The effects of water-based exercise in combination with blood flow restriction on strength and functional capacity in post-menopausal women

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Abstract Water-based exercise and low-intensity exercise in combination with blood flow restriction (BFR) are two methods that have independently been shown to improve muscle strength in those of advancing age. The objective of this study was to assess the long-term effect of water-based exercise in combination with BFR on maximum dynamic strength and functional capacity in post-menopausal women. Twenty-eight women underwent an 8-week water-based exercise program. The participants were randomly allocated to one of the

three groups: (a) water exercise only, (b) water exercise+BFR, or (c) a non-exercise control group. Functional capacity (chair stand test, timed up and go test, gait speed, and dynamic balance) and strength testing were tested before and after the 8-week aquatic exercise program. The main findings were as follows: (1) water-based exercise in combination with BFR significantly increased the lower limb maximum strength which was not observed with water-based exercise alone and (2) water-based exercise, regardless of the application of BFR, increased functional performance measured by the timed up and go test over a control group. Although we used a healthy population in the current study, these findings may have important implications for those who may be contraindicated to using traditional resistance exercise. Future research should explore this promising modality in these clinical populations.

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Introduction

Skeletal muscle mass plays an important role with both metabolism and functional capacity. It is well established that the aging process leads to a significant decline in both muscle mass and strength (Janssen et al. 2002), which is associated with frailty (Capodaglio et al. 2005), an increased risk of falls (Grundstrom et al. 2012; O'Halloran et al. 2011), and decreased physical fitness

and function (ACSM 2009; Guralnik et al. 1995). Given the increasing proportion of older people in developed countries (Marengoni et al. 2011; Reinhardt 2003), interventions designed to increase or maintain strength and functional capacity are needed to help combat this decline.

In this context, high-load resistance training has been shown to reduce the risk of falls (Persch et al. 2009) and increase strength and functional capacity (ACSM 2009; Vale et al. 2006) in middle-aged and/or elderly individuals. However, some individuals are contraindicated to participating in high-load resistance training and are in need of other modalities to increase strength and functional capacity. Aquatic exercise is one method that has previously been shown to improve muscle strength, balance, and coordination in those of advancing age (ACSM 1995; Alves et al. 2004; Douris et al. 2003; Melzer et al. 2008; Takeshima et al. 2002). Another method is low-intensity exercise (20–30 %) one repetition maximum (1RM) in combination with moderate blood flow restriction (BFR). Studies have shown that the increases in muscle strength and mass that occur with this technique are similar to that observed with high-intensity training (≥ 80 % of 1RM) (Laurentino et al. 2012; Martín-Hernández et al. 2013; Takarada et al. 2000). Two common concerns with applying BFR include the potential for blood clots and muscle damage (for a review of safety please see (Loenneke et al. 2011). However, it is important to consider that this restriction stimulus is acute in nature. Studies to date have found no evidence that BFR increases the risk for blood clots in healthy participants (Clark et al. 2011; Madarame et al. 2010) or those with stable ischemic heart disease (Madarame et al. 2013). Further, exercise in combination with BFR results in minimal to no muscle damage (Loenneke et al. 2014) which makes it potentially useful for middle-aged and elderly population who may be contraindicated to the mechanical stress of high-load resistance training (Takarada et al. 2000).

Although the evidence supports the effectiveness of both water-based exercise (Alves et al. 2004; Ambrosini et al. 2010; Cardoso et al. 2010; Takeshima et al. 2002) and low-intensity strength training with BFR (Karabulut et al. 2010; Thiebaud et al. 2013; Vechin et al. 2015; Yasuda et al. 2014) in middle-aged and elderly individuals, the combination of these exercises has, to our knowledge, never been investigated. Thus, the objective of this study was to assess the long-term effect of water-

based exercises in combination with BFR on maximum dynamic strength (1RM) and functional capacity in post-menopausal women. Given that benefits have previously been observed with both of these alternative methods of training, we hypothesized that water-based exercises in combination with BFR would significantly improve muscle strength and functional capacity compared with water-based exercises performed without BFR.

Method

Participants

Twenty-eight post-menopausal women (54 ± 4 years) participated in the study. The sample size was chosen between groups based on an estimated effect size of 0.8 for 1RM strength from our pilot study as recommended by Beck (Beck 2013). Using G*Power software (GPower 3.1), an estimated sample size of 15 people was recommended to appropriately observe statistical significance at the 0.05 alpha level with a power level of 0.8. However, it was estimated that 28 people would be needed to be adequately powered for the post-hoc analysis.

The inclusion criteria were as follows: (a) apparently healthy post-menopausal women, (b) absence of osteoarticular dysfunctions in the lower limbs, (c) negative answers in the PAR-Q questionnaire (Shephard 1988), (d) no personal history of cardiovascular disease, (e) non-smokers, (f) no water trauma, and (g) normal range on the ankle-brachial index test ($0.90 \leq \text{ABI} \leq 1.40$) that characterizes the presence of peripheral arterial disease (Resnick et al. 2004). After being told about the risks and benefits of the study, the participants signed an informed consent form created according to the Declaration of Helsinki. The study was approved by the CCS/UFPB human research ethics committee, campus I João Pessoa, under no. 0341/13.

Experimental approach

Anthropometry, determination of the pressure for BFR, functional capacity, and muscle strength were assessed at the first and second visits to the laboratory. After these visits, the participants were randomly allocated (randomizer.org) to one of the three groups: (a) water exercise without BFR ($n=10$), (b) water exercise+BFR

($n=10$), or (c) control group ($n=8$). The participants allocated to the experimental groups underwent an 8-week water-based exercise program with three sessions per week (24 sessions in total). The participants in the control group received no intervention but were included to demonstrate stability of the measurements over time (Fig. 1). Before pre-testing, the experimental groups underwent a familiarization period over 1 week (one set of 30 repetitions and three sets of 15 repetitions) for the three exercises including practice on the 1RM to ensure that the participants could properly execute the movement prior to pre-testing. All participants were asked not to engage in any other physical activity program while participating in this study but, rather, to maintain their current level of activity and eating habits. Post-testing was completed 48–72 h following the last training session. None of the participants were taking medications that we felt would meaningfully impact the training response (e.g., HMG-CoA reductase inhibitors), though some of our participants were taking medication. Three of our participants were taking nonsteroidal anti-inflammatory drugs, and seven were taking analgesics (e.g., acetaminophen).

Functional performance assessment

Functional performance was assessed by tests related to activities associated with normal daily function: (a)

chair stand test: the participants were instructed to stand and sit five consecutive times from a chair with a 43-cm seat height (Podsiadlo and Richardson 1991), (b) timed up and go test: the participants were instructed to rise from a chair with a 43-cm seat height and walk 3 m along a straight line, turn around, walk back to the chair, and sit down (Podsiadlo and Richardson 1991), (c) normal gait speed and maximum gait speed: the participants walked 4 m at two different speeds (normal and as fast as possible), without running (Guralnik et al. 1995). To minimize the acceleration and deceleration effects, the participants started walking 1 m before the starting point and decelerated 1 m after the end; (d) dynamic balance: participants walked on a straight line marked on the ground with adhesive tape 5 cm wide and 6 m distance. The participants were instructed to place one foot in front of the other making sure that, with each step, the heel of one foot was directly in front of the toes of the other foot as previously described here (Nelson et al. 2004). All tests were performed twice in every session, and the best result was used for statistical analysis.

Dynamic strength assessment (1RM)

To minimize possible errors in the 1RM test, the following strategies were used (Phillips et al. 2004): (a) all participants received standard instructions for the

Fig. 1 Experimental protocol. 1RM=One repetition maximum

assessment routine and the exercise techniques prior to testing, (b) the exercise technique performed by the participants was monitored every session and corrected if necessary, and (c) the participants received verbal encouragement during the tests.

The maximum load that could be lifted through a full range of motion with proper form was assessed and recorded as the concentric 1RM. The unilateral knee extension (dominant leg) 1RM was assessed using standard 1RM procedures described previously (Brown and Weir 2001). All 1RMs were determined within five attempts, and approximately 1 min of rest was allotted between attempts.

Blood flow restriction determination

A portable Vascular Doppler (MedPeg® DV 2001, Ribeirão Preto, SP, Brazil) was used to set the pressure for exercise as described previously (Laurentino et al. 2012). Briefly, with the participants in a supine position an adapted sphygmomanometer (18 cm wide×80 cm long) was placed on the most proximal portion of both thighs and inflated to the point of arterial occlusion. The pressure for exercise was set to 80 % of the arterial occlusion pressure (pressure needed to completely occlude blood flow out of water) to ensure that the participants were only under partial BFR. Cuff pressure was maintained for the duration of the exercise bout (including rest periods) and deflated immediately following the final set of exercise for the day. The cuff pressure was constantly monitored to ensure that the pressure was maintained at ~80 % of the resting arterial occlusion pressure. The mean pressure applied to the lower limbs during the experiment was 96 ± 10 mm Hg to right leg (range of 80 to 113 mmHg) and 106 ± 10 to left leg (range of 88 to 120 mmHg).

Water-based exercise program

The water-based exercise program consisted of two different training methods over 8 weeks, with three sessions per week (24 sessions in total). Exercise was completed while immersed in a temperature-controlled (26 to 29 °C) swimming pool to a depth set at the xiphoid process. Both training groups performed four sets, one with 30 repetitions and three with 15 repetitions, with 1 min interval between sets. The group training with BFR performed the exercises while wearing an adapted sphygmomanometer (18 cm wide×

80 cm long). The control group was instructed to continue their daily routine until the end of the 8-week follow-up for assessment.

The training sessions lasted approximately 45 min and consisted of low-intensity walking to warm-up (10 min), the main exercise phase (20 min) and post-exercise stretching (15 min). The intervention groups performed the exercises for the lower limbs (hip flexion and extension of the right leg, hip flexion and extension of the left leg, hip adduction and abduction of the right leg, hip adduction and abduction of the left leg and knee flexion and extension of the right leg and knee flexion and extension of the left leg), in the same order for all sessions. Hip flexion and extension were executed with the hips flexed at 90°. Hip adduction and abduction were performed with the leg laterally extended, and knee flexion and extension were performed by flexing the knee at 90°. The water exercise+BFR group performed exercises with the cuffs inflated simultaneously to both legs. To help insure safety and correct exercise technique, the movement velocity was fixed at 2 s for both concentric and eccentric phases of all exercises. All exercises were performed at the edge of the pool, leaning on the upper limbs, with a perceived effort between 9 and 11 on the standard Borg scale (6–20) (Borg 2000) with the load being increased by the ankle weights approximately 5 % (1 kg) every six training sessions, with a 1-minute interval between the exercises. The water-based exercise program is detailed in Table 1.

Statistical analyses

Data normality was assessed by Shapiro-Wilk's test, and variance homogeneity was assessed by Levene's test. The variables presented normal distributions and homogeneity ($p>0.05$). Descriptive data were expressed by the mean and standard deviation. A repeated measures ANOVA for time (Pre vs. Post) with a between subject factor for group was used to assess the strength and functional capacity test results. All post-hoc comparisons were completed using the least significant difference test with a Bonferroni corrected p value to control for the family-wise error rate. Significance was set at $p<0.05$. All statistical analyses were performed with the SPSS 18.0 software (SPSS Inc., Chicago, IL).

Table 1 Water-based exercise program

Week	Sets/repetitions	Exercise (both right and left)	IBS	Load	Total time
1–2	1×30	Hip flexion and extension	1 min	0	20 min
	3×15	Hip adduction and abduction			
		Knee flexion and extension			
3–4	1×30	Hip flexion and extension	1 min	1 kg	20 min
	3×15	Hip adduction and abduction			
		Knee flexion and extension			
5–6	1×30	Hip flexion and extension	1 min	2 kg	20 min
	3×15	Hip adduction and abduction			
		Knee flexion and extension			
7–8	1×30	Hip flexion and extension	1 min	3 kg	20 min
	3×15	Hip adduction and abduction			
		Knee flexion and extension			

IBS interval between sets,
kg kilogram, min minutes

Results

Participant characteristics

The participants' characteristics at the pre-test are shown in Table 2. There were no significant baseline differences between groups ($p>0.05$).

Muscle strength (1RM)

There was a significant group x time interaction for 1RM strength ($p=0.001$). Follow-up tests revealed between group differences post-training ($p=0.001$), with both-water based exercise groups being significantly higher than the control group (Fig. 2a). The water exercise+BFR group increased 1RM from pre to post (+2.4 kg, $p=0.008$); however, no significant increase was observed with water exercise only (+1.2 kg, $p=0.338$, Fig. 2b). The control group decreased from pre to post (−2.8 kg, $p=0.003$).

Functional capacity

There was a significant group x time interaction for the timed up and go test ($p=0.005$). Follow-up analysis revealed significant between group differences post-training ($p=0.016$), with water exercise+BFR decreasing more than the control group (Fig. 3a). Further, there were pre to post decreases with both exercise conditions (Fig. 3b), but no change in the control group. For the chair stand test, there was a main effect of time ($p=0.001$) with performance increasing regardless of the group (pre 11.6 SE 0.3 vs. post 10.3 SE 0.3 s). No other significant differences were observed in the other measures of functional capacity.

Discussion

To our knowledge, this is the first study to compare the effects of water-based exercises with and without BFR

Table 2 Participant characteristics

Characteristics	Water exercise+BFR ($n=10$)	Water exercise ($n=10$)	Control group ($n=8$)	p
Age (years)	54±5	53±3	55±3	0.401
Body mass (kg)	60.1±9.0	64.1±11.3	57.9±7.6	0.387
Height (m)	1.53±6.3	1.55±5.1	1.52±4.9	0.420
BMI (m/kg^2)	25.3±2.7	26.4±4.6	24.9±2.6	0.644
1RM (kg)	35.6±3.3	33.9±5.2	32.5±3.2	0.293

1RM one repetition maximum
(dominant leg)

Fig. 2 Muscle strength (1RM) comparative analysis. (a) The individual response in 1RM strength from before (pre) and after (post) the 8-week intervention. (b) The mean difference in strength

between pre and post. *Circles* represent individual mean differences (*some circles* may represent more than one individual, if they both had similar mean difference)

on strength and functional performance in post-menopausal women. The main outcomes were as follows: (1) water-based exercise in combination with BFR significantly increased lower limb maximum strength which was not observed with water-based exercise alone and (2) water-based exercise, regardless of the application of BFR, increased functional performance measured by the timed up and go test over a control group.

Our study did not find a significant increase in 1RM strength with water-based exercise in the absence of BFR which is in contrast to two previous studies (Ambrosini et al. 2010; Tsourlou et al. 2006). For

example, Ambrosini et al. (2010) observed an increase in hip extensor strength following 12 weeks of training. In addition, Tsourlou et al. (2006) observed a 29 % increase in knee extensor strength following 24 weeks of training. In the present study, there were no significant increases in 1RM strength from pre to post with water exercise only which may be due to the duration of the current study (8 weeks). However, a look at the individual responses suggests that some participants did get stronger but the collective group response was quite variable (Fig. 2). In contrast, almost every participant in the water exercise+BFR group saw an increase

Fig. 3 Timed up and go rest analysis. (a) The individual response from before (pre) and after (post) the 8-week intervention. (b) The mean difference in the timed up and go test between pre and post

(*some circles* may represent more than one individual, if they both had similar mean difference)

in 1RM strength suggesting that BFR was able to provide a sufficient augmentation to the training response of traditional water-based exercise without increasing the exercise load.

Regarding the functional capacity results, only the timed up and go tests were significantly affected by the training with and without BFR. To our knowledge, only one other study in the literature has assessed the effect of strength training with BFR on functional capacity in elderly women (Teixeira et al. 2012). These authors concluded that there were greater improvements in muscle strength in the group training with BFR, though both groups improved in the chair stand test. These results are in agreement with the current findings in that we observed an augmentation in 1RM with BFR but not in functional capacity. Outside of the timed up and go test, no other measure of functional capacity changed with training. This may be the result of participants being relatively healthy at baseline.

Although no previous study had assessed the effect of water-based exercises combined with BFR, several studies have evaluated muscle strength (Karabulut et al. 2010; Vechin et al. 2015; Yasuda et al. 2014) and muscle mass (Vechin et al. 2015; Yasuda et al. 2014) in older participants after low-intensity strength training combined with BFR. The data from the present study are in line with previous findings (Karabulut et al. 2010) reporting increased strength in the lower body following low-intensity exercise (20 % 1RM) in combination with BFR. The mechanisms behind these effects were not investigated in the current investigation but previous studies suggest that metabolic accumulation-induced fatigue may be playing an important role. To illustrate, metabolic accumulation in combination with a reduced oxygen environment may increase recruitment of higher threshold (type II) muscle fibers (Suga et al. 2012; Yasuda et al. 2010). It has also been hypothesized that acute swelling following the application of the cuff may be playing some role in the adaptation. For example, Yasuda et al. (Yasuda et al. 2012, 2014) provided data that acute changes in muscle swelling may be important for increases in muscle mass following training with BFR. Another potential mechanism is the accumulation of metabolites (e.g., lactate) around the working muscle (Sugaya et al. 2011). This accumulation of metabolites may provide some explanation for why differences in muscle mass are observed even when the volume of work is similar (Laurentino et al. 2012).

Limitations

In view of the results presented here, our study has some limitations. First, the pressure was based off of arterial occlusion that was measured in the supine position but the exercises were performed in the standing position in water. This method was chosen based on previous literature (Laurentino et al. 2012), though we acknowledge that it is presently unknown how water submersion affects this measurement. Although this may have been a limitation, our stimulus appeared adequate given the beneficial response we observed with strength. Second, although previous studies routinely observe metabolic accumulation and cell swelling with BFR, we were unable to measure these variables in the current investigation to determine if they were playing a mechanistic role in our findings. Third, we did not include a measure of aerobic capacity which is classical index of functional capacity and is a strong predictor of mortality and morbidity. Finally, the results of this study are limited to post-menopausal, recreationally active women. Although we did not have adherence issues within the current population, previous research suggests that discomfort may be increased compared to traditional high-load exercise (Loenneke et al. 2015), albeit to a small extent. It is presently unknown if this would affect adherence to protocols in more clinical populations.

Conclusions

In conclusion, water-based exercise increased strength in the current study only when it was combined with BFR. The changes in maximal dynamic strength were quite variable in the water exercise only group which is likely due to the low intensity nature of the training protocol. The finding that BFR elicited changes in maximal strength despite this is in line with previous studies supporting an augmentation in muscle adaptation when partial BFR is combined with otherwise low-intensity exercise. Both groups saw an increase in timed up and go performance; however, no other functional performance measures changed with training (i.e., chair stand test, normal/maximal gait speed, dynamic balance). Although we used a healthy population in the current study, these findings may have important implications for those who may be contraindicated to using traditional resistance exercise. Future research should explore this promising modality in these clinical populations.

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Compliance with ethical standards The participants signed an informed consent form created according to the Declaration of Helsinki, and the study was approved by the CCS/UFPB human research ethics committee, campus I João Pessoa, under no. 0341/13.

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