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RESEARCH

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The effectiveness of individualized blood flow restriction training following patellar fracture surgery: a case series

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Abstract

Background Patellar fracture surgeries are associated with subsequent atrophy and weakness in the muscles of the lower limb. Individualized blood flow restriction training is progressively being recognized as a potential technique for improving muscular hypertrophy and accompanying strength in participants recovering from surgery. This study aimed to investigate the overall feasibility and observational outcomes of individualized blood flow restriction training for participants recovering from patellar fracture surgery.

Methods A 47-year-old male (Participant one, body mass: 65 kg, height: 1.75 m, body mass index: 21.2 kg/m^2, three months post-patellar fracture surgery) and a 28-year-old female (Participant two, body mass: 53 kg, height: 1.67 m, body mass index: 19.8 kg/m^2, three months post-patellar fracture surgery) performed straight leg raises and leg extensions with individualized blood flow restriction for six weeks. The blood supply to the leg with the patellar fracture was partially restricted using a thigh pressure cuff inflated to 60% of the limb occlusion pressure. Peak torque of knee extensor, rectus femoris cross-sectional area, rectus femoris stiffness, and Lysholm score were measured at baseline and post-training.

Results Compared to baseline, the post-training peak torque of the knee extensor, rectus femoris cross-sectional area, rectus femoris stiffness, and Lysholm score of participants one post-surgical leg increased by 48.2%, 7.9%, 7.9%, and 23 points, respectively; those of participant two increased by 134.7%, 6.8%, 14.2%, and 30 points, respectively.

Conclusions The results showed that the individualized blood flow restriction training was feasible and suggested promising outcomes for participants after surgery. Further research with a large sample size is required to flesh out and generalize the training program.

Trial registration The Nanjing First Hospital's ethics committee accepted the research before testing. The clinical test was documented with clinicaltrials.gov (NCT05371431, Registered 08–20-2020, prospectively registered).

Keywords Blood flow restriction, Patellar fracture surgery, Post-surgical rehabilitation, Muscle strength, Musculoskeletal rehabilitation

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Introduction

Patellar fracture (PF) is a common orthopedic injury that can significantly impact patients' mobility and quality of life. Among the subtypes of PFs classified by the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) system, the most frequently encountered fracture clinically is AO/OTA 34 C. AO/OTA 34 C1 fractures typically involve a simple transverse and minimally comminuted pattern with relatively less displacement. They may be considered less severe compared to other types of PFs. AO/OTA 34 C2 fractures are characterized by more complex fracture patterns with increased displacement and comminution and often involve fragmentation of the patella. AO/OTA 34 C1 and C2 PF lies in their distinct characteristics and severity [1]. After surgery, immobilization prevents re-displacement of the fracture, but it may also lead to muscle atrophy in the lower limb [2]. Participants exhibit considerable loss of lower limb strength, mostly owing to quadriceps femoris atrophy [3]. One study has provided detailed insights into mid-term outcomes (mean follow-up of 6.5 years) following operative treatment for PF, uncovering notable and persistent functional deficits. Key findings included a mean isometric extension strength deficit of 26% in the quadriceps compared to the unaffected side. Furthermore, isokinetic extension power was reduced by 31% and 29% at angular velocities of 90°/sec and 180°/sec, respectively [4]. Lower limb paralysis may remain for years following PF surgery, increasing the risk of re-injury and joint deterioration [5]. As a result, immediate rehabilitation is essential for maintaining and improving quadriceps strength.

High-intensity resistance training has been recommended as the gold standard for maximizing morphological and functional skeletal muscle adaptations [6]. However, the training loads (60–80% of 1-repetition maximum (1-RM)) [6] necessary to elicit muscle and strength changes are not always possible because they may induce excessive discomfort and/or joint aggravation. Several musculoskeletal disorders adopt blood flow restriction (BFR) training as a rehabilitative approach. These disorders include surgical procedures involving knee arthroscopy and arthroplasty, as well as achilleas tendon ruptures [7]. BFR training commonly involves total blockage of the venous supply and subtotal occlusion of the arterial blood supply. The restricted blood flow allows for strength training under low-intensity methods that improve muscle size and strength, which may result in comparable or faster effects compared to high-intensity strength training [7]. The idea of employing individualized BFR training following PF surgery is appealing; yet there is no research on individualized BFR training in PF participants.

Peak torque of the knee extensor has been reported as an important predictor of lower limb muscle strength [8]. Some studies have shown the ultrasonographic assessment of lower limb muscle cross-sectional area (CSA) was commonly utilized [9]. CSA of the lower limb muscle was positively correlated with the muscle strength of the lower limbs, which affects the patient's ability to complete daily living activities [10]. As a result, the peak torque of the knee extensor and muscle CSA were evaluated as objective variables. Stiffness is defined as the ratio between an imposed force and the elastic distortion of a biological arrangement. The larger the deformation, the less stiffness, such as the increased number of compliant components, and the structure under consideration. Muscle stiffness assessment has been utilized to determine the factors that impact power and the danger of injury (e.g. strains, sprains, tears of muscles, ligaments, tendons, as well as joint instability or fractures) [11]. Muscle stiffness plays a key role in maintaining dynamic joint stability, and it is linked with lower limb strength and function [12]. Lower muscle stiffness may impair dynamic joint stability and reduce the ability to generate force efficiently, thereby increasing the risk of instability-related injuries. Excessive muscle stiffness can reduce the range of motion, increase joint loading, and elevate the risk of strains or tears during high-intensity or sudden movements [13]. However, changes in muscle stiffness after individualized BFR training for participants with PF have not been determined. Currently, the Lysholm score is commonly used to assess lower limb pain and function [14]. This is due to the high sensitivity, validity, and reliability of the Lysholm score as an assessment tool for lower extremity injuries [14].

In addition, each participant of PF and subsequent recovery is unique due to factors such as injury severity, surgical approach, pre existing conditions, and individual response to treatment. By determining a small number of cases, we can provide valuable insights into the feasibility and external validity of innovative interventions like individualized BFR training, lighting the way for further research and the development of evidence-based rehabilitation protocols. To our knowledge, this study represents the pioneering endeavor in applying BFR training specifically for the rehabilitation of participants with PF.

This study aimed to investigate the overall feasibility and observational outcomes of individualized BFR training for participants recovering from patellar fracture surgery. We hypothesized that individualized BFR training would produce improvements in peak torque of knee extensor, rectus femoris (RF) CSA, RF stiffness, and Lysholm score for participants who had undergone surgery treatment of PF (AO/OTA 34 C).

Methods

Study design

A case series.

Study setting

The participants will be recruited, assessed, and subjected to intervention at Nanjing First Hospital, China.

Eligibility criteria

Inclusion criteria

1. Age: Adults aged 18–65 years; 2. Surgery: Participants who have had patellar fracture surgery within the last 6 months; 3. Health Status: Medically stable individuals with physician clearance for physical rehabilitation; 4. Consent: Ability and willingness to provide informed consent and comply with the study protocol; 5. Mobility: Participants who have regained partial weight-bearing status post-surgery; 6. Cognitive Function: Sufficient cognitive function to understand and follow rehabilitation instructions [7].

Exclusion criteria

Comorbid Conditions: Significant comorbidities like cardiovascular disease, uncontrolled hypertension, severe diabetes, or other conditions contraindicating blood flow restriction training; 2. Previous Injury: History of significant lower limb injuries or surgeries affecting rehabilitation outcomes; 3. Contraindications: Known contraindications to BFR, including deep vein thrombosis (DVT), severe varicose veins, peripheral vascular disease, or clotting disorders; 4. Other: Pregnant women, due to potential risks with blood flow restriction training. History of non-compliance with medical or rehabilitation advice. Use of anticoagulant medication or any that affects blood clotting. Known allergy or sensitivity to materials used in blood flow restriction cuffs [15]. Participants were recruited consecutively from a clinical population meeting the inclusion criteria.

Participant

1st participant

The first participant is a 47-year-old male (body mass: 65 kg, height: 1.75 m, body mass index (BMI): 21.2 kg/m^2, three months post-PF surgery) who suffered from a closed, displaced PF (AO/ATO 34 C1) in his right knee diagnosed by X-ray and MRI. He had not undergone any rehabilitation training before our intervention and had not received any other surgical treatments. His father has hypertension, but no one in his family has undergone similar surgical procedures or has diseases such as osteoporosis. Three months after surgery, he exhibited noticeable quadriceps weakness, confirmed by isokinetic testing, which caused gait issues and an inability to run. He reported slight knee pain, severe locking, and weakness in his right leg. His long-term rehabilitation goal is to return to running, cycling, and other regular physical activities.

2nd participant

The second participant is a 28-year-old female (body mass: 53 kg, height: 1.67 m, BMI: 19.8 kg/m^2, three months post-PF surgery) who suffered from a closed, displaced PF (AO/ATO 34 C2) in her right knee diagnosed by X-ray and MRI. She has no history of previous surgeries, chronic conditions, or known allergies. There are no family members with conditions such as osteoporosis, nor has anyone in the family undergone similar surgical procedures. At the time of the initial interview, the participant had not received any rehabilitation training and was walking independently without assistive devices. She experienced difficulties due to an antalgic gait when descending stairs and was unable to participate in regular physical activities. She reported mild knee joint pain, slight edema, and weakness in her right leg. Her long-term rehabilitation goal is to return to walking, house cleaning, and work.

Operative technique

The participants were positioned supine during the operation. A prophylactic antibiotic (2 g cefazolin) was prepared and administered intravenously before placing a thigh tourniquet. A longitudinal surgical incision was implemented from the proximal to the distal border of the patella. The patellar fracture area was evaluated along with the condition of the joint capsule and the respective aponeuroses. The articular cavity was thoroughly irrigated after the removal of identified intra-articular hematomas. Fracture reduction was accomplished with a large towel clamp and confirmed via fluoroscopy. After achieving adequate articular alignment, the knee was flexed to 40°, and two parallel Kirschner wires (2.0-mm) were inserted into the fracture fragments. The introduction was systematic from the proximal to the distal end under fluoroscopic guidance. The Kirschner wires were secured with a titanium cable (1.3 mm in diameter) beneath the quadriceps and patellar tendons, forming a figure-eight structure. The tension band was constructed by tightening the titanium cable and securing it with appropriate crimps before trimming the extra wire.

Procedure

Figure 1 depicts the experimental design and procedures used in this investigation. The Nanjing First Hospital's ethics committee approved the research prior the testing (KY20200820-01). The clinical trial was registered with clinicaltrials.gov (NCT05371431, Registered

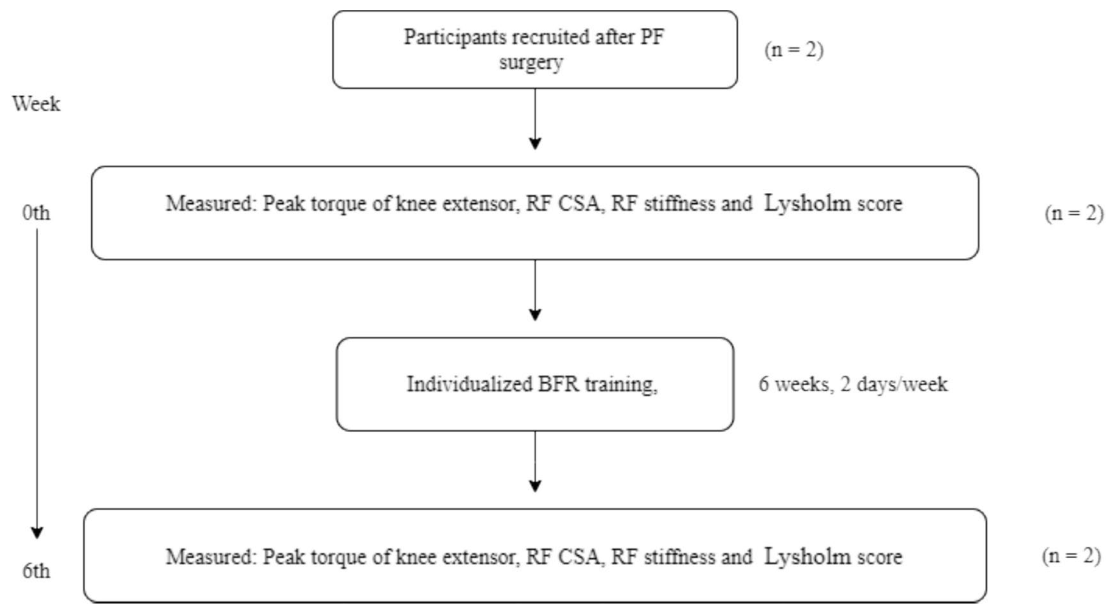

Fig. 1 Experimental design, and study procedure. Abbreviations: PF, patellar fracture; RF, rectus femoris; CSA, cross-sectional area; BFR, blood flow restriction

08–20–2020, prospectively registered). This study was conducted in accordance with the Declaration of Helsinki. Individualized BFR training was designed according to post-fracture rehabilitation recommendations, and included straight leg raises and knee extensions (Table 1). Straight leg raises are a foundational exercise that isolates the quadriceps muscle while minimizing stress on the knee joint. This is particularly important in the early stages of rehabilitation when the joint may still be healing, and excessive load or range of motion could compromise recovery. This exercise helps to maintain or rebuild quadriceps strength without placing undue strain on the healing patella or surrounding structures [16]. Knee extensions directly target the quadriceps, a muscle group crucial for knee stability, function, and mobility. After a patellar fracture, quadriceps atrophy and weakness are common due to immobilization or reduced activity. Knee extensions enable progressive strengthening of the quadriceps in a controlled manner, helping to restore the knee's ability to bear weight, extend fully, and perform functional movements [17]. The participants trained twice weekly for six weeks, with at least 48 h of recovery allowed between sessions. Individualized BFR training, twice weekly for a month and a half, has been shown to produce gains in muscular hypertrophy and strength. Every training session was overseen by the same trained member of the study team. Both groups of participants underwent a 5-min load-free warm-up followed by a 5-min rest. Participants had an initial load of 35% 1-RM for 12 repetitions, which corresponded to a Rating of Perceived Exertion level of 11 on the Borg 6–20 scale. The training load was raised by 10% if all repetitions were completed in two consecutive sessions [18]. Before beginning the research, participants provided written informed consent and agreed to the publication of all photographs, clinical data, and other data contained in the study. Participants were instructed not to engage in any other rehabilitation programs during the training. They were advised to maintain the regular nightly sleep (7–8 h) and abstain from caffeine for 8 h and from nutritional intake (excluding water) for 2 h before attending the laboratory. Both individuals completed the training outlined in Table 1. No adverse events were recorded.

Table 1 Individualized BFR training program for participants enrolled in this study

Exercises	Initial load	Frequency	Volume	Intra-set rest (s)	Duration
Single-leg knee extension	35% 1-RM	2 days/week	4 sets of 30/15/15/15 repetitions	45	6 weeks
Straight-leg-raising movement	35% 1-RM	2 days/week	4 sets of 30/15/15/15 repetitions	45	6 weeks

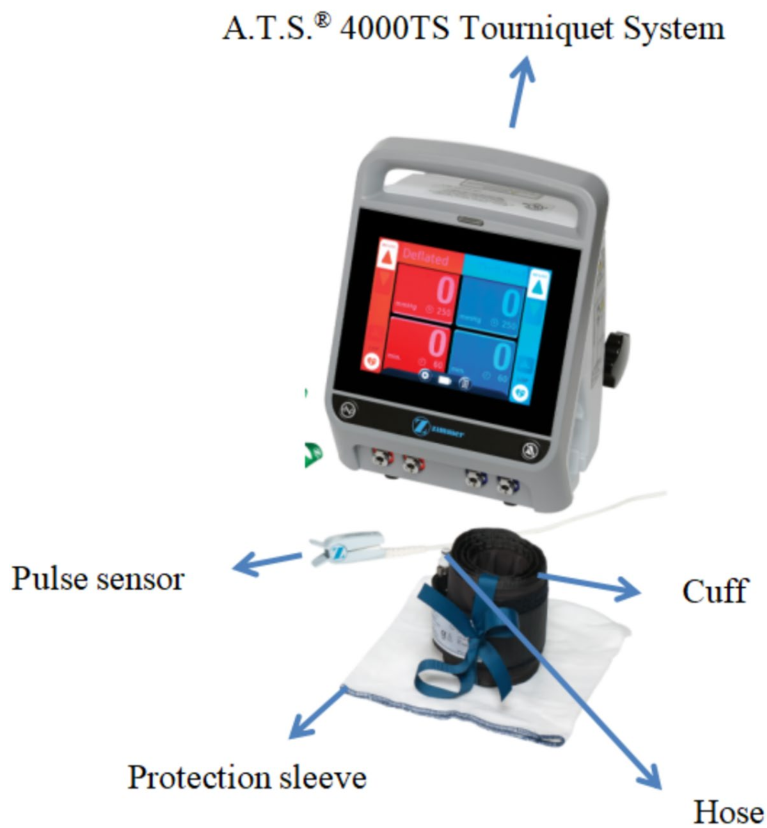

Fig. 2 Tourniquet system

Blood flow restriction procedure

The participants underwent rehabilitation training using a medical-grade tourniquet system (A.T.S.® 4000TS Tourniquet System, Zimmer Surgical, Inc., Dover, OH USA) (Fig. 2). The tourniquet system consists of an A.T.S.® 4000TS with a pulse sensor and a tourniquet cuff with a protective sleeve.

The A.T.S.® 4000TS Tourniquet System individualizes the tourniquet pressure to every participant after establishing the affected lower limb occlusion pressure (LOP). Patterson et al. (2019) showed that 60% LOP is safe and effective in the rehabilitation of fracture participants. Lower limb occlusion pressures were re-evaluated before each training session using the tourniquet system. Participants performed each exercise (including intra-set rest periods) at 60% LOP (Participant 1's LOP: 102 ± 6 mmHg; Participant 2's LOP: 90 ± 5 mmHg) with the tourniquets released during the 2 min inter-set rest periods (between sets). A study suggested that a wide pressure cuff width (11.5 cm) results in lowered pain and increased safety for participants with an integral impact in promoting muscle strength. It was also suggested that 4 sets of 75 repetitions per set (30, 15, 15, and 15 repetitions) and a break of 45 s were sufficient for skeletal muscle hypertrophy [15].

Measurement

Peak torque of knee extensor measurement on the affected lower limb

Following a moderated warm-up on a bicycle ergometer (ten minutes at 1.5 Watts per kilogram of body weight, 60–70 RPM), the maximal strength of the knee extensor was evaluated using the leg-extension module of the IsoMed 2000 (D&R Ferstl, Hemau, Germany). Participants familiarized themselves by performing a leg extension warm-up consisting of 5 repetitions at increasing but submaximal intensity in concentric mode. After a 1-min rest, peak torque was measured from 5 repetitions at an angular velocity of 60°/s and another 5 repetitions at 180°/s, ranging from 10° to 90° of knee flexion for each leg separately. Participants sat upright with their hips flexed at 90°, arms folded over the chest and were secured with shoulder pads and a belt across the hips and thighs. The axis of rotation was aligned with the middle of the lateral femoral condyle, and the force application pad was positioned mid-tibia to ensure proper leg extension testing for PF participants [19].

Rectus femoris cross-sectional area measurement on the affected lower limb

RF CSA measurements were performed using a "brightness mode" (B-mode) US imaging device (GE LOGIQ e, USA) and a "multifrequency linear-array probe" (L-RS, 5–13 MHz, 40.0 mm field of view). The measurements were performed in the supine position for the RF. The affected lower limb was allowed to remain relaxed for a minimum period of 10 min to stabilize physiological body fluids [20]. A multifrequency linear-array probe was used to image the muscle. To promote the reliability of measurements among the members, signs were set on the skin in the main site on the leg: RF (50% on the line from the anterior spine iliaca superior to the superior part of the patella) [21]. The same investigator performed both participants' measurements and analyzed images. A minimum of five ultrasound scans were obtained and the mean (SD) values were analyzed.

Rectus femoris stiffness measurement in the affected lower limb

Ditroilo et al. indicated that the RF stiffness was determined with MyotonPRO modern equipment (Myoton AS, Tallinn, Estonia). The MyotonPRO has demonstrated great reliability and validity in assessing stiffness properties during field testing [22]. Participants were asked to stand barefoot and expose the legs in an anatomical posture. To ensure that measures were consistent among participants, markings were put on the skin at 50% on the line from the anterior spine iliaca superior to the superior section of the patella [23]. The myometer probe was released at an angle of 90° onto the muscle belly, and the muscle received an automated mechanical force (time taken was 15 or 12 ms, the force of 0.3–0.4 N). The resulting damped natural oscillations were measured with a built-in accelerometer sampling at 3200 Hz [11]. Five successive readings were obtained for averaging – the average was utilized for further investigation.

Lysholm score

The Lysholm score was utilized in evaluating lower limb function. The Lysholm score is a sensitive, accurate, and reliable evaluation tool for participants with lower extremity injuries [14]. The Lysholm score involves participants' subjective items for the assessment of everyday activity limits following surgery. It has been tested for a wide range of knee diseases, including "ligament injuries, chondral disorders, meniscal injuries, and patellar dislocation". A total Lysholm score of 0 to 100 is generated by eight components: "limping, locking, pain, stair climbing, support, instability, swelling, and squatting". The outcome scores are condition-specific and significantly subjective used by physicians to assess the progress in the injured knees or knees after surgeries. Excellent scores range between 95 to 100, good scores 84 to 94, fair scores range between 65 to 83, and scores less than 65 are poor [24]. The Minimal Clinically Important Difference (MCID) for the Lysholm Scoring in patients recovering from PF surgery is commonly set at 10 points. This value represents the smallest measurable improvement in the Lysholm score that patients typically perceive as a meaningful enhancement in knee function and overall recovery [25].

Data analysis

All the data were computed for each outcome as (Post − Pre) / Pre × 100%. We evaluated percentage changes.

Results

Peak torque of knee extensor

Participant 1's peak torque of the knee extensor increased from 27.6 N.m/kg to 40.9 N.m/kg, with an increment of 48.2%, after the 6-week individualized BFR training intervention. Participant 2's peak torque of knee extensor increased from 36 N.m/kg to 84.5 N.m/kg, with an increment of 134.7%, after the 6-week individualized BFR training intervention (Fig. 3a).

Rectus femoris cross-sectional area

Participant 1's RF CSA increased from 7.09 cm^2 to 7.65 cm^2, with an increment of 7.9%, after the 6-week individualized BFR training intervention. Participant 2's RF CSA increased from 5.66 cm^2 to 6.04 cm^2, with an increment of 6.8%, after the 6-week individualized BFR training intervention (Fig. 3b).

Rectus femoris stiffness

Participant 1's RF stiffness increased from 226 N/m to 244 N/m, with an increment of 7.9%, after the 6-week individualized BFR training intervention. Participant 2's RF stiffness increased from 255 N/m to 297 N/m, with an increment of 14.2%, after the 6-week of individualized BFR training intervention (Fig. 3c).

Lysholm score

Participant 1's Lysholm score increased from 63 to 86 points after the six-week of individualized BFR training intervention, reflecting an improvement of 23 points, which exceeds the MCID threshold of 10 points. This change signifies clinically meaningful progress and a shift in classification from "poor" to "good" functional status. Participant 2's Lysholm score increased from 43 to 73 points after the six-week individualized BFR training intervention, reflecting an improvement of 30 points, which also surpasses the MCID threshold of 10 points.

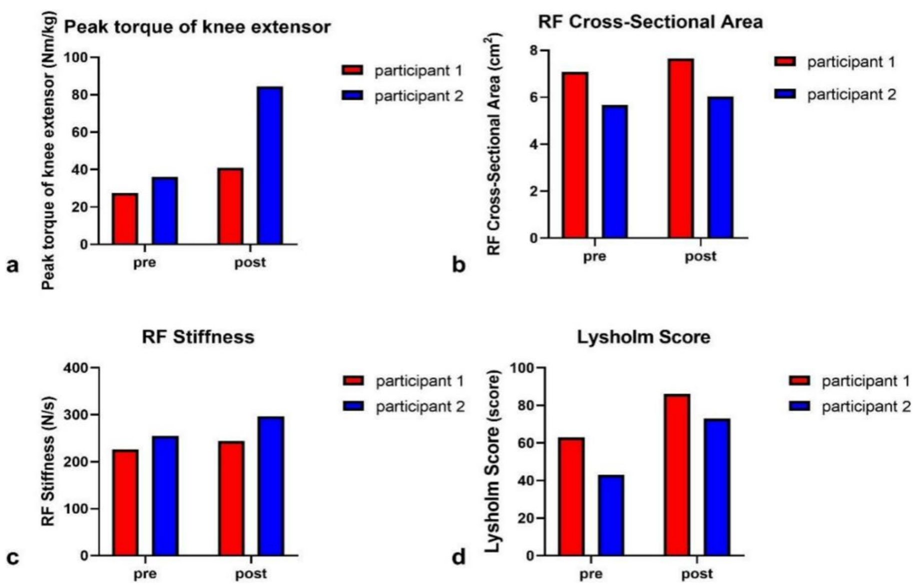

Fig. 3 Results of peak torque of knee extensor, RF cross-sectional area, RF stiffness, and Lysholm score. Abbreviation: RF, rectus femoris

Table 2 Pre- and post-intervention test data

	Gender	Test time	Age (year)	Height (cm)	Weight (kg)	Lysholm Score	Averages of peak torque of knee extensor (N.m/kg)	Averages of rectus femoris cross-sectional area (cm$^{2)}$	Averages of rectus femoris stiffness (N/m)
Participant 1	Female	Before-intervention	52	153	51.7	43	36	5.66	255
		Post-intervention	52	153	52	73	84.5	6.04	297
Percentage Change (%)							134.72	6.71	16.47
Participant 1	Male	Before-intervention	47	170	70	63	27.6	7.09	226
		Post-intervention	47	170	71.5	86	40.9	7.65	244
Percentage Change (%)							48.19	7.90	7.96

This change is clinically meaningful and represents a shift from "poor" to "fair" functional status (Fig. 3d, Table 2).

Discussions

In this study, we found that individualized BFR training of the PF participants resulted in large increases in peak torque of the knee extensor, RF CSA, RF stiffness, and Lysholm score.

Peak torque of the knee extensor

In this study, we observed that six weeks of BFR training was associated with an increase in the peak torque of the knee extensor, which is comparable to result obtained in a previous study on load-compromised populations [26]. First, BFR results in metabolic accumulation, including indicators such as lactate in whole blood and muscle cells. The build-up of these metabolic products creates an acidic environment within the muscle cells that increases sympathetic nerve activity, which can induce greater muscle fiber recruitment [27]. Schoenfeld (2013) used electromyography to demonstrate that during BFR training, rapid twitch fiber recruitment increased. Second, a hypoxic environment is the applied pressure cuff promotes a hypoxic environment for the muscle fibers [28]. Such hypoxic conditions result in elevated levels of angiogenic factors such as nitric oxide synthase, vascular endothelial growth factor, and hypoxia-inducible factor-1 [29]. Anabolic effects of muscle growth rely on these angiogenic features. Therefore, individualized BFR training associated with a large increase in the peak torque of the knee extensor in the PF participants.

Rectus femoris cross-sectional area

We observed a large increase in the RF CSA of the post-surgery PF participants following individualized BFR training. This is consistent with research showing that BFR training improves muscle CSA after five weeks [30]. The intramuscular buildup of metabolites has been demonstrated to activate the sympathetic nervous system and the hypothalamus-pituitary system via muscle metaboreceptors, resulting in elevated growth hormone (GH) levels and adrenaline concentrations in the plasma [31]. High-intensity resistance training (~70% of 1 RM) increased plasma GH concentration by 100-fold, whereas low-intensity BFR exercise (30% of 1 RM) increased it by 290-fold [32]. The production of GH promotes muscle cell proliferation, thereby improving RF CSA. Stimulating adrenergic receptors in rat muscles, in particular, promotes selective hypertrophy of rapid type II fibers by presumably reducing protein catabolism [33]. Fry et al. (2010) found that BFR training increased protein synthesis via phosphorylation of mTOR and its downstream effector, p70 ribosomal S6 kinase (S6K1) [34]. S6K1 has consistently been proven to influence mRNA translation initiation and play a role in training-induced hypertrophy [35]. Therefore, individualized BFR training led to a large increase in the RF CSA of the PF participants.

Rectus femoris stiffness

We observed a significant increase in RF stiffness in the PF participants following individualized BFR training. The increase in muscular stiffness following BFR exercise might be attributed to enhanced muscle power. It is widely documented that the mechanical characteristics of the muscle influence their force production via the force–length-velocity relationship [36]. Gubler-Hanna et al. recently reported that Myoton assessments of muscle stiffness were significant associations with surface electromyographic readings following muscular stimulation and the resulting joint force during voluntary isometric knee extensions in young male volunteers [37]. Kovanen et al. demonstrated that skeletal muscle stiffness is substantially influenced by the quantity and structure of collagen [38]. Collagen, the predominant connective tissue protein in muscle, is primarily responsible for mechanical strength [39]. Rossi et al. (2017) found that adding BFR to training boosted the production of basic fibroblast growth factor, which is critical for fibroblast growth and results in elevated collagen synthesis rates [40]. Consequently, RF stiffness increased following the individualized BFR training. However, the underlying mechanism of this effect is not yet fully understood and will require additional investigation in the future.

Lysholm score

We observed a significant rise in the Lysholm scores of PF participants following individualized BFR training. The Lysholm score is a collection of questions assessing a participant's "limp, locking, pain, stair climbing, support, instability, swelling, and squatting" [24]. Cancio et al. (2019) found that low-intensity BFR training substantially decreased pain in individuals with distal radius fractures compared to resistance training of similar intensity [41]. Ischemia and pressure-induced muscular soreness are frequently utilized as conditioned stimuli for pain modulation. These stimuli influence and define the sensitivity to pain in healthy individuals [42]. Training-induced hypoalgesia (TIH) is defined as an immediate decrease in pain sensitivity following training [43]. Training intensity has been identified as an essential driver of the magnitude of TIH [44]. Hughes and Patterson (2020) found that low-intensity BFR resistance training resulted in greater TIH than low-intensity resistance training alone [45]. This demonstrated an important factor in the participants' ability to progress in the predetermined metrics assessed during training. This improvement is attributed to the perceived comfort and security of the low load during movements and the muscle strengthening promoted by occlusion. The reduction in discomfort and improvement in muscular strength aided participants in activities of daily living (such as squatting and climbing stairs), leading to higher Lysholm score [46]. Therefore, the individualized BFR training had a comprehensively impact on the factors contributing to the Lysholm score calculation, resulting in its improvement of the Lysholm score.

Limitations

This study has several limitations. First, the small sample size restricts the generalizability of the findings, emphasizing the need for future research to validate these results with a larger and more diverse population. Second, the heterogeneity between the two participants—including differences in age, gender, category of patellar fracture, baseline fitness and activity levels, and rehabilitation goals—further limits the applicability of these findings to a broader demographic. Moreover, the absence of a control group precludes any causal inferences about the intervention's effectiveness. Future studies should address this limitation by employing a randomized controlled trial design. These limitations highlight the need for further research to confirm, refine, and expand upon the findings presented in this case study.

Conclusions

In this study, we observed that six weeks of individualized BFR training was associated with improvements in the peak torque of the knee extensors, RF CSA, RF stiffness, and Lysholm scores in participants three months post- PF surgery. These improvements suggest that participants may regain functional capacity for activities such as working, cycling, and other regular physical activities. However, given the study's limitations, causal relationships cannot be established, and future research is needed to confirm these findings in larger and more diverse populations.

This study highlights the potential feasibility of individualized BFR training for post-surgical PF participants, making it a promising area for further investigation. Future studies should include randomized controlled trials to evaluation the effectiveness of BFR training in this population. Additionally, the safety and tolerability of BFR training should be thoroughly examined, particularly considering potential adverse effects such as pain, discomfort, and safety concerns in a rehabilitation setting. Understanding the risk–benefit profile of BFR training is crucial to ensure its safe application in post-surgical populations. To the best of our knowledge, this is the first report describing the use of individualized BFR training for PF participants, providing a foundation for future research in this area.

Trial registration

The Nanjing First Hospital's ethics committee accepted the research before the testing. The clinical test was documented with clinicaltrials.gov (NCT05371431, Registered 08–20–2020, prospectively registered).

Abbreviations

BFR	Blood flow restriction
PF	Patellar fracture
RF	Rectus femoris
CSA	Cross-sectional area
1-RM	1-repetition maximum
BMI	Body mass index
LOP	Limb occlusion pressure
RPE	Rating of Perceived Exertion
CV	Coefficient of variation
SD	Standard deviation
AVE	Average value
GH	Growth hormone

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Authors' contributions

Primary manuscript writers: MMY. Primary manuscript reviewer/reviser: DW, BL, MYX, QPS. Concept and design: MMY, DW, BL. Participant recruitment: BL, XZ, YW. Participant evaluation: XZ, YW. Provision of instruments and equipment: MYX. Provision of experimental intervention sites: BL. Data analysis and interpretation: MMY, DW. Statistical expertise: DW, MYX.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Due to participants privacy, the datasets are not publicly available but can be obtained from the corresponding author under reasonable conditions.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki. The protocol was approved by the Nanjing first hospital Ethics Committee, reference number NCT05371431.

All participants provided written informed consent (See Attachment 1) to participate. They were informed about the study's purpose, procedures, potential risks, and benefits. Participants were assured that participation was voluntary and that they could withdraw at any time without any consequences.

Consent for publication

Written informed consent for publication of their data (including any individual details, images, or videos) was obtained from all participants involved in the study. In the case of children, consent was obtained from their parent or legal guardian.

Consent forms have been securely stored and can be made available to the journal upon request. All presentations of case reports have been conducted in accordance with the participants' consent, ensuring their privacy and confidentiality.

Competing interests

The authors declare no competing interests.

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