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Original research papers

COMPARING THE EFFECTS OF LINEAR AND UNDULATING PERIODIZED RESISTANCE TRAINING ON SERUM LEVELS OF TESTOSTERONE, FOLLISTATIN, AND STRENGTH IN SEDENTARY MEN

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Abstract
Introduction. The mechanisms of hypertrophy induced by resistance training are thought to be related to the effects of testosterone on Follistatin (Fst). Furthermore, determination of the most effective periodization model for strength and creating anabolic conditions is an important step for strength and conditioning professionals. Therefore, the aim of the current study was to compare the effects of linear periodized (LP) and weekly undulating periodized (WUP) resistance training on testosterone, Fst and one repetition maximum (1RM). ***Material and Methods.*** Twenty young sedentary men were randomly divided into equal groups of LP and WUP. The subjects performed whole body LP and WUP interventions for 9 weeks (corresponds to 80-90% 1RM). Fasting blood samples were taken pre and post training. 1RM of upper and lower body was also estimated by bench press and squat, respectively. ***Results.*** Intra-group comparisons showed that LP ($p = 0.005$ and $p = 0.001$ for bench press and squat, respectively) and WUP ($p = 0.001$ for both bench press and squat) induced a significant increase in 1RM. In contrast, neither LP nor WUP interventions had a significant effect on serum testosterone ($p = 0.258$ and $p = 0.609$ for LP and WUP, respectively), cortisol ($p = 0.797$ and $p = 0.079$ for LP and WUP, respectively), and Fst ($p = 0.768$ and $p = 0.852$ for LP and WUP, respectively). Finally, inter-group comparisons did not show any significant differences between 1RM ($p = 0.247$ and $p = 0.478$ for upper and lower body), Fst ($p = 0.381$), testosterone ($p = 0.813$), and cortisol ($p = 0.724$) at the end of the protocol. ***Conclusions.*** Both LP and WUP resistance training regimens, independent of Fst and testosterone changes, similarly improve maximal strength in sedentary men.

Keywords: linear undulating periodized resistance training, weekly undulating periodized resistance training, maximal strength, follistatin, testosterone, cortisol

Introduction

Resistance training leads to increased skeletal muscle strength through both neural responses and hormonal adaptations [1, 2]. Recent research has claimed that follistatin (Fst) acts as a potent myokine in muscle growth [3-5]. Fst is an autocrine glycoprotein that belongs to a large family of transforming growth factors β [6]. This cytokine is abundantly expressed in myocytes and promotes muscle fiber formation and growth [7, 8], while its depletion results in perinatal lethality associated with impaired muscle development [4]. Fst is thought to allow greater muscle hypertrophy by activating satellite cell [6]. In addition, Fst prevents myostatin from binding to the activin IIb receptor, through binding and thereby neutralizing myostatin in the circulation [6, 8]. Furthermore, it has been shown that overexpression of Fst prevents muscle wasting disorders such as Duchenne Muscular Dystrophy and age-related sarcopenia [1, 6, 7, 8].

The mechanisms of hypertrophy induced by resistance training are thought to be related to the effects of testosterone on Fst [1]. In other words, Fst is essential for mediating testosterone's effects on myogenesis [9, 10]. In this context, it has been demonstrated that testosterone promotes myogenic differentiation of muscle progenitor cells through activating AR/β-catenin pathway and up-regulating the expression of Fst [9]. In contrast, blocking Fst's action using either siRNAs or anti-follistatin antibodies inhibits testosterone's effects on myogenic differentiation of muscle progenitor cells [10].

Importantly, resistance training is considered as a potential myogenic inducer. In this context, the existing report indicates that resistance training improves physical performance and muscle quality by hindering muscle degradation pathways via Fst rather than inducing muscle growth through the insulin-like growth factor-1 pathway [11]. The work by Willoughby [12] revealed a concurrent increase in myostatin and Fst-like related gene following lower body resistance training. Moreover, it has been demonstrated that both eccentric and concentric muscle actions elicit a similar increase in serum levels of Fst-like related gene [7]. In addition to type, the intensity of resistance training may not be a crucial factor for increasing serum Fst in sedentary women [1]. In contrast, Fst level was not affected by long-term cognitive and coordinative tasks in one study [11]. Therefore, muscle contraction induced by resistance training can be a stimulus for the remodeling of muscle tissue by altering serum Fst levels [11].

American College of Sports Medicine (ACSM) recommends resistance training as an effective method to a wide variety of populations [13, 14]. ACSM has claimed that non-periodized resistance training interventions are less effective in improving power and strength than periodized interventions [15]. Previous meta analyses have also concluded that periodized resistance training programs are more effective in promoting maximal strength and muscle hypertrophy compared to non-periodized training programs [14, 16]. Periodization of the resistance training program is a logical method and systematic structuring of training variables (intensity, volume, frequency, and rest) throughout designated training timeframes in order to maximize adherence to the training protocol, help to avoid plateaus, allowing for constant progression, while minimizing the potential of overreaching [13, 14, 16]. Commonly used types of periodization are the classical linear periodization (LP) and undulating periodization model [17]. LP resistance training was previously characterized by initial low intensity and high volume, with progressive increases in intensity and decreases in volume as training progresses [13, 18]. Depending on whether intensity and volume of resistance training are manipulated on a daily or weekly basis, undulating periodization is characterized as daily undulating periodization (DUP) or weekly undulating periodization (WUP), respectively [17, 18, 19].

Resistance training has been recommended for promoting maximal strength in sedentary young [18] and older participants [11, 20]. However, previous literature has reported conflicting results on the effect of different types of resistance training on maximal strength gains [18, 19, 20, 21]. According to Harries and colleagues [22], non-linear manipulation of volume and intensity, providing more frequent changes in stimuli, is recommended to be more effective on strength gain. To our knowledge, only one study has compared the effect of 9-week LP and WUP resistance training on one repetition maximum (1RM) in volunteers with prior history of strength training and no significant differences were observed between models in maximal strength [23]. However, no previous study has compared the effects of LP and WUP resistance training protocols on maximal strength gain, testosterone to cortisol ratio and Fst. Since determining the most effective periodization model for strength gain and creating anabolic condition is an important step for strength and conditioning professionals [24], the purpose of the current study was to compare the effects of LP and WUP resistance training interventions on testosterone to cortisol ratio, Fst and maximal strength in sedentary men.

Material and Methods

Participants

Twenty sedentary healthy men (means ± standard deviations; age, 25.75 ± 5.56 years) volunteered to take part in the present study [18, 20]. All participants were recruited by sending messages through social media and notifying them through putting up some notices. The inclusion criteria were: 1) being sedentary (no experience of resistance training for at least 6 months prior to the study) [24]; 2) receiving medical approval for participation in interventions; 3) being non-smokers and non-alcoholic; 4) absence of any chronic or acute diseases; 5) no consumption of anabolic-androgenic steroids or protein supplementation [1, 18, 20]. The exclusion criteria were: 1) any neuromuscular or joint disease during interventions that limited resistance training; 2) absence of more than three sessions in the interventions. The current quasi-experimental research protocol was approved by the institutional human ethics committee (IR.UB.REC.1401.007). In addition, all procedures were in accordance with guidelines for the use of human subjects set forth by the ACSM [24]. The subjects were informed about the experimental procedures, purpose, benefits, and potential risks of the study. Then, an informed consent document was obtained from participants. They were also free to withdraw from the study without any penalty. Finally, they were randomly assigned to equal groups of LP and WUP.

Anthropometric Measurements

The subjects' body mass and height were measured using a standard digital platform scale and wall-mounted stadiometer (Sahand CO. Tabriz, Iran), respectively. Body mass index (BMI) was calculated as body mass in kilograms divided by the square of height in meters. The waist to hip ratio (WHR) was calculated by dividing waist measurement (at the smallest circumference of the waist) by hip measurement (the widest part of the buttocks). A 3-site skin fold equation of Jackson and Pollock (chest, abdominal and thigh) was used to estimate body density. Body fat percentage (BF%) was subsequently estimated as follows: BF% = ((4.95 / body density) - 4.50) x 100) (Siri equation). Finally, lean body mass (LBM) was calculated by subtracting body fat mass from total body mass. The subjects' anthropometric profiles are presented in Table 1.

Table 1. Baseline anthropometric profiles of subjects

Variables	LP	WUP
Height (cm)	174.10 ± 4.99	1.72 ± 3.50
Body mass (kg)	68.71 ± 10.94	69.50 ± 9.52
BMI (kg/m^2)	22.56 ± 2.65	23.40 ± 3.38
WHR	0.83 ± 0.04	0.84 ± 0.03
BF%	14.91 ± 3.15	15.71 ± 4.33
LBM (kg)	58.26 ± 8.15	58.25 ± 5.70

Values are means ± standard deviations. Abbreviation: BF%, Body fat percentage; BMI, Body mass index; LBM, Lean body mass; WHR, Waist to hip ratio.

1RM measurement

The subjects were familiarized with equipment and correct exercise techniques. Then, the upper and lower body maximal strength was determined by 1RM over two separate days [18]. Strength tests were preceded by 5 min general warm-up on a cycle ergometer. In addition, the participants lifted light to moderate free weights and performed light stretching exercises as specialized warm-up. After 3-minute rest, they were asked to choose a weight that they can lift at least once and up to 10 times. Finally, the 1RM of all the exercises was determined according to Brzycki equation as follows: 1RM = weight ÷ ((0.027 × number of repetitions) – 1.027)).

LP and WUP protocols

Prior to LP and WUP trials, the participants performed one set of 10 repetitions of shoulder press, bench press, leg press, step-ups and abdominal crunch at an intensity corresponding to 60-70% of the individual's 1RM for 2 weeks as a preparatory phase [18]. In the main phase, both LP and WUP models were conducted for 9 weeks, 3 sessions per week at an intensity corresponding to 80-90% of the individual's 1RM [7]. Exercise sessions were separated by a minimum of 48 hours [23, 25]. At the beginning and end of LP and WUP protocols, warm-up and cool-down were carried out with lifting light weight for 10 repetitions and some light stretching exercises, conducted for 9 weeks, 3 sessions per week at an intensity corresponding to 80-90% of the individual's 1RM, respectively [23, 25]. The participants in both groups performed the barbell squat, barbell bench press, seated machine leg extension, standing barbell arm curl, lying machine leg curl, lying barbell triceps extension, calf raises, and seated barbell shoulder press. In addition, they performed abdominal crunch, low back extension and side crunches for 3 sets of 10 to 15 repetitions [23]. The subjects were instructed to perform each exercise at a constant speed (eccentric contraction in 2 seconds and concentric contraction in 2 seconds) [19]. Training sessions were supervised by a certified strength and conditioning specialist. Studies have indicated that the acute fluctuations in testosterone from a workout are not significantly affected by the time of day [2]. Hence, both interventions were carried out in the afternoons over the investigated period. The details of LP and WUP regimens are depicted in Table 2.

Table 2. Details of LP and WUP models over the main phase

Training variables	Group	Week								
		1	2	3	4	5	6	7	8	9
Set	LP	3	3	3	3	3	3	3	3	3
	WUP	3	3	3	3	3	3	3	3	3
Repetition	LP	8	8	8	6	6	6	4	4	4
	WUP	8	6	4	8	6	4	8	6	4
Intensity (% 1RM)	LP	80	80	80	85	85	85	90	90	90
	WUP	80	85	90	80	85	90	80	85	90
Rest interval between sets	LP	60	60	60	90	90	90	120	120	120
	WUP	60	90	120	60	90	120	60	90	120
Repetition of abdomen and low back exercises	LP	15	15	15	12	12	12	10	10	10
	WUP	15	12	10	15	12	10	15	12	10

Abbreviations: 1RM – One-Repetition Maximum; LP – Linear Periodization; WUP – Weekly Undulating Periodization.

Assessments of maximal strength

Before and 72 hours after the last weight training session [18, 23], the upper and lower body maximal strengths were determined through barbell bench press and barbell squat, respectively.

Blood sampling and biochemistry assay

Before and after the interventions, 12-hour overnight fasting blood samples (7 ml) were taken from superficial antecubital vein in Javad Al-Aeme Hospital (Jajarm, North Khorasan Province, Iran). Vamvini et al. [26] have displayed no day/night variation in the concentrations of Fst in young males. Therefore, the sample was taken at rest between 7:30 and 8:30 a.m. Moreover, it has been demonstrated that the peak secretion of Fst occurs 24 hours after a single bout of eccentric and concentric weight exercises [7]. In addition, one study has claimed that 7-fold increase in plasma Fst returned to baseline 24 hours after long term exercise on a bicycle ergometer [6]. Hence, to avoid data misinterpretation due to the remaining effects of the last training session, the samples were obtained 48 h after the last weight session. Blood samples were centrifuged (Universal model, Behdad CO, Iran) at 2500 rpm for 20 min at 4°C. Finally, serum was extracted and stored at -80°C (GFL upright freezer, Model 6481, Germany) until further analysis.

Serum levels of free testosterone (#ZB-10041-H9648, ZellBio GmbH, Ulm, Germany), free cortisol (#ZB-11003-H9648, ZellBio GmbH, Ulm, Germany) and Fst (#CK-E10682, Hangzhou Eastbiopharm, CO., LTD. China) were measured using enzyme-linked immunosorbent assay (ELISA) kits. The assay range and sensitivity for testosterone was 0.08-16.7 ng/ml and 0.02 ng/ml, respectively. In addition, the assay range and sensitivity for Fst was 0.5-200 ng/ml and 0.25 ng/ml, respectively. Moreover, the assay range and sensitivity for cortisol was 0.5-60 µg/dl and 0.4 µg/dl, respectively. The absorbance of testosterone, cortisol and Fst was measured at 450 nm by BioTek microplate reader (EpocH2 model, BioTek Instruments, Inc., USA).

Diet

The daily energy intake was analyzed using a 24-hour dietary recall. The analyses revealed that the calorie intakes from carbohydrates, proteins and fat were 58%, 15%, and 27%, respectively. It has been claimed that such diet regimen has no demonstrable effect on the circadian rhythm of testosterone [2]. In addition, a diet including more than 44% of fat is known to influence the testosterone level [2]. Furthermore, a diet consisting of low carbohydrate (30%) increases free testosterone to cortisol ratio induced by short term intensive exercise on cycle ergometer [27]. Therefore, the participants were instructed to adopt a balanced diet and to load glycogen before each session. Amino acid or a combination of protein and carbohydrate intake upregulates androgen receptors and testosterone concentrations [2]. Hence, the subjects were asked not to consume any dietary supplements or anabolic steroids during the course of study. Due to caffeine's possible effects on responses of testosterone and cortisol to resistance training [28], explosive power [29] and body composition, the participants were encouraged not to consume foods containing caffeine throughout the study course. It has been proven that energy deprivation and weight loss regimen lead to an increase in circulating levels of Fst in healthy males [26]. They were therefore prohibited from participating in weight loss programs throughout the training period.

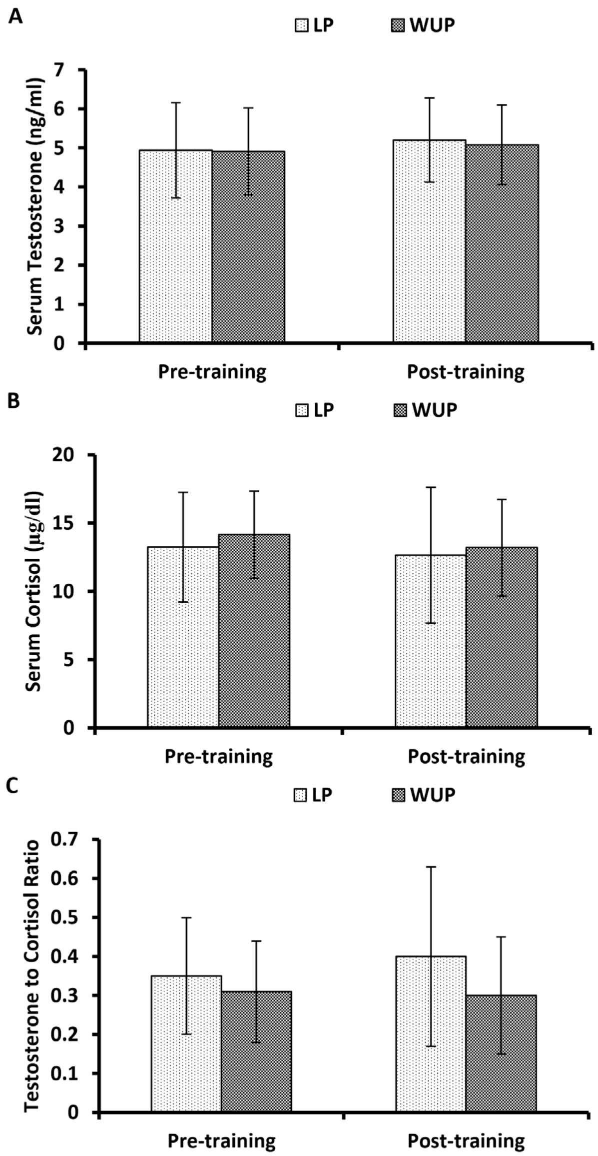
Statistical analysis

All statistical analyses were performed using the statistical package for social sciences software (SPSS Inc, version 16.0, Chicago, USA). The level of significance was set at $p < 0.05$. Initially, normal distribution of data was tested using Shapiro-Wilk test. Then, intra-group changes were assessed using paired t-test and Wilcoxon test for parametric and nonparametric variables, respectively. In addition, inter-group differences were assessed using Student's t-test and Mann-Whitney U-test for parametric and nonparametric variables, respectively. The results were expressed as the mean ± standard deviation.

Results

In the context of anthropometric assessments, the results revealed no significant differences between the baseline values of height ($p = 0.418$), weight ($p = 0.866$), BMI ($p = 0.544$), WHR ($p = 0.549$), BF% ($p = 0.642$), and LBM ($p = 0.999$) in LP and WUP groups (Tab. 1).

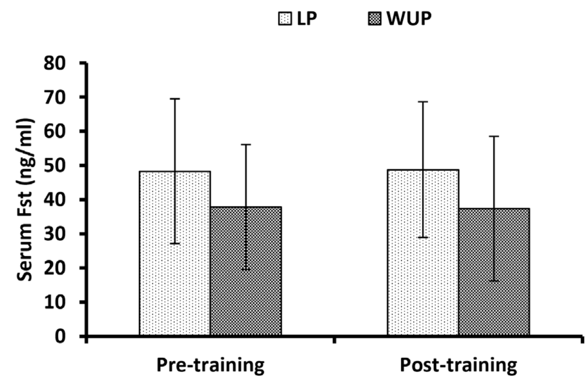
With regard to anabolic/catabolic balance, our findings showed that LP model made no significant changes in serum levels of testosterone (4.98 ± 1.22 vs. 5.20 ± 1.08 ng/ml for pre and post, respectively) ($p = 0.258$), cortisol (13.22 ± 4.03 vs. 12.62 ± 4.98 µg/dl for pre and post, respectively) ($p = 0.797$) and testosterone to cortisol ratio (0.35 ± 0.15 vs. 0.40 ± 0.23 for pre and post, respectively) ($p = 0.458$). Moreover, WUP model made no significant changes in serum levels of testosterone (4.91 ± 1.11 vs. 5.08 ± 1.02 ng/ml for pre and post, respectively) (p = 0.609), cortisol (14.15 ± 3.19 vs. 13.19 ± 3.53 μg/dl for pre and post, respectively) (p = 0.079) and testosterone to cortisol ratio (0.31 ± 0.13 vs. 0.30 ± 0.15 for pre and post, respectively) (p = 0.138). In addition, no significant difference was observed between serum levels of testosterone (p = 0.813), cortisol (p = 0.724) and testosterone to cortisol ratio (p = 0.443) in LP and WUP groups at the end of the protocol. The changes in factors involved in anabolic/catabolic balance are depicted in Fig 1.



LP – Linear Periodization; WUP – Weekly Undulating Periodization.

Figure 1. Comparing the effects of LP and WUP interventions on serum levels of testosterone (A), cortisol (B), and testosterone to cortisol ratio (C) in sedentary men.

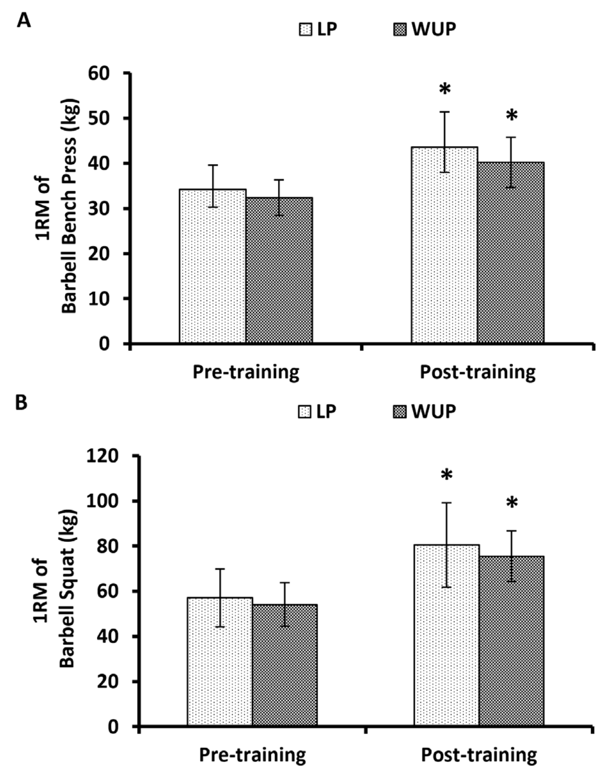
In terms of cytokine, the LP (48.28 ± 21.19 vs. 48.77 ± 19.87 ng/ml for pre and post, respectively) (p = 0.768) and WUP (37.86 ± 18.26 vs. 37.38 ± 21.11 ng/ml for pre and post, respectively) (p = 0.852) had no significant effect on serum Fst levels. Furthermore, no statistically significant difference was found for serum Fst levels between two groups after intervention (p = 0.381). Fst changes are presented in Fig 2.



Fst – Follistatin; LP – Linear Periodization; WUP – Weekly Undulating Periodization.

Figure 2. Comparing the effects of LP and WUP interventions on serum levels of Fst in sedentary men.

In relation to maximal strength changes, 1RM of barbell bench press (34.20 ± 5.43 vs. 43.60 ± 7.82 kg for pre and post, respectively) (p = 0.005) and 1RM of barbell squat (57.01 ± 12.81 vs. 80.40 ± 18.70 kg for pre and post, respectively) (p = 0.001) were significantly increased following LP model. In addition, 1RM of barbell bench press (32.40 ± 3.94 vs. 40.20 ± 5.57 kg for pre and post, respectively) (p = 0.001) and 1RM of barbell squat (54.10 ± 9.62 vs. 75.50 ± 11.24 kg for pre and post, respectively) (p = 0.001) were significantly increased following WUP model. In contrast, no significant differences were observed in barbell bench press (p = 0.247) and barbell squat (p = 0.478) between the two interventions at the end of the protocol. Maximal strength gains are shown in Fig 3.



1RM – One-Repetition Maximum; LP – Linear Periodization; WUP – Weekly Undulating Periodization; * – significant difference compared to pre-training ($p < 0.05$).

Figure 3. Comparing the effects of LP and WUP interventions on 1RM of barbell bench press (A) and 1RM of barbell squat (B) in sedentary men.

Discussion

The current study was conducted to compare the effects of LP and WUP resistance training on testosterone, Fst and maximal strength. The findings showed that both LP and WUP resistance exercise regimens, independent of Fst and testosterone changes, similarly improve maximal strength in sedentary men.

The findings of our study revealed no significant differences in serum testosterone, cortisol and testosterone to cortisol ratio between LP and WUP groups after intervention. The testosterone to cortisol ratio has been proposed as a key indicator of the balance between anabolic and catabolic processes. These findings are supported by research of Painter et al. [30], who demonstrated no significant differences in serum testosterone, cortisol and testosterone to cortisol ratio between two types of block periodization and DUP resistance training. In addition, neither LP nor WUP resistance training resulted in significant changes in serum testosterone, cortisol and testosterone to cortisol ratio. Our own observations align with one study that suggested long-term supervised progressive strength training made no significant alternations in total and free testosterone in untrained men [31]. In contrast, our findings are inconsistent with the research which demonstrated that split body resistance training resulted in greater increase in testosterone and cortisol concentrations and greater reduction in testosterone to cortisol ratio than full body resistance-training [32]. In addition, it has been revealed that high-volume resistance training (4 × 10-12 repetitions with ~70% of 1RM) compared to high-intensity resistance training (4 × 3-5 repetitions with ~90% of 1RM) resulted in greater serum cortisol concentration [33]. Whole-body multi joint resistance training for 3 weeks induced an increase in testosterone levels. However, 6-week resistance training had no significant effect on testosterone levels [34]. Therefore, one reason for the lack of change in testosterone levels in our study is that serum testosterone change manifests itself in early periods of training. In men, roughly 70% of circulating testosterone is bound with high affinity to sex hormone-binding globulin (SHBG), while the remainder is either weakly bound to albumin or exists as free testosterone [31, 35]. Importantly, it has been reported that resistance training enhances serum SHBG concentration [31, 35]. Although SHBG levels were not measured in the current study, it can be concluded that part of the unchanged serum testosterone level may be due to elevated SHBG levels induced by resistance training.

In the present study, no significant changes in Fst concentration were observed after LP and WUP intervention. Our findings are aligned with other studies that reported no significant changes in serum Fst levels after low-intensity resistance training [1] and wrestlers training [5]. In addition, the work by Jensky et al. [3] showed that single bout or multiple bouts of maximal eccentric and concentric training may not significantly alter Fst mRNA gene expression in young women. Similarly, our findings are supported by Diel et al. [8], who demonstrated no significant changes in Fst levels in serum and skeletal muscle following both endurance and strength training. Despite no significant change in serum Fst levels during early 3 months, serum Fst concentrations increased after 6-month elastic band resistance training in elderly women [11]. Therefore, contradiction in the results can stem from a long period of resistance training and older subjects. In this regard, it has been proven that muscle wasting induced by sarcopenia is attributed to reduced serum Fst and increased myostatin levels in older women [11]. Conversely, in an inconsistent study it has been revealed that 12-week lower body heavy resistance training (3 × 6-8 repetitions at 85-90% of 1RM) through up-regulation of Fst results in an increase in total body mass, fat-free mass, strength, and thigh volume and mass [12]. Testosterone not only up-regulates Fst expression as a myogenic factor, but also decreases the expression of myostatin [36]. In this context, previous in vivo research has revealed that expression of Fst mRNA decreased in the gastrocnemius muscle of castrated trained rats compared to the intact sedentary and the intact trained rats [36]. Moreover, it has been demonstrated that testosterone up-regulates the expression of Fst [9]. In contrast, anti-Fst antibodies inhibit testosterone's effects on myogenic differentiation of muscle progenitor cells [10]. Hence, no noticeable change in serum Fst in the current study may be due to a lack of meaningful change in serum testosterone.

Both LP and WUP programs resulted in a substantial increase in 1RM of squat (LP 41.02%, WUP 39.55%) and 1RM of bench press (LP 27.48%, WUP 24.7%). The results are in agreement with previous reports indicating an increase in 1RM of chest press (11%) and back squats (13%) following a 6-week resistance training program in rugby players [37]. Furthermore, Kok et al. [35] demonstrated that 12-week hypertrophy-, strength- and power-type LP and DUP interventions induced an increase in 1RM of squats (LP 34.8%, DUP 41.2%) and chest press (LP 21.8%, DUP 28.3%) in untrained women. It has been reported that maximal strength gains are related to individual hormonal fluctuations and baseline levels of muscular strength [32]. On this matter, slope testing on the individual responses indicated positive associations between cortisol and testosterone concentrations and absolute 1RM strength in stronger, but not weaker men [32]. Moreover, Souza and colleague [19] reported a 7.7% and 12.9% increase in dynamic strength following 6-week LP and DUP interventions, respectively. The observed increase in maximal strength in the above-mentioned study was lower than in the current study. In reality, our findings are inconsistent with this study potentially due to insufficient training volume or duration. Another work has shown an increase in 1RM of leg press (12% and 15% for LP and DUP, respectively) and chest press (12% and 15% for LP and DUP, respectively) following 8-week progressive resistance training (at an intensity corresponding to 50-85% of 1RM) in overweight sedentary men [18]. The percentage increase in 1RM can vary significantly depending on exercise intensity. LP and WUP interventions in the current research were conducted at an intensity corresponding to 80-90% of 1RM throughout the study. In this regard, it has been concluded that resistance training at high intensity appears to be more beneficial in increasing maximal strength because of stimulating high-threshold motor units [14]. Despite changes in hormonal levels, the results of the present study showed a significant increase in strength following the two training interventions. In reality, in untrained individuals, it has been previously reported that initial improvements in maximal strength are often not solely attributable to morphological adaptations, but rather to neural mechanisms such as enhanced motor unit recruitment, improved intermuscular coordination, and greater technical proficiency in executing the prescribed exercises [39].

The findings revealed no meaningful difference in 1RM of the performed exercises between LP and WUP groups at the end of the protocol. Similarly, our own observations align with the report that showed no significant differences between LP and DUP groups for maximal strength of squat and bench press increases after 12 weeks [22]. In addition, Souza et al. [19] reported no noticeable difference in gains of squat 1RM between short-term non-periodized, LP, and DUP models. In contrast, another study has claimed that ondulatory periodization of resistance training through making greater fluctuations in volume and intensity provides greater training stimulus, which in turn results in more neuromuscular adaptions in each session [38].

One limitation of the present study is that testosterone levels were assessed only at two points: before and after the training interventions. Given that significant changes in testosterone can occur early in training, it is recommended that future studies evaluate serum testosterone at multiple stages throughout the intervention. In addition, the lack of observed changes in specific variables may be partly due to the application of training overload based on pre-intervention assessments; therefore, future studies are recommended to dynamically adjust training loads based on the values of maximal strength achieved during the intervention to better reflect training gains.

Conclusions

In general, both LP and WUP resistance training regimens, independent of Fst and testosterone changes, similarly improve maximal strength in sedentary men. Hence, performing both models of resistance training is suggested for sedentary men to gain maximal strength.

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