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Low-load resistance training with blood flow restriction versus traditional training exercises in patients with knee osteoarthritis

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ABSTRACT

Osteoarthritis (OA) of the knee is a disabling condition and results in impaired quality of life. Strength training is an important treatment for patients with knee OA. The aim of this study was to investigate the impact of low load resistance training (LLR) accompanied by blood flow restriction (BFR) training compared to conventional high load resistance training (HLR) on quadriceps muscular strength, proprioceptive accuracy, and function of the knee joint. A total of 42 patients, from both sexes, with mild to moderate OA in one tibiofemoral joint and whose age ranged from 45 to 60 years old, were randomized into two groups (control and experimental). The control group (HL group) included twenty-one patients (7 men, 14 women) with a mean age of 49.57±4.37 who received the conventional training program (high load resistance training). The experimental group (BFR group) included twenty-one patients (5 men, 16 women) with a mean age of 48.61±3.8 who received LLRT with BFR. Quadriceps muscle strength was evaluated using a hand-held dynamometer (HHD), knee joint function was assessed using the WOMAC questionnaire, and proprioception was assessed with a digital inclinometer. The results revealed a statistically significant improvement in mean WOMAC, HDD, and proprioception values assessed post-treatment in both groups compared to the corresponding mean values pre-treatment ($p < 0.05$). There was no statistically significant difference between the two groups on the examined dependent variables at baseline ($p > 0.05$). Conventional HLR and LLR-BFR training are efficient in managing knee OA by improving quadriceps muscle strength, enhancing the function of the knee joint, and proprioceptive accuracy. Following 4 weeks of treatment, the BFR group had lesser WOMAC and proprioception mean values and greater HHD mean values than the HL group.

KEYWORDS

Blood Flow Restriction Training; Knee Osteoarthritis; Handheld Dynamometer; Strengthening Exercises

1. INTRODUCTION

Osteoarthritis of the knee (OA) is considered the most debilitating problem leading to severe morbidity and physical dysfunction (Mora et al., 2018). The most frequent weight-bearing joint influenced by OA is the knee joint (Murphy et al., 2008). Due to increased knee OA prevalence and the increased cost of its medical management, total knee replacement (TKR) surgery for the terminal phase of knee OA treatment pushes researchers to look for options to decelerate the development of knee OA (Altman et al., 2015).

Knee OA has been accompanied by a reduction in lower limb muscular strength and modifications in muscular activation patterns (Bennell et al., 2008). Muscle weakness is among the most common clinical features associated with knee OA, especially quadriceps weakness, which leads to arthritis progression and is among the main contributing factors to functional disability (Zhang et al., 2010; Neogi et al., 2013). Therefore, most exercise programs designed for knee OA patients primarily concentrate on strengthening the quadriceps muscle (Jegu et al., 2014; Schiphof et al., 2018). The strength of lower extremity muscles is important for knee loading and joint stability during walking. A broad range of therapeutic programs is used to contain relatively simple exercises like strengthening exercises of the quadriceps muscle and aerobic programs like walking or complex exercises as strengthening exercises of the upper limb and/or trunk muscles and proprioceptive training combined with strengthening exercises of lower limb muscles (Fransen et al., 2015).

In traditional rehabilitation programs for strengthening muscles, the concept of muscular strengthening was based on high-load exercise with increasingly higher resistance (Stand, 2009). However, healthy individuals should follow these guidelines (Fujita et al., 2007), high-load programs, which are advised to induce strength improvements, may be less tolerated by knee OA patients (Messier et al., 2013). Therefore, to reduce the risk of the disease and promote physical performance, it is necessary to do proper strengthening exercises of the knee extensor muscle while restricting the deleterious joint overloading in individuals suffering from knee OA (Segal et al., 2015).

BFR (Blood Flow Restriction) combined with LLRT (Low Load Resistance Training) provides an alternative to conventional strengthening exercises for knee OA with less deleterious joint loading (Pope et al., 2013). It is achieved by exerting external pressure using an inflated cuff or tourniquet. The exerted pressure obstructs venous drainage while preserving arterial supply, causing blood to pool in the capillaries of the extremity muscles distally from the tourniquet (Slysz et al., 2016).

Kubota et al. (2008) demonstrated that BFR could be used to reduce limb disuse muscle atrophy throughout periods of immobilization. It can also be mixed with exercise to help with muscle development. When combined with BFR, resistance training seems to provide large muscle gains (Slysz et al., 2016).

Otherwise, knee OA patients have sensorimotor dysfunction in decreased functional activity (Roos et al., 2011) and altered muscle activation patterns (Bennell et al., 2013). This sensorimotor dysfunction is caused by pain, oedema, inflammation, joint laxity, and destruction of the sensory receptors in the joint, stopping the muscle from being fully stimulated, leading to weakness of muscles as quadriceps in knee OA patients (Rice et al., 2010). Proprioceptive accuracy, however, appears to be an adjustable element in knee OA (Knoop et al., 2011). So, rehabilitation programs should emphasize improving neuromuscular and functional stabilization to improve patients' symptoms and function (Ageberg et al., 2015)

There are numerous methods used to evaluate improvements in knee OA, including muscle power, functional and proprioception accuracy assessments. Muscle strength is measured using isokinetic dynamometers, manual muscle testing, and HHD (Hand-Held Dynamometer) (Le-Ngoc et al., 2012). HHD is a reproducible and valid device for evaluating muscle strength for knee joint muscles. It is a simple assessment instrument that could be utilized in exercise and clinical settings to evaluate the strength of the knee joint muscle (Arnold et al., 2010). Knee function is assessed using a range of patient-reported outcome measures. The 24-item Western Ontario and McMaster Universities Arthritis Index (WOMAC) is a valid reproducible and responsive questionnaire for assessing pain, disability, and knee joint stiffness in knee OA patients (McConnell et al., 2001). The Arabic version of the WOMAC questionnaire (Appendix I) is reliable in its original form. It has validity in the Tunisian population, indicating that it can work well for other Arab populations, particularly in North Africa (Guermazi et al., 2004). The digital inclinometer is a valid and reproducible device for the evaluation of knee proprioception in terms of JPS, and it is easy to use, inexpensive, portable, and affordable (Romero-Franco et al., 2017)

The aim of this study is to compare the impact of LLRT accompanied with BFR versus conventional strengthening programs in terms of quadriceps muscular strength, knee joint function, and proprioception in knee OA patients.

2. METHODS

2.1. Study Design

A double-blinded, comparative, experimental, clinical study was conducted.

2.2. Participants

42 patients, from both sexes, with mild to moderate OA in one tibiofemoral joint and whose age ranged from 45 to 60 years old, were randomized into one of two groups utilizing opaque, closed envelopes carrying the names of the two groups (control and experimental group), as shown in Figure 1. The control group included twenty-one patients (7 men, 14 women) with a mean age of 49.57±4.37. This group received the conventional training program (high load resistance training). The experimental group included twenty-one patients (5 men, 16 women) with a mean age of 48.61±3.8. This group received LLRT with BFR. Before the study began, every patient provided written informed consent. An orthopedic surgeon referred all of the patients, and their diagnosis of knee OA relied on clinical and radiographic examinations.

Patients were recruited according to the following inclusion criteria: age ranged from 45 to 60 years (Segal et al., 2015), ambulatory patients with symptomatic knee OA (not using supportive aids), BMI less than 30 kg/m2 (not considered obese), mild to moderate one-sided tibiofemoral knee OA grade II-III (K/L) (Bryk et al., 2016) and no resistance training in the last three months before recruitment (Jan et al., 2008). Participants were excluded if they suffered from a severe degree of knee OA (grade IV as specified by the classification of K/L), knee OA on both sides, as well as secondary OA of the knee, congenital or acquired Inflammatory, autoimmune, or neural (systemic or localized) disorders of the knee. They were also excluded if they received repetitive management with steroids or knee and/or hip joint arthroplasty surgery, in addition to diabetic patients and patients with cardiovascular and neuromuscular disorders or psychiatric disorders (Bryk et al., 2016).

The study was approved by the Institutional Review Board of Cairo University's Faculty of Physical Therapy before starting the treatment sessions. Evaluation and treatment procedures were accomplished at the Physical Therapy outpatient clinic, Pharos University in Alexandria. Before participating in the study, all participants signed a consent form. They were also notified that the data obtained would be published.

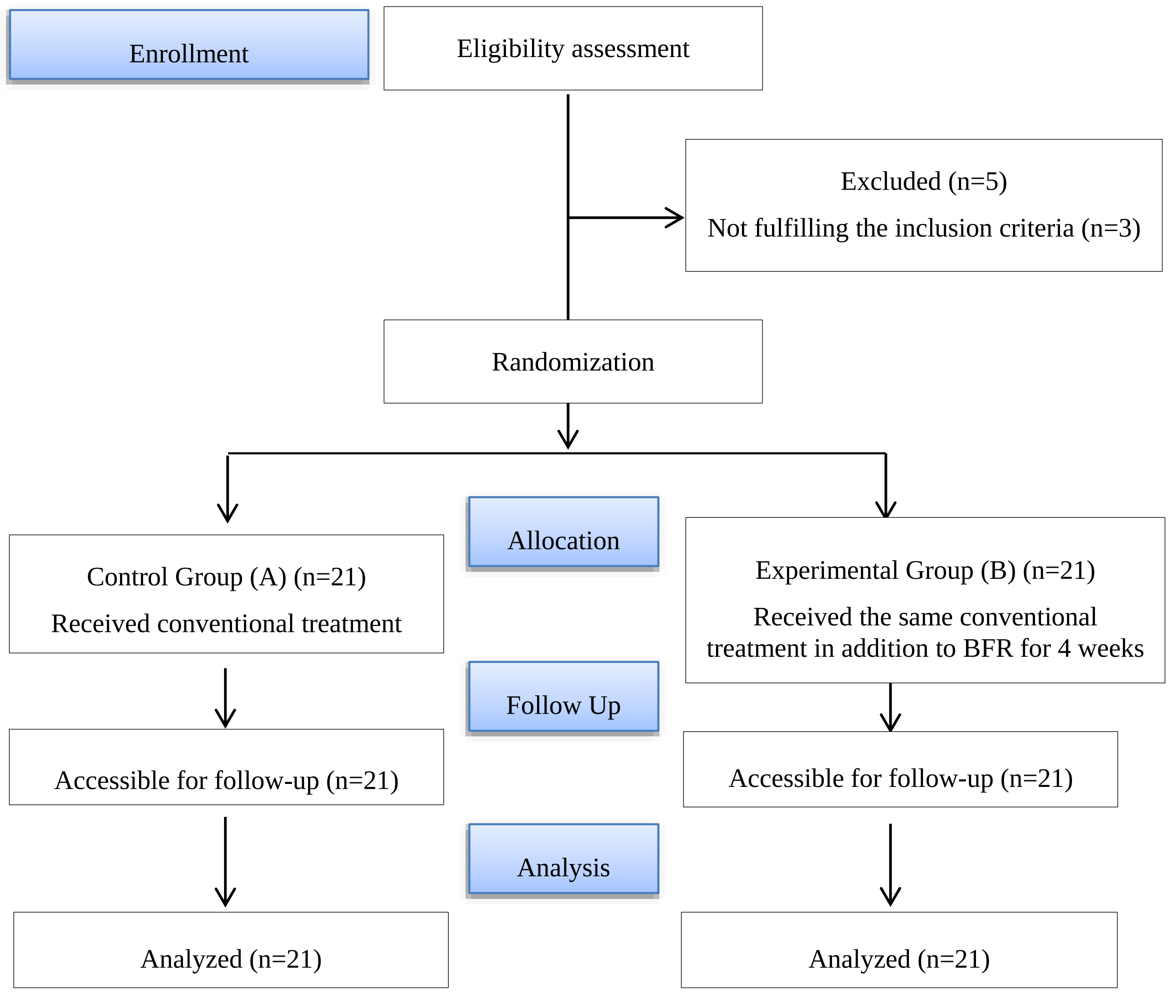

Figure 1. Flow chart of study participants

2.3. Instruments

- The Lafayette Hand-Held Dynamometer (HHD) was used to measure muscle strength. HHD is a valid and reproducible tool for evaluating knee strength in knee OA patients (Chopp-Hurley et al., 2019).
- To assess knee function in an Arab population, the WOMAC was used (Guermazi et al., 2004).
- A digital inclinometer was used for the assessment of JPS (Romero-Franco et al., 2017 & Cho et al., 2011).
- Portable Doppler ultrasound (Giles et al., 2017).

- A specially designed sphygmomanometer for BFR (Bryk et al., 2016).
- Sandbags for resistance, a universal scale for height, weight, and BMI

2.4. Assessment Procedures

Before and after the physiotherapy sessions, all patients in both groups received the subsequent assessment.

2.4.1. Quadriceps Muscle Strength

Quadriceps Muscle Strength was evaluated using the Lafayette HHD. The patient was seated with their hands placed against their trunk. 2 belts were used for stabilization, one placed against the thighs to limit compensatory movements and the other placed on the ankle of the tested extremity to keep 90˚ flexion of the hip and knee. The pad of the HHD was placed two inches proximal to the lateral malleolus in front of the tibia, perpendicular to the tested limb. Maximum isometric strength for knee extension was held for 5 s. Two learning trials were performed, the rest for 30 s, followed by 3 measurement trials. A 30-second period separated the subsequent measurements of the same limb. The measurement was repeated if the variation between the two testing trials in the same limb was greater than 10%. (Almeida et al., 2019). The trial was repeated if it didn't display maximum effort and if the HHD wasn't placed parallel to the tested surface. Each participant performed 3 trials. The mean peak force was recorded in newton's (N) and used as the strength measure. Normative strength can also be quantified as torque per kilogram. HHD reading in Newtons multiplied by distance divided by body weight in kilograms (Arnold et al., 2010).

2.4.2. Knee Joint Function

Knee joint function was assessed using the WOMAC questionnaire Arabic version (Appendix I) (Guermazi et al., 2004). It was accurately filled before starting treatment sessions. The patient was asked to fill out the printed Arabic questionnaire at a quiet place. The patient was informed of the questionnaire subscales and was asked to fill the physical function subscale, which involves 17 items, pain involves 5 items, and stiffness involves 2 items. All items were evaluated from 0, which means nothing, 1 means slight, 2 is moderate, 3 is very, and 4 is extreme. All discussions were in the Arabic language.

2.4.3. Proprioception accuracy (Joint Position Sense) using digital inclinometer (Digital Protractor, 82201b-00, INSPEC, China).

Patients were ordered to sit with 90-degree flexion of the hips and knees, and the digital inclinometer was connected to the lateral side of the leg. Patients were assessed in a quiet environment while being Blindfolded. The patients started the test with an extended knee. He was instructed to flex their knee up to the desired angle of 30 degrees. after reaching the desired angle, they were instructed to maintain this position for 5 seconds and then return to the beginning position (full knee extension). After the patient had detected the desired angle three times, they were instructed to reproduce it as precisely as possible. This way was replicated 3 times, and the angles were documented. The absolute angular error was calculated as the difference between the angle sensed by the patient and the reproduced angle (Suner-Keklik et al., 2017). The inclinometer showed excellent validity for proprioceptive errors in JPS tasks (Romero-Franco et al., 2017).

2.5. Treatment Procedures

10 minutes of general warming up was done before every session for the two groups during the intervention. The maximum load for all strengthening exercises was (70 percent of one-repetition maximum in the conventional group and 30 percent of one-repetition maximum in the BFR group). It was assessed throughout the initial treatment session and reassessed weekly to perform any required adjustments. As strength improved, resistance was gradually increased. The patients were not asked to do exercises at home and only performed them during physiotherapy sessions**.** The treatment protocol was 12 sessions (3 sessions a week) for 4 weeks for the 2 groups, with an average time of the session of 30-60 Minutes (Bryk et al., 2016).

2.5.1. Control Group (Conventional Training Group)

Patients assigned to the control group (conventional training group) received stretching and strengthening exercises of the lower extremity muscles, including resistive quadriceps exercises for an overall 12 sessions (3 sessions a week) for 4 weeks. Rehabilitation exercises included multiple angle isometric seated quadriceps knee extension (30°, 60°) with ankle weights, hamstring stretching, straight leg raising, hip abductors and adductors strengthening with weights in side-lying position utilizing ankle weights and ankle plantar flexion with resistance using TheraBand (Batterham et al., 2011).

2.5.2. Experimental Group (BFR group)

Patients allocated to the experimental group (BFR group) received similar exercises as in the conventional therapy group but with some variations which are: the resistance exercises included were performed with low load resistance (30% 1RM), and BFR was added during exercise for an overall 12 sessions (3 sessions a week) for 4 weeks. The BFR device consists of a uniquely designed sphygmomanometer that can limit the thigh's blood flow (Libardi et al., 2015). A 12-cm-wide pneumatic nylon tourniquet was placed around 33% distal to the inguinal crease. A tape measurement was utilized to measure the distance from the inguinal crease to the apex of the patella, and a mark was placed to serve as a reference point. The thigh circumference was measured to indicate the cuff's position (Loenneke et al., 2014). The pressure inside the cuff is 60% of the individual arterial occlusive pressure; it was recorded while the patient was standing on each participant's legs. Also, the gauge attached to the cuff was used as visual biofeedback for muscle contraction during exercise. The cuff's pressure was gradually increased until no pulse could be felt at the dorsalis pedis by Doppler ultrasound used before the first session to determine the cuff pressure (Giles et al., 2017). The hand-held Doppler ultrasound is a valid method for determining arterial occlusion pressure during BFR exercises (Laurentino et al., 2018). Throughout the LLR, continuous instead of intermittent BFR was applied, which is superior for increasing metabolic needs and motor unit activation (Fahs et al., 2012).

2.6. Statistical Analysis

SPSS for Windows (Version 23) was utilized to run all statistical tests (Chicago, IL, USA). The WOMAC, HDD, Proprociption of the groups were statistically evaluated to compare the impacts of HL and BFR in knee OA patients. The Shapiro Wilk test ensured data normality before the final analysis. Descriptive statistics (mean and standard deviation) were generated for all data. While inferential statistics, 2x2 mixed design MANOVA was utilized to compare within and between the two groups. For all the statistical tests, a p-value of <0.05 was considered statistically significant.

3. RESULTS

Table 1 summarizes the characteristics of patients of the two groups (control and experimental). The mean, standard deviation (SD) of the age and the body mass index (BMI) for the two groups are shown. There were no differences between groups (p>0.05) at baseline.

Table 1. Patients' demographics, including age and BMI values, for both tested groups at baseline (n= 42).

Variables	Mean ± SD[a]		p-value[b]
	Control (HL) Group (n=21)	Experimental (BFR) Group (n=21)	
Age (years)	49.57±4.37	48.61±3.8	0.456
BMI (kg/m^2)	26.21±1.6	26.33±1.65	0.814

[a]SD (standard deviation); significance level set at ≤ 0.05

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Regarding the overall intervention effects, there was no statistically significant (p > 0.05) effect of the tested group on the dependent variables (WOMAC, HDD, and Proprioception).

In contrast, measurement periods significantly affected all dependent variables (p < 0.05). The interaction between the two independent variables was statistically significant (p < 0.05), meaning that the impact of the tested group on all dependent variables was affected by the assessment times (Table 2).

Table 2. Overall interaction for all outcome measures at various measurement periods between both groups.

Source of Variation	F-value	p-value	Partial Eta square
Groups	1.898	0.146	0.13
Measuring periods	1207.71	0.000[a]	0.99
Interaction	40.313	0.001[b]	0.761

[a] Significant effect of the measuring periods on all dependent variables (P ≤ 0.001), [b] significant interaction among the two independent variables.

Pre- and post-treatment WOMAC, HDD, and Proprioception values between groups are shown in Table 3. Within every group, the findings of the pre-and post-treatment values were compared. The result revealed a statistically significant improvement in mean WOMAC, HDD, and Proprioception values assessed post-treatment in both groups compared to the corresponding mean values pre-treatment (p<0.05). There was no statistically significant difference between the two groups on the examined dependent variables at baseline (p > 0.05). Following 4 weeks of treatment, the BFR group had lesser WOMAC and Proprioception mean values and greater HHD mean values than the HL group (Table 3).

Table 3. Both groups' descriptive and inferential statistics of WOMAC, HDD, and Proprioception.

Measure	HL group **(mean ± SD)**	BFR group **(mean ± SD)**	F	p **
		WOMAC		
Pre-intervention	55.95 ± 5.88	56 ± 5.39	0.001	0.978
Post-intervention	49.47 ± 4.91	42.71± 6.5	14.44	**0.0001****
P value*	0.0001*	0.0001*		
		HHD		
Pre-intervention	101.37±13.42	110.04±15.27	3.822	0.058
Post-intervention	132.95±17.1	144.52±17.44	4.712	**0.036****
P value*	0.0001*	0.0001*		
		Proprioception		
Pre-intervention	10.9±1.65	11.22±1.39	0.468	0.498
Post-intervention	9.28±2.41	7.78±1.83	5.148	**0.029****
P value*	0.0001*	0.0001*		

P value: within groups comparison, P value**: between groups comparison, HL group: Traditional group, BFR group: Blood flow restriction group.*

4. DISCUSSION

This study compared the effectiveness of BFR with LLRT compared with the conventional program in terms of strength of quadriceps muscle, the function of the knee joint, and proprioception in knee OA patients. The results revealed statistically significant improvement in mean values of HHD, WOMAC, and digital inclinometer assessed in both groups post-treatment compared to the corresponding mean values pre-treatment ($p < 0.05$). At the same time, no statistically significant differences were observed between both groups ($p > 0.05$) concerning tested dependent variables. These improvements confirmed the results of several previous studies.

The present study revealed a statistically significant improvement in quadriceps muscle strength using HHD after traditional HLR Training ($p < 0.05$). These results confirmed its effective role in improving quadriceps muscle strength. The findings of this study matched are consistent with an RCT performed by Jan et al. (2008). They evaluated the therapeutic impact of HLR and LLR training on 102 older adults who had mild to moderate knee OA. They observed that HLR and LLR training significantly enhanced knee extensor and flexor muscle strength as evaluated by an isokinetic dynamometer). The effects of HLR training seem to be greater than LLR training, without statistically significant differences between groups.

Reduced muscular strength, increased stiffness of the ligaments, and changes in activation patterns of the muscles, all have been associated with knee OA (Bennell et al., 2008). Muscle activation patterns and joint mechanics may be normalized with strength training restoring muscular strength while promoting physical function and decreasing cartilage deterioration (Vincent et al., 2012).

The current study results revealed a significant improvement in knee joint function in terms of WOMAC score reduction post-treatment in comparison with pre-treatment ($p < 0.05$) after traditional HLR strength training. The study's finding was augmented by those of Topp et al. (2002), who compared isometric versus dynamic resistance training to test the impact of different types of resistance training on the WOMAC questionnaire in knee OA patients. The investigators in this study concluded that dynamic and isometric resistance training exercises improve knee joint function in knee OA patients. A meta-analysis published in 2004 by Pelland et al. (2004) supported the present study results as they found that strengthening exercises alone improved functional outcomes in knee OA patients. A study done by Baker et al. (2001) agreed with our results. They investigated the impact of the home-based progressive strength training program on high physical function and muscle strength in knee OA patients. They used the WOMAC questionnaire to assess physical function. There were statistically significant improvements in muscle strength and physical function in the strength training group.

Lin et al. (2009) performed an RCT to evaluate the clinical and functional effectiveness of two non-weight-bearing exercise programs for knee OA patients: proprioceptive training compared with strength training. The WOMAC questionnaire assessed physical function and walking time on 3 different terrains pre-and post-treatment. Findings showed a significant improvement in function in both types of exercises. However, the improvement in WOMAC function scores secondary to strength training was greater.

This agreement could be that muscle weakness is a usual abnormality in osteoarthritic patients (Barker et al., 2004). All voluntary human motion is carried out by skeletal muscles (Bennell et al., 2008). Muscle characteristics and performance can significantly impact one's capability to walk and function independently (Latham et al., 2010). So, strength training interventions would improve strength, function, and pain reduction, resulting in significant improvement in the WOMAC function scale.

A study conducted by Wortley et al. (2013) agreed with our results. They compared the effectiveness of 10-weeks of resistance training versus Tai Ji exercise (kind of flexibility training) on enhancing symptoms of osteoarthritis and mobility in elderly knee OA patients. The WOMAC questionnaire assessed physical performance and three physical performance tests. Results revealed significant improvement in the TUG test and WOMAC physical function sub-score in the resistance training group. In contrast, the Tai Ji group significantly improved on the TUG test only. Resistance training was more beneficial than Tai Ji in improving knee OA mobility and symptoms.

To further support the current study results, a systematic review evaluated 18 RCTs involving 2832 participants to see if isolated resistance training may improve the symptoms of osteoarthritis and physical performance in knee OA patients. They discovered that Resistance training enhanced physical performance in knee OA patients (Lange et al., 2008).

Research by Thorstensson et al. (2005), on the other hand, contradicted previously published papers on resistance training exercises in knee OA. Its purpose was to see how a simple, high-intensity exercise regime affected knee joint function and quality of life in 61 knee OA patients. There was no change in pain or function in the exercise group compared to the control group. However, there were some impacts on quality of life. Possible causes for this variation may result from patients having moderate to severe knee OA, compared with mild to moderate in almost previous research, are likely to be younger than the previously investigated groups, and the treatment is likely to be of relatively high intensity.

The present study revealed a statistically significant improvement ($p < 0.05$) in proprioceptive accuracy of the knee joint after conventional HLR Training. A study by Lai et al. (2018) supports our findings. It was conducted to investigate the effect of strength training on proprioception of the lower limb in knee OA patients. The finding of the study indicated that strengthening exercises enhanced the threshold for detecting passive movement in a knee flexion movement.

Otherwise, a study done by Lin et al. (2009) indicated that non-weight-bearing strengthening exercises did not affect knee reposition errors. However, our current findings contradict these conclusions. The diverse exercise modes and proprioception testing methodologies utilized in our study and Lin et al. study could lead to various strengthening exercises effects on knee joint proprioception.

Proprioceptive receptors surrounding the knee joint, particularly flexion muscle spindles, may be triggered by feedback from the lower limbs, enhancing proprioception of the knee joint (Shields et al., 2005). According to Knoop et al. (2011), exercise therapy may enhance proprioception by increasing the sensitivity of the muscle spindle or by stimulating the mechanoreceptors.

The current study revealed a statistically significant improvement ($p < 0.05$) in quadriceps muscle strength using HHD after LLR-BFR training. A double-blinded RCT was done by Segal et al. (2015) to evaluate whether concurrent BFR during LLR training is an effective means of increasing the strength and volume of the quadriceps muscle in women over the age of 45 at risk of having symptomatic knee OA. Patients were randomly assigned to either LLR training (30 percent of 1RM) only or LLR training combined with concurrent BFR for four weeks of leg press resistance training. Dependent variables utilized in the study were: maximum test of isotonic bilateral leg pressing strength, isokinetic and strength of knee extensor, and quadriceps volume were measured using MRI pre-and post-treatment. The results of the study indicated that there was a significant improvement in isotonic 1 repetition maximum in the BFR group. The addition of BFR to a 30 % of 1 repetition maximum strength training program enhanced knee extensor muscle strength in women at risk of having asymptomatic knee OA compared to a similar exercise program without BFR (Segal et al., 2015).

Our study came into agreement with an RCT of level I evidence conducted by Bryk et al. (2016) to investigate if women with knee OA who did a treatment program that included LLR (30 % of 1 repetition maximum) in addition to BFR had the same finding in terms of quadriceps muscle strength improvements as women who did a program that included HLR (70 % of 1 repetition maximum) without BFR. During the quadriceps strengthening, a pressure cuff was attached to the superior part of the thigh and inflated to 200 mmHg to achieve the BFR.

The Lequesne questionnaire, the TUG test, and quadriceps muscle strength assessments with the HHD were utilized as dependent variables pre-and post-treatment. The finding of the study revealed that a rehabilitation program combining BFR with LLR exercises provided equal improvement in knee function and quadriceps muscle strength compared to an HLR exercises program in knee OA patients; using BFR in combination with LLR exercises led to a reduction in anterior knee pain throughout the training sessions (Bryk et al., 2016).

For further support of our finding, an RCT was done to investigate the impacts of an exercise program combined with BFR and an exercise program alone on muscle strength in a group of older adults who were randomly assigned into 3 groups: exercise program includes endurance training and HLR training (70–80 % of 1-RM), same exercise program combined with BFR but with LLR (20–30 % 1-RM) or control group. The 1-RM test was utilized to measure muscle strength pre-and post-treatment sessions. Both groups showed similar increases in the 1-RM test. The exercise program combined with BFR at low exercise loads promotes similar neuromuscular adaptations as the exercise program alone at high exercise loads. Their findings suggested that an exercise program containing endurance and strength training combined with BFR is an efficient substitutional to the current exercise prescription guidelines for the elderly (Libardi et al., 2015).

The present study results revealed a statistically significant improvement ($p<0.05$) in knee joint function in terms of WOMAC score reduction post-treatment in comparison with pre-treatment ($p<0.05$) after BFR-LLR training. According to the author's knowledge, no study compared the impact of HLR training and BFR-LLR training on knee joint function in the WOMAC questionnaire in knee OA patients.

Most recently, Hughes et al. (2017) did a systematic review that assessed all the previous studies that examined BFR training in clinical musculoskeletal management. They postulated that the BFR combined with LLR training does not seem to deteriorate their complaint.

We suggest that the BFR combined with LLR exercises can improve muscle strength and, consequently, physical performance by larger stimulation of fast-twitch muscle fibers (type II). This BFR would produce an anaerobic condition in the muscle belly, increasing type II muscle fibers activation while lowering slow-twitch muscle fibers (type I) activation. Our suggestion was supported by some authors (Laurentino et al., 2008; Wernbom et al., 2008). Other researchers believe the BFR benefits are linked to improved growth hormone release and the activating of the protein formation pathway (56).

A study was performed by Yokokawa et al. (2008) to investigate the impact of LLR training combined with BFR in comparison with dynamic balance exercises in aged patients who are at risk of developing knee OA. 51 patients aged 65 and up were randomized into two groups. Both groups' performance was evaluated before and after the 8-week treatment program. Post-treatment, there were general improvements in performance and balance. But there were no significant differences between groups. The functional mobility was evaluated using a timed up and go test.

An RCT was done by Bryk et al. (2016) to investigate if 34 knee OA patients with a mean age of 61 years who completed a treatment program containing low-load strengthening exercises and incomplete vascular occlusion had similar functional improvement as patients who completed a program containing high-load exercises. TUG was used to assess functional performance after a six weeks rehabilitation program. The result revealed that a treatment program involving incomplete vascular occlusion combined with low-load strengthening exercises had the same functional improvements as a program containing high-load strengthening exercises in knee OA patients.

The current study revealed a statistically significant improvement in knee joint proprioceptive accuracy after BFR-LLR training. According to the authors' knowledge, no studies examined the impact of BFR combined with any therapeutic exercise on knee joint proprioception.

5. CONCLUSIONS

Conventional HLR training and LLR-BFR training are efficient in managing knee OA by improving quadriceps muscle strength, enhancing the function of the knee joint, and proprioceptive accuracy. However, it can be noted that the LLR-BFR training had a lower mean value of WOMAC and Proprioception and a higher mean value of HHD than the HL group. Thus, the LLR-BFR training appears to be more tolerable for elderly knee OA patients.

6. RECOMMENDATIONS

Based on the results of our study, we recommend the following:

- Further studies with other outcome measures (with a period of follow-up) are needed to investigate the impact of LLR in combination with BFR in knee OA patients.
- Further research is essential to determine the effects of BFR in combination with other types of therapeutic exercise, also to investigate how BFR affects other musculoskeletal problems.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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