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Original Article

The Effect of Low-Intensity Suspension Training with Blood Flow Restriction on Serum Sex Hormones, Muscular Hypertrophy, and Balance in Young Women

Shenow Doghi[1], MSc; Kazem Khodaei[1]*, PhD; Mohammadreza Zolfaghar Didani[1], PhD

[1]Sport Physiology and Corrective Exercises Department, Sport Sciences Faculty, Urmia University, Urmia, Iran

Corresponding author:* Kazem Khodaei, PhD; Sport Physiology, Urmia University, Urmia, Iran. **Email: K.khodaei@urmia.ac.ir

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Abstract

Background: Suspension training induce acute physiological and vascular stress. This study aimed to evaluate the effectiveness of eight weeks of low-intensity TRX training with BFR (LITRX+BFR) versus high-intensity TRX training (HITRX) in terms of sex hormones, power, muscle hypertrophy, and balance in young women.
Methods: This study was carried out in 2018 using a semi-experimental pretest-posttest design. Thirty-six active female students were selected and then assigned to LITRX+BFR, HITRX, and control groups through random number generation. Training groups exercised three weekly sessions for eight weeks. Each session consisted of 7 low/high intensity suspension training. The control group only engaged in routine physical activity. After blood sampling, testosterone, cortisol, and estradiol hormones were measured by ELISA method. Muscular hypertrophy evaluated by anatomical method, power with jumping performance, and balance were measured via tecnobody-pk212. SPSS version 26 was used to analyze data using ANCOVA with Bonferroni post-hoc test.
Results: The findings indicated that LITRX+BFR and HITRX had a significant increase in testosterone (P=0.000 and P=0.001), testosterone to cortisol ratio (P=0.001 and P=0.001), and estradiol (P=0.000 and P=0.003) while no significant change in cortisol levels (P=0.227). Moreover, muscular hypertrophy (P=0.001 and P=0.001), power (P=0.001 and P=0.000), static (P=0.011 and P=0.005) and dynamic balance (P=0.001 and P=0.001) significantly higher in both LITRX+BFR and HITRX compared with the control group. No significant differences found between suspension training with/without BFR in all variables.
Conclusion: It seems LITRX+BFR had improvement in sex hormones levels, muscular hypertrophy, power, and balance as like HITRX. Therefore, LITRX+BFR can be a good alternative to HITRX in young females.

Keywords: Resistance training, Blood flow restriction training, Sex hormones, Hypertrophy, Balance

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1. Introduction

Regular physical activity, recommended by various public health agencies around the world for primary or secondary prevention, is a good way to prevent many health problems, including cancer (1). The average risk of breast cancer in women decreased by 25% due to physical activity which seems to be independent of menopausal status (2). Multiple interconnected biological processes could be responsible for this link, including how exercise affects glucose metabolism, inflammation, immune response, and sex hormone levels. It appears that tumors are initiated, promoted, and progressed through the use of endogenous sex hormones, particularly estrogens (3).

Total body resistance exercise (TRX) is a form of suspension training performed using body weight training in instability status. This training provides the possibility of exercising in small spaces with fasten straps attached to the ceiling. Suspension training are designed to augmentation of muscular strength and endurance, balance, flexibility and focusing on core stability during exercise (4). Previous research indicated that desirable strength and muscle volume gain occurred in resistance training with a range of intensity from moderate to high (5). In order to increase both muscle mass and strength, it is generally recommended to engage in high-intensity resistance exercise using weights equivalent to 70–85% of one repetition maximum (1-RM). However, heavy-load resistance exercise may pose challenges or be contraindicated for certain populations, such as the elderly, individuals with chronic conditions, or athletes undergoing rehabilitation and recovery. Consequently, it is noteworthy that recent research has indicated the potential effectiveness of low-load exercise (<25% of maximal capacity) in inducing significant muscle adaptations when blood flow to a muscle or muscle group is restricted that this method known as "KAATSU" or blood flow restriction method (BFR) (6). Local hypoxia appears to be the predominant mechanism underlying the anabolic response to BFR. Additionally, studies have demonstrated that anabolic and anti-catabolic signaling pathways, along with the stimulation and multiplication of myogenic stem cells, are outcomes of this training modality. Furthermore, considerable focus has been placed on investigating the endocrine response to BFR (7).

Testosterone, a hormone that is both anabolic and androgenic, is a vital androgen in the body. It plays a significant role in promoting protein synthesis and supporting muscle tissue growth and maintenance. Moreover, it improves energy levels, promotes bone formation, and enhances immune system functionality (8).

Estrogen is another hormone with a primary role in cell proliferation and the growth of reproductive and genital tissues. It is also involved in the development of mammary glands and the accumulation of fat in breasts. Estrogen contributes to increased bone formation, while a lack of estrogen after menopause can lead to decreased bone ossification activity, bone matrix development, and storage of calcium and phosphate in bones. Unlike testosterone, estrogen enhances the rate of basal metabolism in subcutaneous tissues (9).

Cortisol, the primary glucocorticoid in the human body, possesses properties associated with tissue breakdown and inhibition of tissue growth. Monitoring its levels may serve as a marker for heightened stress levels in athletes (10). This hormone is classified as catabolic and serves a crucial function in the body's reaction to stress. However, prolonged elevation of this hormone can lead to various issues, notably concerning the immunity and breakdown of proteins (11).

The testosterone to cortisol (T/C) ratio is a key indicator that can be used to diagnose overtraining, as an elevated level of cortisol in relation to testosterone indicates overtraining and the prevalence of the body in a catabolic state rather than an anabolic state (12). Previous studies indicated that participating in sports over a prolonged period leads to raised levels of plasma cortisol and reduced levels of testosterone. Engaging in increased sports activity is linked to a decrease in the T/C ratio (13). Moreover, findings indicated that athletes may be susceptible to overtraining if the proportion of the two hormones decreases by over 30% and this reduction persists over an extended period (12).

The enhancement of muscle mass and strength is generally connected to the rise in levels of circulating hormones as like testosterone in women (14). Moreover, increased resting blood testosterone levels have been suggested as a potential indicator of enhanced physical fitness in women (14). Insufficient maintenance of skeletal muscle mass and reduced quality of remaining skeletal muscle contribute to muscle strength reductions caused by estrogen deficiency (15).

Low-intensity resistance training results in the same amount of muscle mass and strength gain as high-intensity resistance training based on valid evidence (16, 17). TRX suspension training is a commonly used form of functional resistance training that is well-liked by gym-goers, athletes, and fitness instructors due to its advantageous benefits, cost-effectiveness, minimal space requirements, and accessibility. Despite its popularity, there has been no research conducted on how combining low-intensity suspension exercises with BFR affects sex hormones and muscle function in women. Therefore, the main objective of this study was to evaluate the effectiveness of 8 weeks of TRX suspension training with BFR against high-intensity TRX suspension training in terms of their effect on sex hormone levels, power, muscle hypertrophy, and balance in physically active young women. This is the first study to examine the effect of suspension training with BFR on levels of 17-beta estradiol, as well as on both static and dynamic balance using an advanced measurement instrument.

2. Methods

2.1. Participants

This was a semi-experimental pretest-posttest study. A CONSORT diagram is presented in Figure 1. The study population included all female students in Physical Education and Sports Science at Urmia University, Urmia, Iran in 2018. Thirty-six female students who were actively engaged in physical education were selected for participation in the study.

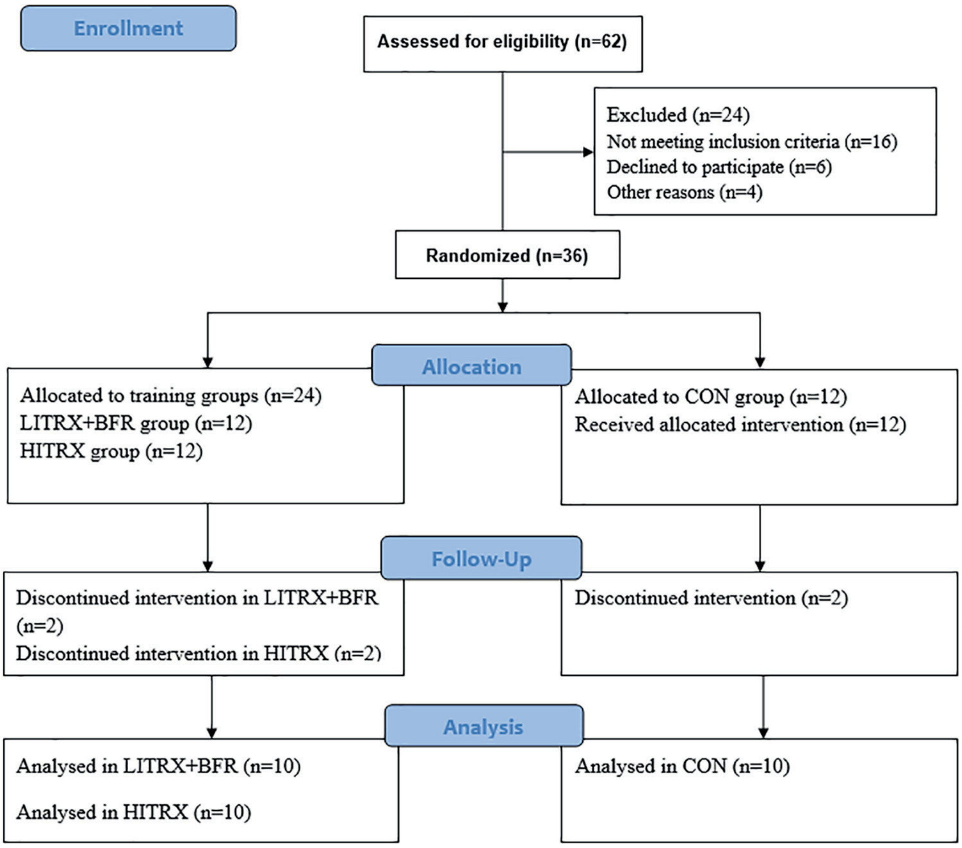

Figure 1: The figure shows the CONSORT flow diagram. HITRX: High-Intensity TRX, LITRX+BFR: Low-Intensity TRX+Blood Flow Restriction. CON: Control.

G*power software was used to estimate the total sample size, considering previous research in exercise training and estrogen hormone (Exercise group: 18.42±1944, Control group: 17.29±22.13) (3, 18), with a power of 0.80, and an alpha level of 0.05. Using G*Power calculations, to guarantee sufficient statistical power, a minimum sample size of 30 participants was determined. To account for potential attrition, an attrition rate of around 6 individuals was projected, leading to the decision to recruit 36 female students for the study. The participants who met the inclusion criteria had engaged in regular exercise training within the previous year, were not using medication or food supplements, and did not have any specific diseases. Individuals were excluded if they exhibited irregular participation in training sessions, experienced a sports injury during the study intervention, or required medication or hospitalization. After familiarizing the participants with the procedures for both testing and training, they signed a written consent form to participate in the study. The study participants were randomly allocated to three groups: low-intensity suspension training with BFR (n=12), high-intensity suspension training (n=12), and a control group. The simple random allocation with central randomization technique (using a random-numbers of phones or table in enrollment) was implemented at the time of enrollment following initial evaluations through random number generation (1:1:1 allocation ratio via random number generation). A total of six female students (two from each group) discontinued participation due to injury, illness, or personal reasons. All stages of the study were successfully completed by ten participants in each group. The Ethics Committee at Urmia Medical Sciences University approved this study, which was conducted in accordance with the Declaration of Helsinki (IR.UMSU.REC.1397.484).

2.2. Biochemical Analysis

The serum levels of Testosterone, cortisol and 17-beta estradiol hormones were analyzed using the Enzyme-Linked Immunosorbent Assay (ELISA) method with commercial human kits manufactured by DiaMetra Company (made in Italy). Blood samples were collected in the morning, specifically between 8 and 9 A.M., both the initial intervention session and the final training session are scheduled 48 hours apart. These samples were obtained after fasting. The serum obtained was immediately frozen at a temperature of -80°C following centrifugation of the blood samples at 3000 rpm for a duration of 10 minutes.

2.3. Muscle Hypertrophy

The assessment of muscle hypertrophy or muscle volume involved measuring the cross-sectional area (CSA) of the entire thigh using an anthropometric method developed by Knapik and colleagues (19) This particular method demonstrates a strong correlation with MRI data (r=0.96). To calculate thigh muscle CSA, a formula was employed which involved measuring the circumference of the thigh muscle (CM) using a measuring tape, the skinfold of the quadriceps muscle (SQ) in the middle section of the thigh using a skinfold caliper (Slim guide, USA), and the distance between the epicondyles of the femur (dE) using a bone caliper (model 01291; Lafayette Instrument Company, USA). The obtained data were then inputted into a formula to determine the anatomical CSA (AM) of the thigh muscle.

$$A_M = 0.649 \cdot \left(\left(\frac{C_T}{\pi} - S_Q \right)^2 - (0.3 \cdot d_E)^2 \right)$$

2.4. Power

Lower body peak and average power was then estimated by the vertical jump with the Johnson and Behammond formula via the following formula (20). Countermovement jump performance was assessed via the ‘Sargent jump test. The participants stood with their right side beside a wall and extended their right arm, with fingers covered with calk powder, above their head and marking the wall as high as possible. The participants subsequently extended their arms to their sides, then flexed their knees and hips to execute a countermovement to a depth of their choosing. The participants quickly altered their direction and executed the jump, aiming to reach the highest point possible and making a second mark on the wall. The calculation of jump height was done by subtracting the participant’s standing reach height from their jumping reach height.

Peak power (W)=78.5 x VJ (cm) + 60.6 x mass (kg) -15.3 x height (cm) -1308

Average power (W)=41.4 x VJ (cm) + 31.2 x mass (kg) -13.9 x height (cm) + 431

2.5. Balance

The tecnobody-pk212 device, manufactured in Italy, was used for the assessment of both static and dynamic balance. In accordance with the instructions, the participants were positioned on the platform comfortably, looking straight ahead at a screen and keeping their arms at their sides. It was necessary for them to maintain a normal forward-facing stance with their eyes fixed on a stationary target. Each person performed two standing tests, one with their eyes open (OE) and the other with their eyes closed (CE), which lasted 30 seconds each. The test was duplicated twice, and the average score was recorded (21).

2.6. Exercise Training Programs

The 6-20 Borg rating of perceived exertion (RPE) scale was used to calculate exercise intensity before we implemented the suspension training protocol, as there was a lack of a standardized approach for quantifying the intensity of suspension exercises. This particular scale serves as a straightforward, subjective, non-intrusive, and convenient means of evaluating physiological stress during exercise sessions (22). In order to accomplish this objective, all the individuals performed ten repetitions of the prescribed suspension exercises and assessed their perceived effort using the Borg RPE scale. The average RPE score for each exercise was used to gauge the level of intensity associated with it. The assessment of training intensity in this study was carried out without the use of BFR in either of the groups. The average RPE score for the lower-body exercises was computed and documented in Table 1, categorizing them as either low-intensity or high-intensity suspension training. The participants in both training groups performed seven suspension exercises in three sessions per week, additionally to their routine exercise program. They completed this training program by doing it three days per week for eight weeks. To increase their familiarity with suspension exercises, both training groups engaged in low-intensity suspension exercises during their first two weeks. To apply training overload, the time spent on exercises was gradually increased. During each training session, there was a 10-minute warm-up and cool-down. Table 2 outlines the training protocols in detail.

Table 1: Mean the rate of perceived exertion in suspension training

Low-intensity exercises	Mean RPE	High-intensity exercises	Mean RPE
Reverse lunge	6.3	Reverse to lateral lunge	15.3
Squat	6.5	Cradle lateral lunge	18.7
Hamstring curl	9.2	One leg squat	16.2
TRX lunge	9.2	Cradle lunge	17.1
Cycling	8.1	Omega	17.3
Lateral lunge	7.5	High hamstring curl	18.6
Glute bridge	7.6	One leg Glute Bridge	17.5

RPE: Rate of perceived exertion

Table 2: Suspension training programs

Groups	1st two weeks	2nd two weeks	3rd two weeks	4th two weeks
High-Intensity TRX	- 7 TRX exercises with low intensity - 3 sets and each exercise executed in 20 seconds - 1:2 work to rest ratio - 2 min rest between exercises	- 7 TRX exercises with high intensity - 3 sets and each exercise executed in 30 seconds - 1:2 work to rest ratio - 2 min rest between exercises	- 7 TRX exercises with high intensity - 3 sets and each exercise executed in 40 seconds - 1:2 work to rest ratio - 2 min rest between exercises	-7 TRX exercises with high intensity - 4 sets and each exercise executed in 40 seconds - 1:2 work to rest ratio - 2 min rest between exercises
Low-Intensity TRX +BFR	-7 TRX exercises with low intensity - 3 sets and each exercise executed in 20 seconds - 1:2 work to rest ratio -2 min rest between exercises	- 7 TRX exercises with low intensity - 3 sets and each exercise executed in 30 seconds - 1:2 work to rest ratio - 2 min rest between exercises	- 7 TRX exercises with low intensity - 3 sets and each exercise executed in 40 seconds - 1:2 work to rest ratio - 2 min rest between exercises	- 7 TRX exercises with low intensity - 4 sets and each exercise executed in 40 seconds - 1:2 work to rest ratio - 2 min rest between exercises

TRX: Total-body Resistance Exercises

The method of using BFR in the present study was based on the practical BFR method applied in the study of Wilson and co-workers. The knee wraps (75 mm wide) were fastened to the proximal ends of the legs. The perceived pain scale rated the tightness of the warp as 7 out of 10 (23). Figure 2 indicated suspension training performed in the present study.

2.7. Statistical Analysis

The Shapiro-Wilk test was used to determine the normality of the distribution, and Levene's test was used to evaluate the equality of variance. Pre-test between-group changes analyzed with one-way ANOVA test. Then, post-test between-group changes analyzed with ANCOVA and Bonferroni post hoc test. Furthermore, paired sample T-test was used for analyzing of within-group changes. All of these analyses were set to have a significance level of $P<0.05$. SPSS version 26 was used to analyze the data, which is available from IBM Corporation in Armonk, NY, USA.

3. Results

Demographic characteristics of the study participants are presented in Table 3. Thirty-six young female students engaged in physical education and sport sciences with the mean age (23.25±3.89), height (161.03±4.90), weight (56.58±6.77), and body mass index (22.05±1.88) participated in this study. Following baseline comparisons, there were no significant differences between groups in demographic variables according to the between-group results ($P>0.05$).

Figure 3 illustrates the outcomes of sex hormones. One-way ANOVA result indicated no significant pre-test between-group changes in testosterone (P=0.616), cortisol (P=0.602), T/C ratio (P=0.721), and 17 beta estradiol (P=0.337). The between-group ANCOVA results showed significant changes in testosterone (P=0.616), T/C ratio (P=0.001), and 17 beta estradiol (P=0.001). The post-hoc test results confirmed that the LITRX+BFR group higher testosterone (P=0.001, Mean difference=0.35), T/C ratio (P=0.001, Mean difference=0.009), and 17 beta estradiol levels (P=0.001, Mean difference=1.72) compared with the control group. Moreover, the HITRX group showed significantly higher testosterone (P=0.001, Mean difference=0.28), T/C ratio (P=0.001, Mean difference=0.009), and 17 beta estradiol levels

Figure 2: The figure shows the suspension training performed in the present study.

Table 3: Demographic characteristics of participants

Variables	CON (Mean±SD)	LITRX+BFR (Mean±SD)	HITRX (Mean±SD)	P value
Age (years)	22.74±3.60	23.85±4.50	23.16±3.58	0.32
Height (cm)	161.12±4.09	159.87±6.17	162.12±4.73	0.09
Weight (kg)	56.62±6.12	56.12±6.90	57.00±7.31	0.41
BMI (kg/m^2)	21.86±2.03	22.56±1.17	21.75±2.45	0.15

HITRX: High-Intensity TRX, LITRX+ BFR: Low-Intensity TRX + Blood Flow Restriction. CON: Control. BMI: Body Mass Index.

(P=0.003, Mean difference=1.33) compared with the control group. No significant changes were found between the LITRX+BFR and the HITRX groups. Within-group results indicated that both suspension training with and without BFR significantly increased testosterone, T/C ratio, and 17-beta estradiol levels (P=0.001).

Table 4 demonstrated that One-way ANOVA result indicated no significant pre-test between-group changes in thigh muscle CSA (P=0.052), static balance (P=0.312), Dynamic balance (P=0.60), peak power (P=0.88), and average power (P=0.091). The between-group ANCOVA results showed significant changes in thigh muscle CSA (P=0.001), static balance (P=0.003), Dynamic balance (P=0.001), peak power (P=0.001), and average power (P=0.002). Post hoc test results indicated that LITRX+BFR group significantly higher thigh muscle CSA (P=0.001, Mean

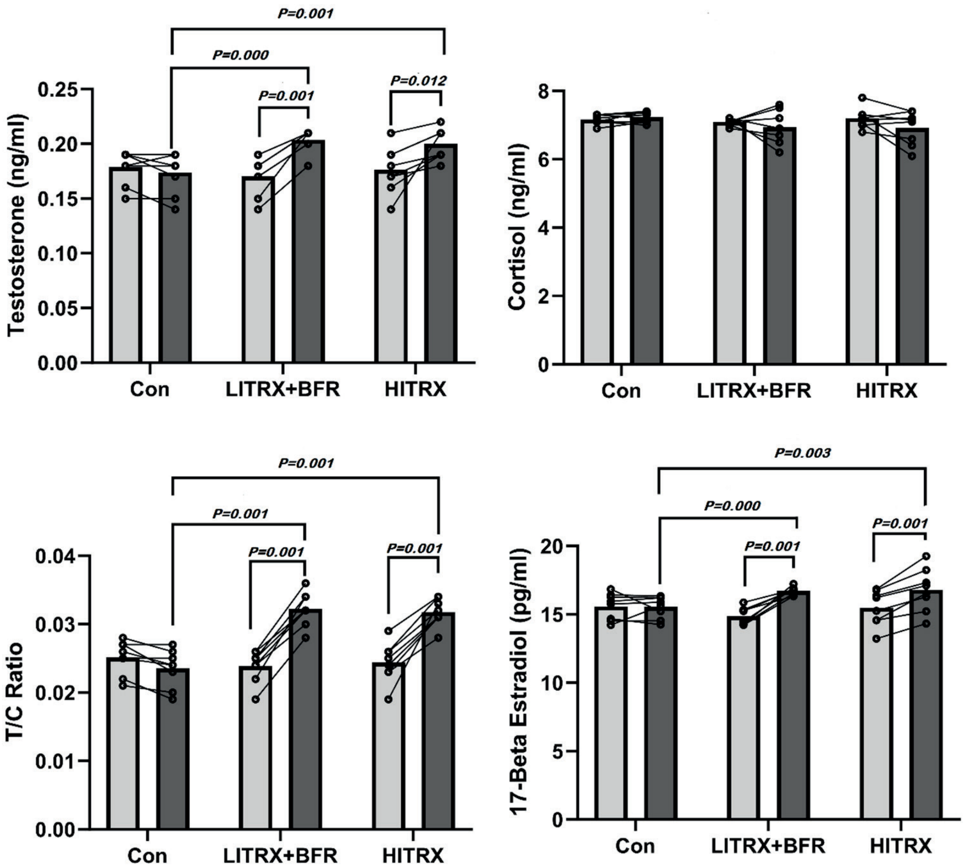

Figure 3: The figure shows the Serum hormone concentrations changes after interventions. HITRX: High-Intensity TRX, LITRX+BFR: Low-Intensity TRX+ Blood Flow Restriction. T/C ratio: testosterone to cortisol ratio. Con: Control. Data presented in Mean±SD.

Table 4: Muscle hypertrophy, balance, and power changes after intervention.

Variables	Groups	Pretest (Mean±SD)	Posttest (Mean±SD)	Within-group P value	ANOVA Pretest P value	ANCOVA Posttest P value
Thigh muscle CSA (m^2)	LITRX+BFR	141.05±11.18	160.33±14.88*	0.001	0.052	0.001
	HITRX	155.11±12.41	171.62±13.03*	0.001		
	CON	154.75±8.10	151.92±9.53	0.102		
Static balance	LITRX+BFR	67.34±15.61	78.86±13.87*	0.001	0.312	0.003
	HITRX	63.49±18.79	76.79±16.60*	0.017		
	CON	54.55±15.63	54.98±16.73	0.516		
Dynamic balance	LITRX+BFR	0.47±0.08	0.63±0.12*	0.001	0.060	0.001
	HITRX	0.54±0.16	0.70±0.14*	0.001		
	CON	0.40±0.06	0.41±0.06	0.401		
Peak power (Watt)	LITRX+BFR	1516.3±546.2	2154.1±586.3*	0.001	0.088	0.001
	HITRX	2066.4±320.2	2723.8±365.7*	0.001		
	CON	1955.4±585.1	2004.5±618.5	0.180		
Average power (Watt)	LITRX+BFR	949.8±276.2	1189.3±326.1*	0.001	0.091	0.002
	HITRX	1212.7±172.5	1286.2±281.5*	0.001		
	CON	1163.4±309.7	1188.3±312.1	0.192		

HITRX: High-Intensity TRX, LITRX+BFR: Low-Intensity TRX+ Blood Flow Restriction. CON: Control. * Indicated a significant change compared with the CON group. CSA: Cross-Sectional Area

difference=23.36), static balance (P=0.011, Mean difference=13.23), Dynamic balance (P=0.001, Mean difference=0.154), peak power (P=0.001, Mean difference=134.02), and average power (P=0.001, Mean difference=180.05) compared with the control group. Moreover, the HITRX group showed higher thigh muscle CSA (P=0.001, Mean difference=19.30), static balance (P=0.005, Mean difference=14.35), Dynamic balance (P=0.001, Mean difference=0.154), peak power (P=0.001, Mean difference=125.66), and average power (P=0.000, Mean difference=192.32) compared with the control group. No significant changes were found between LITRX+BFR and HITRX groups. Within-group results indicated that both suspension training with and without BFR significantly increased thigh muscle CSA, dynamic and static balance, average and peak power compared with the pretest (P≤0.001).

4. Discussion

The study was focused on examining the effect of 8 weeks of TRX suspension training and BFR on sex hormones, muscle hypertrophy, and balance in female students who are active. The present study revealed that testosterone levels experience similar changes after low-intensity suspension training with BFR. Cortisol, T/C ratio, and 17-beta estradiol levels as high-intensity suspension training in active young female students. No study has investigated the effect of suspension training with BFR on sex hormones concentration in women. However, previous studies conducted other types of resistance training with BFR with similar results of the increase of testosterone and decrease of cortisol after BFR intervention (7, 24, 25). On the other hand, several studies indicated no changes in sex hormones after resistance training with BFR (26, 27). The inconsistency in the results may be due to the difference in the training period (3 vs. 8 weeks) or the participant's age (young versus elderly). The main reason behind the anabolic response to BFR appears to be localized hypoxia. Increased muscle fiber recruitment has been reported by many studies as a result of the accumulation of metabolites. Furthermore, BFR training has been proven to boost both anabolic and anti-catabolic signaling, as well as the stimulation and expansion of myogenic stem cells (7, 16, 17). The increase of lactate and catecholamine concentration during exercise is a possible mechanism for increasing testosterone with low-intensity exercise and BFR. It increases, which stimulates the leydig cells of the testicles to produce more testosterone (25).

The present study revealed that TRX training with and without blood flow restriction did not affect cortisol hormone concentration. Both healthy individuals and those with diseases have shown an effect on immune function due to physical activity and exercise training. The immune system can be affected by a significant increase in cortisol levels during intense exercise. Nonetheless, after prolonged exercise, cortisol levels tend to decrease (28). Acute low-intensity resistance exercise with BFR has been shown by several studies to decrease cortisol serum levels (29, 30). Lipolysis and protein breakdown in adipose tissue are increased by cortisol, a hormone that breaks down fats and proteins. In addition, it decreases protein synthesis in muscle cells and encourages the release of fats and amino acids into the bloodstream. Myofibril proteins are affected by this hormone in a catabolic manner, particularly by inhibiting protein synthesis. Furthermore, the catabolic effect of cortisol on type II muscle fibers is more significant than that of type I fibers. By activating fast-twitch muscle fibers in low-intensity resistance exercises with BFR, cortisol levels may be elevated after these workouts (10).

To assess exercise response and predict performance, the T/C ratio is used. An increase of over 30% in this ratio from the baseline signifies an enhancement in anabolic processes. Conversely, a reduction of more than 30% from the baseline indicates a rise in catabolic conditions (7, 25). In the present study, young women experienced an increase in their 17-beta estradiol concentration in both suspension training with and without BFR. Previous studies has demonstrated that estrogen levels in young women increase after consistent resistance and aerobic training, which aligns with the findings of this study (18, 31). However, results of a meta-analysis review indicated of decrease of estrogen after physical activity in young healthy women (3). Changes in 17-beta estradiol hormone levels post-training, whether it be endurance or resistance training, have shown inconsistency, likely due to variations in experimental protocols and significant differences in the duration, intensity, and amount of training programs.

The present study revealed that TRX suspension training with/without BFR led to a significant increase in muscle hypertrophy. The use of a cuff or band during BFR exercises leads to an increase in systolic blood pressure. This restriction causes turbulent arterial blood flow, raises metabolic pressure, and activates fast-twitch motor units in skeletal muscles (32). The mammalian target of rapamycin complex (mTORC1) can be activated and muscle protein synthesis can be enhanced by low-intensity exercise with BFR, resulting in anabolic effects facilitated by mitogen-activated protein (MAPK). MAPK may play a role in promoting muscle growth through such exercises, potentially leading to muscle hypertrophy by raising metabolic stress within the muscle, like depleting muscle phosphocreatine, raising growth hormone levels, increasing inorganic phosphate levels, and reducing muscle pH (17).

According to the findings of the present study, TRX suspension training with or without BFR resulted in an increase in both average and peak muscle power. Systematic review and meta-analysis of Xiaoli and colleagues found that blood flow restriction training is superior to traditional resistance training for improving lower limb explosive power in healthy individuals. Furthermore, using a wide cuff (≥10 cm) for blood flow restriction during exercise resulted in greater improvements in explosive power compared with a narrow cuff or during rest periods (33). Wilk and co-workers suggested that short-term BFR training also enhances power output and bar velocity in the bench press exercise. Nonetheless, only BFR using a broad cuff had a substantial impact on bar speed and power production, underscoring the importance of cuff width in influencing immediate exercise adjustments in BFR resistance training (34).

In this study, static and dynamic balance showed improvement following suspension training with or without BFR. Clarkson and colleagues found in a comprehensive review that 13 studies involving 332 participants demonstrated that blood flow restriction exercise, regardless of type, notably improved performance on various physical function tests such as 30s sit-to-stand and timed up and go, as well as other walking, sit-to-stand, balance, jumping, and stepping tests (35). Wen and co-workers also concluded that over 6 weeks, low-load BFR training was as effective as high-load training in improving ankle muscle strength, muscle thickness, and balance in functional ankle instability patients (36). In contrast, some previous systematic reviews did not found significant improvement in balance (37, 38). It seems contradictory results could be variations in experimental training protocols and testing procedure, differences in the duration, intensity, and amount of training programs. Similar to previous studies, suspension training used in this study could play a key role in enhancing the balance of young women, regardless of blood flow restriction intervention (4).

4.1. Limitations

The present study was the first study to investigate the efficacy of suspension training with BFR on sex hormones in women in a longitudinal controlled trial. Nevertheless, there were several limitations. The participants were physical education students who had no experience with suspension training or BFR. Therefore, people who have had experience with suspension training or BFR training are expected to show altered adaptations. The intervention in the present study lasted for a period of eight weeks. Nevertheless, various months or years could lead to varying adjustments or deteriorating adjustments with BFR. The volume load in training has not been distributed evenly across groups. Another limitation was the lack of regulation on food consumption and sleeping schedule prior to blood sample collection. Our findings were expected to vary from those achieved by contrasting groups with the same amount of work completed over an eight-week period. Further investigation necessitates accurate monitoring and comparison of the overall volume load across different groups.

5. Conclusions

This study was the inaugural examination of the effect of long-term suspension training with BFR on serum sex hormones, muscle hypertrophy, power, and balance in young women. Based on our findings, it appears that low-intensity suspension training with BFR led to enhancements in sex hormone levels, muscle growth, strength, and stability similar to high-intensity and low-intensity suspension training. Therefore, low-intensity training with BFR can be a good alternative to high-intensity suspension training in active young female students. As a result, it is recommended that TRX training with blood flow restriction is an appropriate method for enhancing the health of women, particularly those looking to boost strength, muscle mass, and recovery.

Acknowledgements

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Authors' Contribution

Kazem Khodaei: Substantial contributions to the conception and design of the work; the acquisition, analysis, interpretation of data for the work, and drafting the work and reviewing it critically for important intellectual content. Shenow Doghi: Substantial contributions to the conception and design of the work; the acquisition, analysis, interpretation of data for the work, and drafting the work. Mohammadreza Zolfaghar Didani: Substantial contributions to the conception and design of the work; the acquisition, analysis, interpretation of data for the work, and drafting the work. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work, such that the questions related to the accuracy or integrity of any part of the work.

Conflict of interest: None declared.

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Ethical Approval

The Ethics Review Board of Urmia Medical Sciences University approved the present study with the code of IR.UMSU.REC.1397.484. Furthermore, written informed consent was obtained from the participants.

References

1. Dhuli K, Naureen Z, Medori MC, Fioretti F, Caruso P, Perrone MA, et al. Physical activity for health. J Prev Med Hyg. 2022;63(2 Suppl 3):E150-E159. doi: 10.15167/2421-4248/jpmh2022.63.2S3.2756. PubMed PMID: 36479484; PubMed Central PMCID: PMC9710390.
2. Xu Y, Rogers CJ. Physical Activity and Breast Cancer Prevention: Possible Role of Immune Mediators. Front Nutr. 2020;7:557997. doi: 10.3389/fnut.2020.557997. PubMed PMID: 33134306; PubMed Central PMCID: PMC7578403.
3. Ennour-Idrissi K, Maunsell E, Diorio C. Effect of physical activity on sex hormones in women: a systematic review and meta-analysis of randomized controlled trials. Breast Cancer Res. 2015;17(1):139. doi: 10.1186/s13058-015-0647-3. PubMed PMID: 26541144; PubMed Central PMCID: PMC4635995.
4. Blasco J-M, Domínguez-Navarro F, Tolsada-Velasco C, de-Borja-Fuentes I, Costa-Moreno E, García-Gomáriz C, et al. The Effects of Suspension Training on Dynamic, Static Balance, and Stability: An Interventional Study. Medicina. 2024;60(1):47. doi: 10.3390/medicina60010047. PubMed PMID: 38256308; PubMed Central PMCID: PMC10818514.
5. Lasevicius T, Ugrinowitsch C, Schoenfeld BJ, Roschel H, Tavares LD, De Souza EO, et al. Effects of different intensities of resistance training with equated volume load on muscle strength and hypertrophy. Eur J Sport Sci. 2018;18(6):772-780. doi: 10.1080/17461391.2018.1450898. PubMed PMID: 29564973.
6. Slysz J, Stultz J, Burr JF. The efficacy of blood flow restricted exercise: A systematic review & meta-analysis. J Sci Med Sport. 2016;19(8):669-75. doi: 10.1016/j.jsams.2015.09.005. PubMed PMID: 26463594.
7. Laurentino GC, Loenneke JP, Ugrinowitsch C, Aoki MS, Soares AG, Roschel H, et al. Blood-Flow-Restriction-Training-Induced Hormonal Response is not Associated with Gains in Muscle Size and Strength. J Hum Kinet. 2022;83:235-243. doi: 10.2478/hukin-2022-0095. PubMed PMID: 36157947; PubMed Central PMCID: PMC9465748.
8. Alemany M. The Roles of Androgens in Humans: Biology, Metabolic Regulation and Health. Int J Mol Sci. 2022;23(19):11952. doi: 10.3390/ijms231911952. PubMed PMID: 36233256; PubMed Central PMCID: PMC9569951.
9. Hamilton KJ, Hewitt SC, Arao Y, Korach KS. Estrogen Hormone Biology. Curr Top Dev Biol. 2017;125:109-146. doi: 10.1016/bs.ctdb.2016.12.005. PubMed PMID: 28527569; PubMed Central PMCID: PMC6206851.
10. Hayes LD, Grace FM, Baker JS, Sculthorpe N. Exercise-induced responses in salivary testosterone, cortisol, and their ratios in men: a meta-analysis. Sports Med. 2015;45(5):713-26. doi: 10.1007/s40279-015-0306-y. PubMed PMID: 25655373.
11. Boucher P, Plusquellec P. Acute Stress Assessment From Excess Cortisol Secretion: Fundamentals and Perspectives. Front Endocrinol. 2019;10:749. doi: 10.3389/fendo.2019.00749. PubMed PMID: 31749763; PubMed Central PMCID: PMC6848065.
12. Castro-Sepulveda M, Cancino J, Fernández-

Verdejo R, Pérez-Luco C, Jannas-Vela S, Ramirez-Campillo R, et al. Basal Serum Cortisol and Testosterone/Cortisol Ratio Are Related to Rate of Na+ Lost During Exercise in Elite Soccer Players. Int J Sport Nutr Exerc Metab. 2019;29(6):658-663. doi: 10.1123/ijsnem.2019-0129. PubMed PMID: 31629352.
13. Ficarra G, Caccamo D, Rottura M, Bitto A, Trimarchi F, Di Mauro D. Testosterone:cortisol ratio as a predictor of podium in adolescent rowing athletes. Heliyon. 2023;9(11):e22315. doi: 10.1016/j.heliyon.2023.e22315. PubMed PMID: 38053894; PubMed Central PMCID: PMC10694314.
14. Taylor S, Islam RM, Bell RJ, Hemachandra C, Davis SR. Endogenous testosterone concentrations and muscle mass, strength and performance in women, a systematic review of observational studies. Clin Endocrinol (Oxf). 2023;98(4):587-602. doi: 10.1111/cen.14874. PubMed PMID: 36585396.
15. Collins BC, Laakkonen EK, Lowe DA. Aging of the musculoskeletal system: How the loss of estrogen impacts muscle strength. Bone. 2019;123:137-144. doi: 10.1016/j.bone.2019.03.033. PubMed PMID: 30930293; PubMed Central PMCID: PMC6491229.
16. Vechin FC, Libardi CA, Conceição MS, Damas FR, Lixandrão ME, Berton RPB, et al. Comparisons Between Low-Intensity Resistance Training With Blood Flow Restriction and High-Intensity Resistance Training on Quadriceps Muscle Mass and Strength in Elderly. J Strength Cond Res. 2015;29(4):1071-6. doi: 10.1519/JSC.0000000000000703. PubMed PMID: 25264670.
17. Ogawa H, Nakajima T, Shibasaki I, Nasuno T, Kaneda H, Katayanagi S, et al. Low-Intensity Resistance Training with Moderate Blood Flow Restriction Appears Safe and Increases Skeletal Muscle Strength and Size in Cardiovascular Surgery Patients: A Pilot Study. J Clin Med. 2021;10(3):547. doi: 10.3390/jcm10030547. PubMed PMID: 33540756; PubMed Central PMCID: PMC7867301.
18. Razzak ZA, Khan AA, Farooqui SI. Effect of aerobic and anaerobic exercise on estrogen level, fat mass, and muscle mass among postmenopausal osteoporotic females. Int J Health Sci (Qassim). 2019;13(4):10-16. PubMed PMID: 31341450; PubMed Central PMCID: PMC6619462.
19. Knapik JJ, Staab JS, Harman EA. Validity of an anthropometric estimate of thigh muscle cross-sectional area. Med Sci Sports Exerc. 1996;28(12):1523-30. doi: 10.1097/00005768-199612000-00013. PubMed PMID: 8970148.
20. Johnson DL, Bahamonde R. Power Output Estimate in University Athletes. J Strength Cond Res. 1996;10(3). doi: 10.1519/1533-4287(1996)010<0161:POEIUA>2.3.CO;2.
21. You H, Zhang H, Liu J, Han T, Zhang M, Zhao W, et al. Effect of balance training with Pro-kin System on balance in patients with white matter lesions. Medicine (Baltimore). 2017;96(51):e9057. doi: 10.1097/MD.0000000000009057. PubMed PMID: 29390433; PubMed Central PMCID: PMC5758135.
22. Khodaei K, Mohammadi A, Hamedinia MR. Evaluation of plyometric exercises intensity using ratings of perceived exertion scale. Med Sport. 2017;70(3):299-306. doi: 10.23736/S0025-7826.17.02952-0.
23. Wilson JM, Lowery RP, Joy JM, Loenneke JP, Naimo MA. Practical blood flow restriction training increases acute determinants of hypertrophy without increasing indices of muscle damage. J Strength Cond Res. 2013;27(11):3068-75. doi: 10.1519/JSC.0b013e31828a1ffa. PubMed PMID: 23446173.
24. Bemben DA, Sherk VD, Buchanan SR, Kim S, Sherk K, Bemben MG. Acute and Chronic Bone Marker and Endocrine Responses to Resistance Exercise With and Without Blood Flow Restriction in Young Men. Front Physiol. 2022;13:837631. doi: 10.3389/fphys.2022.837631. PubMed PMID: 35370772; PubMed Central PMCID: PMC8969015.
25. Nosratihashi A, Bolboli L, Anoushirvani S. The effect of a resistance training with and without blood flow restriction on cortisol, testosterone and testosterone-to-cortisol ratio in male judo players. J Sport Exerc Physiol. 2023;16(3):34-43. doi: 10.48308/joeppa.2023.103854. Persian.
26. Mohammadiyan M, Ghahremani Moghaddam M, Hakkakdokht E. The effect of two different intensities of resistance training with blood flow restriction on muscle strength, body fat percentage and serum level of Irisin in overweight women. IJOGI. 2021;24(3):42-50. doi: 10.22038/ijogi.2021.18302. Persian.
27. Rashidi E, Hosseini Kakhak SAR, Askari R. The Effect of 8 Weeks Resistance Training With Low Load and High Load on

Testosterone, Insulin-like Growth Factor-1, Insulin-like Growth Factor Binding Protein-3 Levels, and Functional Adaptations in Older Women. Salmand: Iranian Journal of Ageing. 2019;14(3):356-67. doi: 10.32598/sija.13.10.470. Persian.
28. De Nys L, Anderson K, Ofosu EF, Ryde GC, Connelly J, Whittaker AC. The effects of physical activity on cortisol and sleep: A systematic review and meta-analysis. Psychoneuroendocrinology. 2022;143:105843. doi: 10.1016/j.psyneuen.2022.105843. PubMed PMID: 35777076.
29. Hjortshoej MH, Aagaard P, Storgaard CD, Juneja H, Lundbye-Jensen J, Magnusson SP, et al. Hormonal, immune, and oxidative stress responses to blood flow-restricted exercise. Acta Physiol (Oxf). 2023;239(2):e14030. doi: 10.1111/apha.14030. PubMed PMID: 37732509; PubMed Central PMCID: PMC10909497.
30. Hwang PS, Willoughby DS. Mechanisms Behind Blood Flow-Restricted Training and its Effect Toward Muscle Growth. J Strength Cond Res. 2019;33:S167-S79. doi: 10.1519/JSC.0000000000002384. PubMed PMID: 30011262.
31. Malandish A, Rahmati-Yamchi M. The effect of moderate intensity aerobic exercise on cardiovascular function, cardiorespiratory fitness and estrogen receptor alpha gene in overweight/obese postmenopausal women: A randomized controlled trial. Journal of Molecular and Cellular Cardiology Plus. 2022;2:100026. doi: 10.1016/j.jmccpl.2022.100026.
32. Kim E, Gregg LD, Kim L, Sherk VD, Bemben MG, Bemben DA. Hormone responses to an acute bout of low intensity blood flow restricted resistance exercise in college-aged females. J Sports Sci Med. 2014;13(1):91-6. PubMed PMID: 24570611; PubMed Central PMCID: PMC3918573.
33. Xiaolin W, Xin-Min Q, Shuyu J, Delong D. Effects of Resistance Training with Blood Flow Restriction on Explosive Power of Lower Limbs: A Systematic Review and Meta-Analysis. J Hum Kinet. 2023;89:259-268. doi: 10.5114/jhk/168308. PubMed PMID: 38053964; PubMed Central PMCID: PMC10694717.
34. Wilk M, Krzysztofik M, Filip A, Zajac A, Bogdanis GC, Lockie RG. Short-Term Blood Flow Restriction Increases Power Output and Bar Velocity During the Bench Press. J Strength Cond Res. 2022;36(8):2082-2088. doi: 10.1519/JSC.0000000000003649. PubMed PMID: 32379236.
35. Clarkson MJ, May AK, Warmington SA. Chronic Blood Flow Restriction Exercise Improves Objective Physical Function: A Systematic Review. Front Physiol. 2019;10:1058. doi: 10.3389/fphys.2019.01058. PubMed PMID: 31496953; PubMed Central PMCID: PMC6712096.
36. Wen Z, Zhu J, Wu X, Zheng B, Zhao L, Luo X, et al. Effect of Low-Load Blood Flow Restriction Training on Patients With Functional Ankle Instability: A Randomized Controlled Trial. J Sport Rehabil. 2023;32(8):863-872. doi: 10.1123/jsr.2022-0462. PubMed PMID: 37558223.
37. Li S, Wang P, Xin X, Zhou X, Wang J, Zhao J, et al. The Effect of Low Intensity Resistance Training with Blood Flow Restriction on Fall Resistance in Middle-Aged and Older Adults: A Meta-Analysis. Int J Environ Res Public Health. 2023;20(6):4723. doi: 10.3390/ijerph20064723. PubMed PMID: 36981632; PubMed Central PMCID: PMC10049074.
38. Vinolo-Gil MJ, Rodríguez-Huguet M, Martin-Vega FJ, Garcia-Munoz C, Lagares-Franco C, Garcia-Campanario I. Effectiveness of Blood Flow Restriction in Neurological Disorders: A Systematic Review. Healthcare (Basel). 2022;10(12):2407. doi: 10.3390/healthcare10122407. PubMed PMID: 36553931; PubMed Central PMCID: PMC9778162.