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Addition of Blood Flow Restriction in Squat Exercises to Increase the Strength of Quadriceps Muscle Groups

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Abstract

The quadriceps muscle group is important for daily activities and generating power during sports, especially sports involving the lower extremities. Squat is an effective exercise to increase the strength of the quadriceps muscle group. The Blood Flow Restriction (BFR) can increase the load during exercise leading to a significant increase in strength. The purpose of this study was to determine the effect of adding BFR in squat exercises to increase MVIC values in the quadriceps muscle group. This research was a pilot study using an experimental method with a pretest-posttest control group design. The samples of this study were 11 respondents selected using a purposive sampling technique. The samples were divided into two groups. Group 1 involved 5 respondents given a squat training with BFR, while group 2 involved 6 respondents given a squat training without BFR. The measurement of muscle strength was carried out using SEMG with the MVIC method. The result of the effect test using the paired sample t-test in group 1 obtained p-values of rectus femoris (0.018), vastus medial (0.030), and vastus lateral (0.014). The test of group 2 gained p-values of rectus femoris (0.141), vastus medial (0.034), and vastus lateral (0.04). The result of independent t-test for the different effects of the test obtained p-values of the rectus femoris (0.885), vastus medial (0.211), and vastus lateral (0.404). It concludes that squat training with BFR could significantly increase the strength of the quadriceps muscle group. Meanwhile, the squat exercise without BFR did not significantly increase the strength of the rectus femoris muscle but there was a significant muscle strength on the vastus lateral and medial muscle. There was no significant difference in the effect of squat with BFR and squat without BFR.

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INTRODUCTION

Human activities cannot be separated from the influence of muscle strength, especially in the lower extremities, to carry out daily activities to avoid injury (Muehlbauer et al., 2015). In objective measurements, physical activity correlates more strongly with the lower extremity strength compared to the upper extremity (Leblanc et al., 2015). Muscle strength is important, especially for athletes, to produce the maximum strength (power) during sports (Schoenfeld et al., 2015). In sports, one of the skills that requires power is the lower extremities for running or jumping, such as in soccer, volleyball, basketball, and so on (Rodríguez-Rosell et al., 2016).

One of the muscle regions that plays an important role in the lower extremities is the quadriceps muscle (m. rectus femoris, m. vastus medialis, m. vastus intermedius, and m. vastus lateralis). The quadriceps muscle is the largest muscle group that passes through the knee joint (Nooryana et al., 2022). This muscle group plays a role in knee extension, hip flexion, walking, and maintaining patella stability. The strength of the quadriceps muscle group is important for daily activities, such as for shifting from sitting to standing or climbing stairs (Bordoni & Varacallo, 2022). To increase the strength of the quadriceps muscle group, you can do a resistance training, including squatting (da Silva et al., 2017).

Squats are the most common exercises to activate and increase the lower extremity muscle strength. Squat exercises involve contractions of various muscles, namely the quadriceps muscle group as well as the co-contraction of the hamstrings and gastrocnemius muscle groups (Lee et al., 2022). Squats are included in the close kinetic chain exercises which require a lot of joint movement in the lower extremities (Kojic et al., 2021).

Exercises to increase muscle strength can be combined with the Blood Flow Restriction (BFR). These exercises can increase the muscle strength and hypertrophy to a greater degree than the low-load resistance training alone, without BFR (Early et al., 2020). In the resistance training, it is necessary to carry out progressions by increasing the training dose (overload) by changing the modulation of training variables to facilitate the increased muscle strength and endurance (Pristianto et al., 2018). An exercise with BFR involves decreasing blood flows to the muscle by applying an external constriction device, such as a blood pressure cuff or tourniquet (Slysz et al., 2016). The tourniquet is applied to the proximal area of the muscle to be trained (Saputra et al., 2022). Blood Flow Restriction (BFR) training can trigger increased muscle fiber recruitments and increased levels of Growth Hormone (GH) so that it can increase the muscle strength and hypertrophy (Christian et al., 2014).

Muscle performance can be assessed with an electromyography (EMG). In some studies, EMG is used to measure muscle conditions. Maximum isometric muscle contraction data on EMG can be normalized by using Maximum Voluntary Isometric Contraction (MVIC) (Illera-Domínguez et al., 2018). MVIC normalization is a method with a high reliability used in measuring the muscle strength and has become a standard for evaluating and studying muscle activities (Lee & Jo, 2016). The assessment of muscle activation can be conducted through the Surface Electromyograph (sEMG) method. Typically, this approach is employed to identify muscle groups engaged in an activity. It offers crucial insights to identify active muscles and assess the intensity of muscle activation during the walking process (Pristianto al., 2024). This study aimed to determine the effect of adding BFR in squat training on MVIC values in the quadriceps muscle group. Based on the description above, to improve the ability of the quadriceps muscle group, we conducted research by adding BFR. The aim of this research was to see whether the addition of BFR is effective in increasing the quadriceps muscle group.

METHODS

Participants

This This research used a pilot study design. The method used was the quasi experimental with pretest-posttest control group design. The population of this study were 25 students joining the futsal community. The samples of this study were 11 respondents.

Sampling Procedures

The sampling technique of this research used the purposive sampling, in accordance with predetermined criteria. Inclusion criteria included (a) male respondents, (b) 19-25 year old, (c) having a normal knee alignment during inspections, (d) having a normal Q-Angle, and (e) willing to take part in the research. Exclusion criteria involved (a) having a history of lower extremity fractures, (b) having a valgus posture in the lower extremities, and (c) having intermittent claudication disorders. The sample was declared a drop out when (a) the respondent did not participate in the training process 3 times in a row and (b) the respondent suddenly became ill.

Table 1. Characteristics of Respondents

Characteristics	Group 1 (n=5)		Group 2 (n=6)	
	Frequency	(%)	Frequency	(%)
Gender				
Male	5	100%	6	100%
Age (Year)				
19	1	20%	1	16.7%
20	2	40%	0	0%
21	1	20%	3	50.0%
22	1	20%	2	33.3%
Total	5	100%	6	100%
Q-Angle				
Right				
12-20 (Normal)	5	100%	6	100%
Left				
13-20 (Normal)	5	100%	6	100%

Materials and Apparatus

Strength measurements were carried out through muscle activations using the MVIC method using sEMG with units of μV on a ratio scale. Electrodes were placed on the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles according to SENIAM guidelines.

Procedures

The division of the samples into 2 groups in this study was carried out randomly using a lottery. Group 1 (experimental) was given the treatment with the addition of BFR in the squat training, while Group 2 (control) was given a squat training without the addition of BFR. As a form of training progressions and the overload principle, the number of repetitions was increased periodically (Pristianto et al., 2018). The training program for both groups was conducted 3 times/ week for 4 weeks in 4 sets (intensity) with 18, 17, 16, 15 repetitions in week 1. The rest time was 30 to 60 seconds per set. The BFR tool used was the BFR Band measuring 5 cm x 66 cm with the Livepro brand.

Table 2. Training Programs

Weeks	Group 1		Group 2	
	BFR in Squat Training		Squat Training	
1	4 Sets	15 Reps	4 Sets	15 Reps
2	4 Sets	16 Reps	4 Sets	16 Reps
3	4 Sets	17 Reps	4 Sets	17 Reps
4	4 Sets	18 Reps	4 Sets	18 Reps

Data Analysis

The data analysis techniques used were the normality test using Saphiro Wilk, the influence test using the paired sample t-test, and the difference of influence test using the independent t-test. This research was conducted based on EC number: 087/EC/XII/2022 dated 21 November 2022 issued by the Research Ethics Committee of RST dr. Soedjono Magelang.

RESULT

The characteristics of respondents in this study were based on the inclusion and exclusion criteria so that the following data were obtained:

From the characteristics of respondents presented in Table 1, it can be seen that respondents in Group 1 and Group 2 had a minimum age of 19 and a maximum of 22 years. The age of most respondents in Group 1 was 20 years with a frequency of 2 and a percentage of 40%. In Group 2, the highest age data was 21 year old with a frequency of 3 and a percentage of 50%. The right and left quadriceps angle (Q-Angle) of all respondents in Group 1 and Group 2 were in the normal category.

The measurement of the quadriceps muscle group strength using the MVIC value obtained the following average results:

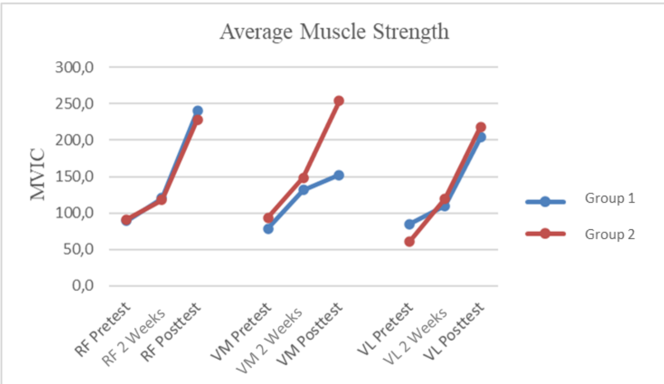

Fig 1. The Average Muscle Strength Graph

The image above is a graph of the average strength of the quadriceps muscle groups (m. rectus femoris (RF), m. vastus medialis (VM), and m. vastus lateralis (VL)). The image shows an increase in the strength of the RF, VM, and VL muscles in Group 1 and Group 2. The increase of strength in the RF muscle was higher in Group 1 compared to Group 2. Meanwhile, the increase in the VL and VM muscles was higher in Group 2 compared to Group 1. The normality test in this study was carried out using the Shapiro Wilk test. The effect test was carried out using a paired sample t-test and the following results were obtained:

Table 3. Effect Test Results (Paired Sample T-Test)

Muscle	Explanation	Mean Diff.	SD	p-value	Conclusion
RF	G1 Post-Pre	151.3	86.7	0.018	Ha accepted
	G2 Post-Pre	137.4	192.4	0.141	Ha rejected
VM	G1 Post-Pre	73.5	49.7	0.030	Ha accepted
	G2 Post-Pre	160.8	136.3	0.034	Ha accepted
VL	G1 Post-Pre	119.3	64.5	0.014	Ha accepted
	G2 Post-Pre	157.5	77.1	0.004	Ha accepted

Based on Table 3 above, in Group 1, the RF, VM, and VL muscles obtained a p-value < α value (0.05), meaning that Ha was accepted. It can be said that the squat training with BFR could influence the strength of the quadriceps muscles (RF, VM, and VL).

Table 4. Effect Difference Test Results

Muscle	Group	n	Mean	SD	Levene's test	p-value
RF	1	5	151.3	86.7	0.046	0.885
	2	6	137.4	192.4		
VM	1	5	73.5	49.7	0.090	0.211
	2	6	160.8	136.3		
VL	1	5	119.3	64.5	0.376	0.404
	2	6	157.4	77.1		

In Group 2, the RF muscle had a p-value of 0.141 > 0.05, meaning that Ha was rejected, concluding that a squat training alone had no effects on increasing the RF muscle strength. Meanwhile, the VM (0.034) and VL (0.004) muscles had a p-value <0.05, meaning that Ha was accepted, concluding that the squat training could influence the strength of the VM and VL muscles.

Based on Table 4, the results of the Levene's test on the RF muscle were not homogeneous with a significance of 0.046 < 0.05. The significance value of the VM muscle was (0.201) and the VL muscle was (0.324); as the significance value was set at > 0.05, the data were homogeneous. The obtained p-values were RF muscle (0.885), VM muscle (0.211), and VL muscle (0.404) so that the p-values were > 0.05. It indicated that there was no effect differences of the two treatments on increasing the strength of the quadriceps muscle group in Group 1 and Group 2.

DISCUSSION

Respondents in this study were men aged 19-22 years. At this age, the cross-sectional area (CSA) that occurs in men is larger than in women in all types of muscle fibers, namely Type I and Type II (Esbjörnsson et al., 2021). All respondents had a normal Q-Angle so that the Vastus Medialis (VM) and Vastus Lateralis (VL) muscles were more stable. A larger quadriceps angle (Q-Angle) can increase the pressure on the Patellofemoral Joint, causing an imbalance between the VM and VL muscles (Hwangbo, 2015). The Q-Angle was measured using a universal Goniometer. This angle is obtained by paying attention to the meeting point formed by two lines crossing at the center of the patella. The Q-Angle only impacts lower leg measurements in the frontal plane, so the distance between the upper hip and knee joints affects the quality of the abduction and adduction muscles, possibly causing weakness or stiffness (Naufal et al., 2019).

Based on the results of this study, the control group with Squat Training without BFR could increase a significant strength in the VM and VL Muscles, but there was no significant effects on the Rectus Femoris (RF) muscle. In the graph showing the average increase in the muscle strength, there was an increase in the strength of the quadriceps muscle groups (RF, VM, and VL). Changes in the muscle strength after the exercise are the results of the combination of neurological activations and skeletal muscle adaptations. Resistance trainings increase the concentration of the Cortisol, Testosterone, Growth Hormone (GH), IGF-1, and insulin hormones as a response to the exercise, where the higher the training volume, the greater the increase. Increasing the Anabolic Hormones, Testosterone, Growth Hormone, and IGF-1 is beneficial for increasing the muscle strength and hypertrophy (Mangine et al., 2015). In this study, most muscles experienced higher increases in strength after 2 weeks of training. This might be due to the greater training volume, which increased the adaptive response.

There was no significant effects in the RF muscle in the control group because the RF muscle is not the main target of the squat training. The vastus muscle provides much greater excitation than the RF during the squat movement. This is due to the biarticular nature of the RF, which in addition to crossing the knee joint, also crosses the hip joint. Therefore, RF does not make a significant contribution to the knee extension during hip flexions, especially in the proximal part (Ribeiro et al., 2022). To maximize the RF muscle strength, additional exercises are needed for an optimal RF training due to the multi-joint function of these muscles (Kojic et al., 2021). The single joint knee extension exercise is more suitable for training the RF muscles (Ema et al., 2016).

The experimental group given the squat training with BFR resulted in a significant increase in the strength of the quadriceps muscle group. The Blood Flow Restriction added to the squat training places an additional load on the quadriceps muscle group which can provide a mechanical tension and metabolic stress. The increased mechanical stress can increase the Reactive Oxygen Species (ROS) to induce adaptive antioxidant defense mechanisms (Patterson et al., 2019). The metabolic stress that occurs is the result of the accumulation of by-products from physical exercises in the distal extremities. Therefore, BFR causes more intense fiber recruitments from the fast twitch muscles, cell swelling, and increased GH levels after the exercise. These responses are interrelated and provide a pattern of neuromuscular adaptation thereby strengthening intramuscular signaling that stimulates the protein synthesis resulting in the increased muscle hypertrophy. The muscle strength after BFR trainings is related to the increased CSA in muscle fibers rather than neural adaptations (Wilk et al., 2018).

Based on the results of this study, there was no significant differences of the effect on the experimental group given the squat training plus BFR and the control group given the squat training. In the average muscle strength, there was a difference in the increase of the muscle strength between the two groups, where the RF muscle was higher in the squat training with BFR while the VM and VL muscles were higher in the squat training without BFR. This might happen because the training duration was not long enough. The duration of exercise has a significant effect on increasing the muscle strength. Longer exercise durations result in higher increases in the muscle strength (Borde et al., 2015). Adaptive responses appear to occur more fully after several training sessions. The muscle adaptation process shows a long-term adaptation because it lasts for several weeks or even up to 6 months (Hody et al., 2019). In this study, the training was carried out for 4 weeks. According to Scali et al. (2018), 4 weeks of training is not long enough for a significant increase in the CSA and hypertrophy compared to 6 weeks of training which shows a greater increase in the muscle strength and hypertrophy.

There was an influence of the treatments on the strength of the quadriceps muscle group in the experimental group and on the VM and VL muscles in the control group. Differences in the strength of each muscle in this study could be caused by the position and resistance factors when measuring the MVIC muscle strength. Changes in the ankle muscle activation can cause some knee muscle activations (Li et al., 2018). The position of the respondent, in the inversion or eversion position, when taking MVIC measurements could result in differences in the strength of the quadriceps muscle group. Ankle eversion movements can increase VM activations compared to the inversion (Johnston et al., 2017). In this study, the manual resistance applied during the MVIC might have resulted in the suboptimal muscle activation. According to Delgado et al. (2019), the manual resistance does not represent an adequate or consistent fixation to induce maximal isometric contractions.

CONCLUSION

Squat exercises added with BFR could provide a significant increase in the strength of the quadriceps muscle group. Meanwhile, the squat training without BFR did not provide a significant increase in the rectus femoris muscle strength, but there was a significant increase in the strength of the vastus medialis and vastus lateralis muscles. The increase occurred in the muscle strength is the result of neurological activations and musculoskeletal adaptations. There was no significant differences in the effect of treatments in the squat training with BFR group and the squat training without BFR group, which might be due to the shorter training duration. Statistically, there was no significant differences in the effect of the treatments in the squat training with BFR group and the squat training without BFR group on the MVIC values of the quadriceps muscle group. However, based on the table of the MVIC value progression, there was a significant increase in the muscle strength, specifically in the vastus medialis muscle and vastus lateralis muscle in the treatment group.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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