

REVIEW ARTICLE

Literature review: The effect of blood flow restriction training on enhancement strength quadriceps muscles in anterior cruciate ligament (ACL) injuries

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Abstract

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Anterior cruciate ligament injury is one of the most common ligament injuries in adults. The aim of this study was to analyze the available literature on the effect of BFR training on quadriceps muscle strength in ACL injuries. The method used is a literature study in accordance with PRISMA guidelines. A systematic search was conducted using ScienceDirect, Scopus, and Springer. The articles included in this study had the following inclusion criteria: related to the effect of BFR training on quadriceps muscle strength in ACL injuries, experimental research, published from 2016 to 2023. The results of this study showed that of the 240 articles identified, 10 articles that met the inclusion criteria were included in this systematic review. 6 of 10 studies showed a significant increase in quadriceps muscle strength associated with BFR training compared to controls; 2 of 10 noted increased quadriceps muscle strength, but no significant difference compared with controls; and 2 out of 10 reported no significant increase in the use of BFR training in quadriceps muscle strength. The conclusion of the study shows that although the dosage and intervention parameters of BFR training vary, low-intensity BFR training is still useful for increasing quadriceps muscle strength in ACL injuries. Further research is needed to find optimal occlusive pressures and refine protocols to maximize training gains.

Introduction

The Anterior Cruciate Ligament (ACL) is one from four ligament functioning knee guard stability joints knee. Ligaments This works as stabilizers that prevent exists shift to excessive front, of tibia bone against stable femur, or prevent exists shift to excessive rear from femur bone against stable tibia bone (Ikhwan Zein, 2015). ACL is one of them the most common ligament experience injury especially in athletes. Incidence rate ACL injury is around 30-78 cases in 100,000 people (Priono et al., 2018). According to the World Health Organization (WHO) in 2019, it is estimated that as many as 200,000 incidents of cruciate ligament injuries occur every year. Around 70% of them occur due to non-contact mechanisms when playing agility sports, such as basketball, football and skiing, while the remaining 30% occur due to direct contact mechanisms. Of all cruciate ligament injury incidents, almost half of the total numbers of incidents are incidents of ACL ligament tears (Kochhal et al., 2019).

Priono et al. (2019) explains that happen injury to the ACL can caused by existence trauma mechanisms with position knee rotation, hyperextension (non-pivoting injury) or

Because contraction muscle quadriceps femoris occurs in a way suddenly. There can be an injury to the ACL result instability knee and resulting change function the knee will influence activity daily (Herman & Komalasari, 2022). Weakness muscle quadriceps often appears after happen ACL injuries and also related tightly with decreasing ability function knee post ACL reconstruction (Kacin et al., 2021). For someone or experienced athletes ACL injury, there are two methods for treat injury that is method operative and non- operative methods. Utilise modality therapy like ultrasound and diathermy, uses knee brace, and strengthening program muscle used in non- operative therapy, meanwhile technique reconstruction used in therapy operative. Reconstruction is method operative for replace ACL ligament uses other materials (graft). Generally graft the taken of the hamstring tendon or patellar tendon patient That Alone so that called autograft (Ikhwan Zein, 2015). Reconstruction (operative) is one choice main handling ACL injuries compared with action sewing repair of the broken ACL ligament or torn, because sewing repeat often experience failure. This thing happens because the ACL ligament does

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not have fibrin so that in each the tear that occurred No can experience healing yourself.

One of the problems that arise in the ACL injury rehabilitation process is the long time required for injury rehabilitation, where the average time required is around 9-12 months (Grindem et al., 2016). Recovery in need time long enough to be injured or post ACL reconstruction, resulting decline mass and strength muscles, especially muscle quadriceps (Iversen et al., 2016). The results of the study by Yang et al. (2019) explain that there is permanent quadriceps muscle atrophy and decreased strength in patients after ACL reconstruction. Decline strength muscle quadriceps and decline mass muscle can impact negative on performance athlete likewise with activities life every day. Because that is necessary fast method with results good for problems that exist in patients quick resolved. One of them is using blood flow restriction (BFR) training. BFR training is something method combination between exercise intensity low with hinder Genre blood from both arteries and veins enter or who came out from muscle (Scott et al., 2015).

Mario (2016) explains that blood flow restriction (BFR) training is form exercise resistance intensity safe low for implemented and capable increase growth muscle, increase strength muscle, through delivery oxygen and utilization (VO_2max). Application BFR training method done with method install tourniquet or rubber ligature in the proximal area from muscles that want trained (Hughes et al., 2018). The training dose given is at a low intensity of around 20-30% of 1 RM (maximum repetition), with 15-30 repetitions per set, and a short rest period between each set, namely 30 seconds (Bowman et al., 2019). The results of research conducted by Kacin et al., (2021) stated that BFR training is capable increase strength muscle quadriceps in ACL injuries, as well as research conducted by Vieira et al. (2022), and Hughes et al., (2019) found that BFR training effective in increase strength muscle quadriceps and muscles hamstrings in patients post AC reconstruction. Whereas results research by Curran et al., (2020) found that there was no significant effect of providing BFR training on increasing quadriceps and hamstring muscle strength in patients after ACL reconstruction.

Based on the background and results of several previous studies, researchers found that there were still inconsistencies in the results regarding BFR training being able to increase quadriceps muscle strength in ACL injuries seeing the fact that ACL injuries are one of the most common types of injuries that occur every year.

Methods

Type of research used is studies References or review references because researcher will study results study before. Literature study is a research design used to collect

data sources related to a topic obtained. There is no general agreement regarding the use of several articles as research samples regarding the last year of the article used, but in most studies that have been conducted by previous researchers using the last 3 to 10 years the article was published (Hadi et al., 2020). This research selects articles and presents several research results that are in accordance with the predetermined themes. The article that will be reviewed and is in accordance with the research topic is the difference in the influence of blood flow restriction on increasing the quadriceps muscle in anterior cruciate ligament (ACL) injuries. The data screening process from the total population of 872 will use Preferred Reporting Items for Systematic Reviews and Meta Analyzes (PRISMA). The flow of information from the prism can be seen in the image below as follows.

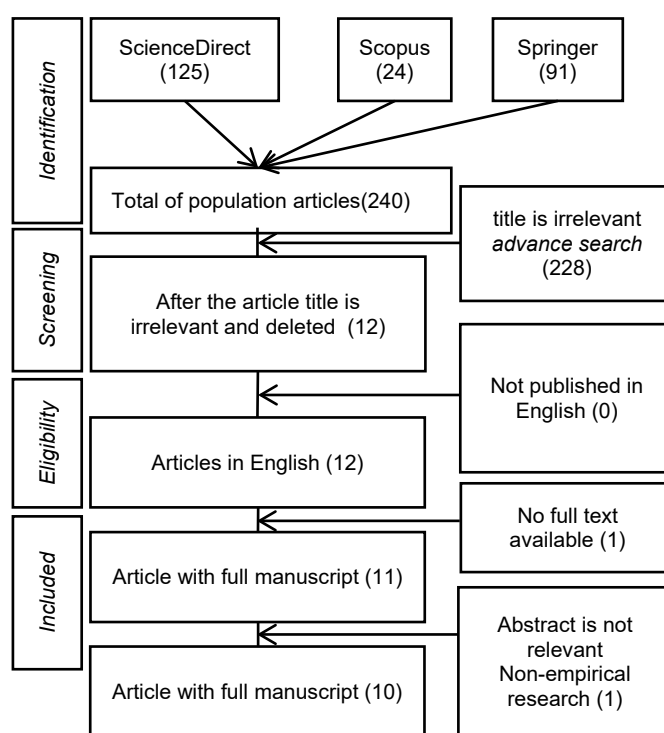


Figure 1. Article Screening Process.

Results

The aim of this study was to determine the effect of BFR on increasing quadriceps muscle strength in ACL injuries. The research system used is literature research using a literature review to obtain results in the form of the effect of BFR on increasing quadriceps muscle strength in ACL injuries. After searching several databases using a combination of keywords related to the research that had been determined, ScienceDirect obtained 125 articles, Scopus 24 articles, and Springer 91 articles. After carrying out the screening, eligibility, and inclusion processes, a sample of 7 articles

was obtained. After that, a review of the articles is carried out using the Quartile standard, and then the PEDro Scale will be used to assess each article used.

Table 1. PEDRO checklist.

<i>Blood Flow Restriction Training Applied With High-Intensity Exercise Does Not Improve Quadriceps Muscle Function After Anterior Cruciate Ligament Reconstruction - A Randomized Controlled Trial (Curran et al., 2020)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	✓	x	✓	x	x	x	✓	x	✓	✓
PEDro scale score 6/11											
<i>Comparing the Effectiveness of Blood Flow Restriction and Traditional Heavy Load Resistance Training in the Post-Surgery Rehabilitation of Anterior Cruciate Ligament Reconstruction Patients: A UK National Health Service Randomized Controlled Trial (Hughes et al., 2019)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	✓	x	✓	✓	Not clear	✓	x	x	✓	✓
PEDro scale score 7/11											
<i>Intermittent blood flow restriction does not reduce atrophy following Anterior Cruciate Ligament reconstruction (Iversen et al., 2016)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	✓	x	✓	x	x	x	x	x	✓	✓
PEDro scale score 5/11											
<i>Effects of Rehabilitation Exercise with Blood Flow Restriction after Anterior Cruciate Ligament Reconstruction (Jung et al., 2022)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	Partials	x	Partials	x	x	x	✓	Partials	✓	✓
PEDro scale score 4/11											
<i>Functional and molecular adaptations of quadriceps and hamstring muscles to blood flow restricted Training in patients with ACL rupture (Kacin et al., 2021)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	✓	x	✓	x	x	x	✓	✓	✓	✓
PEDro scale score 7/11											
<i>Exercise with Blood Flow Restriction to Improve Quadriceps Function Long After ACL Reconstruction (Kilgas et al., 2019)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	x	x	✓	x	x	x	✓	✓	✓	✓
PEDro scale score 4/11											
<i>Effects of Neuromuscular Electrical Stimulation and Blood Flow Restriction in Rehabilitation after Anterior Cruciate Ligament Reconstruction (Kong et al., 2022)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q2	✓	✓	x	✓	x	x	x	✓	x	✓	✓
PEDro scale score 6/11											
<i>Effect of quadriceps Training at different levels of blood flow restriction on quadriceps strength and thickness in the mid-term postoperative period after Anterior Cruciate Ligament reconstruction: a randomized controlled external pilot study (Li et al., 2023)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q2	✓	✓	x	✓	x	x	x	✓	✓	✓	✓
PEDro scale score 7/11											
<i>Blood Flow Restriction Therapy for Two Weeks Prior to Anterior Cruciate Ligament Reconstruction Did Not Impact Quadriceps Strength Compared to Standard Therapy (Tramer et al., 2023)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	✓	x	✓	x	x	x	✓	x	✓	✓
PEDro scale score 6/11											
<i>Comparison of quadriceps and hamstring muscle strength after exercises with and without blood flow restriction following Anterior Cruciate Ligament surgery: a randomized controlled trial (Vieira de Melo et al., 2022)</i>											
Q	Eligibility criteria	Random allocation	Hidden allocation	Basic compatibility	Subjects were blinded	Therapists were blinded	Raters were blinded	Basic follow-up	Basic analysis	Comparison between groups	Point estimation and variability
Q1	✓	✓	Unclear	✓	x	x	x	✓	Unclear	✓	✓
PEDro scale score 6/11											

After find a number of article and accordingly with Q1 to Q4 and has through an assessment process through Pedro scale, next will described PICO from every articles used. The PICO standard is points in criteria inclusion in the study this, is used for determine Appropriate and relevant articles are used as foundation in studies this. PICO standards ensure that the study you are looking for in accordance with statement clinical. The PICO standard consists of from a number of points namely P: Population or the problem being analyzed in accordance with theme that has been determined in do study literature review, I: Intervention is giving something action from appropriate problem with themes discussed in the research literature review, C: Comparison is something action used as comparison from intervention, usually shared group in the design study from article , and O: Outcome is results end or output that has been found at a time appropriate research with theme research raised (Wibowo & Putri, 2021).

PICO standard plays a big role in determine articles used as the basis for this research. In 8 articles used as foundation in research this is the population used own condition weakness strength muscle quadriceps consequences ACL injury, meanwhile for interventions provided in the article the using BFR. The result of all articles found show that BFR has effect related with strength muscle quadriceps.

Furthermore will explained related with all over type interventions used and outcomes from study that is discussed about BFR training or eccentric exercise. In the Table 3, this will attached in a way detailed related with interventions and outcomes study from all appropriate articles with criteria inclusion from study this.

Discussion

In general, based on research results from several articles, it was found that there were significant differences between

the low intensity BFR training group compared to the group without BFR. Research conducted by Li et al in 2023 provided training at various BFR levels, namely 40% AOP compression and 80% AOP compression combined with conventional quadriceps rehabilitation for a total of 16 training sessions over 8 weeks, with each session lasting around 60 minutes. The training sessions included warm-up, quadriceps muscle training, and stretching exercises, both the AOP 40% and AOP 80% groups showed an increase in outcome indicators compared to the control group, but training with AOP 80% compression intensity showed a significant increase in quadriceps muscle strength and thickness compared to the control group ($p < 0.01$). The combination of low-intensity BFR training with quadriceps training can effectively increase muscle strength and thickness in participants after ACL reconstruction (Li et al., 2023).

Implementation of BFR training for participants five to five seven year post ACL reconstruction, which is still experience difference strength quadriceps muscles $\leq 90\%$ asymmetrical. Exercises are done at home for 25 minutes, 5x per week for 4 weeks with exercise includes single-leg knee extensions, bodyweight half-squats, and toe walking cuff compression of 50%, capable increase thickness and strength quadriceps muscles, as well reduce asymmetry strength (Kilgas et al., 2019). Kacin et al., 2021 divide group exercise at BFR intensity low (LL-BFR) and false vascular occlusion (SHAM-BFR) for carry out 9 sessions exercise done three times a week on the injured leg. After 3 weeks, peak torque in the extensors knee show LL-BFR results experienced enhancement strength extensor knee (quadriceps muscle) 14% compared to SHAM-BFR 1.3% (Kacin et al., 2021). Implementation exercise in the BFR group and group control for 12 weeks on the injured leg proved more efficient for increase strength quadriceps and hamstring muscles than the same exercise without BFR (Vieira de Melo et al., 2022).

Table 2. PICO Standard.

No	Title	Population	Intervention	Comparison	Outcomes
1	Blood Flow Restriction Training Applied with High-Intensity Exercise Does Not Improve Quadriceps Muscle Function After Anterior Cruciate Ligament Reconstruction - A Randomized Controlled Trial (Curran et al., 2020)	34 patients scheduled to undergo ACL reconstruction. The average age is 16.5 years.	Concentric training intensity high, eccentric exercise, intensity tall	Concentric with BFRT, Eccentric with BFRT.	Addition of BFR training with high-intensity training does not provide better results compared to high-intensity training alone on quadriceps muscle function in patients undergoing reconstruction ACLs.
2	Comparing the Effectiveness of Blood Flow Restriction and Traditional Heavy Load Resistance Training in the Post-Surgery Rehabilitation of Anterior Cruciate Ligament Reconstruction Patients: A UK National Health Service Randomized Controlled Trial (Hughes et al., 2019)	24 patients post ACL injury	BFR Resistance Training (BF-RT)	Traditional Heavy Load Resistance Training (HL-RT)	BFR Resistance Training can increase muscle size and strength quadriceps was almost as effective as HL-RT.

Table 2. PICO Standard (Continued).

3	Intermittent blood flow restriction does not reduce atrophy following anterior cruciate ligament reconstruction (Iversen et al., 2016)	24 patients post ACL injury ages 18-40 year who planned the operation. No previous knee injury, and ACL injury no more than 6 months before surgery)	Intermittent BFR	Control group	Application of intermittent BFR for 14 days after ACL reconstruction did not reduce quadriceps muscle atrophy, as measured by MRI, in an athlete population.
4	Effects of Rehabilitation Exercise with Blood Flow Restriction after Anterior Cruciate Ligament Reconstruction (Jung et al., 2022)	24 p patient post reconstruction ACLs	BFR training program	General rehabilitation exercise (GRE) program without BFR	Both groups showed improvements, but the BFR group showed superior results (improved muscle activity, muscle function, and overall recovery)
5	Functional and molecular adaptations of quadriceps and hamstring muscles to blood flow restricted Training in patients with ACL rupture (Kacin et al., 2021)	12 patients with ACL rupture planned for ACL reconstruction, age 37.5 ± 9 years)	Low load blood flow restriction (LL-BFR) training.	SHAM-BFR training (same training as sham vascular occlusion)	Changes in muscle strength, muscle size, transcriptional response of hypoxia-regulated genes (e.g. HIF-1 α , VEGF-A), and myokines (e.g. IL-6, musclin).
6	Exercise with Blood Flow Restriction to Improve Quadriceps Function Long After ACL Reconstruction (Kilgas et al., 2019)	9 p patient post ACL injury and 9 patients without ACL injury.	BFR exercise	Conventional low weight resistance training	BFR exercises as effective intervention for increase function quadriceps long post ACL reconstruction.
7	Effects of Neuromuscular Electrical Stimulation and Blood Flow Restriction in Rehabilitation after Anterior Cruciate Ligament Reconstruction (Kong et al., 2022)	45 patients underwent reconstruction ACL (Age 28.76 ± 0.8 years)	Rehabilitation exercise (RE) + NMES rehabilitation exercise (RE) + BFR	Rehabilitation exercise (RE)	RE using NMES and BFR effectively improves muscle function and balance in ACL reconstruction patients.
8	Effect of quadriceps training at different levels of blood flow restriction on quadriceps strength and thickness in the mid-term postoperative period after anterior cruciate ligament reconstruction: a randomized controlled external pilot study (Li et al., 2023)	30 patients post ACL injury	BFR 40% AOP BFR 80% AOP	Control group	BFR combined with muscle training Low-intensity quadriceps can effectively improve muscle strength and thickness in post- patients reconstruction ACL, especially when using 80% AOP compression.
9	Blood Flow Restriction Therapy for 2 Weeks Prior to Anterior Cruciate Ligament Reconstruction Did Not Impact Quadriceps Strength Compared to Standard Therapy (Tramer et al., 2022)	45 patients with ACL rupture, mean age 26.5 ± 12.0	BFR	Control	Significant improvements in personal quadriceps peak strength measurements, both with and without BFR use.
10	Comparison of quadriceps and hamstring muscle strength after exercises with and without blood flow restriction following anterior cruciate ligament surgery: a randomized controlled trial (Vieira de Melo et al., 2022)	28 patients post ACL injury.	Exercise with BFR.	Same workout without BFR.	Practice with BFR more effective in increase strength muscle quadriceps and hamstrings compared to with exercise without BFR in the patient post ACL reconstruction.

In research conducted by Kong (2022), there were 45 patients post ACL reconstruction retrospective shared become three group that is group control, NMES and BFR. All participant carry out the RE program for 60 minutes, three times a week for 12 weeks. Show results Where strength as well as Power stand quadriceps and hamstring muscles suffer significant improvement through interventions on NMES and BFR, compared with CON ($p < 0.05$) in patients post ACL reconstruction (Kong et al., 2022). Meanwhile, Jung et al. (2022) divided into 2 groups into the BFR group carried out an exercise program rehabilitation general with use Smart Cuffs device, and the GRE group did a practice program rehabilitation the same general without BFR. Applied for 4 weeks post ACL reconstruction, the BFR group showed significant improvement in functionality muscle isokinetic, including peak torque ($p = 0.005$, $h_2 = 0.311$) and total work ($p = 0.015$, $h_2 = 0.240$). Found exists significant increase in peak

torque ($p < 0.01$) and total work ($p < 0.05$) in BFR (Jung et al., 2022).

BFR resistance training involves use tourniquet system for limit part Genre blood to exercising muscles while use burden mild external (30% of 1RM), in comparison with traditional heavy load training (HL-RT) training programs resilience traditional with burden more external weight (70% of 1RM) without restrictions genre blood. Second group complete a rehabilitation program for 8 weeks covering. Unilateral leg press training is carried out for two weeks once on the second limbs, for a total of 16 sessions. Although second group experience enhancement strength significant quadriceps muscle gain, after 8 weeks exercise enhancement strength 10RM scale in the BFR resistance training group was $104 \pm 30\%$ and $33 \pm 13\%$, compared with HL-RT group, namely $106 \pm 43\%$ and $39 \pm 17\%$ in injured and uninjured limbs (Hughes et al., 2019).

Table 3. Interventions and outcomes study.

No	Articles	Intervention	Results
1	Curran et al. (2020)	<ol style="list-style-type: none"> 1. Group intervention eccentric and concentric, leg press isokinetic one leg, with intensity 70% 1RM, 4 sets x 10 rep, 2x/ week, for 8 weeks starting at 10 weeks post operation. 2. Patient in the BFR group did exercise leg press with cuff mounted on the thigh, set to pressure occlusion extremities by 80%. 	BFR training for 8 weeks added intervention exercise intensity tall No in a way significant increase strength , activation , or muscle volume quadriceps compared with without BFR training (P > 0.05).
2	Kacin et al. (2021)	<ol style="list-style-type: none"> 1. L-BFR, 9 sessions training 3x/ week, 4 sets/ session (extension and flexion knee at 40 RM to fail total) in the injured limb with burden constant. After warmup beginning with burden minimum work (10-12x), cuff pumped to 150 mmHg let it go while muscle rest 30 seconds, then exercise extension knee isotonic until failure, after first and third sets, 45 seconds Rest without reperfusion. After the second set, cuff deflated. For reperfusion for 90 seconds. Same protocol. Then repeated For exercise flexion knee. 2. SHAM-BFR, do protocol the same exercise with amount the same repetition with BFR group, with inflated cuff only 20 mmHg. 	Change CSAquad in a way significantly (p < 0.01) more greater in BFR (4.9%) in comparison with SHAM-BFR (1.3%). Likewise, peak torque changes extensor knee in a way significantly (p < 0.05) greater in BFR (14%) in comparison with SHAM-BFR (-1%). In conclusion, training increases knee extensor strength and endurance but has less effect on knee flexors.
3	Hughes et al. (2019)	<ol style="list-style-type: none"> 1. Blood Flow Resistance Training (BFR-RT) (4 sets of 30,15,15 and 15 repetitions each exercise Unilateral leg press with 30 seconds Rest each set along 0-90 ° ROM with 30% 1RM) 2. Traditional Heavy Load Resistance Training (HL-RT) (3x 10 repetitions exercise unilateral leg press with 30 seconds Rest each set, throughout 0-90 ° ROM at 70% 1RM) 3. Second group complete a rehabilitation program for 8 weeks covering training Unilateral leg press 2x/ week on both sides limbs, for a total of 16 training sessions. 	The BFR-RT and HL-RT groups experienced enhancement significant in scale 10RM power on members injured body and not injury during period 8 weeks training , strength 10RM scale in the BFR resistance training group was 104 ± 30% and 33 ± 13%, compared with HL-RT group , namely 106 ± 43% and 39 ± 17% in the injured and uninjured limbs , respectively . Nothing significant difference between second group in matter enhancement strength muscle.
4	Iversen et al. (2016)	<ol style="list-style-type: none"> 1. Intermittent BFR (started on day 2 post injury, got stimulation occlusion for 5 minutes, followed by removal of occlusion pressure for 3 minutes. Repeated 5x in one training session, 2x a day. During the occlusion stimulus period, subjects performed 20 low-load muscle exercises quadriceps). 2. Control group (followed the same training protocol as the occlusion group but did not receive the occlusion stimulus) 	Second groups (intermittent BFR and control) experienced decline wide cross section anatomy muscle quadriceps (ACSA) significant (p < 0.0001) since 2 days before injury up to 16 days post construction.
5	Jung et al. (2022)	<ol style="list-style-type: none"> 1. General Rehabilitation Exercise Group (GRE) (ROM exercises, exercises withhold weights, CKC and OKC training for 60 minutes, 3x/ week, 12 weeks) 2. Blood Flow Restriction Group (BFR) (rehabilitation program general with applying BFR 40% pressure using device Smart Cuffs) 	BFR group showed significant improvement in functionality muscle isokinetic, including peak torque (p = 0.005, h2 = 0.311) and total work (p = 0.015, h2 = 0.240). Found exists significant increase in peak torque (p < 0.01) and total work (p < 0.05) on BFR .
6	Kilgas et al. (2019)	<ol style="list-style-type: none"> 1. Participants post ACL injury (BFR home exercise program for 25 minutes, 5x/ week for 4 weeks . which includes exercise single-leg knee extension, bodyweight half-squat and walking with BFR 50 %). 2. Group control (participant without injury) 	Application BFR workouts at home , even a number of year post ACL injury , shows exists enhancement strength muscle quadriceps 20 ± 14 % in the trained leg (p<0.01).
7	Kong et al. (2022)	<ol style="list-style-type: none"> 1. CON group, practice started day 3rd after surgery, 60 minutes, 3x/ week, for 12 weeks. Exercise in the form of ROM exercises, exercises load, CKC, and OKC. 2. NMES, starting 4 weeks post surgery, ROM exercises and exercises the same load like CON group with implementing NMES. With device KneeHab (50 Hz frequency, time contractions 5 seconds, time 10 seconds of relaxation, and duration time 20 minutes). 3. BFR, the same CKC and OKC drills with CON group with implementing BFR. With device Smart Cuffs intensity intensity 10–30% 1RM, pressure 40% SBP, and increase 10 mmHg per 2 weeks. 	Significant improvement through interventions on NMES and BFR on strength muscle quadriceps (NMES, p = 0.001; BFR, p = 0.001). And there is significant improvement through interventions on NMES and BFR were compared with CON (p < 0.05).
8	Li et al. (2023)	<ol style="list-style-type: none"> 1. BFR AOP 40% + rehabilitation conventional quadriceps 2. BFR AOP 80% + rehabilitation conventional quadriceps 3. Group control (rehabilitation conventional quadriceps without BFR) <p>Entire patient operate intervention for 8 weeks, 2x/ week, 2 sessions per workout, 4 sets/ session, 30 reps on the first set, 15 reps on 2-4, rest between sets 30 seconds. Session the practice covers warm up, exercise quadriceps, and exercises stretching.</p>	Combination BFR drills and exercises muscle quadriceps (AOP 40% and AOP 80%) showed enhancement strength and thickness muscle quadriceps in patients post ACL injury. Practice with intensity 80% AOP compression provides greatest benefit significant compared to group control (p<0.01).
9	Tramer et al. (2022)	<ol style="list-style-type: none"> 1. BFR, training standard 5x/ week for 2 weeks with cuff pneumatic 80% pressure occlusion. 2. Control, training standard 5x/ week for 2 weeks. 	Significant improvement in measurement strength peak quadriceps personal, however there is no difference significant on strength muscle quadriceps between BFR and group control (P > 0.05).
10	Vieira de Melo et al. (2022)	<ol style="list-style-type: none"> 1. Exercise rehabilitation with BFR for 12 weeks (20–30% of strength maximum) 2. L same workout without BFR for 12 weeks 	Group that used BFR during exercise rehabilitation post suffered an ACL injury enhancement strength muscle significant quadriceps (p < 0.01) compared to with group controls that don't using BFR.

Research by Tramer et al. (2022) divided two groups randomly into the BFR group and, the BFR group was instructed to do basic exercises with a pneumatic cuff set at 80% of the extremity occlusion pressure placed on the

proximal thigh, while the control group only did basic exercises without BFR. Both groups exercised 5 days per week during the 2-week control period. After completing a 2-week home exercise protocol, both groups were able to

produce significant improvements in peak quadriceps muscle strength measurements. However, no significant differences were found in strength measures between the BFR and control groups (Tramer et al., 2023).

There is 1 article research shows that implementation of BFR does not reduce atrophy ACSA quadriceps muscles were measured with MR in the population athlete post ACL reconstruction ie is research by Iversen et al. (2016). Iversen et al. (2016) divided two groups in a way random, since 2nd day after surgery; the BFR group received an occlusion stimulus for 5 minutes, followed with disappearance pressure occlusion for 3 minutes, repeat five times in One session exercise, twice a day. During occlusive stimulus period, subject do 20 exercises burden low for quadriceps. Group control follow protocol the same exercise, but without occlusion stimulus. After 16 days post reconstruction, measurement return done, and obtained results group occlusion loss $13.8\% \pm 1.1\%$ (mean \pm SEM) and group control lost $13.1\% \pm 1.0\%$ ACSA of their quadriceps muscles respectively. So that not found significant difference between BFR group and group control connection with atrophy quadriceps muscle (Iversen et al., 2016). Research results 1 article others also expressed the addition of BFR training does not in a way significant increase strength, activation, or volume of quadriceps muscles in patients undergoing ACL injury when combined with exercise intensity high where the p value is > 0.05 (Curran et al., 2020). Eight article proves that BFR training is capable increase strength quadriceps muscle in ACL injury. However, 2 articles study report the use of BFR training is not in a way significant increase strength quadriceps muscles compared with group control (Curran et al., 2020; Iversen et al., 2016). There are differences results This Possible caused by various factor including However No limited to size cuff, pressure occlusive, duration session maintenance individual, duration period intervention and intensity the practice.

Although on some article results BFR training research is sufficient promising, however base deep BFR physiology increase strength muscle Still need explored. BFR training is something method combination between exercise intensity low with hinder Genre blood from both arteries and veins enter or who came out from muscle (Scott et al., 2015). Usage cuff pneumatics placed in the most proximal location in the BFR training program are capable give vein occlusion in the targeted muscle so that possible happen atrophy or disappearance mass muscle because happen shrinkage consequence from reduced incoming oxygen in muscle. The reduced oxygen supply to the muscles during exercise using BFR training contributes to increased fatigue and also reduces the energy of production, which leads to

increased motor unit recruitment. Subsequently, increased production of reactive oxygen species, such as oxide nitrate, results from the fluctuation of oxygen, thereby activating the cell satellite, which can stimulate muscle growth (Humes et al., 2020).

Conclusion

The review systematic shows that BFR training with intensity low beneficial for increase strength quadriceps muscle in ACL injury. However, research more carry on required for perfect protocol before can recommended for used in arrangement clinical. Invention that BFR training can increase strength quadriceps muscle in ACL injury indicates that method this worthy considered in a rehabilitation program. However, it's important for practitioner health for understand that patient own different responses to method rehabilitation this. Therefore that is adjustments to the rehabilitation program based on needs and abilities individual is very important for reach optimal results.

Conflict of Interest

The authors hereby declare that there was no conflict of interest in conducting this research.

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