit significant improvements in strength.

Yamanaka et al (2012) and Luebbers et al (2014) found increased strength (squat 1RM) with interventions lasting 4 and 7 weeks, respectively. These studies (Yamanaka et al, 2012; Luebbers et al, 2014) performed PBFRT (20% of 1RM) in combination with other resistance training exercises, which makes it difficult to determine which exercise contributed to the gains in strength. The participants from both studies performed PBFRT and conventional resistance training together for 4 and 5 days per week, respectively. Resistance training for 4–6 days a week is recommended for the greatest increases in muscular strength (McKenzie, 1981; Braith et al, 1989; Ratamess et al, 2009).

The present study consisted of two sessions per week over 6 weeks as a result of previous BFRT and PBFRT research finding significant improvements in muscular strength and hypertrophy using these parameters (Loenneke et al, 2012a; Yamanaka et al, 2012; Wilson et al, 2013; Lowery et al, 2014; Luebbers et al, 2014). The combined sessions of PBFRT (20% of 1RM) with conventional HIRT (60% of 1RM and over) could have increased the volume of muscular work performed (Ratamess et al, 2009; Burd et al, 2012), explaining the improvements in muscular strength seen in Yamanaka et al (2012) and Luebbers et al (2014).

Another difference between previous PBFRT research (Yamanaka et al, 2012; Wilson et al, 2013; Lowery et al, 2014; Luebbers et al, 2014) and the present study is that sets to fatigue were used to ensure each participant performed the maximal amount of repetitions possible. In previous PBFRT research (Yamanaka et al, 2012; Luebbers et al, 2014), participants have commented that the repetitions specified for each set were either insufficient or too difficult. The present study recorded no difference in average repetitions performed in each set between groups.

Previous PBFRT research (Yamanaka et al, 2012; Luebbers et al, 2014) supports our finding that there was no change in muscular hypertrophy, measured by thigh girth. This does, however, contrast with previous BFRT research using bodyweight exercise (Ishii et al, 2005; Abe et al, 2006; 2010) and PBFRT research that used ultrasonography to measure changes in muscular hypertrophy (Wilson et al, 2013; Lowery et al, 2014). Abe et al (2006) compared walking at 50 m/minute and Abe et al (2010) compared cycling with and without a blood flow restriction stimulus in young men. Both these studies (Abe et al, 2006; 2010) reported BFRT to significantly increase thigh muscle cross-sectional activity. Ishii et al (2005) investigated whether circuit bodyweight resistance exercise, with and without blood flow restriction, caused thigh muscle hypertrophy (pneumatic cuffs) (n=22). There was a significant difference seen in the right limb, in favour of the BFRT group, but no difference seen in the left limb.

Only one (Ishii et al, 2005) of the three above mentioned studies (Ishii et al, 2005; Abe et al, 2006; 2010) assessed BFRT and control group differences at post-intervention testing. These results, therefore, do not support the effectiveness of BFRT during bodyweight exercise alone for increasing muscular hypertrophy. Two PBFRT studies using a training load of 20–30% of 1RM (Wilson et al, 2013; Lowery et al, 2014) found an increase in muscular hypertrophy as measured by ultrasonography. These findings are in contrast to the present study, possibly due to the accuracy of the measure used (Ross et al, 1994; Weiss et al, 2000; Miyatani et al, 2002). Thigh girth measurements were used in the present study because of its correlation with ultrasound in measuring hypertrophic changes and also due to its use in previous PBFRT research to assess muscular hypertrophy (Weiss et al, 2000; Yamanaka et al, 2012; Luebbers et al, 2014). Despite this, ultrasonography imaging has been shown to be more accurate than thigh girth measurements in assessing changes in muscular hypertrophy in young adults (Ross et al, 1994; Miyatani et al, 2002).

The present study agrees with Wilson et al (2013) that BFRT causes no change in vertical jump height. Recent meta-analytical data shows that plyometric exercise provides statistically significant ($p<0.05$) improvements in vertical jump height in young adults (Markovic, 2007). As plyometric exercises were not performed during Wilson et al (2013) or the present study, this could explain why no change in jump height was found (Markovic, 2007).

Limitations

There are a number of limitations in this study. First, the activity levels of participants were recorded before commencing this study. Participant activity level was neither controlled nor restricted during the study period, which may have led to confounding results. Second, ultrasonography imaging was not used to assess changes in muscular hypertrophy, which would have provided more accurate and valid hypertrophy measurements (Ross et al, 1994; Weiss et al, 2000; Miyatani et al, 2002). Finally, the outcome variables were only reassessed after the 6-week training intervention, with no medium to long-term follow-up.

Clinical implications

Bodyweight SLS exercise did not improve strength, function or hypertrophy with a PBFR stimulus compared with bodyweight exercise alone. Findings from the present study and previous BFRT research using only bodyweight exercise (Ishii et al, 2005; Abe et al, 2006; 2010) suggest that PBFRT during bodyweight exercise, with said parameters, is not effective for increasing muscular strength compared with body weight exercise alone. Clinicians should use exercises with a greater load to achieve significant gains in muscular strength during PBFRT.

Future research

Future research should include larger sample sizes to determine whether the significant difference found in the PBFRT group for concentric peak torque is substantiated. PBFRT RCTs need to be conducted using individuals who are less active, older age groups and females to be able to generalise the results. The long-term effects of PBFRT on skeletal muscle strength and hypertrophy of training durations over 10 weeks should be investigated (Loenneke et al, 2012a).

Future research should compare different training loads and dosages using the validated 7/10 perceived wrap tightness method (Wilson et al, 2013), isolated from other resistance training interventions. Future PBFRT studies should also measure how much blood flow restriction (venous or arterial) has occurred to support previous findings (Wilson et al, 2013). Studies should use isokinetic dynamometry to assess muscular strength changes due to its accuracy over 1RM assessments (Farrell and Richards, 1986; Knapik et al, 1996; Sole et al, 2007). Studies should also use ultrasound imaging for hypertrophic changes (Ross et al, 1994; Miyatani et al, 2002).

CONCLUSIONS

This study demonstrated that the use of PBFRT in conjunction with an SLS bodyweight resistance exercise was not effective at increasing lower limb muscular strength, hypertrophy or function in young adults when compared with SLS bodyweight resistance exercise alone. Previous research suggests that PBFRT can be effective for increasing muscular strength and hypertrophy when performing exercise at 20–30% of 1RM. The present study and previous PBFRT research performed using only bodyweight exercise suggest that this load of exercise is insufficient to significantly increase muscular strength or hypertrophy.

Future PBFRT research needs to be performed using rigorous and standardised methodologies to discover whether PBFRT using a perceived wrap tightness of 7/10 is effective at increasing muscular strength. The findings of the present study concern the dynamic SLS exercise performed with and without a PBFR stimulus on quadriceps strength, hypertrophy and function in young adults. They may not be generalisable to other exercises, muscles or age groups. IJTR

Conflict of interest: none declared.

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KEY POINTS

- Blood flow restriction training during body weight exercise alone is not sufficient to increase muscular strength or hypertrophy
- Practical blood flow restriction training requires a training load of at least 20% of one repetition maximum to significantly increase muscular strength and hypertrophy
- A wrap tightness of 7/10 needs to be validated in further research to increase muscular strength and cause venous occlusion in a wide range of population groups.

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