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**Original article**

# The Effect of Combining Blood Flow Restriction and Plyometric Exercise on Quadriceps Muscle Strength, Functional Ability and Balance Capacity - A Pilot Study Amongst Amateur Soccer Players

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## Abstract

Football is one of the most popular sports employing a plethora of people around the world. Plyometric exercise and Blood Flow Restriction (BFR) exercise are two different means used to enhance athletic performance in healthy athletes and also during the rehabilitation of musculoskeletal injuries. To our knowledge, the combination of plyometric exercise and BFR has not been studied so far. The aim of this study is to investigate the effect of BFR during plyometric lower limb exercise on quadriceps muscle strength, functional capacity and dynamic balance of the lower limb in amateur football players. This is a comparative study with a parallel 10-week, twice/week intervention in 2 different groups. Group A (N = 5) performed a plyometric exercise program and group B (N = 5) performed the same plyometric exercise program with the simultaneous application of BFR. Outcome measures were 1 Repetition Maximum of the squat exercise, Y Balance Test, Horizontal Countermovement Jump, Vertical Countermovement Jump, and single leg Triple Hop Test (THT). There was statistically significant improvement in both groups in all variable except THT on the non-dominant leg. There was no statistically significant difference between groups. Plyometric exercise, whether applied with or without blood flow restriction, improved strength, balance and functional capacity in male amateur football players.

**Keywords:** ***plyometric training; blood flow restriction; strength, functional capacity; balance.***

## Introduction

Injury prevention is important for a team's performance especially in soccer [1]. One of the strategies for preventing injuries is to include specific exercise programs into their training routine [2]. The ability of soccer players, whether they are healthy or have recovered from an injury, to produce strong, explosive movements during the match is very important for their performance but also for injury prevention and should be practiced during training [3]. Such movements are plyometric-specific exercises which involve fast and powerful movements that include a cycle of lengthening followed by shortening of the muscle, i.e. exercise execution is preceded by the agonist muscle contracting in a lengthened position [4]. This sequence of eccentric contraction that precedes concentric muscle contraction has been found to increase strength and speed more than a concentric muscle contraction [5]. The effect of the lengthening-shortening cycle is due to the storage and use of elastic energy and the release of the myotatic reflex [6]. Plyometric training has been linked to improved vertical jump, acceleration performance, and improved neuromuscular function, such as increased motor unit activation [7]. Beato et al. [8] indicate that the addition of plyometric exercise in combination with directional exercises twice a week for more than 6 weeks, in the training of young professional soccer athletes, brought about a significant improvement in parameters related to acceleration and jump performance. Similar results were reported by Michailidis et al. [9] in the physical conditioning of young soccer players, who, following a 6-week combined program improved jumping, acceleration as well as endurance parameters.

Blood flow restriction (BFR) training has recently gained much attention. It corresponds to training with added pressure by utilization of a strap or a compressed air cuff usually applied at the proximal end of the upper or lower limb during training. This external pressure causes a reduction in arterial blood flow but mainly restricts venous return, creating conditions of hypoxia in the contracting muscle [10]. The action of BFR is due to the metabolic stress, which arises in the conditions of hypoxia, but also to the mechanical stress that arises from the pressure in the area. These two basic mechanisms work in partnership to activate secondary mechanisms that stimulate the endocrine system to produce more muscle work and finally induce muscle hypertrophy and increase strength [11]. There is evidence to suggest that low-load training of 20-50% of 1 repetition maximum (RM), in combination with BFR, is effective in causing an increase in muscle strength and mass [12]. In terms of increasing muscle strength with BFR training, high-load training is superior to low-load training, while for causing muscle hypertrophy, high-load training was found to produce comparable results to low-load training [13]. Recent evidence indicates that low load training with BFR can bring about a significant improvement in the strength and size of the muscle exercised even in well-trained athletes. Hosseini Kakhak et al. [14] studied the effect of soccer practice in combination with BFR on the performance of young athletes and the findings showed that team training with BFR can improve the physical characteristics associated with the performance of young soccer athletes. Similarly, Korkmaz et al. [15] found that low-load strength training with BFR may provide advantages over high-load strength in terms of improving muscle hypertrophy in young soccer athletes.

To the authors' knowledge, combination of plyometric exercise with BFR has not yet been investigated. Thus, the purpose of this pilot study was to investigate the effects of BFR during plyometric lower limb exercise on quadriceps muscle strength, functional ability and balance capacity on amateur soccer players.

## Materials and Methods

This was a small-scale comparative pilot study with parallel intervention in two different groups. It involved athletes of a local amateur soccer team in the Greek island of Kos, which competes category A of the Association of the Dodecanese Soccer Clubs (ADSC). During the start-up period, 14 people participated in the group's practice, of which 13 agreed to participate in the study. Inclusion criteria were male gender, age over 18 years and participation in team practice. Exclusion criteria were the goalkeeper's position, recent (<1 year) lower extremity injury or surgery, history of deep vein thrombosis, circulatory dysfunction, hypertension, heart problems, neurological problems, pathologies that could affect muscle and joint function and body mass index (BMI) > 30 [16].

Participants were randomly divided into 2 groups by the method of drawing lots by someone unrelated to the study. Plyometric group performed a relevant progressive exercise program and BFR group performed the same exercise program combined with BFR application. The duration of the intervention was 10 weeks with a twice per week frequency. The intervention took place on the soccer field during training, after warming up and before recovery. The test variables were measured before the intervention, at 7 weeks and after the end of the intervention (week 11).

The research was approved by the ethics committee of the University of Patras (protocol no. 11965). All participants signed an informed consent form and during the first meeting, the Waterloo Footedness Questionnaire (WFQ-R, Greek) was completed to determine leg dominance [17].

The plyometric exercise program (Table 1) lasted 10 weeks and was divided into 3 progressive phases. The first phase lasted 3 weeks, the second 4 and the third 3 weeks. There was progression in all exercises, both in the ground contact and the level of difficulty and skill. The number of ground contacts ranged from 80 in the first week of intervention to 140 in the 10th week. Each week the sets or repetitions increased, while in each phase the difficulty in the exercises increased, too. In the first phase there were bipedal exercises, in the second phase an obstacle was added to the bipedal exercises and unipodal exercises were introduced. In the third and last phase, an obstacle was added to the one-legged exercises and the height of the obstacle in the two-legged exercises was increased. During the 7th week of the intervention the volume of exercise decreased as the intermediate evaluation of the variables was performed.

The program of the first week was piloted in two groups (without BFR and with BFR) one week prior to the intervention so that the participants become familiar with the intervention process, the application of BFR as well as for ensuring the appropriate level of difficulty of the exercise regime. They were also asked to rate the difficulty of each exercise on the Borg CR10 scale (>4 scored exercises were acceptable), to ensure an above average difficulty in the prescribed exercises for the sample [18].

In the BFR group, the Fitcuffs system (Fit Cuffs ApS, Odder, Denmark) consisting of 10 cm wide nylon cuffs with manual inflation and a manometer were used to control the pressure applied. The cuffs were placed on both legs at the upper third of the thigh, below the gluteal line. The application of pressure, was done in the upright position until it reached 100 mmHg [19]. During the breaks, the pressure was checked and adjusted to 100 mmHg.

To assess the quadriceps muscle strength, 1RM was calculated with the Brzycki type, which shows a high level of prediction accuracy of 1RM of the quadriceps using the sub-maximum load of 10RM [20]. The Y balance test (YBT) was used to assess dynamic balance [21]. To examine functional ability, the Vertical Countermovement Jump (VCJ) [22], the bipedal Horizontal Countermovement Jump (HCJ) [22] and the Single Leg Triple Hop Test (THT) [23] were used.

For all evaluation tests, a reliability procedure was performed prior to the main study. A sample of 10 people was selected for each test. After getting acquainted with the tests, individuals performed them on two different non-consecutive days, in the same way that they were scheduled to be performed by the participants. Prior to initial measurements, all participants familiarized themselves with the tests. The tests were evaluated one week before the beginning of the intervention, during the 7th week of the intervention and 2 days after the end of the intervention. YBT, VCJ, HCJ, and THT were evaluated on the same day in random order. The 10RM was evaluated on a different day from the other tests and 2 days apart from the other measurements.

**Table 1: Plyometric exercise programme**

| **Plyometric Exercises** | **Week 1** | **Week 2** | **Week 3** | **Week 4** | **Week 5** | **Week 6** | **Week 7** | **Week 8** | **Week 9** | **Week 10** |
|---|---|---|---|---|---|---|---|---|---|---|
| Counter movement Jump | 2x8 | 2x12 | 2x15 | | | | | | | |
| Scissor hops | 2x8 | 2x12 | 2x15 | | | | | | | |
| Horizontal (front-back) bipedal jumps | 2x8 | 2x12 | 2x15 | | | | | | | |
| Lateral (left-right) bipedal jumps | 2x8 | 2x12 | 2x15 | | | | | | | |
| Bounds | 2X8 | 2x12 | 2x15 | | | | | | | |
| Horizontal (front-back) single leg jumps | | | | 1x8 | 2x8 | 2x10 | 1x8 | | | |
| Lateral (left-right) single leg jumps | | | | 1x8 | 2x8 | 2x10 | 1x8 | | | |
| Landing from a height of 50cm + 2 jumps over 15cm obstacles | | | | 1x8 | 2x8 | 2x10 | 1x8 | | | |
| Bipedal cross jumps over a 15cm obstacle | | | | 1x8 | 2x8 | 2x10 | 1x8 | | | |
| Countermovement Jump and climbing of a 50cm plyometric box | | | | 1x8 | 2x8 | 2x10 | 1x8 | | | |
| Horizontal single leg jumps over a 15cm obstacle | | | | | | | | 1x8 | 2x8 | 2x10 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lateral (left-right) single leg jumps over a 15cm obstacle | | | | | | | | 1x8 | 2x8 | 2x10 |
| Counter movement Jump and climbing of a 70cm plyometric box | | | | | | | | 1x8 | 2x8 | 2x10 |
| Landing from a height of 70cm plus 2 jumps over 30cm obstacles | | | | | | | | 1x8 | 2x8 | 2x10 |
| Bipedal jumps over a 30cm obstacle | | | | | | | | 1x8 | 2x8 | 2x10 |

The t-test for independent samples was used to determine the homogeneity of the characteristics and baseline measurements between the groups. The intraclass correlation coefficient (ICC) was used to determine the reliability of the outcomes. Adherence (compliance) to exercise was calculated by dividing the number of sessions conducted by each participant with the total number of sessions they should have performed during the study. To compare the effect of plyometric exercise without BFR (plyometric group) and plyometric exercise with BFR (BFR group) on strength, balance and functional capacity, repeated measures ANOVA was conducted for each variable separately. The assumption of sphericity was tested with Mauchly's Test of Sphericity and was found not statistically significant for all variables. Statistical analysis was performed with SPSS program (version 26) and the statistical significance (p) was set at ≤ 0.05 for all variables.

## Results and Discussion

### Results

Out of the initially 13 volunteers who agreed to participate in the study, three dropped out before the beginning of the programme for personal reasons, not related to the study. Thus, 10 subjects enrolled and completed the study. There were no statistically significant differences in baseline demographic and outcome measures across the two groups, except for weight (Table 2).

**Table 2: Demographics and baseline measures.**

| | **Plyometric Group** (N=5) | **BFR Group** (N=5) | **p-value** |
|---|---|---|---|
| | mean ± SD | | |
| Age (years) | 33.8 ± 6.94 | 28.8 ± 8.1 | 0.89 |
| Weight (kg) | 78.6 ± 4.03 | 71.4 ± 7.93 | 0.02 |
| Height (m) | 1.75 ± 0.06 | 1.75 ± 0.03 | 0.06 |
| Body mass index (BMI) (kg/m²) | 25.68 ± 2.01 | 23.16 ± 2.47 | 0.42 |
| Thigh Circumference (cm) | 57.8 ± 2.59 | 57.0 ± 2.55 | 0.8 |
| Strength (1RM) (kg) | 76 ± 7.68 | 89.4 ± 13.65 | 0.44 |
| Vertical Countermovement Jump (cm) | 41 ± 5,48 | 42.38 ± 7.31 | 0.67 |
| Horizontal Countermovement Jump (m) | 1.82 ± 0.19 | 2.09 ± 0.25 | 0.5 |
| Triple Hop Test Dominant Leg (m) | 4.18 ± 0.23 | 4.59 ± 0.36 | 0.28 |
| Triple Hop Test Non-Dominant Leg (m) | 4.19 ± 0.33 | 5.03 ± 0.35 | 0.783 |
| Y Balance Test Anterior direction- Dominant Leg (cm) | 54.1 ± 6.25 | 56.2 ± 4.53 | 0.33 |
| Y Balance Test Posteromedial direction- Dominant Leg (cm) | 71.5±6.11 | 84±14.35 | 0.6 |
| Y Balance Test Posterolateral direction - Dominant Leg (cm) | 65.2±8.52 | 77.2±13.91 | 0.068 |
| Y Balance Test Anterior direction- Non-dominant Leg (cm) | 54.5 ± 7.63 | 58.7 ± 3.29 | 0.229 |
| Y Balance Test Posteromedial direction- Non-dominant Leg (cm) | 72.8±9.15 | 90.2±13.44 | 0.326 |
| Y Balance Test Posterolateral direction – Non-Dominant Leg (cm) | 66±6.58 | 70.8±17.23 | 0.225 |

*kg: kilograms, cm: centimeters, m: meters*

The compliance rate for the participants was 74%±14.36% and 72% ± 23.61% for the plyometric and BFR group, respectively. All outcome measures, yielded high to excellent test-retest reliability. Overall there was a statistically significant improvement in both groups at the variables 1RM (p=0.001), VCJ (p=0.005), HCJ (p=0.01), THT dominant leg (p=0.004), YBT-Anterior direction dominant leg (p=0.06), YBT dominant leg – posteromedial direction(p=0.009), YBT dominant leg – posterolateral direction (p=0.005), YBT non-dominant leg - anterior direction (p=0.006), and YBT non-dominant leg – posterolateral direction (p=0.001).

There was no statistically significant improvement overall in both groups in THT of the non-dominant leg (p=0.665). Repeated measures ANOVA showed non-statistically significant differences in time with group interaction, although in the VCJ, p value approximated significance (p=0.067). Of note were differences in the rates of change per group. At 7 weeks, Plyometric group had a far greater improvement rate than BFR group, in the HCJ (6.6% vs 2.8%), THT non-dominant leg (8.3% vs -1.6%) and YBT Anterior direction- Dominant Leg (9.72% vs 2.3%). The BFR group had a higher improvement rate than plyometric group in the YBT Posteromedial direction- Dominant Leg (12.85% vs 8.11%), YBT Posterolateral direction - Dominant Leg (25.7% vs 11.96%) and YBT Posterolateral direction non-dominant Leg (24.1% vs 12.72%).

At 11 weeks, the plyometric group had a greater improvement rate than BFR group in the variables YBT Anterior direction- Dominant Leg (15.08% vs 7.65%) and YBT Posteromedial direction– non-dominant leg (11.4% vs 8.2%). The BFR group had a higher improvement rate than plyometric group in strength (1 RM) (19.23% vs 15.8%), VCJ (23.73% vs 10.58%), again YBT Posteromedial direction- Dominant Leg (16.78% vs 12.02%), also YBT Posterolateral direction - Dominant Leg (22.79% vs 12.57%) and YBT Posterolateral direction non-dominant Leg (26.27% vs 17.12%). A summary of the results at week 7 and week 11 are presented on Table 3.

**Table 3: Across group results**

| **Variable** | **Group** | **Baseline** | **Week 7** | **Week 11** | **ANOVA p-value** |
|---|---|---|---|---|---|
| Strenth (1RM) (kg) | Plyometric<br>BFR | 76.0 ± 7.68<br>89.4 ± 13.65 | 82.6 ± 7.64<br>99 ± 15.44 | 88.0 ± 9.95<br>106.6 ± 19.92 | p=0.548, F=0.657 |
| Horizontal Countermovement Jump (m) | Plyometric | 1.81 ±0.19 | 1.93 ± 0.18 | 1.98 ±0.21 | p=0.205, F=2.001 |

| | | | | | |
|---|---|---|---|---|---|
| | BFR | 2.09 ±0.25 | 2.15 ± 0.25 | 2.24 ± 0.25 | |
| Vertical Countermovement Jump (m) | Plyometric<br>BFR | 41.0 ± 5.48<br>42.38 ± 7.3 | 44.02 ± 5.8<br>46.58 ±6.29 | 45.34 ±6.07<br>52.44 ± 7.29 | p=0.067, F=4.071 |
| Triple Hop Test Dominant (right) Leg (m) | Plyometric<br>BFR | 4.16 ± 0.26<br>4.59 ± 0.36 | 4.48 ± 0.22<br>4.86 ± 0.65 | 4.68 ± 0.12<br>5.15 ± 0.6 | p=0.937, F=0.066 |
| Triple Hop Test Non-Dominant (left) Leg (m) | Plyometric<br>BFR | 4.2 ± 0.31<br>5.03 ± 0.35 | 4.55 ± 0.56<br>4.95 ± 0.44 | 4.38 ± 1.26<br>5.19 ± 0.61 | p=0.228, F=0.002 |
| Y Balance Test Anterior direction- Dominant Leg (cm) | Plyometric<br>BFR | 54.1 ± 6.25<br>56.2 ± 4.53 | 59.36 ± 5.06<br>57.5 ± 6.2 | 62.26 ± 2.04<br>60.5 ± 4.31 | p=0.253, F=1.520 |
| Y Balance Test Posteromedial direction- Dominant Leg (cm) | Plyometric<br>BFR | 71.5 ± 6.11<br>84 ± 14.35 | 77.3 ± 10.9<br>94.8 ±13.38 | 80.1 ± 8.74<br>98.1 ± 9.53 | p=0.6, F=0.546 |
| Y Balance Test Posterolateral direction - Dominant Leg (cm) | Plyometric<br>BFR | 65.2 ± 8.52<br>77.2 ± 13.91 | 73±16.43<br>97.1±17.14 | 73.4 ± 14.03<br>94.8 ± 12.81 | p=0.25, F=1.712 |
| Y Balance Test Anterior direction- non-dominant Leg (cm) | Plyometric<br>BFR | 54.5 ± 7.63<br>58.7 ± 3.29 | 56.5 ± 8.15<br>61.9 ± 8.98 | 61 ± 6.52<br>65.3 ± 5.61 | p=0.9, F=0.098 |
| Y Balance Test Posteromedial direction non-dominant Leg (cm) | Plyometric<br>BFR | 72.8 ± 9.15<br>90.2 ± 13.44 | 81.2 ± 12.84<br>100.1 ± 16.26 | 81.1 ±9.63<br>97.6 ± 15.72 | p=0.833, F=0.187 |
| Y Balance Test Posterolateral direction non-dominant Leg (cm) | Plyometric<br>BFR | 66 ± 6.58<br>70.8 ± 17.23 | 74.4 ± 12.56<br>87.9 ± 14.29 | 77.3 ± 7.02<br>89.4 ± 15.04 | p=0.258, F=1.653 |

## Discussion

In both experimental groups there was a statistically significant improvement in strength, bilateral limb balance, vertical and horizontal jump as well as the triple hop test on the dominant leg. The triple hop test on the non-dominant leg did not reach statistical significance on either group but showed an, albeit small, improvement in both. At 11 weeks, the plyometric group had a greater improvement rate than BFR group in the variables YBT Anterior direction- Dominant Leg and YBT Posteromedial direction– non-dominant Leg. The BFR group had a greater improvement rate than plyometric group in strength, VCJ, YBT Posteromedial direction- Dominant Leg, YBT Posterolateral direction - Dominant Leg and YBT Posterolateral direction non-dominant Leg. Furthermore, in the VCJ p value was 0.067 which was close to being statistically significant and there was a difference of 13.15 percentage points in favor of the BFR group.

Jumping ability has been extensively researched in relation to plyometric training. A recent randomized controlled trial investigated the change of direction training combined with a plyometric training regime on young professional soccer players [8]. The authors suggested that the horizontal jump as well as Triple Hop Test improved in the team that undertook the plyometric training. In agreement were also the results of another systematic review on the effects of plyometric training on adult male soccer players [24], where, it was suggested that plyometric training improved vertical jump, acceleration and endurance but did not improve their strength. Interestingly, the positive effects of plyometric training on jumping ability extends beyond soccer to other sports, as indicated in a recent systematic review on volleyball [25].

Unlike jumping, balance has not been extensively studied in relation to plyometric exercise. Most research on plyometric exercise and balance relates to basketball. The improvement offered by plyometric training in balance was similar to the improvement offered by other types of training, such as balance exercises [26]. In a randomized controlled trial [27], the effect of plyometric exercise in combination with balance exercises on women basketball players was found to improve balance, agility and drop jump in comparison to the control group, who carried out the standard training. The intervention, however, was not limited to plyometric training and therefore direct comparison with the current study cannot be made.

With regards to quadriceps strength, Oxfeldt et al. [7] conducted a systematic review examining the effects of plyometric training on lower limb muscle strength, among other measures. The authors observed a small to moderate positive effect on jumping ability, acceleration and lower limb strength in healthy adults whether they are athletes or active in recreational sports. Ramírez - Campillo et al. [28] in their review on the effect of plyometrics on various physical condition markers of basketball athletes came to similar conclusions. The researchers observed that plyometric training improves muscle strength and power, jumping ability, balance, change of direction and acceleration in basketball athletes regardless of gender, age and training variables, which is in line with the findings of this study. In contrast are the results of another systematic review [24] examining the effects of plyometric training on adult male soccer players, which found that, although plyometric training improved vertical jump, acceleration and endurance in male soccer players, it did not improve their strength. Plyometric training has also been compared with resistance training and their effect on muscle hypertrophy [29]. They observed that both types of training can have similar effects on lower extremity muscle hypertrophy, but it is noted that the evidence for the effect of plyometric training on muscle fiber hypertrophy is limited. In this study there was a statistically significant change in both groups. The plyometric exercise programme was progressive, it contained the common plyometric training exercises used and even though it was not individualized, all participants rated the exercises as >4 in the BORG scale throughout the programme.

Regarding the application of BFR, most studies investigated patient populations rather than asymptomatic athletes. Hughes et al. [30] concluded that a low-load BFR workout provides a more effective approach to resistance exercise in a population with musculoskeletal conditions. Similar were the results in a review [31] investigating BFR training in musculoskeletal rehabilitation; they found that the effectiveness of low-intensity BFR training is lower than conventional high-resistance training but is useful for populations where high load is not tolerated or contraindicated. In sports world, current data suggest that low-resistance BFR training may enhance muscle hypertrophy and strength in well-trained athletes who would not normally benefit from low-load training. In healthy athletes, low-load BFR training can be applied in conjunction with high-load training and provide additional stimuli to muscle growth [32]. Similar were the results in a randomized controlled trial that investigated BFR training in college soccer players' muscle strength and suggested that BFR training provided an additional advantage to conventional strength training in improving muscle hypertrophy and power 33). Luebbers et al. [34] suggested that a low-resistance and BFR strength training program increased quadriceps strength during the back-squat test in high school soccer players. However, in Australian soccer it was found that the addition of low-load strength training and BFR did not offer any additional benefits to healthy Australian soccer athletes who were already following the team's demanding training [35]. Both experimental teams in this study followed the same progressive plyometric training program at moderate intensity, and a difference in the increase in strength by 3.43 percentage points was observed in the BFR group, which is in line with data from low-intensity training with BFR [34]. This could be helpful in introducing plyometric training in an athlete's either post-injury recovery programme or performance enhancement. Of interest, however, is the improvement in the vertical jump in BFR group (23.73%), which was superior to Plyometric group (10,58%) and in combination with the albeit marginal 0.067 p value, is indicative of BFR superiority in this exercise. Further research on the effect of BFR training vertical jump could provide better insight on this area.

Balance is also a variable that is not often evaluated in BFR studies. A study examining low-load resistance training and BFR in musculoskeletal rehabilitation found that balance improved in both the BFR plyometric group and the high-load resistance group [36]. Another study comparing high-resistance with low-resistance strength training and BFR in postoperative rehabilitation of patients with anterior cruciate ligament reconstruction, found that the BFR group had a statistically and clinically significant improvement in balance in the high resistance group [37]. In the present study, both groups improved in balance with the plyometric group outperforming the BFR group by 7.43 percentage points in the YBT anterior direction non-dominant leg and the BFR group faring better in the YBT Posteromedial direction- Dominant leg, YBT Posterolateral direction - Dominant leg and YBT Posterolateral direction non-dominant leg by 4.76, 10.22 and 9.15 percentage points respectively.

With regards to limitations, the most important was the small sample which, while making it difficult to highlight any statistically significance differences between the two groups, falls within the design of a pilot study. The philosophy of BFR lies in the challenge of strengthening with low load, so for this reason a plyometric training program of moderate intensity was formed, evaluated with the Borg CR10 scale. Although an individualized intensity-based exercise programme would have been desirable for the athletes' sample, pre-testing of the exercise programme utilizing Borg scale was helpful. In addition, similar workout training would ensure consistency throughout groups. However, the same program was followed by the group without the BFR, which could potentially have limited the maximum possible improvement of the variables in this group. Another limitation was the way muscle strength was measured. Strength of the concentric contraction of the quadriceps muscles was measured simultaneously in both lower limbs and not in each leg separately, while the eccentric muscle contraction was not evaluated. Future studies should investigate each leg separately for maximal eccentric and concentric contraction. The 10-week exercise intervention could also be a limitation, as it was observed that the rate of improvement of some variables increased from the 7th week onwards. Perhaps an application period of more than 10 weeks might have influenced the effect of BFR and plyometric exercise on variables utilized.

## Conclusions

In conclusion, a 10-week progressive plyometric exercise programme of moderate intensity, whether applied with or without blood flow restriction, has improved strength, balance, and functional ability in a small sample of male amateur soccer players. This was a pilot study. Future studies including larger cohorts and considering the training results and limitation of the current study, will be able to shed further light in the use of blood flow restriction combined with plyometric exercises.

## Ethics approval and consent to participate

The research was approved by the ethics committee of the University of Patras (protocol no. 11965). All participants signed an informed consent form and during the first meeting

## List of abbreviations

BFR: Blood Flow Restriction
ADSC: Association of the Dodecanese Soccer Clubs
RM: Repetition Maximum
YBT: Y balance test
VCJ: Vertical Countermovement Jump
HCJ: bipedal Horizontal Countermovement Jump
THT: Single Leg Triple Hop Test

## Data Availability

Data will be available upon request

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper


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## Authors' contributions

Conceptualization, CP and EB; Data curation, GK, ET and EB; Formal analysis, GK, ET, MT, PA and EB; Investigation, CP; Methodology, GK, ET, CP and EB; Project administration, CP; Resources, CP; Supervision, EB; Validation, ET, KF and EB; Visualization, CP; Writing - review & editing, GK an EB.

All authors read and approved the final manuscript.


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