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# THE EFFECTS OF LOW-LOAD BFRE TRAINING ON SELF-REPORTED KNEE FUNCTION AND PAIN INTENSITY IN INDIVIDUALS WITH KNEE IMPAIRMENT

Matej IPAVEC[1]

[1]Department of Physiotherapy, Faculty of Health Sciences, University of Ljubljana, Slovenia

*Corresponding author:*
Matej Ipavec
Department of Physiotherapy, Faculty of Health Sciences, University of Ljubljana, Zdravstvena pot 5, SI-1000 Ljubljana, Slovenia
Phone: + 386 40 540 420
E-mail: matej.ipavec@zf.uni-lj.si

*ABSTRACT*

***Purpose:*** *The aim of this study was to investigate the influence of low-load (LL) blood flow restriction exercise (BFRE) on orthopedic patients with knee joint injuries, focusing on the subjective assessment of knee joint function and the perception of pain in the knee joint.*

***Methods:*** *The participants were divided into an LL-BFRE group and a sham LL-BFRE group (SLL-BFRE). The training program to strengthen the quadriceps femoris muscle was carried out for four weeks with three training sessions per week. The LL-BFRE group trained with blood flow obstruction through the active muscles using an inflatable cuff, while the SLL-BFRE group trained without blood flow obstruction. Before and after the training program, knee joint function was assessed using the Lysholm questionnaire, and the intensity of knee pain during the training program was measured using a numerical scale.*

***Results:*** *In the LL-BFRE group, the exercise program did not cause a significant improvement ($p = 0.359$), which was from 74.1 ± 15.1 points to 79.1 ± 15.0 points (7%) in the subjective assessment of knee joint function, whereas it improved significantly ($p < 0.001$) by 17% from 70.8 ± 16.8 points to 82.9 ± 14.0 points in the SLL-BFRE groups. We found no significant differences in pain intensity between the LL-BFRE and SLL-BFRE groups during the training program.*

***Conclusions:*** *The results do not support the hypothesis that LL-BFRE exercises would lead to greater improvements in knee joint function and pain perception compared to standard exercises of the same intensity. These findings highlight the need for further research to optimize training protocols and confirm their effectiveness across diverse patient groups.*

***Keywords:*** *Quadriceps femoris muscle, Arthrogenic muscle inhibition, Ischemic exercise, Lysholm knee scoring scale, Knee joint function*

# VPLIV ISHEMIČNE VADBE NA SAMOOCENO FUNKCIJE KOLENA IN INTENZIVNOST BOLEČINE PRI POSAMEZNIKIH Z OKVARO KOLENA

*IZVLEČEK*

***Namen:*** *Proučiti vpliv ishemične vadbe pri osebah s poškodbo kolenskega sklepa, pri čemer smo se usmerili na subjektivno oceno funkcije kolenskega sklepa in stopnjo občutenja bolečine v predelu kolenskega sklepa.*

***Metode:*** *Pacienti so bili razdeljeni v ishemično in placebo skupino. Vadbeni program za krepitev štiriglave stegenske mišice je potekal štiri tedne s po tremi vadbenimi enotami na teden. Ishemična skupina je vadila z oviranim pretokom krvi, povzročenim z napihljivo manšeto, placebo skupina pa z navidezno oviranim pretokom krvi. Pred vadbo in po njej so preiskovanci ocenili funkcijo kolenskega sklepa z Lysholmovim vprašalnikom. Intenziteto bolečine v kolenu so s številsko lestvico sistematično ocenjevali med vadbenim programom.*

***Rezultati:*** *Preiskovanci ishemične skupine z vadbenim programom niso dosegli značilnega (p = 0,359) povečanja subjektivne ocene funkcije kolenskega sklepa s 74,1 ± 15,1 točke na 79,1 ± 15,0 točke (7 %), medtem ko se je ta v placebo skupini značilno (p < 0,001) izboljšala za 17 % s 70,8 ± 16,8 točke na 82,9 ± 14,0 točke. Značilnih razlik v intenziteti bolečine med ishemično in placebo skupino med vadbenim programom nismo zaznali.*

***Zaključki:*** *Naše ugotovitve ne potrjujejo izhodiščne hipoteze, da ishemična vadba povzroči večje izboljšanje subjektivne ocene funkcije kolenskega sklepa in občutenja bolečine v predelu kolenskega sklepa kot standardna vadba z enako intenziteto. Ti izsledki poudarjajo potrebo po nadaljnjih raziskavah za optimizacijo vadbenih protokolov in potrditev njihove učinkovitosti pri različnih skupinah pacientov.*

***Ključne besede:*** *šibkost štiriglave stegenske mišice, artrogena mišična inhibicija, ishemična vadba, Lysholmov vprašalnik, funkcija kolenskega sklepa*

# INTRODUCTION

Knee joint injuries are among the most common joint injuries (Gage, McIlvain, Collins, Fields, & Dawn Comstock, 2012), and the frequency of surgical treatment is increasing (Adams, Logerstedt, Hunter-Giordano, Axe, & Snyder-Mackler, 2012; Van Kampen, 2013). As life expectancy continues to increase, the amount of time adults dedicate to sports activities is also increasing, likely leading to an increase in the incidence of knee joint injuries in older adults (Gage et al., 2012). The knee joint is most commonly injured in young athletes, especially female athletes who are at increased risk due to anatomical, hormonal, neuromuscular, and biomechanical factors (Gage et al., 2012). The most common knee injuries include torn ligaments, meniscus damage, and patellofemoral dislocations (Austermuehle, 2001)

Weakness of the Quadriceps femoris (QF) muscle is frequently observed after traumatic knee joint injuries, surgical procedures, and in patients with arthritis (Rice & McNair, 2010). The strength and endurance of the QF muscle are critical for normal knee function, so restoring muscle strength and endurance is essential for achieving good functional status after a knee injury (Hart, Pietrosimone, Hertel, & Ingersoll, 2010). Weakness of the QF muscle can have a range of consequences, such as incomplete knee extension, gait abnormalities, atrophy of the QF muscle, joint laxity, and persistent anterior knee pain (Sonnery-Cottet et al., 2019).

The inability to fully activate the QF muscle can most likely be attributed to arthrogenic muscle inhibition (AMI), a process that prevents the full activation of the muscle due to neuromuscular inhibition (Sonnery-Cottet et al., 2019). Factors influencing the development of AMI include joint swelling, inflammation, pain, soft tissue injury, and joint laxity (Rice & McNair, 2010). QF muscle weakness due to post-traumatic AMI reduces the ability to generate muscle force and impairs effective muscle control, which is particularly important during the eccentric loading of the knee joint during walking (Hart et al., 2010). AMI occurs in various knee joint pathologies with deficits in QF muscle activation, including osteoarthritis, rheumatoid arthritis, anterior knee pain, patellar injuries, ACL injuries and reconstructions, meniscus injuries, and/or meniscectomy, and patients undergoing knee arthroscopy (Rice & McNair, 2010).

Reducing AMI remains a priority in knee rehabilitation as the strength and endurance of the QF muscles are critical to knee function (Rice & McNair, 2010). One of the rehabilitation goals following knee injury or surgery is therefore to restore the lost QF muscle strength to pre-injury or pre-surgery levels (Hart et al., 2010). Strength training is an important part of training in most sports, as well as in injury prevention and rehabilitation (Wernbom, Augustsson, & Raastad, 2008). It is particularly important for people who have a higher risk of additional injuries due to muscle weakness.

When focusing on muscle hypertrophy during strength training, it is important to consider factors such as the number of repetitions and sets, rest intervals, speed of exertion, and training frequency. However, the most important factor is the training load for athletes or rehabilitation patients (Bird, Tarpenning, & Marino, 2005). This load is usually determined prior to the training or rehabilitation process using the 1RM (one repetition maximum) method, which represents the maximum weight a person can lift in a single effort (Garber et al., 2011; Wernbom et al., 2008). To induce hypertrophy in the skeletal muscles, the training load should be at least 60-80% of the individual 1RM (Garber et al., 2011; Wernbom, Järrebring, Andreasson, & Augustsson, 2009).

In acute injuries or following knee surgery, particularly in individuals with anterior knee pain and AMI, high-intensity joint loading with heavy weights is contraindicated due to pain and the risk of re-injury (Abe et al., 2012; Grønfeldt, Lindberg Nielsen, Mieritz, Lund, & Aagaard, 2020; Loenneke & Abe, 2012; Loenneke et al., 2012; Patterson et al., 2019). Therefore, in the early phase of rehabilitation after injury or surgery, only low-intensity isometric exercises for the QF muscle, body weight exercises, active-assisted exercises, and neuromuscular electrical stimulation are performed instead of heavy loads (Shaw, McEvoy, & McClelland, 2002). However, the results are often unsatisfactory because the intensity of the muscle effort is too low to stimulate muscle hypertrophy.

However, the literature suggests that low-load (LL) resistance exercise training combined with blood flow restriction (BFRE) is as effective as standard resistance training with a moderate or high load (>70–80% 1 RM) when it comes to muscle hypertrophy and strength gains in individuals with ACL and other isolated joint injuries (Centner & Lauber, 2020; Grønfeldt et al., 2020; Hughes, Paton, Rosenblatt, Gissane, & Patterson, 2017; Kacin & Stražar, 2011).

LL-BFRE training has been shown to be effective following ACL surgery, demonstrating significant improvements in QF muscle endurance (Kacin & Stražar, 2011; Žargi, Drobnič, Stražar, & Kacin, 2018) and has shown improvements in QF muscle torque development (Nielsen et al., 2017). In addition, it has been shown to be effective in preventing muscle atrophy after surgery (Ohta et al., 2003; Takarada, Takazawa, & Ishii, 2000) and atrophy due to limb unloading (Clark, Fernhall, & Ploutz-Snyder, 2006).

In addition to benefits in surgical recovery, LL-BFRE has been shown to reduce pain and improve knee function in patients suffering from anterior knee pain (Korakakis, Whiteley, & Epameinontidis, 2018), rheumatoid arthritis (Rodrigues et al. 2020) and osteoarthritis (Parekh, Vaghela, & Mehta, 2024). Recent results have also shown the effectiveness of LL-BFRE training in the rehabilitation process following ACL reconstruction, where it significantly improves muscle activity and function compared to traditional rehabilitation protocols (Jung, Kim, Nam, Kim, & Moon, 2022).

The aim of this study was therefore to investigate the effect of LL-BFRE in patients with knee joint injuries. Two main objectives were set: 1) to determine whether there is a difference in the subjective assessment of knee joint function between patients who have undergone LL-BFRE training and those who have received sham LL-BFRE training (SLL-BFRE), and 2) to assess whether there is a difference in the perception of pain in the knee joint between these two groups.

## METHODS

The study was approved by the Medical Ethics Committee of the Republic of Slovenia (No. 0120-496/2018/8) and was conducted in accordance with the Declaration of Helsinki. All the included patients signed a written informed consent for voluntary participation after receiving detailed written and verbal information about the study. Patient recruitment took place at the Orthopedic Department of the University Medical Center Ljubljana, while all performance tests and exercise training interventions were performed at the University Laboratory for Physiotherapy Research.

### Participants

A total of 36 orthopedic patients with QF weakness were initially recruited for the study. During the course of the intervention, three patients withdrew due to personal or health-related reasons, resulting in a final sample size of 33 participants, who were divided into two intervention groups.

The LL-BFRE group consisted of 16 (6 males and 10 females) orthopedic patients (39.3 ± 10.5 years. 171.4 ± 7.8 cm. 69.1 ± 13.8 kg) who exercised with restricted blood flow (cuff pressure 120-140 mmHg), while the SLL-BFRE group consisted of 17 (7 males and 10 females) orthopedic patients (39.6 ± 9.5 years. 174 ± 12.8 cm. 174 ± 12.8 kg) who exercised with apparently restricted blood flow (a cuff pressure of 20 mmHg).

The required sample size was determined using a two-way ANOVA model to ensure at least 80% power at an alpha level of 0.05 for detecting significant time × group interactions. The calculation showed that at least 18 participants per group were required for statistical validity. Despite three withdrawals, the final sample size remained sufficient for analysis within this clinical population.

Before starting the study, the participants completed a general health questionnaire to identify possible contraindications to performing BFRE training, as well as the Lysholm questionnaire, which allowed patients to subjectively assess knee joint function (Lysholm & Tegner, 2007).

## Inclusion criteria

The inclusion criteria were:

– Individuals with AMI of the QF muscle as a result of knee joint injury or surgery, which occurred at least six months prior (e.g., ACL injury, meniscus injury, or other intra-articular structures, patellofemoral pain syndrome, etc.),
– A difference (≥ 15%) in peak torque during voluntary isometric muscle contraction between the healthy and injured knee joints was used to confirm AMI.

## Exclusion criteria

The exclusion criteria were:

– Cardiovascular, respiratory, and metabolic disease or impairment,
– Presence of pain > 3 on the visual analog scale (VAS) during the activities planned as part of the study,
– Persons younger than 18 or older than 55 years,
– A history of peripheral or central thromboembolic events,
– Radiculopathies and peripheral neurological disorders of the lower limbs.

## Intervention

A counterbalanced quasi-randomization of the patients was performed to match the patients between groups by age, gender, body mass index, total score on the Lysholm Knee Scoring Scale for the self-assessment of knee function (Lysholm & Tegner, 2007), and the proportional deficit in torque achieved during maximum voluntary isometric contraction (MVIC) between the injured and non-injured leg.

The training program was carried out over a period of four weeks, with the participants completing three training sessions per week, for a total of 12 sessions. The participants trained with the maximum mechanical resistance they could overcome with 30 repetitions (30 repetitions maximum; 30 RM). All the training sessions were supervised by an experienced physiotherapist and included an exercise for the QF muscle in a closed kinetic chain with a leg press machine (Barbarian-Line BB-9091, Germany) (Figure 1) and an exercise for the QF muscle in an open kinetic chain with a knee extension machine (Sokol Gym, Slovenia) (Figure 2). Before the first training session, the 30 RM load was determined individually for each participant.

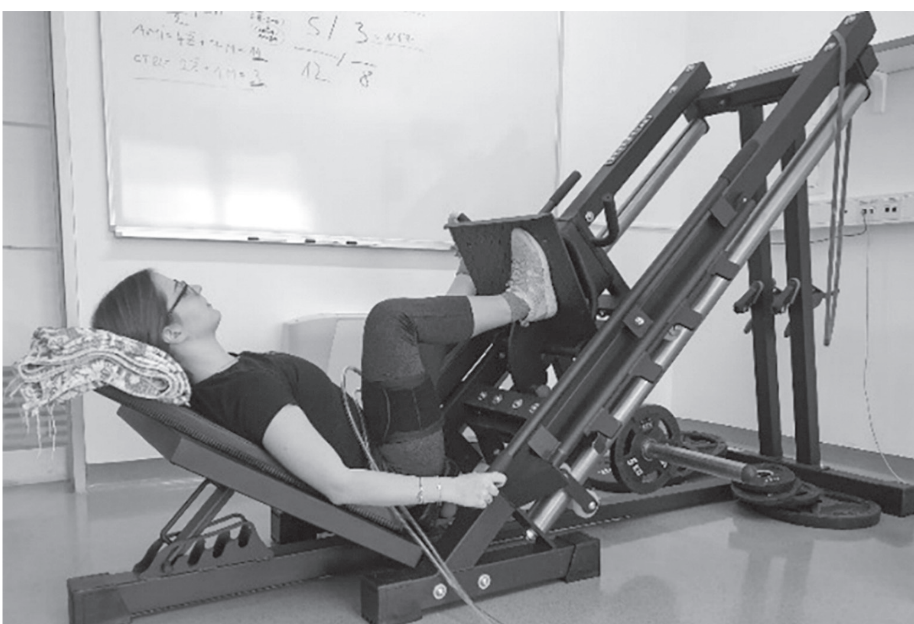


*Figure 1: Exercise for the quadriceps femoris muscle in a closed kinetic chain using a leg press machine*

*Figure 2: Exercise for the quadriceps femoris muscle in an open kinetic chain using a knee extension machine*

Participants in the LL-BFRE group exercised with restricted blood flow using an asymmetric inflatable cuff (University of Ljubljana and Iskra Medical d.o.o., Slovenia) applied to the proximal part of the thigh as previously described by (Ipavec, Grapar Žargi, Jelenc, & Kacin, 2019). The pressure was regulated with a pneumatic system for reducing blood flow (Ischemic Trainer, University of Ljubljana, and Iskra Medical d.o.o, Slovenia). Participants in the SLL-BFRE group followed the same training protocol, with the difference that the cuff was inflated to a lower pressure (20 mmHg), which did not affect normal blood flow to the active muscles. The cuff size (width and length) for both groups was selected to match the participants' thigh length and circumference.

Given the influence of limb anthropometric characteristics on blood flow reduction under the cuff (Jessee et al., 2016; Loenneke et al., 2012), the cuff pressure was adjusted individually for each participant. The initial cuff pressure was set at 120 mmHg and was increased if necessary. If the thigh circumference exceeded 58 cm, the pressure was increased by 10 mmHg. Additionally, if the skinfold thickness exceeded 23 mm, the pressure was increased by another 10 mmHg. Thus, the minimum pressure used in the study was 120 mmHg, while the maximum pressure reached 140 mmHg.

After the initial warm-up, which consisted of 10-12 repetitions at a minimum load, the cuff was inflated with air to an individualized pressure of 120-140 mmHg and left on the resting muscle for 30 seconds. After 30 s, the training session began with leg presses and knee extensions, each consisting of four sets with a decreasing number of repetitions (20, 15, 15, and 10 repetitions). Each repetition included a controlled 2-second concentric and 2-second eccentric contraction to ensure an equal time under tension for all the participants. This cadence was maintained throughout the sets using a metronome. Between sets one and two, as well as three and four, there was a 30-s rest break without reperfusion (cuff ON). In the rest period between sets two and three, a 45-second muscle reperfusion was performed (cuff OFF). A similar BFRE training protocol was successfully used in previous studies with knee patients (Fitschen et al., 2014; M. Jessee et al., 2017; Rossow et al., 2012). A schematic representation of the training session is shown in (Figure 3). The patients were asked not to change their routine of regular daily activities during the intervention and to keep a diary.

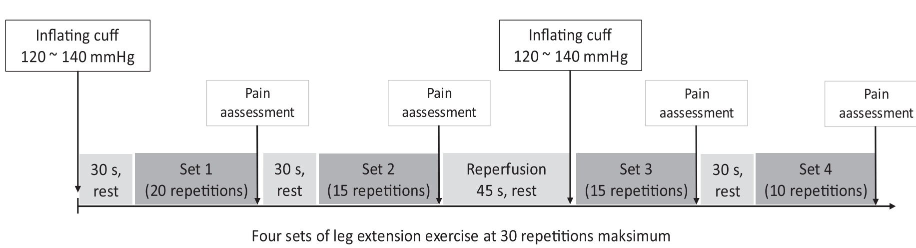



*Figure 3: Training Protocol with Knee Joint Pain Intensity Assessment*

## Pain Intensity Assessment in the Knee Joint

Participants rated the intensity of their knee joint pain before the start of each training session and after each exercise series using a 10-point numerical rating scale (Figure 3). A score of 0 meant that there was no pain, while a score of 10 represented the worst pain the participants had ever experienced in their lives. For the statistical analysis of knee pain intensity, we calculated the average pain score for both exercises (leg press and knee extension) for each individual week of the training period (weeks 1-4).

## Lysholm Assessment of Knee Joint Function

In order to obtain a subjective assessment of knee joint function, the participants completed the Lysholm questionnaire, which evaluates eight domains: limp, support, locking, instability, pain, swelling, stair climbing, and squatting (Lysholm & Tegner, 2007). A higher score indicates better knee function, with a maximum score of 100 indicating optimal results and no functional impairment. The participants completed the questionnaire before the baseline measurements and again after completing the strengthening program.

## Statistical Analysis

Statistical analysis of the data was done using SPSS version 23.0 (IBM SPSS Statistics, Chicago, IL, USA). The normality of the data distribution was tested using the Shapiro-Wilk's test. Most of the variables were normally distributed and the rest were logarithmically transformed before further statistical analysis.

To compare the means, we used a parametric analysis, a t-test for independent samples, and a two-way 2 × 2 (time × group) factor analysis of variance (ANOVA) for repeated measures on one factor (time). In case of a significant effect of either factor or their interaction, a post-hoc pair-wise comparison was made using Tukey's honestly significant difference (HSD) test. Partial eta squared was used to estimate the effect size, interpreting the results as follows: 0.01 = small effect, 0.06 = medium effect, and 0.14 or higher = large effect (Cohen, 2013). The significance level was set at $p < 0.05$ for all the tests. All the values are presented as mean ± standard deviation, unless stated otherwise.

# RESULTS

There were no significant differences ($p > 0.05$) detected between the LL-BFRE and SLL-BFRE groups in anthropometric characteristics for age, body height, body mass, and body mass index (BMI) (Table 1).

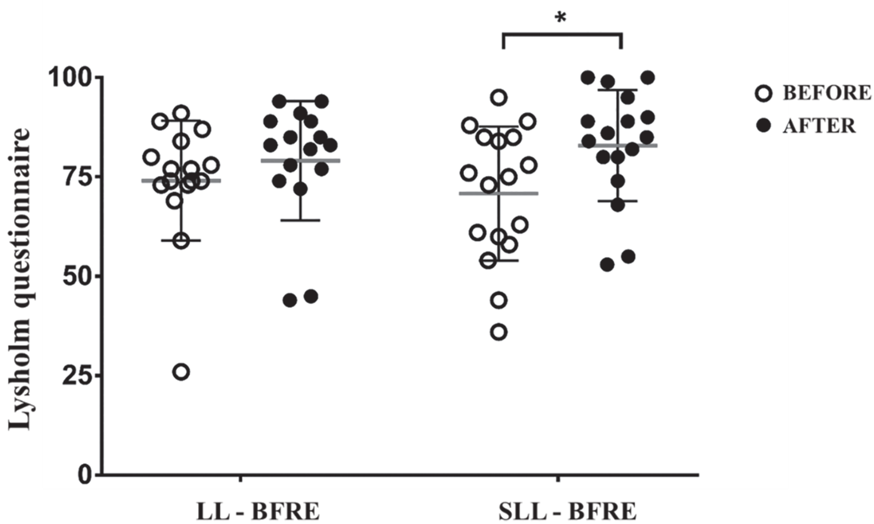
*Table 1: Anthropometric characteristics of the patients*

| | | N | Age (years) | Body height (cm) | Body mass (kg) | BMI (kg/m²) |
|---|---|---|---|---|---|---|
| **LL-BFRE** | M | 6 | 44.3 ± 6.8 | 176.0 ± 4.3 | 81.5 ± 12.9 | 26.2 ± 3.4 |
| | F | 10 | 36.3 ± 11.4 | 168.6 ± 8.3 | 61.6 ± 7.7 | 21.6 ± 1.7 |
| | Total | 16 | 39.3 ± 10.5 | 171.4 ± 7.8 | 69.1 ± 13.8 | 23.3 ± 3.3 |
| **SLL-BFRE** | M | 7 | 38.6 ± 5.3 | 184.9 ± 7.8 | 87.7 ± 13.8 | 25.6 ± 3.0 |
| | F | 10 | 40.4 ± 11.9 | 166.4 ± 9.7 | 63.6 ± 11.5 | 23.0 ± 4.2 |
| | Total | 17 | 39.6 ± 9.5 | 174 ± 12.8 | 73.5 ± 17.2 | 24.1 ± 3.8 |

**Legend:** N = number, M = male, F = female, BMI = body mass index.

For the Lysholm questionnaire, a significant effect of time was observed ($F = 22.872$; $p < 0.001$) with a substantial effect size ($\eta^2 = 0.424$), while the effect of the group was not significant ($F = 0.003$; $p = 0.954$; $\eta^2 = 0.050$). There was a trend toward a significant interaction between the two factors ($F = 3.916$; $p = 0.056$; $\eta^2 = 0.112$) (Figure 4).

Post-hoc pair-wise comparisons revealed that the total Lysholm score in the LL-BFRE group increased from 74.1 ± 15.1 points to 79.1 ± 15.0 points ($p = 0.359$), although this change was not statistically significant. In contrast, in the SLL-BFRE group, the total Lysholm score significantly increased ($p < 0.001$) with training, from 70.8 ± 16.8 points to 82.9 ± 14.0 points.



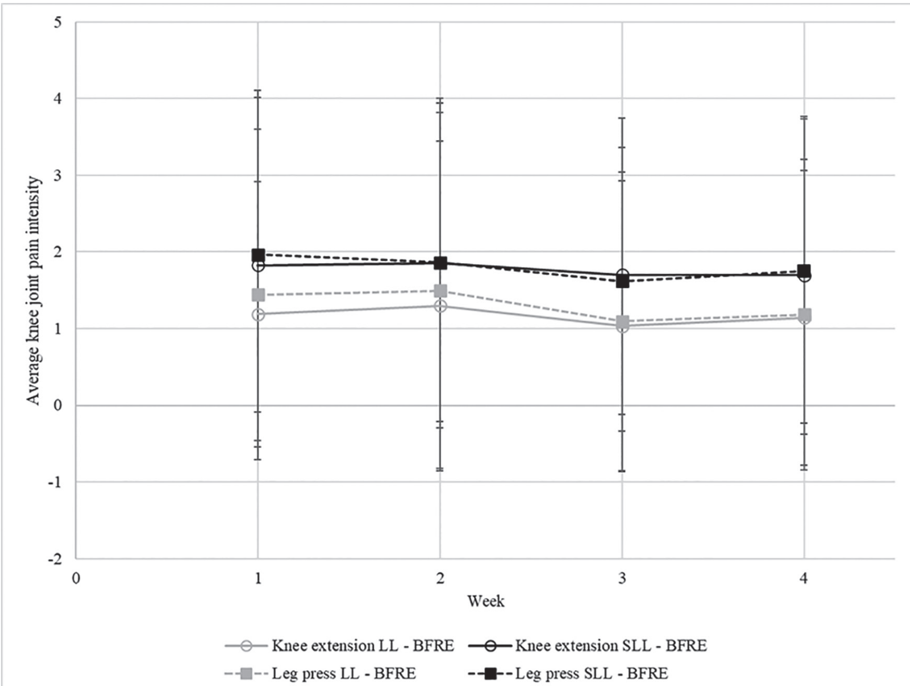

**Legend:** LL-BFRE - low-load blood flow restriction group, SLL-BFRE – sham low-load blood flow restriction group. * – significant effect of time ($p < 0.05$).

*Figure 4: Subjective assessment of knee joint function (Lysholm questionnaire) for the LL-BFRE and SLL-BFRE groups before and after the exercise program.*

During the leg press exercise, the pain levels in the LL-BFRE group changed from 1.4 ± 2.2 to 1.2 ± 2.0 points, while in the SLL-BFRE group, they changed from 2.0 ± 2.1 to 1.7 ± 2.0 points.

The effect of time was not significant ($F = 2.279$; $p = 0.084$; $\eta^2 = 0.068$), nor was the effect of the group ($F = 0.520$; $p = 0.476$; $\eta^2 = 0.016$), and their interaction was also not significant ($F = 0.149$; $p = 0.929$; $\eta^2 = 0.004$) (Figure 5).

During the knee extension exercises, the pain levels in the LL-BFRE group changed from 1.2 ± 1.7 to 1.1 ± 1.9 points, while in the SLL-BFRE group, they changed from 1.8 ± 2.3 to 1.7 ± 2.1 points. The effect of time was not significant ($F = 0.618$; $p = 0.604$; $\eta^2 = 0.019$), nor was the effect of the group ($F = 0.793$; $p = 0.379$; $\eta^2 = 0.024$), and their interaction was also not significant ($F = 0.059$; $p = 0.980$; $\eta^2 = 0.001$) (Figure 5).




**Legend:** LL-BFRE – low-load blood flow restriction group, SLL-BFRE – sham low-load blood flow restriction group.

*Figure 5: The average knee joint pain intensity values during leg press and knee extension exercises throughout the four-week training program*

## DISCUSSION

The aim of this study was to investigate the influence of LL-BFRE exercise on patients with knee joint injuries, focusing on subjective knee joint function and knee pain intensity.

An improvement in subjective knee function was observed in both the LL-BFRE and SLL-BFRE groups, as assessed using the Lysholm questionnaire. However, the improvement was only statistically significant in the SLL-BFRE group ($p < 0.001$), with a 17% increase from 70.8 ± 16.8 to 82.9 ± 14.0 points. In contrast, the LL-BFRE group improved by 7% from 74.1 ± 15.1 to 79.1 ± 15.0 points, but this change was not statistically significant ($p = 0.359$).

There was a trend toward a significant interaction between time and group ($p = 0.056$), suggesting potential differences in how the two interventions influence knee function over time. However, this trend did not reach statistical significance, limiting the conclusions about the comparative efficacy of the two training modalities. Furthermore, no differences in the intensity of knee pain were observed between the LL-BFRE and SLL-BFRE groups throughout the training program.

## Subjective Assessment of Knee Joint Function

The score of the Lysholm questionnaire is the sum of the scores in eight categories: limping, support, locking of the knee, instability, pain, swelling, stair climbing, and squatting. The maximum possible score is 100, with higher scores indicating better knee function (Collins, Misra, Felson, Crossley, & Roos, 2011; Lysholm & Tegner, 2007).

There are very few clinical studies that analyze pain or functional status after interventions with BFRE training. Jørgensen and Mechlenburg (2021) mainly attributed the improvement in knee joint function that they observed in a patient with rheumatoid arthritis after a 12-week BFRE training program to increased QF muscle strength. BFRE training induced tissue hypoxia, the accumulation of metabolites, and the swelling of muscle cells, resulting in increased protein synthesis, the recruitment of type II muscle fibers, stimulation of local and systemic anabolic hormone synthesis, and the activation of muscle satellite cells (Hwang & Willoughby, 2019; Jørgensen & Mechlenburg, 2021). It is assumed that these physiological adaptations can enhance muscle performance, joint stability, and proprioception, alleviating chronic pain and compensatory movement patterns. Clinically, these changes translate into improved functional capacity, reduced disability, and better performance in daily activities, emphasizing the holistic benefits of BFRE training in rehabilitation (Jørgensen & Mechlenburg, 2021).

Ke et al. (2022) conducted a study similar to ours on a sample of patients following partial meniscectomy. One group received routine rehabilitation, while the other received routine rehabilitation in combination with LL-BFRE exercises. The Lysholm questionnaire scores in the study by Ke et al. (2022) improved significantly in both groups 4 and 8 weeks after surgery ($p < 0.01$). Further analysis showed that the Lysholm scores were significantly higher in the LL-BFRE group than in the control group ($p < 0.01$). The results of our study are not consistent with those of Ke et al. (2022), as we found that the Lysholm score improved more in the SLL-BFRE group than in the LL-BFRE group. There are several possible reasons for this discrepancy. The baseline condition of the participants in the SLL-BFRE group was lower, with a baseline Lysholm score of 70.8 ± 16.8 points, compared with 74.1 ± 15.1 points in the LL-BFRE group. However, this difference was not statistically significant ($p > 0.05$).

The results may also have been influenced by the heterogeneity of the patients and the sample size (16 patients in the LL-BFRE group and 17 in the SLL-BFRE group). In addition, the placebo effect may have had a positive impact on the participants' perception of pain and joint function, as belief in treatment may lead to positive physiological changes. Furthermore, random fluctuations in the natural healing process or spontaneous recovery after various knee injuries may have contributed to the results.

Other factors, such as the degree of motivation and the active participation of the patients in the study, may also have played a role. Social factors such as the level of support from the participants' home environment or the level of stress they were exposed to, which were outside the control of the study, may also have influenced the results. Therefore, further research is needed to investigate these variables.

Liu and Wu (2023) conducted a study on individuals with patellofemoral pain syndrome and investigated the effects of soft tissue mobilization with various metal tools in combination with BFRE exercises on knee joint function. The participants were divided into a control and a BFRE exercise group, with the number of sets increasing over the four-week period (from 3 to 6 sets), with each set consisting of 30 to 15 repetitions and rest periods ranging from 30 to 60 seconds. The training sessions were performed twice a week with a cuff applied to the proximal thigh. The pressure in the cuff was between 20 and 50 mmHg, well below the 120 to 140 mmHg used in our study. The participants completed the Lysholm questionnaire before and after the exercise program and the results showed a significant improvement in knee function in both groups ($p < 0.05$). However, no significant differences were found between the ischemic group and the control group.

An important consideration concerns the cuff pressure used in the study, which was almost comparable to the pressure applied in our SLL-BFRE group. This raises the critical question of whether true ischemia was achieved in their study. Cuff pressure is a key factor influencing the perceived exertion and muscle soreness during BFRE exercise. The pressures used in the studies vary greatly and range from 50 mmHg (Kubota, Sakuraba, Koh, Ogura, & Tamura, 2011; Liu & Wu, 2023) to 300 mmHg (Cook, Clark, & Ploutz-Snyder, 2007). Both exertion and pain have been shown to increase proportionally with higher cuff pressure (Jessee et al., 2017), as well as with variations in cuff size and design (Ipavec et al., 2019; Jessee et al., 2016). Given these variations, it is important to question whether the lower pressures used in some studies, such as Liu and Wu's, were sufficient to induce true ischemia, or whether they more closely mimicked the conditions in the placebo groups, as seen in our study. Further investigation into optimal cuff pressure is critical to ensure consistency in BFRE research and to better understand the relationship between cuff pressure, pain intensity, and exercise effectiveness.

## Level of Knee Joint Pain Intensity

The intensity of knee joint pain is an important factor to consider when intervening with BFRE. Pain intensity can affect the participants' adherence to the exercise program and impact the overall rehabilitation outcomes. Studies investigating BFRE training, particularly at low loads, have shown that pain intensity and muscle discomfort vary depending on the cuff pressure, individual condition, and type of exercise (Jessee et al., 2017).

In our study, the intensity of knee pain was assessed using a numerical pain rating scale, with the participants reporting their pain before and after each exercise set. The results showed no significant differences in pain intensity between the LL-BFRE and SLL-BFRE groups during the exercise program, suggesting that LL-BFRE exercise did not exacerbate knee joint pain compared to SLL-BFR.

Li, Shaharudin, and Abdul Kadir (2021) conducted a meta-analysis in which they examined the effects of BFRE exercise on muscle performance and knee joint pain in people with knee injuries. They found that LL-BFRE exercise can improve muscle performance and reduce pain in these individuals. In particular, LL-BFRE training may offer similar benefits to high-load resistance training with a lower risk of injury and pain (Li et al., 2021).

In the study by Rodrigues et al. (2020), they investigated the effects of two resistance training protocols, LL-BFRE and high-load resistance training (HL-RT), on pain levels in women with rheumatoid arthritis. Using the visual analog scale (VAS), the study showed that the LL-BFRE group experienced a significant reduction in pain, with the VAS scores decreasing by 51.41% from a pre-intervention score of 4.73 to 2.30 post-intervention ($p = 0.002$). In contrast, the HL-RT group showed no significant change in the pain scores. The VAS scores decreased by only 2.07% (from 3.22 to 3.15), indicating an insignificant effect ($p=0.969$).

Li et al. (2021) observed that knee joint pain significantly decreased during, immediately after, and 24 hours after exercise in subjects who had undergone ACL reconstruction, suggesting that BFRE training may have a hypoalgesic effect. This effect is thought to be due to increased beta-endorphin levels and decreased pain sensitivity up to 24 hours after training (Li et al., 2021).

Similarly, Reina-Ruiz et al. (2023) found that LL-BFRE training produced better results in reducing knee pain than HL-RT in individuals with various knee pathologies, including rheumatoid arthritis, osteoarthritis, and patellofemoral pain syndrome. This effect could be related to the use of high cuff pressure, which triggers a hypoalgesic mechanism during exercise and thus increases the pain threshold (Jessee et al., 2017, Hughes et al., 2019).

Hughes et al. (2019) conducted a study in which participants performed unilateral leg presses twice a week, with at least 48 hours between sessions. The training program lasted 8 weeks. Participants were divided into a control group, which performed HL-RT, and an LL-BFRE group. The HL-RT group performed 3 sets of 10 repetitions with 30-second rest periods between sets at 70% 1RM, according to the recommended protocol for improving muscle strength. The LL-BFRE group completed 4 sets (30, 15, 15 and 15 repetitions) with 30-second rest periods at 30% 1RM. The knee pain was assessed after each set using the Borg CR10+ scale. The knee pain was highest in both groups during the first session at $1.38 \pm 0.96$ in the LL-BFRE group and $3.43 \pm 1.64$ in the control group but decreased significantly after the fourth and sixth sessions and remained low for the remainder of the program. It is noteworthy that knee pain was significantly lower in the LL-BFRE group compared to the HL-RT group during all the sessions, confirming the results of Ke et al. (2022). This could be due to the reduced external load during LL-BFRE exercise resulting in less stress on the knee joint and reduced joint loading, which is consistent with the conclusions of Li et al. (2021) and Reina-Ruiz et al. (2023) that LL-BFRE exercise can reduce knee pain in individuals with knee injuries.

Ke et al. (2022) also investigated the effect of BFRE exercises on knee joint pain in individuals after partial meniscectomy. Using the VAS to assess pain, they found significant improvements ($p<0.01$) in both groups at 4 and 8 weeks after surgery. The VAS scores for the BFRE group decreased from $2.95 \pm 0.85$ immediately after surgery to $1.00 \pm 0.33$ at 4 weeks and $0.42 \pm 0.51$ at 8 weeks, while the scores for the control group decreased from $2.84 \pm 1.01$ to $2.05 \pm 0.97$ and $1.42 \pm 0.77$, respectively. Further analysis showed that the BFRE group had significantly lower VAS scores than the control group at both 4 and 8 weeks after surgery ($p < 0.01$). These results suggest that LL-BFRE training can significantly alleviate knee joint pain in patients after partial meniscectomy, which is consistent with the findings of Li et al. (2021) and Reina-Ruiz et al. (2023), who also reported that LL-BFRE training can reduce knee pain in individuals with knee injuries.

Liu and Wu (2023) used the VAS in their study to assess the sensation of pain in the knee joint. When comparing the control and BFRE groups, they found a significant difference in pain intensity before the exercise program and after the first exercise session ($p < 0.05$), as the BFRE group achieved a greater improvement in pain level assessment compared to the control group. When comparing the VAS results before the exercise program, after the first exercise session, and after four weeks of the exercise program, a significant difference was found between the groups ($p < 0.05$), as the subjects in the BFRE group achieved a greater improvement in the VAS results than the subjects in the control group.

Based on the findings of Reina-Ruiz et al. (2023), Ke et al. (2022), Li et al. (2021), Liu and Wu (2023), and Hughes et al. (2019), it appears that LL-BFRE exercise can significantly improve the perception of knee joint pain. In our study, we did not find a significant change in pain intensity in any of the groups as a result of the training. The reason for the different results is most likely due to the significantly lower baseline pain intensity of our participants, which was 1.2 ± 1.7 in the LL-BFRE group and 1.8 ± 2.3 in the SLL-BFRE group during the knee extension exercise, 1.4 ± 2.2 for the leg press exercise in the LL-BFRE group and 2.0 ± 2.1 in the SLL-BFRE group, compared to other studies in which the baseline pain intensity in the ischemic groups was 4.73 (Reina-Ruiz et al, 2023), 2.95 ± 0.85 (Ke et al., 2022) and 1.38 ± 0.96 (Hughes et al., 2019), while in the control groups, it was 2.59 (Reina-Ruiz et al., 2023), 2.84 ± 1.01 (Ke et al., 2022), and 3.43 ± 1.64 (Hughes et al., 2019). It appears that pain was not an important symptom of muscle inhibition during exercise in our subjects and therefore did not change significantly with exercise, in contrast to other studies.

## CONCLUSIONS

This study investigated the effect of LL-BFRE exercises on patients with knee joint injuries, specifically focusing on the subjective assessment of knee joint function using the Lysholm questionnaire and knee joint pain perception. Our results revealed improvements in subjective knee joint function in both the LL-BFRE and SLL-BFRE groups, with the SLL-BFRE group demonstrating greater improvement.

The reasons for this outcome are multifactorial, including potential baseline differences, a smaller and heterogeneous sample, and the challenges of clinical implementation. Despite these limitations, this study demonstrates the feasibility and tolerability of both exercise protocols, as evidenced by the low and comparable pain levels between the groups throughout the intervention. As one of the few clinical investigations in this domain, these findings provide preliminary insights into BFRE applications in rehabilitation. Future research with larger, more homogeneous samples and extended follow-up periods is necessary to confirm these findings and further refine exercise protocols to enhance functional recovery.

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