Original Article

Blood Flow Restriction with Low-load Resistance Exercise Improves Strength in Adults with Risk Factors for Knee Osteoarthritis: A Double-Blind Randomized Controlled Trial

Sakolawat Jaroenpakdee, Rachawan Suksathien and Pimpisa Vongvachvasin
Department of Rehabilitation Medicine, Maharat Nakhon Ratchasima Hospital, Nakhon Ratchasima, Thailand

ABSTRACT

Objectives: To assess the efficacy of blood flow restriction (BFR) with Low-load Resistance Exercise improving knee extensor strength in adults with risk factors for symptomatic knee osteoarthritis (OA)

Study design: Double-blind randomized controlled trial

Setting: Department of Rehabilitation Medicine, Maharat Nakhon Ratchasima Hospital, Nakhon Ratchasima, Thailand

Subjects: Forty-four adults aged ≥ 40 years who engaged in irregular physical activity and had at least one risk factor for symptomatic knee OA were enrolled. Participants were randomly assigned to either the BFR or the control group using stratified and mixed block randomization.

Methods: The study employed a double-blind, randomized, controlled trial design. The BFR group exercised twice a week for 4 weeks, performing knee extension exercises at 30.0% of their one-repetition maximum (1RM) (15 reps × 4 sets) with cuff pressure, while the control group performed the same exercises but without using the cuff protocol. The outcomes measured included 1RM isokinetic knee extension, 1RM isokinetic leg press, 30-second chair stand test, and Knee Injury and Osteoarthritis Outcome Score (KOOS). Test results pre-exercise and post-exercise (3 days after the last exercise session) were recorded. Differences in results between groups were compared using the linear regression test.

Results: The post-test mean differences of 1RM isokinetic knee extensor, 1RM leg press, 30 second chair stand test, and KOOS between groups (adjusted mean difference, AMD) were 14.7 kg (95% confidence interval (95%CI) 4.0, 19.3; $p < 0.001$), 30.83 kg (95%CI: 18.0, 43.7; $p < 0.001$), 7.1 times (95%CI: 4.2, 10.1; $p < 0.001$) and 1.4 points (95%CI: 0.3, 2.5; $p = 0.01$) respectively, all of which were statistically significant ($p < 0.05$).

Conclusions: BFR can improve knee extensor strength in adults with risk factors for symptomatic knee OA compared to low-load resistance exercise alone without further worsening knee symptoms.

Keywords: blood flow restriction therapy, resistance exercise, knee osteoarthritis, randomized controlled trial (RCT)

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Introduction

Osteoarthritis (OA) is a degenerative disease with an incidence that is increasing each year. In 2020, more than 654 million people worldwide suffered from OA.[1] Strengthening the muscles around the knee joint, especially the quadriceps muscle, can help reduce and slow the progression of the disease in people with a history of knee OA[2]. The current recommendation is that resistive exercise at a weight level of 70.0-80.0% of the one repetition maximum (1RM) can increase muscle size (hypertrophy) and muscle strength.[3] However, adverse complications have been reported in adults exercising with resistance at this intensity, such as pain in the knee, inability to tolerate exercise, and incidence of knee injury, a factor that increases knee degeneration[4].

Blood Flow Restriction Training (BFR) is a type of resistance training that combines controlling blood flow by wrapping a tourniquet (cuff or band) around the proximal part of the muscle with weight training. BFR uses less weight to train than other systems and can increase muscle mass while reducing unwanted post-exercise effect,[5] especially in individuals who cannot tolerate high-intensity resistance training or who have limitations on performing conventional exercises. For these reasons, BFR is considered an appropriate option in terms of both safety and efficacy. Increased blood flow within the muscles (blood pool) results in a chemical reaction that causes more lactic acid to accumulate in the muscles, the primary mechanism. This change stimulates the body by transmitting signals to the central nervous system, which then prompts the body to react to the repair process by instructing it to increase growth hormone production, thereby generating more protein.[6-13] However, due to a lack of clinical

Correspondence to: Sakolawat Jaroenpakdee, MD, FRCPhysiatrT; Department of Rehabilitation Medicine, Maharat Nakhon Ratchasima Hospital, 49 Chang Phueak Road, Nai Mueang Sub-district, Mueang Nakhon Ratchasima District, Nakhon Ratchasima, 30000, Thailand;
E-mail: Sakolawat.jp@cpird.in.th

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information on the subject and the fact that physical therapy and rehabilitation medicine in Thailand have not yet widely adopted BFR, the practical application of this therapy method remains limited in that country.

A systematic review by Hughes et al.[6] highlighted significant methodological limitations in prior studies, particularly the inadequate control of confounding factors. Many studies have failed to report whether participants in either the intervention or control groups engaged in additional exercise during the intervention period. Consequently, the TESTEXT SCORE (study quality assessment) indicated a score of 0 for both items 4 (presentation of baseline characteristics) and 8 (control group activity is controlled and presented).

To address these limitations, this study aimed to evaluate adults, ranging in age from middle-aged to elderly, who had risk factors for developing symptoms of OA by assessing quadriceps muscle strength. Participants' physical activity undertaken outside of the trial was restricted and monitored using a personal research diary. Participants who engaged in regular physical activity were disqualified from the study. Given the heterogeneity of blood flow restriction (BFR) training protocols in the literature, this study also incorporated key parameters identified in prior systematic reviews, such as the minimum daily exercise duration, the number of exercise sessions per week, and the training intensity, to align with established practices in BFR research. This investigation represents the first clinical study of its kind to be conducted in Thailand.

Methods

Study design

This double-blind, randomized, controlled study was registered with the Thai Clinical Trial Registry (No. TCTR 20210903007). The project additionally obtained approval from the Maharat Nakhon Ratchasima Hospital Institutional Review Board (MNRH IRB) with approval date on June 17, 2021 (Certificate No. 063/2019). This research was conducted in accordance with the CONSORT 2010 guidelines.

Participants

The target population of this study was Thai people aged ≥ 40 years with at least one risk factor for symptomatic knee OA and who engaged in some form of irregular physical activity. All participants in the study were hospital employees with desk jobs and were recruited by viewing a poster located at the outpatient department of the Rehabilitation Clinic between February and August 2021. The sample size was determined using data from a study by Neil A. Segal et al.[14] ($Z = 1.96$, $p = 0.05$, $Z\beta = 0.84$, $\sigma^2 = 12.2$, $\mu\alpha - \mu\alpha = 11.4$) adjusted by adding 20.0% to account for possible dropouts. Forty-four individuals made up the total, with 22 individuals each in the BFR group and the control group.

Inclusion criteria

1. Age 40 years or older as of the start of research
2. Ability to understand the Thai language and consent to participate in the research
3. Ability to stand, walk, and sit normally during the test.
4. Having at least one of the following strong risk factors and symptoms for symptomatic knee OA[15,16] :
   - 4.1 Body mass index (BMI) ≥ 24 kg/m²
   - 4.2 A history of knee injuries or knee surgery
   - 4.3 A history of intermittent knee pain or stiffness lasting less than 30 minutes

Exclusion criteria

1. Engaging in regular physical activity (e.g., ≥ 2-3 times/week, ≥ 150 minutes/week of moderate intensity, or ≥ 5,000 steps/day[17,18]).
2. Having signs of infection or inflammation
3. Having undergone knee-related surgery within the previous 6 months
4. Having a film x-ray record of the knee joint showing grade 2 to 4 on the Kellgren and Lawrence classification.
5. Having contraindications to exercise according to The American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) guidelines.[19]

Randomization

The participants were provided with information about the study by the researcher to enable them to make an informed decisions regarding giving verbal and written consent to participate in the study. In the trial, patients were randomly allocated to one of two groups (a BFR group and a control group) using mixed block randomization (blocks of 2 and 4) using stratified randomization to separate sex into strata. In a process hidden from the participants, a computerized randomization procedure assigned each participant a group code which was then put into a sealed envelope.

Equipment

1. B Strong™ with B-Strong BFR Cuff available in 4 sizes: S, M, L, XL for limb girth circumferences ranging between 11.25 to 37.50 inches.
2. Plate-loaded leg extension machine
3. Leg press machine (MATRIX brand, model VS-S70)
4. Automatic pressure measuring device
5. Stable 4-legged chair with backrest
6. Stopwatch
7. Biodex System 4 Dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA) with software

Procedure

When the participants arrived at the fitness center of Maharat Nakhon Ratchasima Hospital for grouping, the first sports scientist opened the envelope and provided workout instructions for 4 weeks (Table 1 and Table 2) applying the protocol from Segal's research,[20] but with the number of repetitions in the first set reduced to 15. The pre-exercise questionnaire and the patient's baseline data were both documented by the study's author. Another physician, who was not involved in this research, measured the participants' vital signs before and after each daily workout. A second sports scientist tested the participants and recorded the results pre-test (1 day before the first exercise session) and post-test (3 days after the last session of the 4-week exercise program). 1RM was measured in kilograms (kg) using a Biodex System 4 Dynamometer.

Participants in both groups were not informed about the exercises prior to the start of the study and were also told not to discuss the exercises or the measurements until the study had been completed. Additionally, the portion of the BFR device that controlled the pressure in the thighs was covered with a black cloth, so participants could not see it during the exercise. As a result, the participants were unaware of the exact pressure level or any changes in that level during each session.

Although all participants described themselves as being physically inactive, they agreed to record any physical activity in diary books provided to them at the time they consented to join the study. They were also asked to describe their daily activities, including exercise outside the study, any complications that arose after exercise during the study, their daily food intake, and their sleep patterns. This was done to identify any potentially confounding factors, including activities outside the research, and to have a record of their having met the criteria regarding regular exercise as specified in the exclusion criteria.

Outcome measurements

1) Primary outcome: 1RM isokinetic knee extension

2) Secondary outcome: 1RM isokinetic leg press, 30-second chair stand test, Knee injury and OA Outcome Score (Thai version-KOOS; internal consistency with Cronbach's α = 0.88 (95%CI: 0.83, 0.91); Test-retest reliability with ICC = 0.87 (95%CI: 0.77, 0.92). A linear regression test was used to compare the results between groups.

Results

A total of 54 participants were screened; 10 were excluded, 9 because they were regular exercisers, and one who had a history of recurrent uncontrolled hypertension. A total of 44 participants were finally recruited and randomly assigned to either the BFR group (22 participants, comprising 9 men and 13 women) or the control group (22 participants, comprising 9 men and 13 women). No participants withdrew during the study as indicated in Figure 1. Baseline data of both groups are shown in Table 3, including gender, age, height, body mass index (BMI), and pre-exercise test results. The pre-test results of both groups, consisting of 1RM isokinetic knee extension (kg), 1RM isokinetic leg press (kg), 30-second chair stand test (times), and KOOS (points), were similar, with a p-value greater than 0.05, shown in Table 3.

1RM isokinetic knee extension

Before exercise, the experimental group had a mean pre-test weight of 27.7 kg (SD = 10.1 kg), and the control group had a mean of 31.0 kg (SD = 10.0 kg). After 4 weeks of exercise, the mean post-test score of the BFR group was higher than the control group, with an average of 51.1 kg (SD = 15.6 kg) and 39.4 kg (SD = 8.6 kg), respectively, shown in Table 4. The mean post-test difference between groups (unadjusted mean difference, UMD) was 11.65 kg (95%CI: 4.0, 19.3) and after adjusting for the pre-test (adjusted mean difference, AMD), it was 14.7 kg (95%CI: 9.6, 19.9), a statistically significant difference ($p < 0.001$). The difference in average weight between males in the two groups was 21.5 kg (95%CI: 15.1, 28.0), a statistically significant difference ($p < 0.001$). In females, the mean weight was 7.3 kg (95%CI: 1.2, 13.4), also a statistically significant difference ($p = 0.02$) shown in Table 5. The trend of results for both groups is presented in Graph A of Figure 2.

Figure 2. Graphs of outcomes by study group adjusted for pre-test. (A) 1RM knee extension, (B) 1RM leg press, (C) 30-second chair stand test, and (D) KOOS

Table 1. The resistance training protocol of the study

Detail	Intervention group (BFR group)	Control group
Form of exercise	Bilateral knee extension	
Number of repetitions per set	15	
Number of sets	4	
Rest time between sets (seconds)	30	
Intensity	30% of 1RM each week	
Number of sessions per week	2	
Total weeks	4	
Cuff pressure	BFR with incremental inflation pressure protocol	BFR cuff with initial pressure only (no incremental inflation pressure)

BFR, blood flow restriction; RM, repetition maximum

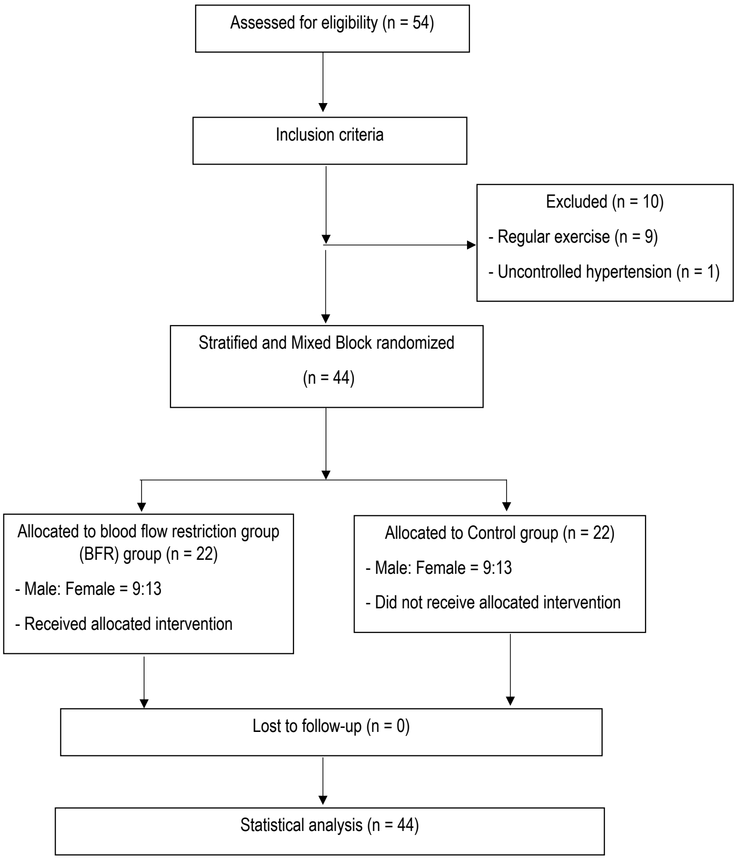

Figure 1. CONSORT diagram

Table 2. Study cuff pressure protocol

Order of week and session (Week. session)	Initial pressure (mmHg)	Incremental inflation pressure (mmHg)				
		Before 1st set	1st set	2nd set	3rd set	4th set
Pre-exercise test (1 day before the first exercise session)						
1.1-1.2	40	80	100	120	140	160
2.1-2.2	40	100	120	140	160	180
3.1-3.2	40	120	140	160	180	200
4.1-4.2	40	120	140	160	180	200
Post-exercise test (3 days after the last exercise session)						

1RM isokinetic leg press

The pre-test of the BFR group had an average of 67.1 kg (SD = 31.1), while the control group had a higher average of 76.3 kg (SD = 32.2 kg). The post-test results for the BFR group and the control group were 110.3 kg (SD = 34.8 kg) and 87.2 kg (SD = 33.1 kg), respectively, shown in Table 4. The UMD equals 23.7 kg (95%CI: 2.4, 43.7) and the AMD equals 30.8 kg (95%CI: 18.0, 43.7), which represent statistically significant differences ($p < 0.001$). When analyzed by sex, the mean weight was 32.4 kg in males (95%CI: 10.7, 54.0) ($p = 0.003$) and 25.1 kg in females (95%CI: 10.7, 39.4) ($p = 0.001$), shown in Table 5. Graph B of Figure 2 shows the trend of results for both groups.

30-second chair stand test

The test of 30-second chair standing, shown in Table 4, yielded pre-test means of 20.0 times (SD = 3.8 times) for the BFR group and 21.4 times (SD = 4.5 times) for the control group. As indicated in Table 4, the difference between UMD and AMD was statistically significant ($p < 0.001$), with UMD being 6.0 times (95%CI: 2.4, 9.6) and AMD being 7.1 times (95%CI: 4.2, 10.1). As indicated in Table 5, when the BFR and control groups were evaluated by gender, AMD was 10.5 times higher (95%CI: 6.2, 14.7) in males and 4.9 times higher (95%CI: 0.9, 8.8) in females ($p = 0.016$). Graph C in Figure 2 displays the trend of outcomes for each group.

Knee Injury and Osteoarthritis Outcome Score (KOOS)

The pre-test means of KOOS for the BFR group and the control group were 95.0 points (SD = 3.9) and 95.6 points (SD = 3.4 points), respectively. The post-test mean of the control group was 95.9 points (SD = 3.0 points), shown in Table 4. The UMD of the two groups was 1.1 points (95%CI:

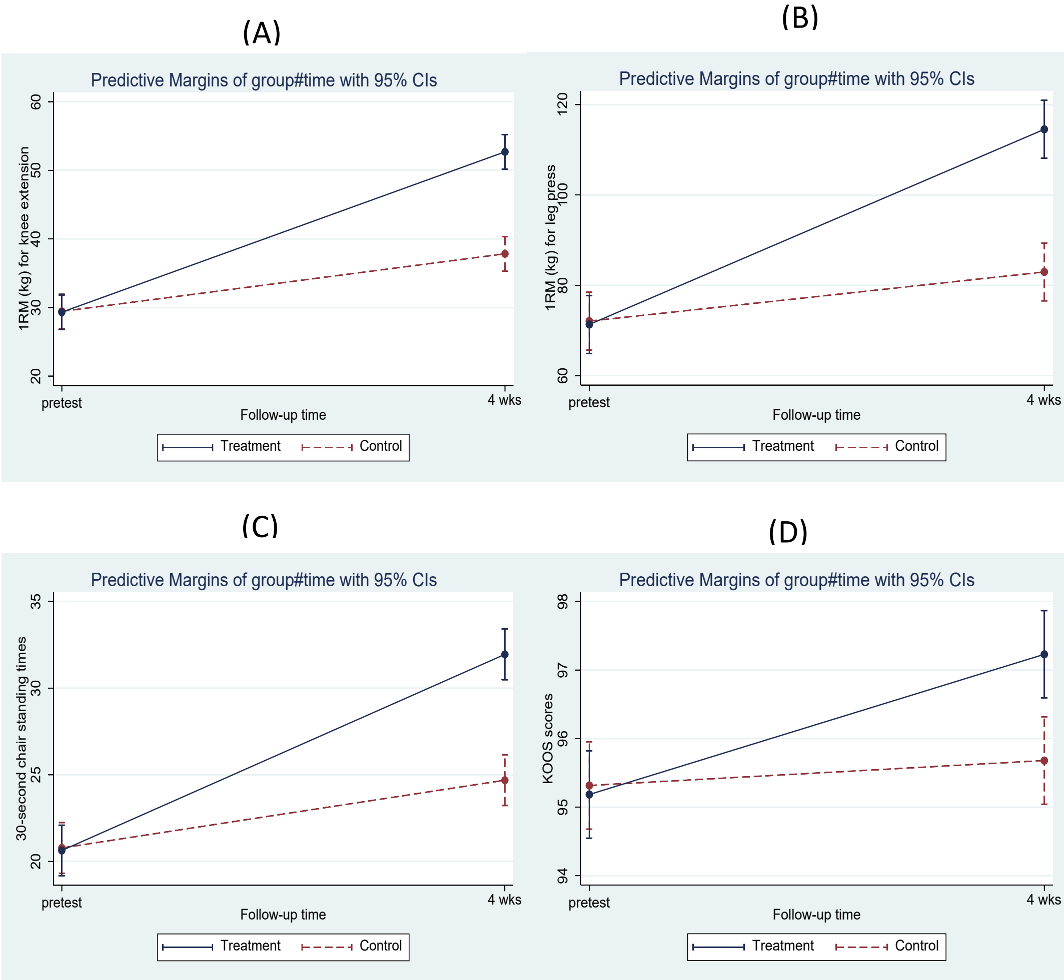

Figure 2. Graphs of outcomes by study group adjusted for pre-test. (A) 1RM knee extension, (B) 1RM leg press, (C) 30-second chair stand test, and (D) KOOS

BFR, blood flow restriction; RM, repetition maximum; KOOS, Knee Injury and Osteoarthritis Outcome Score

Table 3. General characteristics of the study population

Characters	BFR Group	Control group
Gender[1]		
Male	9 (40.9)	9 (40.9)
Female	13 (59.1)	13 (59.1)
Age, years[2]	48.9 (7.2)	50.4 (7.0)
Height, cm[2]	159.5 (8.8)	161.6 (7.9)
Body weight, kg	65.9 (15.7)	66.9 (12.5)
BMI, kg/m[2]	25.8 (5.14)	25.6 (4.0)
18.5 to 24.91	11 (50.0)	11 (50.0)
25.0 to 29.91	6 (27.3)	9 (40.9)
≥ 30.01	5 (22.7)	2 (9.1)
Pre-test of 1RM isokinetic knee extension, kg[2]	27.7 (10.1)	31.0 (10.0)
Pre-test of 1RM isokinetic leg press, kg[2]	67.1 (31.1)	76.3 (32.2)
Pre-test of the 30-second chair stand test, times[2]	20.0 (3.8)	21.4 (4.5)
Pre-test of KOOS, points[2]	95.0 (3.9)	95.6 (3.4)

*$p < 0.05$ indicates statistical significance. [1]Number (%), [2]Mean (SD),
BFR, blood flow restriction; cm, centimeters; kg, kilograms; kg/m2, kilogram per square meter; RM, repetition maximum; KOOS, Knee Injury and Osteoarthritis Outcome Score

-0.6, 2.7), which was not statistically significant, but for AMD it was 1.4 points (95%CI: 0.3, 2.5), a statistically significant difference (p = 0.010) shown in Table 4. The difference in AMD in males was 0.93 points (95%CI: -0.6, 2.4) which was not statistically significant (p = 0.226). In females, the difference was 1.8 points (95%CI: 0.3, 3.3) which was a statistically significant difference (p = 0.02), shown in Table 5. Additionally, the KOOS pain dimension for both groups after 4 weeks of exercise showed no increase in pain, shown in Table 6. Graph D of Figure 2 illustrates the trend of results for both groups.

Skin redness (32.0%) and localized fatigue (43.0% of all participants) were mild and temporary adverse effects that resolved within a short period (48 hours or less for fatigue and 15 minutes for redness). Moderate knee joint pain was reported by only one individual (2.0%) and entirely resolved after rest. There were no reported severe or long-lasting side effects.

Discussion

BFR with low-load exercise increases muscle strength more than low-load training alone by creating high metabolic stress, forcing early recruitment of fast-twitch muscle fibers, boosting anabolic hormone release, and stimulating muscle growth pathways. It mimics the effects of heavy lifting, even at light weights, making it especially useful for rehabilitation or for populations unable to lift heavy loads, as Hughes et al.[6] noted.

As in Fernandes-Bryk et al.[21] and Mattar et al.[22], the workouts in this study were conducted with BFR at 30.0% of 1RM with four sets (15, 15, 15, 15 reps, respectively), which is less than Segal et al.[22], Vechin et al.[23], and Libardi et al.[24], where individuals exercised with four sets (30, 15, 15, 15 reps, respectively) for a total of 4 weeks, which is the same length of time as research by Shimizu et al.[25] and Patterson et al.[26] Participants in this study exercised twice a week, which is similar to studies by Mattar et al., Vechin et al., Libardi et al., and Yasuda et al.[27]. Based on Brad J. et al.'s study which showed that exercising at least twice weekly can increase muscle strength and growth[28], the exercises in this study program are of a suitable length for participants to engage in regularly without skipping follow-up sessions. Jessica. et al.[29] recommend 4 weeks of continuous exercise to develop physical strength, a finding consistent with the results of this study. To ensure that factors other than exercise did not affect the post-test outcomes, we monitored the presence of confounding factors, particularly other exercises not included in this research, during the 4-week study using the participants' diary books. Additionally, there was no potential for harmful side effects while using BFR in vulnerable patients, such as those with OA.

1RM isokinetic knee extension

The exercise protocol in this study involved only knee extension, a movement that primarily targets the quadriceps muscle and increases its strength. After 4 weeks, although

Table 4. Mean (SD) of outcomes by group, unadjusted mean difference (95%CI), adjusted mean difference (95% CI), and p-value

Outcome	BFR group, Mean (SD)	Control group, Mean(SD)	Unadjusted Mean diff.# (95%CI)	Adjusted## Mean diff. (95%CI)	*p-value
Pre-test of knee extension weight, kg	27.7 (10.1)	31.0 (10.0)			
Post-test of knee extension weight, kg	51.1 (15.6)	39.4 (8.6)	11.6 (4.0, 19.3)	14.7 (9.6, 19.8)	< 0.001
Pre-test of leg press weight, kg	67.9 (31.1)	76.3 (32.2)			
Post-test of leg press weight, kg	110.3 (34.8)	87.2 (33.1)	23.1 (2.4, 43.7)	30.8 (18.0, 43.6)	< 0.001
Pre-test of 30-sec chair stand test, times	20.0 (3.8)	21.4 (4.5)			
Post-test of 30-sec chair stand test, times	31.3 (6.9)	25.3 (4.5)	6.00 (2.4, 9.6)	7.1 (4.2, 10.1)	< 0.001
Pre-test of KOOS, points	95.0 (3.9)	95.6 (3.4)			
Post-test of KOOS, points	97.0 (2.4)	95.9 (3.0)	1.1 (-0.6, 2.7)	1.4 (0.3, 2.5)	0.010

*p < 0.05 indicates statistical significance

BFR, blood flow restriction; KOOS, Knee Injury and Osteoarthritis Outcome Score, # BFR group – Control group, ## adjusted pretest outcomes

Table 5. Adjusted mean difference (95%CI) and p-value of outcomes by gender

Outcome	Female; n = 13		Male; n = 9	
	Adjusted# mean diff. (95%CI)	p-value	Adjusted## mean diff. (95%CI)	*p-value
Knee extension	7.3 (1.2, 13.4)	0.020	21.5 (15.1, 28.0)	< 0.001
Leg press	25.1 (10.7, 39.4)	0.001	32.4 (10.7, 54.0)	0.003
30-second chair stand test	4.9 (0.9, 8.8)	0.016	10.46 (6.22,14.70)	< 0.001
KOOS	1.8 (0.3, 3.3)	0.021	0.93 (-0.6, 2.4)	0.226

*p < 0.05 indicates statistical significance, #BFR group – control group, ##adjusted pretest outcomes

KOOS, Knee Injury and Osteoarthritis Outcome Score; N, number of participants

Table 6. Mean (SD) of pre- and post-4-week exercise scores of 5 patient-relevant dimensions of KOOS classified by demographics and gender

5 dimensions of KOOS	BFR group		Control group	
	Female n = 13	Male n = 9	Female n = 13	Male n = 9
Pain				
Pre-exercise	93.4 (4.5)	93.1 (3.3)	92.8 (5.0)	94.9 (2.6)
Post 4 week-exercise	96.8 (3.0)	94.7 (3.4)	95.85 (3.0)	95.11 (3.1)
Other disease-specific symptoms				
Pre-exercise	97.8 (3.1)	97.1 (3.0)	97.5 (3.0)	99.1 (1.8)
Post 4 week-exercise	98.77 (1.9)	97.9 (2.7)	98.2 (3.3)	98.7 (2.0)
Activities of daily living				
Pre-exercise	96.4 (4.1)	96.3 (3.4)	96.7 (3.3)	98.0 (1.2)
Post 4 week-exercise	98.2 (2.6)	97.4 (2.3)	97.3 (2.8)	97.2 (2.0)
Sport and recreation				
Pre-exercise	97.2 (4.9)	93.3 (4.3)	93.1 (6.0)	94.4 (5.3)
Post 4 week-exercise	97.7 (2.6)	96.1 (2.2)	94.2 (5.7)	95 (4.3)
Quality of life				
Pre-exercise	94.3 (7.0)	93.9 (6.2)	94.5 (5.7)	96.7 (3.2)
Post 4 week-exercise	96.3 (3.9)	95.3 (4.0)	93 (6.9)	96 (3.0)

KOOS, Knee Injury and Osteoarthritis Outcome Score; n, number of participants

the post-test values for both groups increased, the post-test and pre-test mean difference of the BFR group was significantly greater than the control group, which is consistent with the research of Matter et al., Segal et al., Yokokawa et al.[30], Karabulut et al.[31], and Abe et al.[32] This research used an exercise protocol which included the minimum intensity, number of reps, number of sets, and duration of the exercise program.

The experimental group's mean difference in BFR before and after exercise was 23.4%, which is higher than the findings of Yokokawa et al. and Karabulut et al., who reported 20.4% and 19.1%, respectively. This result is also lower than the finding of Segal et al., which was 28.3%. This study differs from Segal's in that the present study involved exercising less frequently and for a shorter period (6 minutes, 4 sets, and 15 reps per set; two times a week for a total of four weeks) compared to Segal's (7 minutes, 4 sets, and 30 reps for the first set and then 15 reps for the others; three times a week for a total of four weeks). However, this study outperformed Yokokawa et al. and Karabulut (which included just 3 sets of 30, 15, 15 reps). Based on the "Progressive Overload Principle", muscles only adapt when they are challenged beyond their current capacity. Increasing weight (intensity), reps per set (volume), or training days (frequency) provides a greater stimulus. This stimulus triggers microtrauma in muscle fibers, leading to repair and hypertrophy (muscle growth), as well as improvements in neural efficiency. Therefore, it can be inferred that increasing the intensity or amount of exercise, such as the number of reps, sets, or the frequency of training, can lead to greater strength gains from BFR exercise.

Along with other lower extremity muscles and ligaments, the quadriceps muscle stabilizes the knee joint. When the quadriceps muscle weakens, the passive components of the knee joint are subjected to increased strain, which results in increased stiffness. Strengthening the quadriceps muscles with resistance training lowers the chance of tibiofemoral joint space narrowing and cartilage loss. Therefore, it is believed that by improving knee joint stability and load absorption, resistance training that builds muscle strength also helps alleviate pain and improve function.[2]

1RM isokinetic leg press

The leg press is an exercise that uses multiple muscles, including the quadriceps, hamstrings, glutei, and gastrocnemius. In particular, the vastus medialis and vastus lateralis are the main muscles that work during the exercise. Although the protocol of this research focuses on exercises to increase the strength of the quadriceps muscle, these exercises have also been shown to increase the overall efficacy of exercises that use multiple leg muscles or the dynamic compound action of the lower limbs, as explained in a study by Shimizu et al.[25]

30-second chair stand test

The post-test study showed elevated mean values compared to the pre-test in both groups. According to a study by Abe et al. and Ozaki et al.,[33] there is a significant difference between the post-test and pre-test means of the BFR group compared to the control group. Currently, this test is used to assess fall risk in elderly individuals by evaluating their physical function and lower extremity muscle strength.[34] The BFR exercise used in this study should thus be effective in decreasing the likelihood of falls in the future because stronger quadriceps can generate greater torque at the knee joint which is critical for maintaining upright posture and adjusting to changes in body position or external forces (like being bumped). When balance is perturbed, the quadriceps rapidly contract to extend the knee and restore the center of mass over the base of support. Stronger quadriceps also improve braking ability during descent, reducing uncontrolled motion. Strong quadriceps can also help maintain proper patellar tracking and knee joint alignment, ensuring efficient force transmission through the leg, helping to minimizing abnormal movement patterns and prevent joint wobble which can compromise balance.

The knee injury and osteoarthritis outcome score (KOOS)

The results of this research indicate that both the experimental group and the control group showed statistically significant differences. This result reflects that BFR exercise did not increase pain or make the quality of movement in daily life worse than before participating in the research, which is consistent with the research of Segal et al.[22] When analyzed by gender, this study found that males in the BFR group did not have KOOS values statistically significantly different from those in the control group, indicating that while BFR exercise increased the strength of the quadriceps muscle in males, there was no statistically significant change in pain or movement in daily life compared to the control group. The KOOS of females in the experimental group were significantly higher than that of the control group. It is possible that the female population, which currently has a higher incidence of knee OA than males, tends to use BFR more effectively than males, as suggested in a hypothesis of Segal et al.

Similar to Kevin D. Anderson et al.,[35] this study demonstrated minimal adverse effects following BFR training. The majority of those effects were classified as grade 1 adverse events, which are defined as any change from the usual therapeutic course that does not require pharmacologic, surgical, or radiological intervention. The population in this study consisted predominantly of hospital workers who met the criteria for physical inactivity or sedentary behavior, which is similar to the majority of people worldwide who are at risk for OA. Therefore, the use of BFR in this study can be extrapolated to the general population and can be considered safe, especially for individuals who prefer to use low loads during exercise.

However, the limitations on tracking confounding factors that could potentially have influenced the study's outcomes could only have been addressed through interviews and reviews of each of the participants diary books, something which could not have been monitored in real-time or in day-to-day life. Research could potentially be more reliable in the future if methods are developed for improved monitoring, e.g., incorporating wearable devices or other digital technologies. The outcomes of this trial were reported over 4 weeks, which could serve as a benchmark for future studies examining the long-term efficacy of BFR exercise and various BFR protocols. Moreover, exercising at 70.0-80.0% of 1 RM without BFR proved to be an appropriate standard recommendation. Further study may yield additional valuable information if a comparison between BFR and standard resistance exercise were feasible, particularly by including more diverse groups, e.g., moderate-to-severe OA patients or postmenopausal women.

Conclusion

Compared to the low-resistance group, adults 40 years of age and older at risk of developing symptoms of OA of the knee who performed 30.0% of 1RM resistance exercise plus BFR twice a week experienced a significant increase in quadriceps muscle strength after just 4 weeks of consistent exercise. This may be recommended as a practical supplementary approach that can potentially help slow the progression of joint degeneration in the long term.

Conflict of interest disclosure

This research did not receive any specific grant from commercial agencies or organizations for the benefit and profit.

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Data availability

The data that support the findings of this research article are available from the corresponding author, Sakolawat Jaroenpakdee, upon reasonable request.

Author contribution

Sakolawat Jaroenpakdee: conceptualization, data curation, analysis, methodology, project administration, resources, visualization,

Rachawan Suksathien: conceptualization, methodology, supervision, validation, writing - review & editing,

Pimpisa Vongvachvasin: conceptualization, funding acquisition, data collection.

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