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Low-intensity blood flow restriction (LI-BFR) and moderate-intensity improves quadriceps strength and thigh circumference in older women

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ABSTRACT

Background and objectives. Weakness and atrophy in the quadriceps femoris lead to decreased functional capacity, heightened fall risk, and increased mortality among older women. While moderate-intensity strength training is generally recommended for the elderly, higher-intensity exercises carry a greater risk of injury. Low-intensity exercises with blood flow restriction offer an alternative, providing comparable benefits to high-intensity training. This study aims to evaluate the effects of moderate-intensity and low-intensity blood flow restriction exercises on quadriceps femoris strength and thigh circumference in healthy elderly women.

Materials and methods. The sample size was of 88 subjects equally randomized into a moderate-intensity group and a blood-flow restriction group. The moderate-intensity group performed strengthening exercises with a load of ≥40–60% of 1RM, 3 sets, 36 repetitions. The blood-flow restriction group conducted exercises at 20–30% of 1RM, completing 75 repetitions across 4 sets, using a pressure cuff applied to the upper thigh at 50 mmHg or 40% of the Arterial Occlusion Pressure (AOP). Both groups exercised twice a week over a 6-week period. Muscle strength (assessed via dynamometer and 1RM) and thigh circumference were recorded before and after the intervention.

Results. After six weeks of intervention, both groups showed a significant increase in muscle strength and thigh circumference ($p < 0.001$). However, no notable differences were observed between the moderate intensity group and the blood flow restriction group regarding quadriceps strength (dynamometer), quadriceps 1RM strength, or thigh circumference ($p > 0.05$). Muscle soreness was reported in 18% of participants in the moderate intensity group.

Conclusion. Low-intensity resistance exercises with blood flow restriction in older women can promote strength gains and muscle hypertrophy comparable to moderate-intensity training, while offering a safer alternative.

Keywords: muscle strength, quadriceps muscle, blood flow restriction therapy, resistance training

Abbreviations (in alphabetical order):

1 RM	– 1 Repetition Maximum
BFR	– blood flow restriction
ECG	– electrocardiography
FFM	– fat free mass
IPAQ	– International Physical Activity Questionnaire
MoCA-INA	– Montreal Cognitive Assessment Indonesia Version
VAS	– Visual Analog scale
VEGF	– vascular endothelial growth factor
WFQ-R	– Waterloo Footedness Questionnaire Revised

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INTRODUCTION

Muscle weakness has been reported as an independent risk factor for high mortality in the elderly [1]. Muscle strength is an important component in maintaining physical function, mobility and vitality in old age [2]. Falls in the elderly are one of the main causes of death. Falls in elderly people aged 60-69 years account for 10-15% of all emergency department visits in the world [3]. Muscle mass decreases 1-2% per year after the age of 50 [4]. According to studies on elderly aged 75 years or older, muscle mass decreases by 0.64-0.70% per year in women. There was loss of 1 kg of muscle mass in the 10 day immobilization period. Prolonged muscle atrophy accelerates the decline in muscle performance and physical performance, thereby increasing the risk of physical disability in the future. Prevention and treatment of physical disabilities needed by the elderly population so that physical limitations associated with old age can be minimized [5].

The prevalence of falls is related to quadriceps muscle strength and increases after age 70 years. Elderly people with higher quadriceps muscle strength have a lower risk of falls, so strengthening the quadriceps muscles can be a prevention for the risk of falls [6]. In the relationship between the risk of falls in the elderly, quadriceps strength is a more important factor than balance, so to prevent the risk of falls it is best to focus on quadriceps muscle strength [7].

Loss of strength and muscle mass in adults can be reversed with strengthening exercises with progressive loads 2-3 days per week [8]. Strengthening exercises that are commonly used and recommended for treating and preventing muscle atrophy are training with an intensity of 60 - 80% 1 RM using equipment or bodyweight at least 2 days per week which has been proven to increase strength and muscle mass [9-10]. However, strengthening loads of 60–80% 1 RM may be too difficult for older adults with muscle weakness, joint disorders, neuromuscular disorders, or those undergoing medical treatment that limits physical capacity [10].

In the last two decades, strengthening exercises with low loads (20 – 30% 1RM) combined with blood flow restriction (BFR) for training can be an alternative and have been proven to increase strength and muscle size comparable to high intensity strengthening exercises [11–15]. Low-intensity strengthening exercises with BFR provide less mechanical stress on the joints than high-intensity exercises with relatively similar increases in strength and muscle hypertrophy, so this method can be a muscle strengthening strategy for elderly people with muscle weakness, arthritis, and other orthopedic comorbidities. Adaptation of BFR exercises has been proven to improve physical function and quality of life. The risks and side effects of BFR training methods in the elderly have not been widely reported, but safety and precautions must be considered [10].

Research regarding the comparison of changes in strength and size of the quadriceps muscle with low-intensity exercise combined with BFR and moderate-intensity exercise without BFR in healthy elderly people has never been carried out or published in Indonesia. This study aims to compare the strength and size of the quadriceps muscles after additional strengthening exercises for 6 weeks.

MATERIALS AND METHODS

This study is a randomized controlled trial with pre-test and post-test group study design. The subjects of this study were elderly women aged 60 years and over, who routinely do aerobic exercise 2x/week. This study used simple random sampling to recruit the subject.

Inclusion criteria for this study were: 1) Elderly women aged 60 years and over, 2) Normal cognitive function and able to receive commands well with an Indonesian Version of Montreal Cognitive Assessment (MoCa-INA) score ≥ 26, 3) Passed the BFR exercise screening questionnaire, 4) Willing to participate in this study by signing an informed consent.

The exclusion criteria were: 1) Severe physical disability, 2) Vision and hearing disorders, 3) Balance disorders, 4) Blood clotting disorders which are established through history and physical examination, 5) Peripheral arterial disease in both legs which are established through history, physical examination and ankle brachial index, 6) Peripheral neuropathy and/or polyneuropathy in the lower limbs which is confirmed through history and physical examination, 7) Severe cardiorespiratory disorders which are confirmed through history, physical examination and/or Electrocardiography (ECG) examination, 8) Deep vein thrombosis in both legs which is confirmed by history, physical examination, and Well's score, 9) Uncontrolled hypertension with blood pressure ≥ 140/90, 10) Uncontrolled diabetes mellitus confirmed by history, physical examination and laboratory, 11) History of vascular surgery, 12) History of skin grafts in the lower extremity area, 13) History of lower leg bone surgery in the last 12 weeks, 14) Immobilization in the last 4 weeks, 15) History of compartment syndrome and fasciotomy, 16) History of stroke, 17) Consumption of statins, 18) Sarcopenia, 19) knee osteoarthritis with a Visual Analog Scale (VAS) value of >4 degrees of severity and limited range of motion of the joints as established from the history and physical examination, and 20) Malignancy.

Criteria for drop out were: 1) The research subjects were not willing to continue the research for whatever reason, 2) The subjects were unable to complete the exercise according to the established re-

search protocol (did not carry out 2 consecutive training sessions), and 3) Cardiovascular complications were found during the exercise program such as chest pain, tightness, syncope, and other complaints such as pain, swelling, cramps, redness or changes in skin color on the exercised limb, nerve injury (paresthesia that does not disappear after the cuff is removed), prolonged muscle soreness (>72 hours post-exercise) that does not improve with analgesics and modalities (Trancutaneous Electrical Nerve Stimulation and icing), as well as muscle weakness during/after exercise that makes it impossible to continue exercising.

Simple randomization performed to divide subjects into treatment group and control group with 44 subjects in each group. For all subjects, 1RM strength of the quadriceps femoris muscle was measured with a quadriceps bench, measurement of quadriceps femoris muscle strength with a dynamometer and measurement of thigh circumference with a tape measure was carried out before the first training session. Foot dominance was also assessed using the Waterloo Footedness Questionnaire Revised (WFQ-R).

The moderate intensity group performed quadriceps femoris muscle strengthening exercises with an ankle weight load of ≥40-60% 1RM, each session consisting of 3 sets, 8-12 repetitions in each set with a 2 minute rest period between sets. Training is carried out 2 training sessions/week for 6 weeks with a break of 3-4 days between training sessions. The BFR group performed quadriceps femoris muscle strengthening exercises with an ankle weight load of 20-30% 1RM combined with the application of BFR with a sphygmomanometer cuff. Each session consists of 4 sets, 30 repetitions in the first set and 15 repetitions each in the 2^{nd} - 4^{th} sets with a rest period of 30 seconds between sets. Training is carried out 2 training sessions/week for 6 weeks with a break of 3-4 days between training sessions. During exercise, a sphygmomanometer cuff is placed on the proximal part of the muscle being trained and developed until it reaches a minimum pressure of 50 mmHg or 40% AOP. The pressure is released during the rest between sets. Post-exercise evaluation (at the end of week 6) measured thigh circumference and maximum knee extension strength with a dynamometer and 1RM with a quadriceps bench. Monitoring and assistance during exercise is carried out by assessing vital signs, Borg scale, oxygen saturation, VAS before, during and after exercise.

A comparison of 1 RM strength of the quadriceps femoris muscle, quadriceps femoris muscle strength and thigh circumference was carried out in each group and in both groups before and after 6 weeks of intervention. Data analyzed using SPSS version 26. Paired t test used to compare the strength of the quadriceps femoris muscle, quadriceps femoris 1 RM muscle strength and thigh circumference within each group before and after intervention. Independent t test used to compare strength of the quadriceps femoris muscle, quadriceps femoris muscle strength and thigh circumference in the two groups before and after intervention. The p value is considered significant if $p < 0.05$.

RESULTS

The total number of subjects was 88 subject divided into 2 groups (n=44) with moderate intensity strengthening exercise (40-60% 1RM) and low intensity (20-30% 1RM) with BFR in the quadriceps femoris muscle. The evaluation parameters in this study were dynamic (1RM) and static (dynamometer) knee extension strength as well as thigh circumference which was assessed on the non-dominant leg. There were four subjects suffer side effects during this study in the moderate intensity group. Complaints in the form of delayed onset muscle soreness with Visual Analog Scale (VAS) 2 and immediate post-exercise pain with Visual Analog Scale (VAS) 3 were reported in the 3rd week of training after increasing training intensity. Side effects improved and disappeared within 3 days with icing. The characteristic of subject is shown in Table 1. The homogeneity test results show that there are no significant differences in all variables so it can be concluded that all subject characteristic data is homogeneous.

Table 2 shows comparison of quadriceps strength and thigh circumference within group pre and post intervention. There was significant difference of quadriceps strength (dynamometer), quadriceps 1 RM strength and thigh circumference between pre-intervention and post-intervention ($p < 0.05$).

Table 3 shows comparison of quadriceps strength and thigh circumference between groups after 6 weeks intervention. There was no significant difference of quadriceps strength (dynamometer), quadriceps 1 RM strength and thigh circumference between moderate intensity group and BFR group ($p > 0.05$). There was also no significant difference in delta of quadriceps strength (dynamometer), quadriceps 1 RM strength and thigh circumference between moderate intensity group and BFR group ($p > 0.05$).

DISCUSSION

In this study, the results of quadriceps muscle strength (dynamometer) before and after intervention showed statistically significant changes within each group ($p < 0.001$). Strengthening exercises can improve the performance of the local muscles being trained. The most common adaptations for strengthening exercises are increased maximum

TABLE 1. Characteristics of patients

Variables	Moderate Intensity Group (n=44, 50%) Means ± SD	Blood Flow Restriction Group (n=44, 50%) Means ± SD	p[a]
Age (years)	65.64 ± 5.8	68.82 ± 6.9	0.463
Body Weight (kg)	57.18 ± 10.2	56.18. ± 8.2	0.291
Body Height (cm)	155 ± 5.7	155.9 ± 5.9	0.844
Body Mass Index (kg/m^2)	23.69 ± 3.41	23.28 ± 3.35	0.421
Comorbid - Diabetes mellitus - Hypertension - Dyslipidemia - Knee osteoarthritis on non-dominant leg - Low Back Pain	 12 (27.2%) 24 (54.5%) 20 (45.4%) 4 (9.0%) 8 (18.1%)	 0 (0%) 20 (45.4%) 20 (45.4%) 8 (18.1%) 8 (18.1%)	
Level of Physical Activity (IPAQ-SF) - High - Moderate - Low	 0 (0%) 44 (100%) 0 (0%)	 0 (0%) 44 (100%) 0 (0%)	
Non-dominant Leg (Waterloo Footedness Questionnaire Revised) - Right - Leg	 20 (45.4%) 24 (54.5%)	 16 (36.3%) 28 (63.6%)	
Quadriceps strength (dynamometer) Pre-Intervention (kg)	18.88 ± 5.2	18.48 ± 6.33	0.504
Quadriceps 1 RM strength Pre-intervention (kg)	8.11 ± 0.76	8.4 ± 1.31	0.119
Thigh circumference Pre-intervention (cm)	49.5 ± 4.8	48.13 ± 4.2	0.460

a) Independent T Test. Significant if p < 0.05

TABLE 2. Comparison of quadriceps strength and thigh circumference within group pre and post intervention

Variables	Moderate Intensity Group (n=44, 50%) Means ± SD			Blood Flow Restriction Group (n=44, 50%) Means ± SD		
	Pre-Intervention	Post-Intervention	p[a]	Pre-Intervention	Post-Intervention	p[a]
Dynamometer (kg)	18.88 ± 5.24	28.7 ± 5.45	< 0.001	18.48 ± 6.33	29.34 ± 5.50	< 0.001
1 RM (kg)	8.11 ± 0.76	10.27 ± 0.9	< 0.001	8.46 ± 1.31	11.18 ± 1.25	< 0.001
Thigh circumference (cm)	49.59 ± 4.8	54.04 ± 4.8	< 0.001	48.13 ± 4.26	53.36 ± 4.86	< 0.001

a) Paired T Test. Significant if p <0.05

TABLE 3. Comparison of quadriceps strength and thigh circumference within group pre and post intervention

Variables	Moderate Intensity Group (n=44, 50%) Means ± SD	Blood Flow Restriction Group (n=44, 50%) Means ± SD	p[a]
Dynamometer (kg)	28.70 ± 5.45	29.34 ± 5.50	0.788
1 RM (kg)	10.27 ± 0.9	11.18 ± 1.25	0.065
Thigh circumference (cm)	54.04 ± 4.8	53.36 ± 4.8	0.764
Δ Dynamometer (kg)	9.82 ± 2.79	10.86 ± 4.57	0.529
Δ 1 RM (kg)	2.15 ± 0.77	2.7 ± 0.51	0.057
ΔThigh circumference (cm)	4.54 ± 1.54	5.22 ± 2.36	0.432

a) Independent T Test. Significant if p < 0.05

force production of muscle capacity, nervous system adaptations and increased muscle fiber size [16]. Strengthening exercises performed with moderate to high intensity in the elderly are the most effective way to improve muscle function and neuromuscular function [17]. The effect of training intensity on increasing strength shows that there is no significant difference in increasing strength between moderate and high intensity training in the elderly [18].

Quadriceps strength (dynamometer) and delta of quadriceps strength (dynamometer) did not show a significant difference between the two groups after 6 weeks of intervention (p = 0.788; p = 0.529). The findings in this study in line with systematic review research by Fabero-Garrido et al. (2022) which stat-

ed that low-intensity strengthening exercise with BFR resulted in lower increases in muscle strength than high-intensity strengthening exercise and higher than low-intensity strengthening exercise in a healthy elderly population - 60 years and over. This means that traditional moderate intensity training has similar results or benefits to low intensity training combined with BFR [19]. There have not been many studies comparing isometric muscle strength, especially comparing moderate intensity strengthening exercises and light intensity exercises in combination with BFR. Research comparing knee extensor isometric strength with high-intensity and low-intensity strengthening exercises combined with BFR showed many insignificant results between the two groups.[20] Strengthening exercises in the elderly are sufficient to do at moderate intensity (40-60% 1RM) to achieve increased muscle strength [17].

Increased muscle strength is influenced by increased muscle tension which occurs due to mechanotransduction, increased local release of hormones such as IGF and recruitment of fast twitch muscle fibers [21]. The response to increasing muscle strength by traditional strengthening exercises in young adults is mediated by up to 60% of neural adaptation, whereas in the elderly, this neural contribution is considered to be greater [22]. Meanwhile, the response to increasing muscle strength in training with BFR is dominated by an increase in growth hormones which activate muscle cell adaptation mediated by muscle stem cells [23]. Training with BFR not only increases muscle strength in the elderly, but adaptation also occurs after the exercise is stopped. Yasuda et al. (2014) reported that the increase in muscle strength in elderly people after 12 weeks of training was maintained well even after a 24 week detraining period [24].

1RM strength values and delta of 1 RM strength before and after intervention for 6 weeks showed statistically significant changes in both groups ($p < 0.001$). The increase in dynamic muscle strength in both groups is in line with the results of study by Hua et al. (2022) mentioned that moderate intensity strengthening exercise in elderly women with or without sarcopenia can significantly increase muscle strength to prevent sarcopenia and maintain motor function [25]. The increase in dynamic muscle strength in this study is in line with other studies that conducted research on the elderly where the increase in dynamic strength increased in the low intensity training group with BFR [10,24]. Strengthening training for 6 weeks was considered sufficient to improve muscle quality as assessed by muscle thickness and 1RM of the quadriceps femoris muscle [26]. The percentage increase in strength in the BFR group varied between 7 - 26%, while in the high intensity group there was an increase of between 4 - 56% [10,27,29]. The finding of this study in line with the study by Lixandrão et al. (2018) stated that BFR training significantly increased muscle mass but only produced a lower muscle strength response compared to high intensity training [28].

The size of the thigh circumference before and after the moderate intensity and low intensity quadriceps femoris strengthening exercise intervention with BFR for 6 weeks showed statistically significant changes in both groups ($p < 0.001$). The increase in thigh circumference in this study was higher than the research report on elderly women aged 70 years by Yasuda et al. (2016) where the baseline thigh circumference in the moderate-severe group was 45.1 ± 4.0 cm then after 12 weeks of strengthening exercise with resistance bands it decreased to 44.9 ± 4.1 cm [29]. The difference in changes in thigh circumference in this study may be due to the fact that training with resistance bands is usually low - medium intensity exercise, so it has minimal or no effect on muscle hypertrophy, especially in the elderly population [30].

The thigh circumference size of the BFR group in our study before the intervention was 48.13 ± 4.26 and at the end of the intervention 53.36 ± 4.86. The increase in circumference size in this study was much greater than in the study by Yasuda et al. (2016) where the size at baseline was 43.9 ± 3.8 cm then after 12 weeks of strengthening training with resistance bands it increased to 44.2 ± 3.7 cm [29]. The increase in thigh circumference in both groups suggests that strengthening exercise is a way to combat sarcopenia and provide muscle hypertrophy effects in the elderly. Currently there is a lot of research evidence that light weight training with BFR can overcome sarcopenia in the elderly as well as being very effective in preventing sarcopenia [31].

Thigh circumference and delta of thigh circumference did not show a significant difference between the two groups ($p = 0.764$). Thigh circumference can project muscle mass and fat mass simultaneously. Lean muscle mass or fat free mass (FFM) is generally caused by changes in muscle mass without an increase in fat mass or degradation of fat mass, resulting in lean body mass.[32] BFR exercises can reduce BMI by reducing body weight, % body fat, and waist circumference as well as improving body composition in obese adults [33]. Muscle hypertrophy as a response to strengthening training can be achieved by strengthening training with a load ≥30%1RM. This muscle hypertrophy response does not depend on age so in principle there is no ideal "hypertrophy zone" to stimulate muscle growth. Practically, moderate intensity training is the most efficient way to stimulate muscle growth [34]. Strengthening exercises with high intensity

and heavy weights can provide comparable hypertrophy effects to moderate intensity. High intensity exercise increases joint stress so moderate intensity exercise is a comfortable and relatively safer exercise with similar benefits to high intensity. A meta-analysis study from Fabero-Garrido et al. (2022) reported that low-intensity strengthening exercise with BFR increased muscle hypertrophy similar to high-intensity exercise in an elderly population aged over 60 years so there was no significant difference between the two groups [19].

The presence of side effects in the moderate intensity group can be a consideration that training with BFR might be a safe alternative exercise with similar benefits in the elderly. The difference in delta increase in thigh circumference in the moderate and BFR groups was not statistically significant, indicating that moderate intensity strengthening exercise and low intensity exercise with BFR were equally beneficial for increasing thigh circumference. BFR exercises can stimulate angiogenesis due to ischemic conditions, thus stimulating the expression of Vascular Endothelial Growth Factor (VEGF) which plays an important role in the vascular remodeling process through the production of nitric oxide[35]. Side effects that may occur during and after BFR exercises are dizziness and a spinning sensation. This incidence rate varies between <1% - 20% [36]. This complaint may occur due to a post-exercise hypotensive response or vasovagal reflex [37]. The sensation of numbness in the muscles being exercised, the feeling of numbness and tingling up to the incidence of nerve compression is very low (<2%) and can be modified by adjusting the occlusion pressure of each subject, the duration of cuff application and the application of the correct cuff size [38]. This prevalence is in line with the results of this study where there were no side effects in the BFR group so that the exercise protocol in the study was a safe exercise protocol and had a positive impact on the muscle strength of the elderly.

Limitations

This study has limitations. The level of physical activity during the interval between exercise was not controlled and nutritional factors (protein intake, carbohydrates and hydration status) were not monitored during the intervention. Muscle strength and thigh circumference are closely related to body weight, lifestyle and nutritional factors. The research methods included a relatively short duration of intervention with subjects limited to healthy elderly community women without sarcopenia and variations in cuff pressure adjusted between individuals before each exercise session could result in variable and possibly suboptimal exercise response results. The evaluation was only carried out once at the end of the study so it could not provide an overview of the long-term effects on training. The BFR exercise protocol is currently still a recommendation, so this study uses a low dose recommendation to minimize the risk of side effects considering that there is no research on BFR in the elderly in Indonesia, so the safety element is a concern in this research. Another variable that can influence thigh strength and circumference is that the overall muscle mass and fat mass of each subject was not measured so it cannot provide a bigger picture regarding muscle strength and thigh circumference.

CONCLUSION

Both moderate-intensity weight strengthening exercises and low intensity weight strengthening exercises with BFR for 6 weeks increase muscle strength and thigh circumference in the elderly woman. The difference in muscle strength increases before and after training was significant in both groups (18.88 ± 5.24 to 28.7 ± 5.45 and 18.48 ± 6.33 to 29.34 ± 5.50) for dynamometer and (8.11 ± 0.76 to 10.27 ± 0.9 and 8.46 ± 1.31 to 11.18 ± 1.25) for 1 RM. Thigh circumference increased significantly (49.59 ± 4.8 to 54.04 ± 4.8 and 48.13 ± 4.26 to 53.36 ± 4.86). Low-intensity resistance exercises with blood flow restriction are considered relatively safer compared to moderate-intensity weight strengthening exercise, as muscle soreness was only reported in 18% of participants in the moderate-intensity group.

Authors' contributions
Conceptualization: JWT, RS, NS. Data curation: JWT, RS, NS. Methodology: JWT, RS, NS. Project administration: JWT. Visualization: JWT. Writing - original draft: JWT. Writing - review and editing: JWT, RS, NS. All authors have read and approved the submitted manuscript. The manuscript has not been submitted elsewhere nor published elsewhere in whole or in part.

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