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Comparing the effect of intermittent blood flow restriction training and high-load resistance training in patients with patellofemoral pain: study protocol for a randomised trial

Weiya Kong ,[1] Haonan Wang,[1] Lin Cheng,[2] Guoxin Ni [3]

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[1]School of Sports Medicine and Rehabilitation, Beijing Sport University, Beijing, China
[2]Department of Rehabilitation, Tongzhou District Hospital of Integrated Chinese and Western Medicine, Beijing, China
[3]Department of Rehabilitation Medicine, The First Affiliated Hospital of Xiamen University, Xiamen, Fujian, China

Correspondence to
Professor Guoxin Ni;
guoxinni@fjmu.edu.cn

ABSTRACT

Background Patellofemoral pain (PFP) syndrome is a common knee joint functional disorder. Blood flow restriction (BFR) training has shown promise in improving PFP; however, the effectiveness of intermittent BFR (iBFR) training remains uncertain. This study aims to compare the rehabilitative effects of iBFR combined with low-load resistance training and high-load resistance training in PFP patients and to assess the effectiveness of iBFR combined with low-load resistance training for improving PFP.

Methods and analysis This randomised, patient-assessor blinded, controlled trial will include 42 eligible PFP patients randomly allocated to an intervention group (iBFR combined with low-load resistance training) or a control group (high-load resistance training) in a 1:1 ratio. Participants will receive interventions three times per week for 8 weeks and will be followed up for 24 weeks. The primary outcome measure is pain, and the secondary outcomes include self-reported function, quality of life, muscle strength and muscle thickness. Assessments will be conducted at baseline, 8 weeks and 24 weeks during follow-up. Intention-to-treat analysis will be performed. Collectively, we expect that the findings of this randomised clinical trial will contribute to understanding the potential benefits of iBFR training and provide insightful guidance for developing more effective treatment strategies for patients with PFP.

Ethics and dissemination This study was approved by the Sports Science Experiment Ethics Committee of Beijing Sport University (2022274H). Written informed consent will be obtained from all participants. Trial results will be disseminated through peer-reviewed publications.

Trial registration number Chinese Clinical Trial Registry (ChiCTR2300068281).

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ Intermittent compression: using intermittent blood flow restriction (BFR) over continuous BFR might increase patient compliance due to decreased discomfort and fatigue during training.
⇒ Randomised, concealed allocation and intention-to-treat (ITT) methods: this clinical trial adheres to rigorous methodological standards such as randomisation, concealed allocation and ITT methods, helping to minimise bias, enhance the validity of the study's findings and allowing for a more robust comparison between the study groups.
⇒ Reassessment of percentage of limb occlusion pressure: this will be performed every 2 weeks to prevent any alterations in the participant's haemodynamics and help adjust the training protocol for each individual, optimising the safety and effectiveness of the intervention.
⇒ Long-term follow-up: the protocol includes an 8-week immediate follow-up and a 24-week mid-term follow-up to observe both the immediate and longer-term effects of the interventions.
⇒ Blinding: it is acknowledged that the blinding of physiotherapists to the participants' basic information might affect the treatment outcomes to a certain extent and that being unmasked to the patient grouping might potentially introduce performance bias.

BACKGROUND

Patellofemoral pain (PFP) is a common knee joint dysfunction characterised by pain in the front of the knee joint caused by a series of pathological (ie, functional issues related to muscle strength, balance or flexibility) or anatomical (ie, structural deviations such as unusual shape or position of the patella and abnormal rotation or alignment of the femur) abnormalities.[1] The pain worsens with weight-bearing activities, limits physical activity and reduces quality of life.[2–4] According to epidemiological surveys, the incidence of PFP in the general population ranges from 3% to 40%,[5] and approximately 40% of patients presenting with knee joint issues are related to PFP.[6] Long-term PFP can eventually lead to patellofemoral joint arthritis,[7] resulting in a significant burden on the patient, family and society.[8] Neal *et al* indicated in 2019 that quadriceps weakness is a risk factor contributing

to PFP, especially when normalised by body mass index.[3] Previous studies have shown that decreased quadriceps strength and muscle atrophy are highly correlated with the incidence of PFP and the pain and knee joint function scores.[9–11]

Resistance training is one of the important ways to improve muscle strength and muscle atrophy. Previous research has shown that resistance training of the quadriceps muscle can relieve pain in PFP patients and improve lower limb function scores.[12] According to the resistance training exercise prescription recommended by the American College of Sports Medicine, the resistance training intensity should reach a high load of 70%–85% 1 repetition maximum (RM) in order to improve muscle strength and muscle atrophy.[13] Currently, the resistance training load for quadriceps muscles in PFP physical therapy is generally 60%–85% 1RM.[14] However, performing high-load resistance training may exacerbate patellofemoral joint stress in patients with PFP, potentially causing increased pain and worsening symptoms. This, in turn, could lower patient adherence to treatment protocols in clinical settings.[15]

In recent years, blood flow restriction (BFR) training has gained widespread attention in the field of musculoskeletal rehabilitation, emerging as a form of exercise therapy involving the application of external pressure to the proximal limb using a special occlusion device and is combined with low-load resistance training of 20%–30% 1RM.[16 17] With the help of the occlusion device, similar improvements in muscle strength and muscle circumference can be achieved with low-load resistance training as with high-load resistance training.[18 19] Its mechanism of action involves occluding venous blood flow while partially blocking arterial blood flow to create a state of limb ischaemia, thereby increasing local and systemic metabolic stress, activating the signalling pathways for muscle hypertrophy[20] and enhancing neuromuscular excitability.[21] The low training loads used in BFR training reduce joint loads during training, which is beneficial for increasing patient adherence.[22] Therefore, BFR training is expected to be a more efficient alternative to high-load resistance training in musculoskeletal rehabilitation.

The consensus in 2018 recognised the lack of certainty regarding BFR training as a novel treatment method for PFP and stressed the importance of conducting additional high-quality RCTs (randomised controlled trials) to establish evidence-based recommendations for its usage or avoidance.[8] In the 2019 guidelines, it was proposed that BFR combined with high-repetition knee joint exercises can be used clinically to treat patients with PFP, while highlighting the need to be cautious about potential risks of adverse events.[1] Talbot *et al*[23] argue that the rehabilitative effects of BFR-NMES (neuromuscular electrical stimulation) plus exercise are equivalent to those of traditional NMES plus exercise for patients with PFP. Constantinou *et al*[24] demonstrated that 4 weeks of BFR training targeting hip and knee joint muscle tissues were equally effective as conventional exercise in reducing symptoms in the short term. Giles *et al*[25] compared the rehabilitation efficacy of BFR training and high-load resistance training on PFP patients over an 8-week period and found that BFR training had similar effects as high-load resistance training in improving the Kujala scores and the severity of pain in PFP patients. Constantinou *et al*[24] and Giles *et al*[23] both maintained cuff inflation during inter-set rest periods when using BFR. Although low-load is used in BFR training to reduce joint stress, the continuous BFR caused by the pressure band used throughout the process can lead to significant muscle fatigue and metabolic stress,[26] which can affect the comfort of training. Compared with continuous BFR, which uses BFR throughout the training process, intermittent BFR (iBFR) is a method where BFR is applied during the training phase and the restrictive pressure is released during the resting phase, allowing for periodic occlusion and release of blood flow to the working muscles. iBFR is similar in terms of training effect to continuous BFR. David *et al*[27] confirmed that there was no significant difference between the two forms of BFR training in improving muscle morphological or functional aspects by conducting 21 continuous BFR and iBFR training interventions over 7 weeks on healthy subjects. Additionally, Freitas *et al*[28] found that the subjective discomfort of iBFR training for the lower limb muscles of healthy subjects was less restrictive compared with continuous BFR training. Although these studies indicate that the outcome of continuous BFR versus iBFR could be similar, there were some limitations in their research design (ie, using a fixed restrictive pressure rather than based on the patient's individualised conditions, use of small muscle groups and others) and BFR-related resistance exercises may cause local hypoxia at the proximal portion of the muscles where the cuff is applied, leading to a reducing in arterial inflow, impeding venous return and resulting in venous pooling and discomfort.[29] Thus, it is hypothesised that iBFR might attenuate discomfort and increase exercise tolerability, especially for those with lower pain and discomfort threshold tolerability related to the underlying ischaemia during exercise.[30 31] In this regard, iBFR training could be a potentially effective treatment for improving symptoms and function in PFP patients. However, the effectiveness of iBFR on PFP patients has not yet been confirmed by research. Therefore, we propose to evaluate the effectiveness of rehabilitation by conducting an intervention on PFP patients using a combination of iBFR and low-load resistance training or high-load resistance training, and then evaluating pain, function, muscle strength and thickness, among other indicators.

Hypotheses:

- There will be no difference between iBFR with low-load resistance training and high-load resistance training in pain and functional scores for PFP patients.
- There will be no difference between iBFR with low-load resistance training and high-load resistance training in muscle strength and thickness for PFP patients.

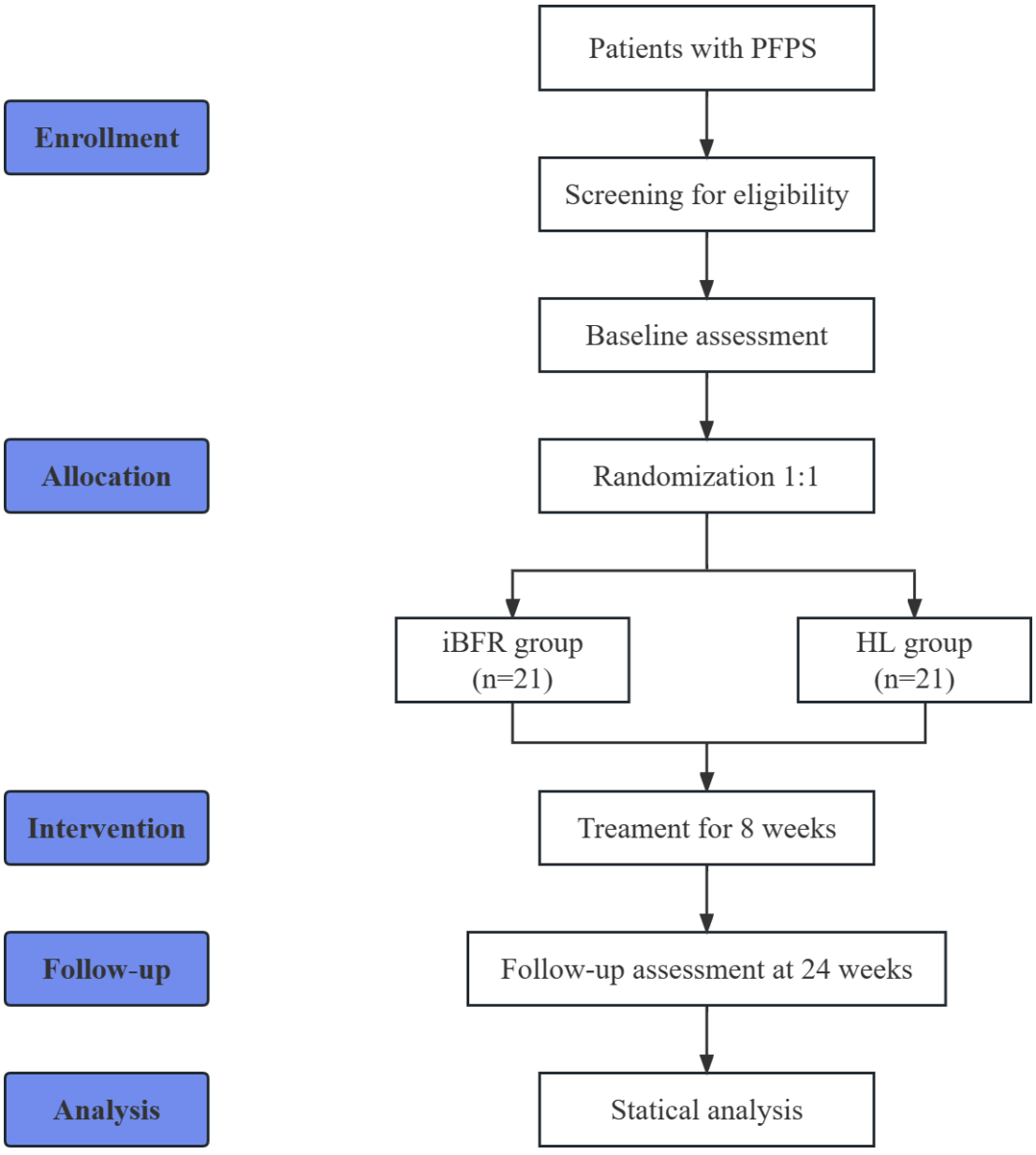

Figure 1 Planned study protocol flowchart. HL, high load; iBFR, intermittent blood flow restriction; PFPS, patellofemoral pain syndrome.

METHODS AND ANALYSIS

Study design

This is a prospective, RCT aiming to compare the rehabilitative effects of iBFR combined with low-load resistance training and high-load resistance training in PFP patients and to assess the effectiveness of iBFR combined with low-load resistance training for improving PFP. Eligible participants will be randomly assigned to either low-load resistance training with iBFR or high-load resistance training, with exercise sessions taking place three times per week over the course of 8 weeks. Clinical outcomes will be measured at the start of the study, after 8 weeks and after 24 weeks (figure 1).

Our study protocol is reported following the Standard Protocol Items: Recommendations for Interventional Trials statement (figure 2).[32] The final outcomes will be presented according to the guidelines set forth in the CONsolidated Standards of Reporting Trials.[33] This study is scheduled to commence in March 2023 and is expected to be completed and reported by 2024.

Participants

Forty-two male and female patients diagnosed with unilateral or bilateral PFP will be recruited from the Sport Rehabilitation Medicine Center and Beijing Sport University Hospital. The department of Sport Rehabilitation Medicine Center is one of the top rehabilitation centre in China, and the clinicians and physiotherapists have rich experience of serving elite athlete and amateur athlete in muscloskeletal disorders.

We will employ a combination of social media, websites and community-based outreach for recruitment purposes.

		Study period				
		Screening	Baseline	Eight weeks	Follow-up	
Time point		Week -2	Week 0	Week 8	Week 9	Week 24
Enrollment	Eligibility screen	×				
	Informed consent	×				
	Allocation		×			
Intervention	iBFR group			◄——►		
	HL group			◄——►		
Assessment	Pain		×		×	×
	Discomfort			×		
	Self-reported function		×		×	×
	Quality of life		×		×	×
	Muscle strength		×		×	
	Muscle thickness		×		×	
	Adverse events			◄——►		

Figure 2 Schedule of enrolment, intervention and assessment (Standard Protocol Items: Recommendations for Interventional Trials figure). HL, low load; iBFR, intermittent blood flow restriction.

All eligible participants will be asked to sign an informed consent form before taking part in the study. Participants will be informed of the study's 6-month duration, and advised of their right to withdraw at any time. No biological specimens will be collected or stored as part of this trial. Should a potential participant express uncertainty about their ability to complete the full 6 months, they will be referred for routine care rather than being included in the study.

Inclusion criteria

Eligible participants must meet the following criteria: (1) aged between 18 and 40; (2) experiencing 4 weeks but no more than 12 months of anterior knee pain, unilaterally or bilaterally (when bilateral, the side with the worse pain intensity, as assessed by Visual Analogue Scale (VAS), will be considered the affected leg); (3) symptoms not resulting from a traumatic injury; (4) pain present in any two of the following: running, jumping, squatting, kneeling, going up or down stairs or prolonged sitting[1]; and (5) displaying clinical examination findings consistent with PFP symptoms, includes the use of patellar tilt and squat as the gold standard tests,[34] along with additional tests such as the apprehension test, patellar compression test, compression test, tenderness on palpation of the posterior surface of the patella or surrounding structures, and resisted knee extension.

Exclusion criteria

The criteria for excluding participants from the study will be outlined as follows: (1) history of patellar dislocation or subluxation, chondral damage or ligament laxity; (2) suspicion of patellar tendinopathy, localised pain on patellar tendon and relieved pain during knee resisted extension; (3) previous knee surgery or arthritis; (4) an invasive procedure, such as arthroscopy or intra-articular injection, in the affected knee within the past 12 months; (5) participation in physical therapy or knee-strengthening exercises in the last 6 months; (6) usage of non-steroidal anti-inflammatory drugs (NSAIDs) within the past 3 months; (7) presence of neurological, cardiovascular or blood-related conditions; (8) abnormally high

blood pressure (resting systolic blood pressure >140 or diastolic blood pressure >90 mm Hg)[35]; (9) existing physical or cognitive conditions; (10) pregnancy.

Patient and public involvement

Due to the rigour of the methodology, it is inappropriate or impractical for patients or the general public to participate in the design, conduct, reporting or dissemination plans of our study.

Criteria and management for withdrawal

The following conditions will allow or request PFP patients to opt out of the study: (1) participants demand to quit; (2) severe adverse event occurs during the study; (3) accidental situations that cause intervention cannot continue, such as injuries; (4) participants consume medication (eg, NSAIDs) or accept other therapy (eg, manual therapy). If a participant withdraws from the trial due to adverse effects, the reason will be investigated and recorded by the researchers.

Randomisation and allocation concealment

The study's research staff will generate a randomisation sequence using SAS software, with the resulting number sequence being placed into sequentially numbered, sealed, opaque envelopes. To preserve the study's blind nature, the researchers involved in measurement, intervention and statistical analysis will not be involved in this process. After eligible PFP patients complete the informed consent and provide baseline information, they will be randomly assigned to the iBFR group or the high-load group in a 1:1 ratio. The order of group assignment will be established by the research coordinator, who will open the envelopes in numerical order and has no involvement in measurement, intervention or data analysis.

Masking

The outcome assessors and statisticians will be masked to ensure unbiased results. The physiotherapists delivering the intervention will be masked to the participants' basic information but not clinical conditions, as they will be responsible for providing personalised guidance and administering the respective exercise programmes to the participants. The participants and therapists are aware of their assigned groups, in order to provide transparency and ensure the completeness of information.

Intervention

All individuals will complete 24 exercise sessions over an 8 week period, with three sessions taking place each week (table 1 and figure 3). In addition to strength training, distal joint, proximal joint and core muscle strength training will also be conducted. This is because current evidence suggests that multi-joint comprehensive strength training may be more effective than unilateral knee joint strength training for PFP patients.[24] To avoid potential injuries during training, we will provide a relatively comprehensive therapeutic exercise programme. Therefore, this study will also incorporate stretching exercises and core training.

They will be able to continue their normal activities without causing an increase in knee symptoms during the 8-week intervention period. Participants are prohibited from seeking any other forms of treatment, including medication. However, considering individuals may have different pain tolerance levels, participants will be asked to report any potential need for pain and/or inflammation reducers during the study period and VAS will be used to assess pain intensity during the exercises, aiming to prevent excessive pain. If the pain intensity registers

Table 1 Treatment protocol performed by the iBFR groups and the HL group

iBFR group	HL group
► Hamstrings stretching, three sets of 30 s	► Hamstrings stretching, three sets of 30 s
► Bridge with isometric contraction of the transversus abdominis-CORE training, three sets of 30 s*	► Bridge with isometric contraction of the transversus abdominis-CORE training, three sets of 30 s*
► Hip abduction with weights (side lying), three sets of 10 repetitions*	► Hip abduction with weights (side lying), three sets of 10 repetitions*
► Calm exercises (side lying) with an elastic band, three sets of 10 repetitions*	► Calm exercises (side lying) with an elastic band, three sets of 10 repetitions*
► Calf raises with weights (standing), three sets of 10 repetitions*	► Calf raises with weights (standing), three sets of 10 repetitions*
► Sensorimotor training (standing) at mini-trampoline, three repetitions of 30 s	► Sensorimotor training (standing) at mini-trampoline, three repetitions of 30 s
► Leg press (machine), 0°–60°, one set of 30 repetitions and three sets of 15 repetitions†	► Leg press (machine), 0°–60°, four sets of 10 repetitions†
► Seated knee extension (machine), 90°–45° of knee flexion, one set of 30 repetitions and three sets of 15 repetitions†	► Seated knee extension (machine), 90°–45° of knee flexion, four sets of 10 repetitions†

*The load will be modified every 2 weeks to keep the perceived exertion between 6 and 7 on the Borg scale.
†The load in the iBFR group is 30% of 1RM and in the HL group is 70%.
HL, high load; iBFR, intermittent blood flow restriction; RM, repetition maximum.

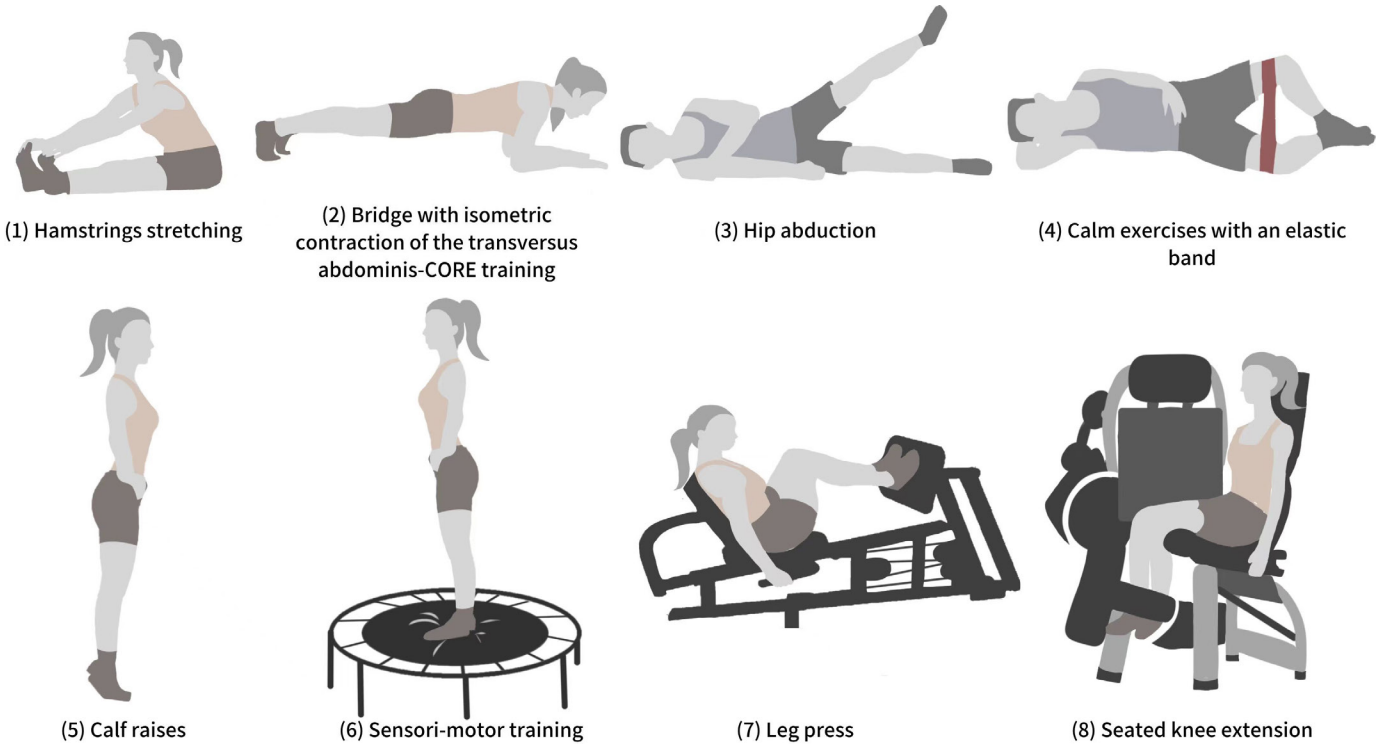

Figure 3 Representation of each exercise movement.

above 2 cm/10 cm on the VAS, the exercise load will be reduced by 20% to ensure participant comfort and safety.[25]

Each group will engage in a 10 min cycling warm-up to reduce the risk of injury before starting formal exercises.[36] In order to minimise the patellofemoral joint stress, the range of motion is limited during the exercises. During each session over the course of 8 weeks, the leg press will be done with knee flexion ranging from 0° to 60°, and the leg extension will involve knee flexion from 90° to 45°.[37] Owing to the loss of flexibility and also a risk of PFP,[38] the stretching will also be performed after thigh muscle strength training.

The exercise load for each exercise during the training will be identified on the percentage of 1RM. The 7–10RM test will serve as an estimate for the 1RM in leg press and knee extension exercises,[39] instead of directly performing a 1RM test that may result in discomfort or injury to the patients. The Bryzcki formula,[40] which is weight/(1.0278–0.0278×reps), will be used to estimate the 1RM. To account for physiological adaptation of resistance training, the exercise load will be re-evaluated and adjusted every 2 weeks.

iBFR exercise

The limb occlusion pressure (LOP) will be measured to determine the pressure of BFR for each individual, and it will be retested every 2 weeks.[41] During the measurement process, participants will recline in a relaxed manner. A portable colour Doppler ultrasound (LOGIQ e, General Electric Company, Boston, USA) will be used to monitor the pedal pulse at the dorsal ankle.[41] The proximal thigh will be secured with a pneumatic cuff, which is 7 cm wide and 56 cm long, and inflated until the pedal pulse vanishes completely. Then the cuff will be slowly deflated, and when the pedal pulse restores, the the pressure will be recorded as the LOP. The iBFR group will perform resistance training at 80% LOP.

The weight will be equivalent to 30% of the estimated 1RM obtained from the 7–10 RM test.[42 43] Participants will complete four sets of repetitions, with the first set consisting of 30 repetitions or until fatigue, followed by three sets of 15 repetitions with a 60 s rest period between sets.[25] The cuff will be inflated immediately to lose after each set and but do not exert pressure for the 60 s rest between sets, and will reinflated quickly to target pressure by hand pumps prior to next set.

High-load resistance exercise

The high-load group will not use BFR. The high-load group's exercise protocol consists of four sets of 10 repetitions with 70% of 1RM and a 60 s break between each set.[25 44]

Outcome measures

Primary outcome measures

Pain

The VAS is considered reliable, valid and responsive for evaluating usual and worst pain. It consists of a 10 cm line, with '0 cm' indicating no pain and '10 cm' representing the most intense pain.[45] It is an easy and effective tool to assess pain and is widely applied in PFP patients. VAS will be used to assess the rest pain and worst pain during the last week from the time of evaluation. The minimal

level of improvement required to be considered clinically significant for regular pain and the most severe pain is 1.5–2 cm and 2 cm, respectively.[46] The VAS will be measured at weeks 0, 8, and 24 after randomisation.

Secondary outcome measures

Self-report function

The knee self-report function will be measured using the Anterior Knee Pain Scale (AKPS) developed by Kujala *et al*.[47] The self-report questionnaire consists of 13 items and assesses an individual's mobility and related symptoms of PFP across six activities. The AKPS score ranges from 0 to 100, with a lower score indicating poorer knee function and more severe symptoms. The AKPS will be measured at weeks 0, 8 and 24 after randomisation.

Quality of life

The 36-item Short Form Health Survey (SF-36) is a widely used self-report questionnaire that measures quality of life across both physical and mental dimensions, consisting of 36 questions.[48] It evaluates eight areas of health, including emotional state, physical state, social life, energy levels, physical pain, overall health, physical functioning and mental health, and is known for its robust psychometric properties. The better health state is reflected by higher scores. The SF-36 in its Chinese version has been established as a credible questionnaire for the general public.[49] The SF-36 will be measured at weeks 0, 8, and 24 after randomisation.

Muscle strength

The strength of the quadriceps muscle will be evaluated using the IsoMed 2000 (made by D&R Ferstl GmbH, Hemau, Germany), an isokinetic testing system. Participants will be secured to a dynamometer chair while sitting at a 90° angle, with the motion of their torso and thighs restricted by rigid belts. The dynamometer's axis will be aligned with the knee joint's rotation centre using a laser device. The maximum range of motion for each participant will be determined by having them actively extend and flex their knees to the fullest extent. Before the formal test, participants will perform three submaximal repetitions for familiarisation. In the formal evaluation, participants will carry out five consecutive flexion and extension movements using a concentric-eccentric contraction model, without gravity compensation, at three angular speeds of 60°/s, 90°/s and 120°/s.[50] The isokinetic strength tests will be performed in order of increasing speed, from fast to slow. There will be a 4 min rest period between each test at two different speeds.[51] Participants will be urged to exert themselves to the fullest during the test,[52] and the results, recorded in Newton-metres, Newton-metres/kg and watts, will be calculated as the peak torque, peak torque per kilogram of body weight and power. Research has shown that the reliability of knee muscle strength assessment using the isokinetic method is 0.94 in test–retest scenarios.[53] Muscle strength will be measured at weeks 0 and 8.

Muscle thickness

The thickness of the quadriceps muscle will be determined with the use of a handheld colour Doppler ultrasound device (LOGIQ e).[54] The ultrasound probe will be positioned at the mid-section of the vastus medialis, vastus lateralis and rectus femoris, taking care not to press down on the skin. The images will be saved and then muscles will be measured by an independent assessor. The measurement of the distance from the adipose tissue-muscle boundary to the muscle-bone boundary will be taken three times for each muscle and then averaged to determine the muscle thickness. The thickness of the quadriceps will be represented by the total of the three muscle thicknesses.[55] Previous research has established a correlation of 0.86, 0.94 and 0.86 between the results obtained through the use of ultrasound and MRI scans in measuring the muscle thickness of the vastus medialis, vastus lateralis and rectus femoris, respectively.[55] Muscle thickness will be measured at weeks 0 and 8.

Adverse events

All adverse events that occur during the entirety of the trial will be recorded by participants, assessor and physiotherapist. Adverse events will be evaluated by physiotherapists and specialists knowledgeable in the treatment, who will determine if they are related to the treatment or not. The severity of any adverse events will be closely monitored within 24 hours. Participants will be informed of the possibility of adverse events before they give consent, and they will be instructed to notify a researcher if they experience any. Adverse events that may result from BFR or resistance training include knee pain, muscle soreness, subcutaneous bleeding and numbness. By the end of trial, all adverse events will be reported and described whether they are related to the study or not. Should any adverse events occur during the study, the researcher will promptly take the necessary actions based on the patient's circumstances.

Sample size estimation

The estimation of sample size was carried out using the G-Power software (V.3.1.9.6) developed by Heinrich-Heine-Universität Düsseldorf in Düsseldorf, Germany. The predetermined difference of two groups is 20 mm of 100 mm VAS in pain intensity (primary outcomes), which is above the minimal clinically important difference in PFP patients.[56] The sample size calculation used an SD of 20 mm and set a type I error at 5% (α=0.05) with a power of 80% (β=0.8). Thus, a minimum of 17 participants per group is required for the study. To account for a potential 15% dropout rate, the final sample size will be set to 21 patients per group.

Statistical analyses

The statistical analyses will be conducted by statisticians who blinded the process of assignment and interventions. The results will be presented as either the mean and SD or the median, depending on whether the data follows

a normal or non-normal distribution. Group differences will be evaluated using independent samples t-tests or appropriate non-parametric tests, such as the Mann-Whitney U test, if the data is non-normally distributed. For outcomes with repeated measurement, they will be compared using iBFR group and high-load group at all following timepoint by using a linear mixed model with repeated measurement. The statistical evaluations will be conducted using SPSS V.22.0 (SPSS Inc., Chicago, USA).

The intention-to-treat (ITT) principle will be adopted to maintain the randomisation of groups. All subjects who are randomised will be included in the analysis, regardless of whether they initiate or complete the treatment, to ensure that participants are analysed according to their assigned treatment group, preserving the integrity of the randomised design. To handle missing data, we will use the multiple imputation technique with chained equations and predictive mean matching, applying the method individually for each group. The estimates from 10 imputed data sets will then be combined through Rubin's rules.[57] A significance level of $p<0.05$ will be applied to all data.

Ethics and dissemination

The principles of the Helsinki Declaration were followed in this study. The research protocol was reviewed and approved by the Sports Science Experiment Ethics Committee of Beijing Sport University (Ethics Approval 2022274H). Written information was provided to participants regarding the study conditions, data security, voluntary participation and the right to withdraw at any time. Written consent was obtained from all participants prior to entering the study to confirm understanding. Data collection was pseudonymous and only accessible by authorised research personnel with confidentiality obligations. Personalised information was deleted after data collection, and all data was fully anonymised. The results will be published in a peer-reviewed journal.

DISCUSSION

This study will evaluate the effectiveness of iBFR combined with low-load resistance training compared with high-load resistance training with a placebo on variables such as pain, self-reported functional outcomes, quality of life, muscle strength and muscle thickness.

Despite previous studies showing that combining BFR with low-load resistance training and high-load resistance training have similar effects,[25] the usage of BFR still requires further optimisation. In previous studies, compliance with continuous compression was low, and switching to intermittent compression may be a good option. Furthermore, previous study results showed a significant increase in muscle thickness in the high-load group but not in the iBFR group,[25] which may be related to the lack of significant clinical effect with 60% LOP. Intermittent compression is typically set to a higher pressure than continuous compression, so this study uses 80% LOP. Our study aims to optimise the BFR treatment plan for PFP patients by providing evidence for its efficacy.

The methodology of this trial adheres to the requirements of randomised, concealed allocation and ITT methods and also meets the masking requirements for the patients. Participants in the iBFR group will engage in three exercise sessions per week for a duration of 8 weeks, totalling 24 sessions. We aim to examine the immediate impact on all clinical outcomes after 8 weeks, as well as the mid-term effect on pain and self-reported function after 24 weeks for both groups.

The percentage of LOP will be reassessed every 2 weeks to prevent any alterations in the participant's haemodynamics. To account for the possibility of a placebo effect in the high-load group, the BFR cuff will be worn during exercise sessions but not inflated. The intensity of pain during training will be evaluated to monitor training side effects.

Despite its benefits, the current study has some limitations. First, the blinding may not be absolute due to the nature of the intervention. Second, like other studies, the LOP assessment is performed in a static position and may change with changes in posture or muscle contraction. Additionally, the protocol includes multiple exercises, such as core strengthening, and stretching, but these may impact some outcomes such as muscle strength. Finally, comparing 75 repetitions of low load with 40 repetitions of high load, even when assessing the overall rehabilitative effects of the two types of training, the difference in the number of repetitions between the two groups could potentially influence the results. Ultimately, this study aims to offer more dependable evidence for the efficacy of iBFR and inform the development of optimal BFR treatment plans for PFP patients.

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Contributors WK, HW and GN designed the study. WK, HW and LC participated in the trial register, communication and monitoring. WK drafted the manuscript. GN contributed to the interpretation of the results and critical revision of the manuscript for important intellectual content and approved the final version of the manuscript. All authors have read and approved the final manuscript.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

ORCID iDs
Weiya Kong http://orcid.org/0000-0002-8611-5671
Guoxin Ni http://orcid.org/0000-0001-9181-8155

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