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Article

Study on the influence of leg strength training on the jump spike of volleyball players

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Abstract: Objective: This paper aims to compare the effects of leg strength training combined with blood flow restriction training (BFRT) to traditional leg strength training (ST) on the jump spike performance of volleyball players. **Methods:** Twenty volleyball players were randomly divided into two groups. One group underwent leg strength training combined with BFRT, while the other underwent traditional leg strength training. Their performance in countermovement-jump (CMJ) free arms, run-up touch, and jump spike before and after the experiments was compared. **Results:** After the experiment, the swing-arm reverse jump height of the BFRT group was 63.26 ± 6.36 cm, the peak speed was 1.73 ± 0.09 m/s, the peak power was 3116.52 ± 456.22 W, the half-court movement performance was 16.33 ± 0.21 s, and the run-up touch performance was 3.11 ± 0.08 m. The 30 s continuous touch performance was 29.06 ± 0.91 times, the score of spiking from position 3 was 83.56 ± 8.67 points, and the score of spiking from position 4 was 81.81 ± 10.89 points. Compared with the BFRT group before the experiment and the ST group, $p < 0.05$. **Conclusion:** The leg strength training combined with BFRT has a better effect on the players' leg strength, explosive power, and jump spike level, which can be applied in practical training.

Keywords: leg strength training; volleyball player; jump spike

1. Introduction

As a sport against the net, volleyball has high requirements for the physical strength and skills of the players [1]. The attack and defense strategy of volleyball requires an effective combination of height and speed, and the lack of explosive power of the legs will limit the players' attack and blocking effect. Therefore, in order to better play the air advantage and obtain the height over the net, volleyball players need to pay attention to the strength training of the legs to obtain better strength and explosive power. However, with the growth of training years, the improvement of sports level, and the gradual adaptation of the body to the load intensity, the training effect gradually reached saturation and fell into the bottleneck [2]. In order to solve this problem, more and more training methods have been applied and researched in volleyball [3]. Latino et al. [4] analyzed the effects of endurance training on male players. They found that after endurance training, there were significant differences in VO2max and other physiological attributes of the players, indicating that endurance training is conducive to improving physical ability. Rebelo et al. [5] evaluated the effect of 6-week triphasic resistance training on the athletic performance of volleyball players and found that the players' squat jumping performance and upper body maximum strength were significantly improved after the intervention. Blood flow restriction training (BFRT) refers to the restriction of blood flow through specific equipment during training [6] to achieve the improvement of body fitness and muscle growth under low-intensity exercise load [7], which has been applied in many scenarios. Liu et al. [8] analyzed the influence of BFRT combined with instrument-assisted soft tissue mobilization on dancers with unstable ankle joints. They found that under such training conditions, the dancers showed higher back flexion and handstand strength, which improved the stability, function, and strength of the ankle joints of the patients. Devana et al. [9] analyzed the effects of BFRT on athletes undergoing anterior cruciate ligament reconstruction and found that BFRT had a positive effect on quadriceps strength. Compared with some current advanced training techniques, such as suspension training and vibration training, BFRT can achieve good training effects under low loads and help the elderly and patients with muscle/skeletal injuries to recover better. Moreover, BFRT is widely applicable due to fewer limitations regarding training equipment and venues. It is also less likely to cause muscle injuries as it uses simple equipment. This paper mainly studied the effect of leg strength training combined with BFRT on the jump spike of volleyball players and compared the performance of players' swing-arm reverse jump and run-up touch indicators before and after the experiment, so as to verify the reliability of BFRT as a volleyball training method. This article provides theoretical support for the application of BFRT in volleyball and more sports.

2. Research subjects and method

2.1. Subjects

The subjects were 20 volleyball players, all male, with leg strength training experience, a healthy body, and no history of lower extremity injury, cardiovascular disease, or sports injury in the past six months. All of them understood the purpose and procedure of the experiment and signed informed consent. The study subjects were randomly divided into two groups. One group performed leg strength training under the condition of blood flow restriction (the BFRT group), and the other group performed traditional leg strength training (the ST group). The basic information for the two groups presented in **Table 1** showed no significant differences.

Table 1. Basic information of subjects.

	BFRT group (*n* = 10)	**ST group (*n* = 10)**	***p***
Age/year	21.21 ± 1.68	20.89 ± 1.87	0.327
Height/cm	188.26 ± 2.64	188.34 ± 2.34	0.625
Weight/kg	85.64 ± 11.26	83.67 ± 12.64	0.521
Training time/year	8.67 ± 1.12	8.48 ± 1.33	0.254

2.2. Experimental method

(1) Experimental control: The subjects were required to prohibit the intake of tobacco, alcohol, and coffee the day before the start of the experiment, prohibit high-intensity training, and ensure regular rest. The pre-test and post-test of the two

groups of subjects were arranged at the same time and completed by the same person. All subjects wore uniform clothes.

(2) Experimental scheme: The experiment was carried out for a total of nine weeks, and the training time was 90 min on Monday, Wednesday, and Friday. The BFRT group completed the leg strength training under the condition of blood flow restriction, while the ST group only performed the traditional leg strength training. The equipment used in the BFRT group was the lower extremity set in the Theratools BRT training belt, and continuous pressure was adopted. Considering the safety of training, 40% arterial occlusive pressure (AOP), which is often used to quantify the degree of blood flow restriction in BFRT, was selected for the pressure value. The subjects selected different pressure values according to their thigh circumference (**Table 2**).

Table 2. Relationship between AOP and thigh circumference [10].

Thigh circumference	40% AOP	50% AOP	60% AOP
45–50.9 cm	80 mmHg	100 mmHg	120 mmHg
51–55.9 cm	100 mmHg	130 mmHg	150 mmHg
56–59.9 cm	120 mmHg	150 mmHg	180 mmHg
≥60 cm	140 mmHg	180 mmHg	210 mmHg

With the help of the same researcher, the subjects in the BFRT group put on the training belt. The pressurized part was the root of the thigh, i.e., the upper third of the thigh. After the subjects completed the warm-up, their legs relaxed and avoided exerting force. After wearing the pressure belt, the pressure was slowly applied with 30 s of air inflation, followed by 10 s of deflation until the target pressure value was reached.

(3) Training process: The training consisted of 10 min warm-up, 70 min formal training, and 10 min relaxation, as follows.

Warm up: Jog around the gym for two laps and then carry out dynamic stretching. Stretch is completed by moving forward with knees hugged and side lunge.

Formal training: The training plan for the two groups is shown in **Table 3**, and the interval between each group was 2 min. One-repetition maximum (1RM) refers to the maximum single weight an individual can bear while maintaining the correct movement.

Table 3. Two training regimens.**1**

	Movement	Load	Times
BFRT group	Weight-bearing squat	60%1RM	12 reps * 4 groups
	Weight-bearing calf raise	25 kg	16 reps * 4 groups
	Barbell squat jump	25 kg	16 reps * 4 groups
	Barbell lunge	25 kg	16 reps * 4 groups
ST group	Weight-bearing squat	60%1RM	12 reps * 4 groups
	Weight-bearing calf raise	25 kg	16 reps * 4 groups
	Barbell squat jump	25 kg	16 reps * 4 groups
	Barbell lunge	25 kg	16 reps * 4 groups

1) Weight-bearing squat: the feet were apart as wide as the shoulder. The knee direction was kept consistent with the toe when the knees were bent. The spine was in a neutral position. The chest was lifted, and the abdomen was pulled in. The angle between the thigh and calf was less than 90° when squatting.

2) Weight-bearing calf raise: the subject stood with feet apart and put the center of gravity in the middle of the legs. The barbell was placed behind the shoulder, and the wide grip distance from the bar was used for calf raise exercise. Moreover, the subject tightened the core while maintaining the upright position.

3) Barbell squat jump: the feet were apart as wide as the shoulder. The subject squatted from the standing position. When squatting to a quarter squat, the subject quickly pushed off the ground and jumped upward. The barbell remained relatively still with the body. After jumping to the highest point, the body naturally fell, and the subject bent the knees and hips.

4) Barbell lunge: the feet were apart as wide as the shoulder. One foot was extended forward as far as possible, with the center of gravity moving forward. The subject landed in a squatting position. Then, the knee and hip were extended. After pushing off the ground, the standing position was restored.

Relaxation: fully relieve muscle fatigue through foam rollers, muscle massage, and static stretching.

2.3. Test indicators

(1) Countermovement-jump (CMJ) free arms

MyJump2 software [11] was used to complete the test, and the weight and leg length of the subjects were measured and input into the software to complete the setting. During the test, the subjects took a standing position, squatted and jumped quickly after hearing the instruction, swung their arms freely to enhance the jumping power, and returned to the starting posture after landing. The test was performed three times, and the best performance was recorded.

(2) Half-court movement

Six mineral water bottles were used to arrange the site (**Figure 1**). After the subject pushed down the water bottle at point 0, the timing began, and the water bottle was pushed down successively in the order of 0-1-0-2-0-3-0-4-0-5-0. Each time, the subject returned to point 0 and ran to the next target, and the timing ended after the last return to point 0. The test was performed twice, and the best performance was taken.

(1) Run-up touch

The subjects held the starting position and running distance. When jumping off, both feet were off the ground simultaneously, the arms were extended to the highest point, and the fingertips touched the high board. The highest point shown by the touch height device was used as the result. The test was repeated twice, and the best result was taken.

(2) 30 s continuous touch

The lower edge height of the touch height device was adjusted to the height obtained by subtracting 40 cm from the run-up touch height. The subject jumped from the standing position to touch the lower edge of the touch height device, and the number of touches completed within 30 s was recorded. The test was repeated twice, and the best result was taken.

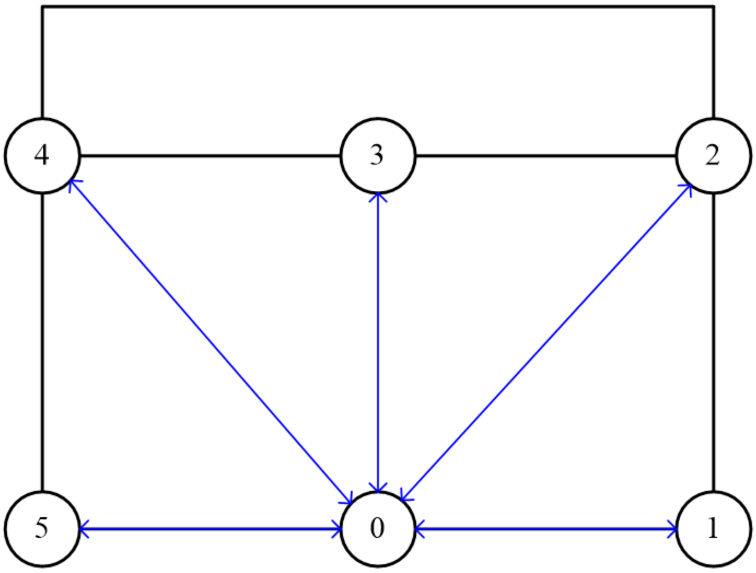

Figure 1. Schematic diagram of half-court movement.1

(3) Jump spike score

The subjects completed the front spike at position 4 and the fast spike at position 3 in the volleyball court, respectively. A successful spike was given four points. Ten spikes were performed at each position. No point was given if the ball went out of the net, touched the net, or went down the net.

2.4. Statistical methods

Excel and SPSS22.0 software [12] were used to process and analyze the collected athlete data. K-S test was conducted to check whether the data were in line with normal distribution [13]. If so, an independent sample t-test was performed for inter-group data, and a paired sample t-test was performed for intra-group data. If not, the Mann-Whitney U test was performed for inter-group data [14], and paired samples Wilcoxon signed rank sum test was performed for intra-group data [15]. The significance level was set at 0.05.

3. Results

As can be seen from **Table 4**, before the experiment, there was no significant difference in the test results between the two groups ($p > 0.05$), indicating that before the experiment, there was no significant difference in leg strength, explosive power, and jump spike level between the two groups, i.e., the grouping was rational.

As can be seen from **Table 5**, after nine weeks of training, the performance of all tests in the BFRT group was significantly improved ($p < 0.05$). After the experiment, the height of the CMJ free arms in the BFRT group was 63.26 ± 6.36 cm, increased by 14.58% compared with before the experiment, the peak speed was 1.73 ± 0.09 m/s, increased by 4.85% compared with before the experiment. The peak power was 3116.52 ± 456.22 W, increased by 18.56% compared with before the experiment. The performance of the half-court movement was 16.33 ± 0.21 s, which decreased by 2.68% compared with before the experiment. The run-up touch height was 3.11 ± 0.08 m, which was 1.97% higher than before the experiment. The performance of the 30 s continuous touch was 29.06 ± 0.91 times, which was 2.29% more than before the experiment. The score of spiking from position 3 was 83.56 ± 8.67 points, which increased by 6.26% compared with before the experiment. The score of spiking from position 4 was 81.81 ± 10.89 points, which increased by 7.48% compared with before the experiment. The results showed that the nine-week leg strength training combined with BFRT could significantly improve the players' leg strength, explosive power, and jump spike level.

Table 4. Comparison of test results between the two groups before the experiment.**2**

		BFRT group (*n* = 10)	**ST group (*n* = 10)**	***p***
CMJ free arms	Height/cm	55.21 ± 5.78	54.36 ± 5.16	0.215
	Peak speed/(m/s)	1.65 ± 0.08	1.64 ± 0.06	0.165
	Peak power/W	2628.64 ± 305.16	2566.54 ± 293.56	0.252
Half-court movement/s		16.78 ± 0.24	16.64 ± 0.23	0.189
Run-up touch height/m		3.05 ± 0.08	3.03 ± 0.09	0.218
30 s continuous touch/n		28.41 ± 1.36	28.12 ± 1.64	0.168
Score of spiking from position 3/point		78.64 ± 7.64	77.89 ± 8.64	0.265
Score of spiking from position 4/point		76.12 ± 10.64	74.64 ± 8.67	0.645

Table 5. Comparison of test results of the BFRT group before and after the experiment.**3**

		Before the experiment	**After the experiment**	***p***
CMJ free arms	Height/cm	55.21 ± 5.78	63.26 ± 6.36	0.000
	Peak speed/(m/s)	1.65 ± 0.08	1.73 ± 0.09	0.003
	Peak power/W	2628.64 ± 305.16	3116.52 ± 456.22	0.000
Half-court movement/s		16.78 ± 0.24	16.33 ± 0.21	0.002
Run-up touch height/m		3.05 ± 0.08	3.11 ± 0.08	0.001
30 s continuous touch/n		28.41 ± 1.36	29.06 ± 0.91	0.001
Score of spiking from position 3/point		78.64 ± 7.64	83.56 ± 8.67	0.000
Score of spiking from position 4/point		76.12 ± 10.64	81.81 ± 10.89	0.000

As can be seen from **Table 6**, after nine weeks of leg strength training, the performance of the ST group also improved. Except for the scores of spiking from positions 3 and 4, the other performance showed significant differences compared to before the experiment ($p < 0.05$). After the experiment, the height of the CMJ free arms of the ST group was 61.26 ± 5.67 cm, which was increased by 12.69% ($p < 0.05$), the peak speed was 1.66 ± 0.07 m/s, which was increased by 1.22% ($p < 0.05$), and the peak power was 2702.26 ± 271.33 W, which was increased by 5.29% compared with that before the experiment ($p < 0.05$). The performance of the half-court movement was 16.56 ± 0.23 s, which was increased by 0.48% compared with before the experiment ($p > 0.05$). The performance of run-up touch was 3.04 ± 0.07 m, increased by 0.33% compared with before the experiment ($p < 0.05$). The 30 s continuous touch performance was 28.54 ± 1.76 times, 1.49% higher than before the experiment ($p < 0.05$). The score of spiking from position 3 was 77.98 ± 8.87 points, which was increased by 0.12% compared with before the experiment ($p > 0.05$). The score of spiking from position 4 was 74.87 ± 8.86 points, which was increased by 0.31% compared with before the experiment ($p > 0.05$). These results indicated that traditional nine-week leg strength training had some effects on the improvement of leg strength, explosive power, and jump spike level of players, but it was not as good as that of the traditional training combined with BFRT.

Table 6. Comparison of test results of the ST group before and after the experiment.**4**

		Before the Experiment	**After the experiment**	***p***
CMJ free arms	Height/cm	54.36 ± 5.16	61.26 ± 5.67	0.000
	Peak speed/(m/s)	1.64 ± 0.06	1.66 ± 0.07	0.000
	Peak power/W	2566.54 ± 293.56	2702.26 ± 271.33	0.000
Half-court movement/s		16.64 ± 0.23	16.56 ± 0.23	0.056
Run-up touch height/m		3.03 ± 0.09	3.04 ± 0.07	0.012
30 s continuous touch height/n		28.12 ± 1.64	28.54 ± 1.76	0.005
Score of spiking from position 3/point		77.89 ± 8.64	77.98 ± 8.87	0.651
Score of spiking from position 4/point		74.64 ± 8.67	74.87 ± 8.86	0.452

From **Table 7**, it can be found that, compared with the ST group, there were significant differences in various test results in the BFRT group ($p < 0.05$). This result showed that compared with traditional leg strength training, the leg strength training combined with BFRT had more advantages and could improve the players' leg strength, explosive power, and jump spike level more effectively.

Table 7. Comparison of test results between the two groups after the experiment.**5**

		BFRT group (*n* = 10)	**ST group (*n* = 10)**	***p***
CMJ free arms	Height/cm	63.26 ± 6.36	61.26 ± 5.67	0.002
	Peak speed/(m/s)	1.73 ± 0.09	1.66 ± 0.07	0.003
	Peak power/W	3116.52 ± 456.22	2702.26 ± 271.33	0.000
Half-court movement/s		16.33 ± 0.21	16.56 ± 0.23	0.012
Run-up touch height/m		3.11 ± 0.08	3.04 ± 0.07	0.001
30 s continuous touch/n		29.06 ± 0.91	28.54 ± 1.76	0.003
Score of spiking from position 3/point		83.56 ± 8.67	77.98 ± 8.87	0.000
Score of spiking from position 4/point		81.81 ± 10.89	74.87 ± 8.86	0.000

4. Discussion

BFRT applies pressure to the extremities through some devices, thus restricting blood flow and leaving them in a state of low oxygen. In order to maintain muscle strength, the motor units in fast muscle fibers are mobilized, resulting in increased blood lactate concentration [16]. The concentration difference increases cell volume, promoting muscle protein synthesis. At present, BFRT has been extensively studied in both sports rehabilitation and competitive sports [17].

CMJ free arms, run-up touch height, and 30 s continuous touch can reflect the athlete's lower limb explosive power and bounce ability. Jump spike, blocking, and other movements in volleyball require players to have excellent jumping height. High jumping height can result in a higher offensive position and increase the difficulty of defense, reducing the opponent's scoring opportunity. After leg strength training, the players' leg strength and explosive power were improved, so they achieved better performance in CMJ free arms, run-up touch height, and 30 s continuous touch performance. From the comparison of the two training methods, the leg strength training combined with BFRT had a more obvious improvement effect on the players' leg strength and explosive power, which may be because BFRT can improve muscle strength and rapid contraction ability under low load conditions and promote the improvement of muscle strength and endurance [18]. However, traditional strength training under low-load conditions can not achieve the same effect. The study by de Queiros et al. [19] also demonstrated the favorable effect of resistance training combined with blood flow restriction on muscle enlargement. Pavlou et al. [20] also found through a meta-analysis that blood flow restriction combined with low-load resistance training may induce an increase in muscle size, which is similar to the results of this article.

Half-court movement can reflect an athlete's ability to change direction. Volleyball involves a lot of emergency stopping and changing direction, which requires players to have a good ability to change direction and respond to changes in time. After leg strength training, the half-court movement performance of the two groups was improved to a certain extent, but $p > 0.05$ after the experiment compared with that before the experiment in the ST group, indicating that the training effect of the BFRT group was better. This may be because BFRT, by restricting blood flow, stimulates muscle fibers and promotes muscle adaptation, thus improving the athletic performance of players. The study by Liu et al. [21] shows that training combined with BFRT can significantly reduce pain and improve the flexibility of tissues. The results of this paper also indicate that the experimental group showed greater flexibility.

The research of Yuan et al. [22] shows that BFRT can effectively promote the increase of muscle mass and strength, and its main mechanism is the metabolic stress response, including muscle fiber recruitment and hormone secretion. From the point of view of jump spike score, after nine weeks of leg strength training, the jump spike score of both groups was improved to a certain extent, but $p>0.05$ after the experiment compared with before the experiment in the ST group. The jump spike of volleyball players is closely related to leg strength and explosive power. After nine weeks of leg strength training combined with BFRT, the leg strength and explosive power of the BFRT group improved more significantly, so they had better performance on the jump spike.

According to the above results, BFRT can obtain good training results in the training of volleyball players, which is conducive to improving leg strength and explosive power and thus enhancing sports performance. It can be used as a new training method in daily training. Scott et al. [23] pointed out through the analysis of existing literature that resistance training combined with BFRT under low load may provide additional stimulation for muscle development and seemingly does not cause measurable muscle damage. Therefore, applying this strategy in training may cause beneficial muscle responses. Pignanelli et al. [24] also pointed out that incorporating BFRT into the training of athletes who undergo strength and endurance training can achieve additional training effects and enhance skeletal muscle and cardiovascular adaptability. Kelly et al. [25] believe that BFRT is a promising exercise training tool, especially beneficial for individuals who cannot tolerate high-load training. Currently, BFRT has been widely applied in practical exercise training. Faltus et al. [26] believe that BFRT can be applied in the management of chronic ankle instability in basketball players. Cuddeford et al. [27] applied BFRT in the rehabilitation plans of two decathlon athletes with patellar tendinopathy and found that both athletes improved through BFRT-based training and were able to participate in competitions throughout the track and field season. Elgammal et al. [28] applied BFRT to the training of basketball players and found that BFRT had an impact on basketball strength and anaerobic and aerobic performance. Judd et al. [29] added six weeks of assisted BFRT to the training of football players and verified the inducing effect of BFRT on the increase of muscle strength and circumference. Camarda et al. [30] added short-term BFRT to the training of professional male football players and found that this training increased the size and strength of the hamstring muscles of the players. Bagheri et al. [31] found that the increase in anaerobic capacity of the players receiving BFRT was more significant compared to those without BFRT.

This study also verified the usability of BFRT in the daily training of volleyball players, providing some references for the arrangement of training plans by coaches and the improvement of players' sports levels. Based on the research results, the following suggestions are put forward.

(1) BFRT can be incorporated into the leg strength training of volleyball players to enhance their leg strength, and it can be combined with high-intensity resistance training to reduce the frequency of training moderately.

(2) BFRT can be incorporated into the leg explosive power training of volleyball players to enhance their leg explosive power and achieve higher efficiency through low-intensity training.

(3) During the application of BFRT, coaches should conduct training monitoring well and adjust training timely according to the situation of the players.

However, this study also has some limitations. For instance, only male volleyball players were studied, the sample size was relatively small, and the duration of the experiment was short. These limitations might make the results less representative. Whether similar results can be obtained in female volleyball players still needs further confirmation. Also, whether the effect of leg strength training combined with BFRT is long-term effective requires further experiments for analysis.

5. Conclusion

This paper compared the effects of leg strength training combined with BFRT and traditional leg strength training. It was found that after a nine-week experiment:

(1) the CMJ free arms performance of the BFRT group was significantly improved, and $p < 0.05$ compared with that before the experiment and the ST group;

(2) the run-up touch height and 30 s continuous touch performance of the BFRT group were significantly improved, and $p < 0.05$ compared with those before the experiment and those of the ST group;

(3) the half-court movement time of the BFRT group was significantly shortened, and $p < 0.05$ compared with those before the experiment and those of the ST group;

(4) the performance of spiking from positions 3 and 4 was significantly better than that before the experiment and that of the ST group ($p < 0.05$).

The results verify that the leg strength training combined with BFRT has positive effects on leg strength, explosive power, and jump spike level and can be further applied in the actual volleyball training.

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