

## Original Article

# The Effect of Blood Flow Restriction Training on Isokinetic Strength Muscle Thickness and Athletic Performance

Necdet Eray Piskin<sup>1</sup>, Zait Burak Aktug<sup>2</sup>, Murat Kara<sup>3</sup>, Gonul Yavuz<sup>4</sup>, Gokhan Tuna Ozturk<sup>5</sup>, Serkan Ibis<sup>2</sup>, Hasan Aka<sup>1</sup>

<sup>1</sup>Faculty of Sports Sciences, Nigde Omer Halisdemir University, Department of Movement and Training Sciences, Nigde, Turkey;

<sup>2</sup>Faculty of Sports Sciences, Nigde Omer Halisdemir University, Department of Physical Education and Sports, Nigde, Turkey;

<sup>3</sup>Hacettepe University Medical School, Department of Physical and Rehabilitation Medicine, Ankara, Turkey;

<sup>4</sup>Faculty of Sports Sciences, Kahramanmaraş Sutcu Imam University, Department of Physical Education and Sports, Kahramanmaraş, Turkey;

<sup>5</sup>Faculty of Medicine, Gazi University, Department of Physical and Rehabilitation Medicine, Ankara, Turkey

## Abstract

**Objectives:** The aim of the study is to compare the effects of low-intensity strength training applied with blood flow restriction (BFR) method to the lower and upper extremities with classical hypertrophy (CH) training on isokinetic strength parameters, muscle thickness (MT), and athletic performance. **Methods:** The participants were divided into 2 groups as BFRG and CHG. The BFRG applied the strength training program with 20-40% of their 1 repetitive maximal (1 RM) and the CH with 60-80% of 1 RM for 8 weeks, including the lower and upper extremities. To analyze the results of different protocols (BFRG and CHG), as well as pre and post-test measurements and the protocol by time interaction effect, a repeated-measures two-way ANOVA test was employed. **Results:** In both groups observed isokinetic strength parameters, MT and athletic performance were increased similarly ( $p < 0.05$ ). **Conclusions:** BFR with low-intensity strength training elicits similar adaptations to that obtained with high-intensity strength training without BFR.

**Keywords:** Athletic Performance, Blood Flow Restriction, Classical Hypertrophy, Muscle Thickness, Peak Torque

## Introduction

Strength training has an important place in sports sciences in terms of increasing performance, preventing atrophy, protecting from injuries and returning to old performance after injury. For maximum strength development, it is stated that a certain exercise should be performed at least at 70% of 1 RM<sup>1</sup>. However, older people, athletes undergoing rehabilitation after injury, and athletes who will just start or suspend strength training cannot resist the mechanical stress that occurs in high-intensity strength training performed at

70% of 1 RM<sup>2</sup>. For this reason, considering the difficulty of applying high-intensity strength training, the necessity of using alternative methods has emerged. One of the most important of these methods is the BFR method, which aims to reduce the amount of oxygen going to, and removing heat and waste products from, the muscle by restricting the blood flow with the help of a special pressure band (cuff) wrapped on the proximal part of the limb, without completely blocking the arterial blood circulation. As the arterial influx is not much impaired, but the venous efflux is, there would be more pooling of blood and impaired removal of waste products and heat that may enhance muscle development<sup>3</sup>.

It has been suggested that the stimulus will become more aerobic over time, since contractions do not produce enough fatigue in low-intensity loading intervals such as 20-40% of 1 RM under normal conditions<sup>4</sup>. In the BFR method, it is supported by studies that when strength training is performed at low intensities such as at 20-40% of 1 RM, significant hypertrophy occurs in the muscle<sup>5-7</sup>. It has been stated that this level of hypertrophy, on the other hand, leads

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Corresponding author: Necdet Eray Piskin, Nigde Omer Halisdemir University, Faculty of Sports Sciences, Nigde, Turkey  
E-mail: eraypiskin@ohu.edu.tr

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to muscle strength gain, similar to high-intensity strength training<sup>8,9</sup>. In addition, it was determined that the training volume decreased with the early formation of the feeling of exhaustion thanks to the pressure created by the cuffs in the low-intensity strength training applied with the BFR method. Thus, it has been stated that the BFR method can provide maximum hypertrophy and strength development in the muscle without the need for a long process of low loads and high training volume<sup>10</sup>. For these reasons, the use of the BFR method to increase the performance of athletes is increasing<sup>9,11</sup>.

Because of these developments, it has been stated that the BFR method can provide benefits by making the training more efficient in athletes or by preventing the athlete from being untrained when high-intensity strength training is not possible<sup>12</sup>. While it is seen in the literature that the BFR method is widely used with fitness equipment<sup>9</sup>, there are also studies in which it is combined with different methods (nordic hamstring exercise, theraband, bicycle, vibration, etc.) and positive effects are provided<sup>13-16</sup>.

In line with all this information, the aim of the study is to examine the effects of low-intensity strength training with the BFR method and high-intensity CH strength training applied to the lower and upper extremities on isokinetic strength parameters, MT and athletic performance and to compare the effects of the 2 methods on these parameters. The hypothesis of the study was determined as "Low-intensity strength training applied with BFR method has a similar effect to high-intensity strength training in improving isokinetic strength parameters, muscle thickness (MT) and athletic performance".

It is important to include both the upper and lower extremity muscles in the study, the training of the participants in personalized limb occlusion pressure (LOP) ranges, and the use of wide pneumatic cuffs in the application of the BFR method. In addition, evaluating isokinetic strength, evaluation of many muscle groups by ultrasonography (USG), and inclusion of athletic performance parameters in the study constitute the originality of the study.

## Materials and Methods

### Participants

Twenty-four male sedentary volunteers without hypertension, congenital heart disease, cognitive dysfunction, peripheral vascular disease, anaemia, varicose veins, myocardial infarction, or similar diseases participated in the study. The body mass index (BMI), age, body mass and height of the BFR (n=12) group were  $23.9 \pm 3.2$  kg/m<sup>2</sup>,  $22.3 \pm 1.1$  years,  $73.7 \pm 6.8$  kg,  $176.2 \pm 6.6$  cm, respectively, and that of the CH (n=12) group  $21.4 \pm 2.8$  kg/m<sup>2</sup>,  $22.8 \pm 1.6$  years,  $67.1 \pm 10.2$  kg,  $176.8 \pm 4.8$  cm, respectively.

### Design

Participants were asked not to participate in any sports activities before the measurement (48 hours) and

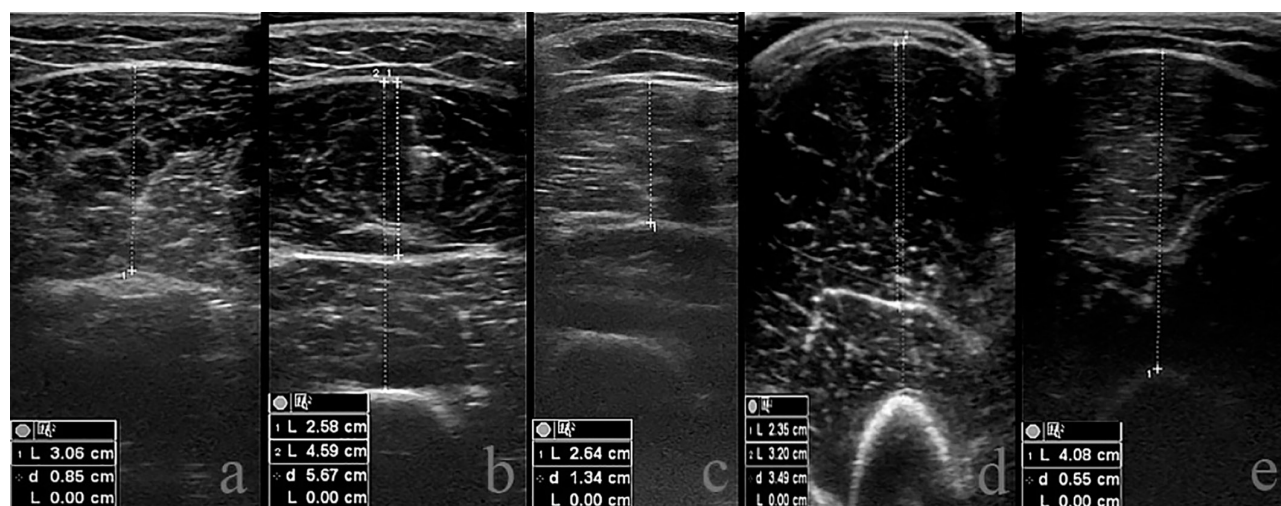
throughout the research process. Before training BMI, MT by USG, isokinetic strength and vertical jump, 30-m sprint performance and agility were determined. Then, 1 RM measurements of the participants<sup>17</sup>, were taken and thus both training loads and muscle fiber types were determined by the Hatfield method<sup>18</sup>. The participants were divided into 2 groups as BFRG (n=12) and CHG (n=12), with muscle fiber types showing similar distribution in both groups. Before starting the training period, lower and upper extremity LOP were determined in order to determine the personalized cuff pressure ranges of the participants in BFR. In addition, the dominant (D) leg region in the lower extremity and the Dominant arm region in the upper extremity of the participants were recorded as D and non-dominant (ND) regions.

Afterwards, both groups started to implement the training protocols given to them. In the fourth week of the study, 1 RM measurement was performed for the second time in order to update the loads in the training program. With the updated training loads, the training process continued for 4 more weeks, and the training period was completed at the end of a total of 8 weeks. In order to exclude acute effects such as excessive growth and loss of strength at the end of the strength training period, 48 hours after the last training, the posttest measurements were repeated in the same order and with the same rest intervals as in the first measurements, and the study was terminated.

### Determination of BFR LOP

It has been stated that the absolute pressure formed after the cuff wrapped around the limb in the trainings performed with the BFR method may lead to different degrees of vascular restriction from person to person, depending on individual blood pressure, anthropometric characteristics and cuff width<sup>6</sup>. Considering this situation, a doppler device which helps to evaluate the deep and superficial blood vessels and allows us to keep the pressure provided in the extremity of the cuff at a certain mm Hg level was used to determine the participant's LOP (Edan SD3 Doppler, US).

According to the exercise forms to be applied in the study, each person's LOP was determined in both sitting and standing positions. While determining the lower extremity occlusion pressure, the cuff was wrapped proximal to the femur. While determining the upper extremity occlusion pressure, the cuff was wrapped proximal to the upper arm. Then, with the doppler probe, the auditory signal of the pulse was found in the radial artery in the arm and in the posterior tibial artery in the leg. The proximally wrapped cuff was inflated with the inflation pump to 50 mm Hg for 30 seconds and then reset for 10 seconds. The inflation-reset cycle was then continued in increments of 10-20 mm Hg and gradually inflated until no pulse was detected. The value at the first point where the pulse is not detected was recorded as the LOP of the person on the manometer screen<sup>19,20</sup>. Then, personal pressure was adjusted according to the percentage of occlusion (upper extremity 40-50%; lower extremity 60-80% LOP) specified



**Figure 1.** (a) biceps femoris (b) rectus femoris - quadriceps (rectus femoris+vastus intermedius) (c) vastus lateralis (d) biceps brachii - biceps brachii+brachialis (e) triceps brachii.

in the training protocol applied with the BFR method. It was found that the LOP did not change significantly over 8 weeks in healthy individuals<sup>21</sup>. For this reason, LOP measurement was performed once before the implementation of the training protocols.

#### Training Protocols

##### Low-Intensity Strength Training Protocol Applied with the BFR Method

In the study, H+ cuff brand (Hplus Cuff Curve 2.0, US) curve series cuffs were used bilaterally to restrict blood flow in participants with BFR. The BFR method was applied on separate days with the help of a cuff wrapped around the proximal part of the legs and arms. In the study, 40-50% of the LOP determined in the upper extremity and 60-80% in the lower extremity were calculated and the pressure of the cuff was adjusted with the help of an inflation pump according to these values<sup>19</sup>.

In the study, 4 movements in the lower extremities (squat, leg extension, deadlift, standing leg curl) and 4 movements in the upper extremity (lat pull down, seated dumbbell curl, close grip bench press, triceps push down) were applied. While the number of repetitions in each movement was 30-15-15, the rest time was 30-45 seconds, the training program included the lower extremity 2 days a week and the upper extremity 1 day. The training time was applied as a total of 20 minutes, excluding the warm-up. In the literature, there are studies in which the pressure in the cuffs is reset between sets and exercise transitions in the trainings performed with the BFR method, or it remains at the same pressure throughout the

training<sup>22</sup>. In the study, the cuff pressure in BFR remained inflated at the determined pressure throughout the exercises applied to the same muscle group. In the transitions between regions, the pressure was reset by resting for 2 minutes<sup>3</sup>.

In one study, when light loads such as 20% of 1 RM are used, it is recommended to use higher pressures to maximize muscle gains<sup>23</sup>. For this reason, a gradual loading was performed in inverse proportion between 1 RM percent and LOP. The trainings were performed in the 1-2-3. weeks with 1 RM 20% and 80% LOP, in the 4-5-6. weeks with 1 RM 30% and 70% LOP, in the 7-8. weeks with 1 RM 40% and 60% LOP in the lower extremity. Also, the trainings were performed in the 1-2-3. weeks with 1 RM 20% and 50% LOP, in the 4. weeks with 1 RM 30% and 50% LOP, in the 5-6. weeks with 1 RM 30% and 40% LOP, in the 7-8. weeks 1 RM 40% and 40% LOP in the upper extremity.

##### High Intensity Strength Training Protocol Applied with CH Method

It was ensured that the participants in the CH performed the training protocol, which included the lower extremity 2 days a week and the upper extremity 1 day, with the specified loading intensity, number of repetitions and rest intervals (15 repetitions with 60% of 1 RM, 12 repetitions with 70%, 10 repetitions with 80%, 60-120 seconds rest between sets) for a total of 40 minutes. In this group, the same exercises in the BFR group were used by applying the pyramidal method, which is widely used in strength training with the CH method. As the weight lifted increased, the number of repetitions decreased.

**Table 1.** BFRG and CHG 60°s<sup>-1</sup> - 180°s<sup>-1</sup> angular velocity D - ND lower extremity extensor and flexor PT variables pretest - posttest comparison.

| Variable                                       | Pre             | Post            | Δ                                | %                                | Two-way Repeated ANOVA              |                                     |                                     |               |
|--|-----------------|-----------------|----------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|---------------|
|  | M±SD            | M±SD            | T <sub>B</sub> -T <sub>end</sub> | T <sub>B</sub> -T <sub>end</sub> | Time                                | Group                               | Time*Group                          | post hoc test |
| <b>60°s<sup>-1</sup> Extension D-PT (Nm)</b>   |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 200.00 ± 32.40  | 210.50 ± 23.09* | 10.5±9.31                        | 5.25                             | F = 17.29                           | F = 4.50                            | F = 0.14                            | CHG >BFRG     |
| CHG (n=12)                                     | 175.08 ± 26.66  | 187.67 ± 30.48* | 12.5±3.8                         | 7.19                             | p < 0.000<br>ηp <sup>2</sup> = 0.44 | p < 0.045<br>ηp <sup>2</sup> = 0.17 | p < 0.711<br>ηp <sup>2</sup> = 0.00 |               |
| <b>60°s<sup>-1</sup> Extension ND-PT (Nm)</b>  |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 201.50 ± 35.74  | 211.17 ± 29.82* | 9.67±5.92                        | 4.79                             | F = 29.05                           | F = 2.89                            | F = 1.06                            |               |
| CHG (n=12)                                     | 177.92 ± 27.10  | 192.17 ± 31.14* | 14.2±4.04                        | 8.00                             | p < 0.000<br>ηp <sup>2</sup> = 0.56 | p < 0.103<br>ηp <sup>2</sup> = 0.11 | p < 0.313<br>ηp <sup>2</sup> = 0.04 |               |
| <b>60°s<sup>-1</sup> Flexion D-PT (Nm)</b>     |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 93.50 ± 17.82   | 111.08 ± 20.30* | 17.5±2.48                        | 18.80                            | F = 20.80                           | F = 4.02                            | F = 0.19                            |               |
| CHG (n=12)                                     | 78.58 ± 20.28   | 99.92 ± 17.57*  | 21.3±2.71                        | 27.15                            | p < 0.000<br>ηp <sup>2</sup> = 0.48 | p < 0.057<br>ηp <sup>2</sup> = 0.15 | p < 0.665<br>ηp <sup>2</sup> = 0.00 |               |
| <b>60°s<sup>-1</sup> Flexion ND-PT (Nm)</b>    |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 94.50 ± 22.36   | 108.92 ± 19.76* | 14.4±2.60                        | 15.25                            | F = 32.21                           | F = 2.07                            | F = 0.93                            |               |
| CHG (n=12)                                     | 81.25 ± 17.99   | 101.58 ± 15.32* | 20.3±2.67                        | 25.02                            | p < 0.000<br>ηp <sup>2</sup> = 0.59 | p < 0.164<br>ηp <sup>2</sup> = 0.08 | p < 0.344<br>ηp <sup>2</sup> = 0.04 |               |
| <b>180°s<sup>-1</sup> Extension D-PT (Nm)</b>  |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 116.08 ± 28.40  | 138.83 ± 15.32* | 22.7±13.0                        | 19.59                            | F = 37.25                           | F = 2.57                            | F = 0.10                            |               |
| CHG (n=12)                                     | 102.75 ± 25.64  | 123.25 ± 23.40* | 20.5±2.24                        | 19.95                            | p < 0.000<br>ηp <sup>2</sup> = 0.62 | p < 0.123<br>ηp <sup>2</sup> = 0.10 | p < 0.754<br>ηp <sup>2</sup> = 0.00 |               |
| <b>180°s<sup>-1</sup> Extension ND-PT (Nm)</b> |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 123.75 ± 28.98* | 140.50 ± 24.32  | 16.7±4.66                        | 13.53                            | F = 31.14                           | F = 6.29                            | F = 0.32                            | CHG >BFRG     |
| CHG (n=12)                                     | 100.58 ± 16.13* | 121.17 ± 17.26  | 20.5±1.13                        | 20.47                            | p < 0.000<br>ηp <sup>2</sup> = 0.58 | p < 0.020<br>ηp <sup>2</sup> = 0.22 | p < 0.572<br>ηp <sup>2</sup> = 0.01 |               |
| <b>180°s<sup>-1</sup> Flexion D-PT (Nm)</b>    |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 63.58 ± 14.10   | 80.17 ± 15.65*  | 16.5±1.55                        | 26.09                            | F = 80.35                           | F = 6.14                            | F = 0.32                            | CHG >BFRG     |
| CHG (n=12)                                     | 50.17 ± 11.39   | 69.00 ± 10.48*  | 18.8±.91                         | 37.53                            | p < 0.000<br>ηp <sup>2</sup> = 0.78 | p < 0.021<br>ηp <sup>2</sup> = 0.21 | p < 0.575<br>ηp <sup>2</sup> = 0.01 |               |
| <b>180°s<sup>-1</sup> Flexion ND-PT (Nm)</b>   |                 |                 |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)                                    | 65.33 ± 16.31   | 80.25 ± 15.13*  | 14.9±1.18                        | 22.83                            | F = 57.03                           | F = 2.88                            | F = 0.05                            |               |
| CHG (n=12)                                     | 55.67 ± 12.12   | 71.50 ± 12.80*  | 15.8±.68                         | 28.43                            | p < 0.000<br>ηp <sup>2</sup> = 0.72 | p < 0.104<br>ηp <sup>2</sup> = 0.11 | p < 0.824<br>ηp <sup>2</sup> = 0.00 |               |

\*BFRG = blood flow restriction group; CHG = classical hypertrophy group; PT = peak torque; D = dominant; ND = non-dominant; Nm = newton meter; values expressed as mean ± SD; Δ = change; Pre = preintervention; Post = postintervention; ηp<sup>2</sup>: partial eta squared. \* There is a significant difference between the pre-test and post-test values.

**Exercises Included in the Training Program**

Both isolated and compound types of exercise have been shown to increase hypertrophy. However, isolated exercises were found to be superior at the point of hypertrophy<sup>24</sup>. In some studies, it was stated that there was improvement in other muscle groups as a cross-effect as a result of compound exercise choices<sup>25</sup>. Since the development of athletic performance was also taken into consideration in our study, one compound and one isolated exercise type were determined for each muscle group. During the training period, compound exercise and isolated exercise were started for each muscle group, respectively.

**Applied Measurements**

**MT Measurement with USG**

The measurement was performed with an ultrasound imaging device (GE Logiq P5, USA) using an electronic caliper with a sensitivity of 0.1 mm. During the measurement phase, the distance between the lower part of the upper fascia of the muscle and the upper part of the lower fascia or bone periosteum was measured with a 5-12 MHz linear probe (Figure 1).

The measurement was done over the sciatic nerve from 1/3 of the distance between biceps brachii and brachialis acromion and antecubital fossa, 1/2 of the distance between

**Table 2.** BFRG and CHG 60<sup>os-1</sup> - 180<sup>os-1</sup> angular velocity D - ND upper extremity extensor and flexor PT variables pretest - posttest comparison.

| Variable                                 | Pre              | Post              | $\Delta$                         | %                                | Two-way Repeated ANOVA                    |   |   |               |
|--|------------------|-------------------|----------------------------------|----------------------------------|---|---|---|---------------|
|  | M $\pm$ SD       | M $\pm$ SD        | T <sub>B</sub> -T <sub>end</sub> | T <sub>B</sub> -T <sub>end</sub> | Time                                      | Group                                     | Time*Group                                | post hoc test |
| 60 <sup>os-1</sup> Extension D-PT (Nm)   |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 40.75 $\pm$ 8.40 | 46.92 $\pm$ 7.65* | 6.17 $\pm$ 0.75                  | 15.14                            | F = 11.96                                 | F = 3.13                                  | F = 2.00                                  | BFRG >CHG     |
| CHG (n=12)                               | 37.83 $\pm$ 6.91 | 40.42 $\pm$ 5.58  | 2.59 $\pm$ 1.33                  | 6.84                             | p < 0.002<br>$\eta$ p <sup>2</sup> = 0.35 | p < 0.091<br>$\eta$ p <sup>2</sup> = 0.12 | p < 0.171<br>$\eta$ p <sup>2</sup> = 0.08 |               |
| 60 <sup>os-1</sup> Extension ND-PT (Nm)  |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 43.33 $\pm$ 8.06 | 44.92 $\pm$ 6.54  | 1.59 $\pm$ 1.52                  | 3.66                             | F = 2.37                                  | F = 7.93                                  | F = 0.00                                  | BFRG >CHG     |
| CHG (n=12)                               | 34.75 $\pm$ 8.97 | 36.17 $\pm$ 7.83  | 1.42 $\pm$ 1.14                  | 4.08                             | p < 0.137<br>$\eta$ p <sup>2</sup> = 0.09 | p < 0.010<br>$\eta$ p <sup>2</sup> = 0.26 | p < 0.933<br>$\eta$ p <sup>2</sup> = 0.00 |               |
| 60 <sup>os-1</sup> Flexion D-PT (Nm)     |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 44.42 $\pm$ 8.81 | 47.67 $\pm$ 7.72  | 3.25 $\pm$ 1.09                  | 7.31                             | F = 6.54                                  | F = 1.57                                  | F = 0.01                                  |               |
| CHG (n=12)                               | 40.33 $\pm$ 9.15 | 43.33 $\pm$ 9.15  | 3.00 $\pm$ .00                   | 7.43                             | p < 0.018<br>$\eta$ p <sup>2</sup> = 0.22 | p < 0.222<br>$\eta$ p <sup>2</sup> = 0.06 | p < 0.919<br>$\eta$ p <sup>2</sup> = 0.00 |               |
| 60 <sup>os-1</sup> Flexion ND-PT (Nm)    |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 46.42 $\pm$ 7.72 | 46.33 $\pm$ 7.98  | -.09 $\pm$ 0.26                  | -.19                             | F = 6.25                                  | F = 2.05                                  | F = 6.82                                  |               |
| CHG (n=12)                               | 39.67 $\pm$ 8.54 | 43.50 $\pm$ 9.26* | 3.83 $\pm$ .72                   | 9.65                             | p < 0.020<br>$\eta$ p <sup>2</sup> = 0.22 | p < 0.166<br>$\eta$ p <sup>2</sup> = 0.08 | p < 0.016<br>$\eta$ p <sup>2</sup> = 0.23 |               |
| 180 <sup>os-1</sup> Extension D-PT (Nm)  |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 25.42 $\pm$ 7.94 | 31.75 $\pm$ 6.70* | 6.33 $\pm$ 1.24                  | 24.90                            | F = 8.11                                  | F = 0.95                                  | F = 1.52                                  |               |
| CHG (n=12)                               | 25.33 $\pm$ 5.44 | 27.83 $\pm$ 4.52  | 2.50 $\pm$ .92                   | 9.86                             | p < 0.009<br>$\eta$ p <sup>2</sup> = 0.26 | p < 0.339<br>$\eta$ p <sup>2</sup> = 0.04 | p < 0.229<br>$\eta$ p <sup>2</sup> = 0.06 |               |
| 180 <sup>os-1</sup> Extension ND-PT (Nm) |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 27.25 $\pm$ 9.18 | 31.75 $\pm$ 5.80* | 4.50 $\pm$ 3.38                  | 16.51                            | F = 6.25                                  | F = 3.99                                  | F = 2.00                                  | BFRG >CHG     |
| CHG (n=12)                               | 23.83 $\pm$ 6.19 | 25.08 $\pm$ 5.28  | 1.25 $\pm$ .91                   | 5.24                             | p < 0.020<br>$\eta$ p <sup>2</sup> = 0.22 | p < 0.058<br>$\eta$ p <sup>2</sup> = 0.15 | p < 0.171<br>$\eta$ p <sup>2</sup> = 0.08 |               |
| 180 <sup>os-1</sup> Flexion D-PT (Nm)    |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 29.08 $\pm$ 8.07 | 33.08 $\pm$ 8.94  | 4.00 $\pm$ .87                   | 13.75                            | F = 12.25                                 | F = 1.80                                  | F = 0.73                                  |               |
| CHG (n=12)                               | 23.92 $\pm$ 7.28 | 30.50 $\pm$ 7.47* | 6.58 $\pm$ .19                   | 27.50                            | p < 0.002<br>$\eta$ p <sup>2</sup> = 0.35 | p < 0.192<br>$\eta$ p <sup>2</sup> = 0.07 | p < 0.402<br>$\eta$ p <sup>2</sup> = 0.03 |               |
| 180 <sup>os-1</sup> Flexion ND-PT (Nm)   |                  |                   |                                  |                                  |   |   |   |               |
| BFRG (n=12)                              | 29.00 $\pm$ 8.86 | 31.75 $\pm$ 6.67  | 2.75 $\pm$ 2.19                  | 9.48                             | F = 11.20                                 | F = 1.46                                  | F = 0.56                                  |               |
| CHG (n=12)                               | 24.75 $\pm$ 7.09 | 29.08 $\pm$ 7.02* | 4.33 $\pm$ .07                   | 17.49                            | p < 0.003<br>$\eta$ p <sup>2</sup> = 0.33 | p < 0.239<br>$\eta$ p <sup>2</sup> = 0.06 | p < 0.462<br>$\eta$ p <sup>2</sup> = 0.02 |               |

\*BFRG = blood flow restriction group; CHG = classical hypertrophy group; PT = peak torque; D = dominant; ND = non-dominant; Nm = newton meter; values expressed as mean  $\pm$  SD;  $\Delta$  = change; Pre = preintervention; Post = postintervention;  $\eta$ p<sup>2</sup>: partial eta squared. \* There is a significant difference between the pre-test and post-test values.

the triceps brachii acromion and the antecubital fossa, 1/2 of the distance between rectus femoris, quadriceps (rectus femoris+vastus intermedius) and vastus lateralis spina iliaca anterior superior and patella upper pole, 1/2 of the distance between the biceps femoris ischial tuberosity and the popliteal fossa.

#### Isokinetic Strength Measurement

The lower extremity (knee) and upper extremity (elbow) isokinetic muscle strength measurements of the participants were performed using the Cybex brand isokinetic dynamometer (Humac Norm Testing and

Rehabilitation System, CSMI, USA). Measurements were applied as 2 sessions on the same day. Lower extremity measurements were made in the first session bilaterally and upper extremity measurements were performed bilaterally in the second session. The measuring device was adjusted by the expert physiotherapist according to the anthropometric characteristics of the person. Knee and elbow flexion-extension strengths were measured with concentric-concentric contraction consisting of 5 repetitions at an angular velocity of 60<sup>os-1</sup> and 15 repetitions at angular velocity of 180<sup>os-1</sup>. peak torque (PT) parameters were included in the measurements.

**Table 3.** Comparison of pre-test and post-test of BFRG and CHG lower extremity D - ND MT variables.

| Variable                 | Pre              | Post              | $\Delta$                         | %                                | Two-way Repeated ANOVA                                      |  |  |               |
|--------------------------|------------------|-------------------|----------------------------------|----------------------------------|---|--|--|---------------|
|                          | M $\pm$ SD       | M $\pm$ SD        | T <sub>B</sub> -T <sub>end</sub> | T <sub>B</sub> -T <sub>end</sub> | Time  | Group  | Time*Group   | post hoc test |
| D-Rectus Femoris (mm)    |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 27.31 $\pm$ 2.93 | 29.24 $\pm$ 3.33* | 1.93 $\pm$ .40                   | 7.06                             | F = 27.59<br><i>p</i> < 0.000<br>$\eta$ <sup>2</sup> = 0.55 | F = 2.60<br><i>p</i> < 0.121<br>$\eta$ <sup>2</sup> = 0.10 | F = 1.75<br><i>p</i> < 0.199<br>$\eta$ <sup>2</sup> = 0.07 |               |
| CHG (n=12)               | 25.29 $\pm$ 4.32 | 26.44 $\pm$ 4.14* | 1.15 $\pm$ .18                   | 4.54                             |   |  |  |               |
| ND-Rectus Femoris (mm)   |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 26.71 $\pm$ 3.60 | 29.16 $\pm$ 2.15* | 2.45 $\pm$ 1.45                  | 9.17                             | F = 19.68<br><i>p</i> < 0.000<br>$\eta$ <sup>2</sup> = 0.47 | F = 4.20<br><i>p</i> < 0.052<br>$\eta$ <sup>2</sup> = 0.16 | F = 0.26<br><i>p</i> < 0.613<br>$\eta$ <sup>2</sup> = 0.01 | CHG >BFRG     |
| CHG (n=12)               | 23.78 $\pm$ 4.93 | 25.72 $\pm$ 4.68* | 1.94 $\pm$ .25                   | 8.15                             |   |  |  |               |
| D-Quadriceps (mm)        |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 50.13 $\pm$ 6.96 | 54.03 $\pm$ 6.07* | 3.90 $\pm$ .89                   | 7.77                             | F = 28.89<br><i>p</i> < 0.000<br>$\eta$ <sup>2</sup> = 0.56 | F = 1.90<br><i>p</i> < 0.181<br>$\eta$ <sup>2</sup> = 0.08 | F = 0.15<br><i>p</i> < 0.697<br>$\eta$ <sup>2</sup> = 0.00 |               |
| CHG (n=12)               | 46.74 $\pm$ 7.24 | 50.10 $\pm$ 6.45* | 3.36 $\pm$ .79                   | 7.18                             |   |  |  |               |
| ND-Quadriceps (mm)       |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 48.77 $\pm$ 7.01 | 52.95 $\pm$ 4.96* | 4.18 $\pm$ 2.05                  | 8.57                             | F = 22.81<br><i>p</i> < 0.000<br>$\eta$ <sup>2</sup> = 0.50 | F = 1.93<br><i>p</i> < 0.178<br>$\eta$ <sup>2</sup> = 0.08 | F = 0.20<br><i>p</i> < 0.658<br>$\eta$ <sup>2</sup> = 0.00 |               |
| CHG (n=12)               | 44.75 $\pm$ 7.34 | 49.80 $\pm$ 7.35* | 5.05 $\pm$ .01                   | 11.28                            |   |  |  |               |
| D-Vastus lateralis (mm)  |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 26.43 $\pm$ 2.38 | 27.06 $\pm$ 3.15  | 0.63 $\pm$ .77                   | 2.38                             | F = 11.10<br><i>p</i> < 0.003<br>$\eta$ <sup>2</sup> = 0.35 | F = 0.56<br><i>p</i> < 0.463<br>$\eta$ <sup>2</sup> = 0.02 | F = 2.04<br><i>p</i> < 0.169<br>$\eta$ <sup>2</sup> = 0.09 |               |
| CHG (n=12)               | 24.90 $\pm$ 3.72 | 26.47 $\pm$ 3.88* | 1.57 $\pm$ .16                   | 6.30                             |   |  |  |               |
| ND-Vastus lateralis (mm) |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 24.84 $\pm$ 3.16 | 28.17 $\pm$ 2.33* | 3.33 $\pm$ 0.83                  | 13.40                            | F = 26.11<br><i>p</i> < 0.000<br>$\eta$ <sup>2</sup> = 0.57 | F = 2.21<br><i>p</i> < 0.153<br>$\eta$ <sup>2</sup> = 0.10 | F = 3.95<br><i>p</i> < 0.061<br>$\eta$ <sup>2</sup> = 0.17 | CHG >BFRG     |
| CHG (n=12)               | 23.60 $\pm$ 4.52 | 25.06 $\pm$ 3.52* | 1.46 $\pm$ 1.00                  | 6.18                             |   |  |  |               |
| D-Biceps femoris (mm)    |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 37.40 $\pm$ 3.65 | 37.07 $\pm$ 4.64  | -0.33 $\pm$ .99                  | -.88                             | F = 4.70<br><i>p</i> < 0.041<br>$\eta$ <sup>2</sup> = 0.17  | F = 2.39<br><i>p</i> < 0.136<br>$\eta$ <sup>2</sup> = 0.09 | F = 0.39<br><i>p</i> < 0.537<br>$\eta$ <sup>2</sup> = 0.01 |               |
| CHG (n=12)               | 34.40 $\pm$ 4.78 | 35.62 $\pm$ 4.61  | 1.22 $\pm$ .17                   | 3.54                             |   |  |  |               |
| ND-Biceps femoris (mm)   |                  |                   |                                  |                                  |   |  |  |               |
| BFRG (n=12)              | 35.83 $\pm$ 4.98 | 37.06 $\pm$ 5.64  | 1.23 $\pm$ .66                   | 3.43                             | F = 14.03<br><i>p</i> < 0.001<br>$\eta$ <sup>2</sup> = 0.40 | F = 0.78<br><i>p</i> < 0.386<br>$\eta$ <sup>2</sup> = 0.03 | F = 2.07<br><i>p</i> < 0.165<br>$\eta$ <sup>2</sup> = 0.09 |               |
| CHG (n=12)               | 33.16 $\pm$ 5.78 | 35.93 $\pm$ 4.68* | 2.77 $\pm$ 1.10                  | 8.35                             |   |  |  |               |

\*BFRG = blood flow restriction group; CHG = classical hypertrophy group; D = dominant; ND = non-dominant; mm = millimeter; Quadriceps = rectus femoris+vastus intermedius; values expressed as mean  $\pm$ SD;  $\Delta$  = change; Pre = preintervention; Post = postintervention;  $\eta$ <sup>2</sup>: partial eta squared. \* There is a significant difference between the pre-test and post-test values.

### Athletic Performance Measurement

In athletic performance measurements, vertical jump, 0-30 m, 0-10 m, 10-20 m sprint and Illinois agility test measurements of the participants were performed with the electronic Smart Speed Lite system (Fusion Sport, AU). All tests were administered as 2 trials, and the best grade was included in the study.

### Statistical Analyses

The normal distribution assumption of quantitative variables was examined through visual methods (histograms

and probability plots) and analytical methods (Shapiro-Wilk test). As the quantitative variables exhibited a normal distribution, they were expressed in terms of mean and standard deviation. To analyze the results of different protocols (BFRG and CHG), as well as pre and post-test measurements and the protocol by time interaction effect, a repeated-measures two-way ANOVA test was employed. Mauchly's sphericity test was used to assess the homogeneity of variances, and a Greenhouse-Geisser correction was applied as needed. Partial eta squared ( $\eta$ <sup>2</sup>) values were calculated to determine the effect size between groups. A *p*<0.05 was considered significant.

**Table 4.** Comparison of pre-test and post-test of BFRG and CHG upper extremity D - ND MT variables.

| Variable                  | Pre          | Post          | Δ                                | %                                | Two-way Repeated ANOVA              |                                     |                                     |               |
|---------------------------|--------------|---------------|----------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|---------------|
|                           | M±SD         | M±SD          | T <sub>B</sub> -T <sub>end</sub> | T <sub>B</sub> -T <sub>end</sub> | Time                                | Group                               | Time*Group                          | post hoc test |
| D-Biceps brachii (mm)     |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)               | 25.44 ± 4.32 | 26.97 ± 3.79  | 1.53±.53                         | 6.01                             | F = 2.96                            | F = 0.14                            | F = 0.11                            |               |
| CHG (n=12)                | 25.38 ± 2.92 | 26.40 ± 3.40  | 1.02±.48                         | 4.01                             | p < 0.100<br>ηp <sup>2</sup> = 0.12 | p < 0.711<br>ηp <sup>2</sup> = 0.00 | p < 0.737<br>ηp <sup>2</sup> = 0.00 |               |
| ND-Biceps brachii (mm)    |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)               | 26.19 ± 4.21 | 26.99 ± 3.14  | .80±1.07                         | 3.05                             | F = 1.06                            | F = 0.32                            | F = 0.02                            |               |
| CHG (n=12)                | 26.05 ± 3.41 | 26.65 ± 3.52  | .60±.11                          | 2.30                             | p < 0.313<br>ηp <sup>2</sup> = 0.04 | p < 0.859<br>ηp <sup>2</sup> = 0.00 | p < 0.884<br>ηp <sup>2</sup> = 0.00 |               |
| D-Biceps+brachialis (mm)  |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)               | 37.11 ± 3.06 | 36.73 ± 3.41  | -.38±.35                         | -1.02                            | F = 0.12                            | F = 0.46                            | F = 0.21                            |               |
| CHG (n=12)                | 35.84 ± 5.00 | 35.90 ± 3.86  | .06±1.14                         | .16                              | p < 0.731<br>ηp <sup>2</sup> = 0.00 | p < 0.504<br>ηp <sup>2</sup> = 0.02 | p < 0.647<br>ηp <sup>2</sup> = 0.01 |               |
| ND-Biceps+brachialis (mm) |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)               | 36.58 ± 4.49 | 37.76 ± 3.60  | 1.18±.89                         | 3.22                             | F = 1.09                            | F = 0.11                            | F = 0.89                            |               |
| CHG (n=12)                | 36.63 ± 4.17 | 36.69 ± 3.64  | .06±.53                          | .16                              | p < 0.307<br>ηp <sup>2</sup> = 0.04 | p < 0.739<br>ηp <sup>2</sup> = 0.00 | p < 0.354<br>ηp <sup>2</sup> = 0.03 |               |
| D-Triceps brachii (mm)    |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)               | 38.87 ± 5.09 | 40.42 ± 4.10  | 1.55±.99                         | 3.98                             | F = 5.78                            | F = 1.45                            | F = 0.57                            |               |
| CHG (n=12)                | 40.49 ± 5.24 | 43.47 ± 6.38* | 2.98±1.14                        | 7.35                             | p < 0.025<br>ηp <sup>2</sup> = 0.20 | p < 0.241<br>ηp <sup>2</sup> = 0.06 | p < 0.455<br>ηp <sup>2</sup> = 0.02 |               |
| ND-Triceps brachii (mm)   |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)               | 36.48 ± 5.28 | 39.38 ± 4.08* | 2.90±1.20                        | 7.94                             | F = 8.90                            | F = 0.73                            | F = 0.91                            |               |
| CHG (n=12)                | 38.75 ± 4.99 | 40.24 ± 4.40  | 1.49±.59                         | 3.84                             | p < 0.007<br>ηp <sup>2</sup> = 0.29 | p < 0.401<br>ηp <sup>2</sup> = 0.03 | p < 0.349<br>ηp <sup>2</sup> = 0.04 |               |

\*BFRG = blood flow restriction group; CHG = classical hypertrophy group; D = dominant; ND = non-dominant; mm = milimeter; values expressed as mean ±SD; Δ = change; Pre = preintervention; Post = postintervention; ηp<sup>2</sup>: partial eta squared. \* There is a significant difference between the pre-test and post-test values.

## Results

When Table 1 was examined, a significant difference was found in favor of the post-test in all of the 60°s<sup>-1</sup> extension-flexion D-ND leg PT, 180°s<sup>-1</sup> extension-flexion D leg PT and 180°s<sup>-1</sup> flexion ND leg PT parameters of both BFRG and CHG groups. In the comparison between the groups, a significant difference was found in favor of CHG in the 60°s<sup>-1</sup> extension D (F = 4.50; p = 0.045, ηp<sup>2</sup> = 0.17), 180°s<sup>-1</sup> extension ND (F = 6.29; p = 0.020, ηp<sup>2</sup> = 0.22) and 180°s<sup>-1</sup> flexion D leg PT parameters (F = 6.14; p = 0.021, ηp<sup>2</sup> = 0.21).

When Table 2 is examined, a significant difference was found in favor of the post-test in 60°s<sup>-1</sup> extension D, 180°s<sup>-1</sup> extension D-ND arm PT parameters in BFRG, and in 60°s<sup>-1</sup> flexion ND, 180°s<sup>-1</sup> flexion D-ND arm PT parameters in CHG. The group\*time interaction (p<0.016) is reflected by a more pronounced improvement in the 60°s<sup>-1</sup> flexion ND PT parameter in CHG compared to BFRG (BFRG -19% CHG 9.65%). In the comparison between the groups, a significant difference was found in favor of the BFRG in

60°s<sup>-1</sup> extension D (F = 3.13; p = 0.091, ηp<sup>2</sup> = 0.12), 60°s<sup>-1</sup> extension ND (F = 7.93; p = 0.010, ηp<sup>2</sup> = 0.26), 180°s<sup>-1</sup> extension ND (F = 3.99; p = 0.058, ηp<sup>2</sup> = 0.15) arm PT parameters.

When Table 3 is examined, a significant difference was found in all of the rectus femoris D-ND, quadriceps D-ND, vastus lateralis D-ND MT parameters of both BFRG and CHG groups in favor of the post-test. A significant difference was found in the vastus lateralis D and biceps femoris ND MT only in CHG. In the comparison between the groups, a significant difference was found in favor of CHG in the rectus femoris ND (F = 4.20; p = 0.052, ηp<sup>2</sup> = 0.16) and vastus lateralis ND (F = 2.21; p = 0.153, ηp<sup>2</sup> = 0.10) parameters.

When Table 4 is examined, a significant difference was found in favor of the post-test in the triceps brachii D MT in CHG (F = 5.78; p = 0.025, ηp<sup>2</sup> = 0.20), and in favor of the post-test in the triceps brachii ND MT in BFRG (F = 8.90; p = 0.007, ηp<sup>2</sup> = 0.29). In the comparison between the groups, no significant difference was found in all parameters.

When Table 5 is examined, a significant difference was

**Table 5.** Comparison of pretest and posttest athletic performance variables of BFRG and CHG.

| Variable            | Pre          | Post          | Δ                                | %                                | Two-way Repeated ANOVA              |                                     |                                     |               |
|---------------------|--------------|---------------|----------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|---------------|
|                     | M±SD         | M±SD          | T <sub>B</sub> -T <sup>end</sup> | T <sub>B</sub> -T <sup>end</sup> | Time                                | Group                               | Time*Group                          | post hoc test |
| Agility (sn)        |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)         | 17.80 ± .88  | 15.64 ± .77*  | 2.16±.11                         | 12.13                            | F = 163.88                          | F = 1.06                            | F = 44.96                           | BFRG >CHG     |
| CHG (n=12)          | 17.43 ± 1.07 | 16.75 ± .91*  | .68±.16                          | 3.90                             | p < 0.000<br>ηp <sup>2</sup> = 0.88 | p < 0.314<br>ηp <sup>2</sup> = 0.04 | p < 0.000<br>ηp <sup>2</sup> = 0.67 |               |
| Vertical Jump (cm)  |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)         | 43.41 ± 3.73 | 47.41 ± 3.52* | 4.00±.21                         | 9.21                             | F = 160.83                          | F = 1.37                            | F = .03                             |               |
| CHG (n=12)          | 41.17 ± 5.27 | 45.28 ± 5.61* | 4.11±.34                         | 9.98                             | p < 0.000<br>ηp <sup>2</sup> = 0.88 | p < 0.253<br>ηp <sup>2</sup> = 0.05 | p < 0.859<br>ηp <sup>2</sup> = 0.00 |               |
| 30 m Sprint (sn)    |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)         | 4.81 ± .34   | 4.34 ± .18*   | .47±.16                          | 9.77                             | F = 94.65                           | F = 0.05                            | F = 39.38                           |               |
| CHG (n=12)          | 4.60 ± .31   | 4.50 ± .30*   | .10±.01                          | 2.17                             | p < 0.000<br>ηp <sup>2</sup> = 0.81 | p < 0.826<br>ηp <sup>2</sup> = 0.00 | p < 0.000<br>ηp <sup>2</sup> = 0.64 |               |
| 0-10 m Sprint (sn)  |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)         | 1.91 ± .21   | 1.87 ± .19    | .04±.02                          | 2.09                             | F = 9.79                            | F = 0.26                            | F = 4.30                            |               |
| CHG (n=12)          | 1.95 ± .31   | 1.75 ± .10*   | .20±.21                          | 10.25                            | p < 0.005<br>ηp <sup>2</sup> = 0.30 | p < 0.613<br>ηp <sup>2</sup> = 0.01 | p < 0.050<br>ηp <sup>2</sup> = 0.16 |               |
| 10-20 m Sprint (sn) |              |               |                                  |                                  |                                     |                                     |                                     |               |
| BFRG (n=12)         | 3.63 ± .39   | 3.33 ± .32*   | .30±.07                          | 8.26                             | F = 78.87                           | F = 0.17                            | F = 42.71                           |               |
| CHG (n=12)          | 3.45 ± .28   | 3.40 ± .27    | .05±.01                          | 1.44                             | p < 0.000<br>ηp <sup>2</sup> = 0.78 | p < 0.678<br>ηp <sup>2</sup> = 0.00 | p < 0.000<br>ηp <sup>2</sup> = 0.66 |               |

*\*BFRG = blood flow restriction group; CHG = classical hypertrophy group; sn = second; cm = centimeter; m = meter; values expressed as mean ±SD; Δ = change; Pre = preintervention; Post = postintervention; ηp<sup>2</sup>: partial eta squared. \* There is a significant difference between the pre-test and post-test values.*

found in favor of the post-test in all of the agility, vertical jump and 30 m sprint parameters of both BFRG and CHG groups. In the 0-10 m sprint parameter, a significant difference was found in favor of the post-test in CHG (F = 9.79; p = 0.005, ηp<sup>2</sup> = 0.30), and in the 10-20 m sprint parameter in BFRG (F = 78.87; p = 0.000, ηp<sup>2</sup> = 0.78). In the comparison between the groups, a significant difference was found in favor of the BFRG in the agility parameter (F = 44.96; p = 0.000, ηp<sup>2</sup> = 0.67). Although there was no difference between the groups in BFRG and CHG except for agility, for the 30-m sprint (p<0.000), 10- 20-m sprint (p<0.000) there was a significant group\*time interaction, reflected by a larger improvement in the BFRG than the CHG.

## Discussion

Many studies comparing low-intensity strength training applied with the BFR with low-intensity strength training without any restrictions, it has been suggested that at a similar exercise intensity the muscle stimulation levels were higher in the group using the BFR method<sup>26,27</sup>. It has been said that this increase in muscle stimulation levels during low-intensity strength training applied with the BFR method is similar or slightly lower when compared to high-intensity

strength training<sup>6,26</sup>. When these studies carried out with the BFR and CH method were examined, similar developments were observed in most of the studies. These developments seen in the literature are also similar to our findings.

When our PT and MT findings, which are among the isokinetic strength parameters, are examined, a similar improvement is observed in the PT parameter in BFRG and CHG at 60°s<sup>-1</sup> - 180°s<sup>-1</sup> angular velocities in the extensor and flexor muscle groups in lower and upper extremity isokinetic strength measurements (Tables 1-2). In support of this situation, it was determined that the muscles of the lower and upper extremities underwent similar development in the evaluation of MT parameters by USG (Tables 3-4). While it is observed that the improvement in both PT, one of isokinetic strength parameters, and MT values, was more dominant in the lower extremities in both groups, it is observed that there was no significant difference in most of the parameters in the comparison between the groups.

Many studies support this observation. Korkmaz et al. (2022), compared the low-intensity strength training (1 RM 20-30%) applied with the BFR method with the CH method (1 RM 80%). In the study, the isokinetic strength measurement values and MT of the BFR group were higher than the group working with the CH method<sup>28</sup>. Bjørnsen et

al. (2019), stated in their study that the cross-sectional area of the vastus lateralis muscle in the BFR group showed a higher level of development compared to the group working with the CH method (BFR group 7.7% - CH group 0.5%)<sup>29</sup>. In the same study, there was no difference between the groups in the isokinetic strength 60°-1 angular velocity PT. Kim et al. (2017), investigated the effects of BFR method (1 RM 30%) and CH method (1 RM 75%) on muscle strength, MT and lactate parameters. In the results of the study, similar changes were observed in muscle strength and MT increase in low-intensity strength training applied with both CH and BFR methods<sup>5</sup>.

There are also studies in the literature in which the findings differ. Some studies have shown that the BFR method provides better results than the CH method due to the fact that the application protocol of the BFR method is not uniform (cuff pressure, training duration, number of repetitions applied, number of exercises applied, exercise structure, cuff type, frequency, population, etc.)<sup>28,29</sup>. In other studies, it is emphasized that the CH method provides better results than the BFR method<sup>22,30</sup>. In addition, there are studies in which the results of both methods are similar, as in our study<sup>27,31,32</sup>. The point that the literature agrees on is that the BFR method can be used as a strong alternative method to the strength training applied with the CH method.

Many mechanisms play an interrelated role in explaining the development of the BFR method. Hypertrophy and increase in strength in the muscle occur with the activation of these mechanisms. One of the three different mechanisms involved in the formation of hypertrophy after strength training is metabolic stress<sup>33</sup>. During strength training, by-products of muscle contractions such as lactate, H<sup>+</sup> ions, ADP and inorganic phosphates are produced in the extremity, and these by-products cannot leave the limb through the venous system due to the restrictive cuff pressure in the BFR method<sup>34</sup>. It has been reported that increased metabolite accumulation and decreased intramuscular pH stimulate group III and IV afferent fibers, leading to earlier neuromuscular fatigue compared to strength training performed without any restrictions<sup>7,10,35</sup>. In another study supporting this situation, it was stated that resistance exercises performed with the BFR method caused more fatigue compared to resistance exercises without the BFR method, but did not impair the 24-hour recovery in neuromuscular function<sup>36</sup>. This increase in neuromuscular fatigue ensures the participation of high threshold motor units in order to complete the expected number of repetitions and maintain the required muscle strength. For this reason, the restriction applied in the BFR method needs more motor unit recruitment to compensate for the loss in strength<sup>3</sup>. This situation causes type II muscle fibers to be activated earlier than the types of exercise performed under normal conditions<sup>37</sup>. At the point of muscle hypertrophy, the participation of type II muscle fibers in the movement is important in order to get maximum efficiency from strength training. The reason for this is that type II muscle fibers are muscle fiber types that are activated

in the anaerobic environment. It has been reported that this process results in a hypertrophic stimulus in low-intensity strength training applied with the BFR method<sup>12</sup>. It has been determined that the inability of muscle cells to use blood glucose adequately due to restriction results in the stimulation of the endocrine system working with the feedback mechanism of the increased acidic environment, and the release of anabolic hormones such as growth hormone increases<sup>12</sup>. It has been stated that the increase in growth hormone increases the production of insulin-like growth factor (IGF-1), a powerful anabolic protein that helps muscle hypertrophy<sup>38</sup>. In our study, it is thought that the similar increase in both MT and PT in BFR when compared to CH are due to these physiological developments.

A limited number of studies have been conducted to compare improvements in athletic performance after BFR and CH. In the comparison between the groups, a significant difference was found in favor of BFR in agility parameters (Table 5). Although there was no difference between the groups in BFRG and CHG except for agility, when the 30 m sprint, 10-20 m sprint results were examined, it was seen that the percentage effect was significantly higher in favor of BFRG.

It is stated that a high level of performance depends on performing coordinated upper and lower extremity movements during a sprint<sup>39</sup>. Supporting this situation, it has been determined that the increase in upper extremity strength along with the lower extremity strength leads to an increase in physical performance<sup>40</sup>. The findings of the study also support this situation. Results similar to our findings showed improvement in athletic performance parameters in parallel with the increase in strength<sup>13,14,41</sup>.

## Conclusion

Low-intensity resistance training with BFR elicited similar improvements in muscle size, strength and performance as high-intensity resistance training without BFR.

### Practical applications

BFR produces muscle hypertrophy and strength gains comparable to high-intensity resistance training, despite using lower loads.

The BFR method may be particularly useful to increase muscle mass and strength in elderly populations that cannot undertake high loads, and in individuals who have had sports injuries.

The BFR method can be preferred as an alternative method in short transition periods to improve the athletic performance of athletes.

This situation will offer different alternatives to trainers and sports scientists in strength training programs.

### Ethics approval

*This study was approved by the Nigde Omer Halisdemir University Non-Invasive Clinical Research Ethics Committee (ID: 2020/25).*

*This study was carried out in accordance with the Principles of the Declaration of Helsinki.*

*Consent to participate*

*Written informed consent was obtained from all the participants.*

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