Effect of Passive Repetitive Isokinetic Training on Cytokines and Hormonal Changes

Shu-Lin Lee¹, Kenny Wen-Chyuan Chen², Szu-Tah Chen³, Po-Ju Chu⁴, Chuan-Show Chen⁵, Mei-Chich Hsu⁶, Tzzy-Yuang Shiang⁷, Mao-Kuan Su⁸, Mu-San Chang⁹, Ying-Ling Chang¹⁰, *, and Shyi-Wu Wang¹¹, *

¹Department of Nutrition and Health Science, Chung Chou Institute of Technology, Yuanlin, Changhua
²Department of Physical Education, Chang Gung Institute of Technology, Kweisan, Taoyuan
³Division of Endocrinology and Metabolism, Department of Internal Medicine, Chang-Gung Memorial Hospital, Taoyuan
⁴Department of Biomedical Sciences, Chang-Gung University, Taoyuan
⁵Department of Physical Education, National Taiwan Sports University, Taichung
⁶Institute of Sports Science, National Taiwan Sport University, Kweishan, Taoyuan
⁷Graduate Institute of Exercise and Sport Science, National Taiwan Normal University, Taipei
⁸Physical Education Room, Chang-Gung University, Taoyuan
⁹Center of Physical Education, Tzu Chi University, Hualien
¹⁰School of Traditional Chinese Medicine, Chang-Gung University, Taoyuan
and
¹¹Department of Physiology and Pharmacology, College of Medicine, Chang-Gung University, Taoyuan 33333, Taiwan, Republic of China

Abstract

It is well known that muscle strength and power are important factors in exercise. Plyometrics is designed to gain muscle strength and power in a shock method. The passive repetitive isokinetic (PRI) machine is developed for plyometrics. The present study aims to understand the effect of ten-week PRI training in different intensities on human plasma concentration cytokines as well as hormonal changes. Thirty young male subjects were enrolled into the ten-week PRI training program and were divided randomly into traditional, low- and high-intensity PRI training groups. Blood samples were obtained before, during, after and 1-, 2-, 3-, 5- and 7-day (D) post-training. The plasma concentrations of cytokines and hormones were measured by an enzyme-linked immunosorbent assay (ELISA). Elevated plasma IL-2 was found in the subjects in all the training programs. Significant increases of proinflammatory cytokines IL-1β and TNF-α were observed at post 7 D in the high-intensity PRI training (29.5 ± 4.4 and 515.8 ± 127.1 pg/ml, respectively). No significance in differences in the plasma concentration of IL-6 was observed in the traditional and low-intensity PRI training. Significant elevation of IL-6 was found at post 5 D in high-intensity PRI training. Higher plasma IL-6 concentration was observed at post 0, 2, 3, and 5 D in high-intensity PRI training compared to low-intensity PRI training (P < 0.05). Significant elevation of plasma IL-15 during (week 6) and after (post 0 D) was observed in low-intensity PRI training. The plasma concentration of cortisol was decreased to the lowest value (118.0 ± 17.3 ng/ml) at post 0 D in traditional training, then returned to the baseline (220.5 ± 19.1 ng/ml). In the high-intensity PRI training, but not in the low-intensity PRI training, the cortisol level dropped from 224.9 ± 25.8 ng/ml at post 0 D down to the 123.2 ± 22.6 ng/ml at post 1 D. Significant differences...
were found at post 1 and 5 D between low- and high-intensity PRI training, and post 0, 1, 2, and 3 D between traditional and high-intensity PRI training. Significant increased testosterone was found post 0, 1, 2, and 3 D in traditional training. Higher plasma testosterone was observed during and the recovery period in low-intensity, but not in high-intensity, PRI training. In conclusion, high-intensity PRI training could induce the proinflammatory cytokines, i.e. IL-1β and TNF-α, and decrease plasma cortisol in the recovery period.

Key Words: passive repetitive isokinetic training, PRI, cytokine, hormone, human

Introduction

For athletes, muscle strength and power are considered as very important components in sports competition. Large muscle strength can produce enough joint torque to accomplish the movement requiring heavy load, and also provide better base foundation for muscle power. In addition to strength, muscle power is essential to most sporting activities involving striking, throwing, jumping and rapid acceleration movements.

There are two contractions for muscle movement, i.e. isometric and isotonic contraction, or eccentric and concentric muscle contractions. In most cases, muscle contractions, stretch and shortening cycle (SSC) are involved in the real movement (36). Therefore, it is well known that successful athletic performance depends on leg-muscle power and vertical-jump performance (4, 69). During the past years, vibration training (8), electrostimulation training (46), heavy-resistance training (92) and explosive type (93) have been widely and effectively applied for the improvement of vertical jump performance. However, studies have indicated that plyometric training (PT) seems to be a better method for enhancement of vertical jump ability and leg muscle power (16, 48). Plyometric training, advocated by Verkhoshanski in Russia in 1969 (90), is the SSC movements involving a rapid, powerful concentric contraction and high-intensity eccentric contraction (47). Passive repetitive isokinetic (PRI) training methods were developed based on the theory of high speed contraction, stretch shortening cycle and isokinetic contraction. The PRI training machine has also been designed to achieve the above mentioned functions. A previous study has shown that in augmentation of muscle power and strength, the effect of PRI training on PRI machine is significantly better than the traditional isotonic weight training (43). Also, long term PRI training (10 weeks) could affect the reflex modulation of spinal cord and plasticity of spinal circuitry (42).

It is well known that the immune function can be influenced by exercise, including strenuous and eccentric exercises. Cytokines are a group of small peptides released from white blood and other body cells in response to different stimuli. Cytokines are considered as immunoregulatory molecules for regulation of immune function and other body responses (83). Physical training and exercise are considered as stressors which induce local or systemic responses including cytokine changes (5). Many reviews have indicated that heavy exertion such as ultramarathon races not only increased the risk of upper respiratory tract infection (URTI) but also the augmented plasma interleukin (IL)-6 levels. In addition, the proinflammatory cytokines, TNF-α and IL-1β, have been reported to be increased during and after exercises. Moreover, mRNAs of IL-6 and IL-15 have been demonstrated to be expressed in muscle tissues, and these three cytokines are classified as “myokines” (61). However, most studies concerning the exercise effects on the plasma levels of cytokines are limited to the short period during and after training or race. Changes of plasma levels of cytokines during and after PRI training are still unknown.

The present investigation was to explore the cytokines change pre-, during and after PRI training. We also investigated the cytokines levels in the recovery period up to 7 days. In addition, we measured the plasma testosterone and cortisol levels which represent the anabolic and catabolic hormones.

Materials and Methods

Subjects

Thirty-two healthy male college students with a mean age of 22 ± 1 years old, height 176 ± 2 cm, weight 70 ± 2 kg, were enrolled in this experiment. All subjects were asked to maintain their usual food intake and no food supplements and medication were taken. The experimental protocol was approved by the Institutional Review Board/Chang-Gung Memorial Hospital, and all subjects gave written informed consent. Two subjects were excluded because of cold disorder. Ten-week training was applied to all subjects who were randomly divided into three groups: traditional weight training control group (n = 10), low-intensity (0.5 Hz) PRI training group (n = 10), and
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high-intensity (2.5 Hz) PRI training group (n = 10).

Experimental Design

All subjects underwent a 10-week regiment of training 3 days/week and maintained their habitual physical activities but performed no additional strength training. Exercise was performed at a resistance that was initially 70% of one repetition maximum (1 RM) on the PRI machine or the traditional squat training method (Smith Press, Cybex, NY, USA). The subjects of low intensity group performed training for 20 sec at a frequency of 0.5 Hz, while high intensity group performed training for 20 sec at a frequency of 2.5 Hz. Resistance used in this study was determined during the training sessions every week for the 10-week training period using the 1 RM approach. Subjects performed 10 repetitions set and performed 5 set with 2-min rest periods.

Blood Collection

Plasma was separated by centrifugation at 10,000 x g for 1 min and stored at -20°C. To measure the concentrations of cytokines and hormones, including interleukin-1β (IL-1β), interleukin-2 (IL-2), interleukin-6 (IL-6), interleukin-15 (IL-15), tumor necrosis factor-α (TNF-α) and testosterone and cortisol, 0.1 ml plasma was used. The concentrations of plasma cytokines and hormones were measured by enzyme-linked immunosorbent assays (ELISA).

ELISA of Cytokines and Hormones

Plasma concentrations of cytokines and hormones were determined by ELISA (Enzyme-linked Immunosorbent Assay) as described previously (10, 25, 94, 95) with some modifications. Briefly, 0.1 ml of capture antibodies (R & D systems, Minneapolis, MN, USA) were coated on the polystyrene microtiter plates (NUNC, U16 Maxisorp type, Rochester, NY, USA) and incubated at room temperature overnight.

<table>
<thead>
<tr>
<th>Cytokines/Hormones</th>
<th>Detection range</th>
<th>Sensitivity</th>
<th>Intraassay CV</th>
<th>Interassay CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL-1β</td>
<td>3.91-250 pg/ml</td>
<td>1 pg</td>
<td>4.0%</td>
<td>6.9%</td>
</tr>
<tr>
<td>IL-2</td>
<td>31.25-2,000 pg/ml</td>
<td>7 pg</td>
<td>6.4%</td>
<td>10.2%</td>
</tr>
<tr>
<td>IL-6</td>
<td>9.375-600 pg/ml</td>
<td>0.7 pg</td>
<td>4.2%</td>
<td>10.8%</td>
</tr>
<tr>
<td>IL-15</td>
<td>7.8-500 pg/ml</td>
<td>1 pg</td>
<td>7.8%</td>
<td>11.7%</td>
</tr>
<tr>
<td>TNF-α</td>
<td>15.6-1,000 pg/ml</td>
<td>1.6 pg</td>
<td>5.0%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Cortisol</td>
<td>50-230 ng/ml</td>
<td>2.5 ng</td>
<td>4.4%</td>
<td>7.1%</td>
</tr>
<tr>
<td>Testosterone</td>
<td>7.8-500 pg/ml</td>
<td>6 pg</td>
<td>4.4%</td>
<td>7.7%</td>
</tr>
</tbody>
</table>

The plates were blocked the next day and then incubated for 1 h. Then, 0.1 ml standard/sample was added and incubated for 2 h. After washing 3 times, 0.1 ml of detection antibody (R & D systems) was applied for 2 h. One hundred microliters streptavidin horseradish peroxidase (R & D systems) and then 0.1 ml tetramethylbenzidine substrate (Clinical Science Products Inc., Mansfield, MA, USA) followed this incubation. The reaction was stopped using 2 N sulfuric acid and optical density (OD) reading was taken at 450 nm (BioTek, Winooski, VT, USA). All samples were run in duplicates. The results were expressed as concentration of cytokines (pg/ml) and hormones (ng/ml) read from standard curves. The detection range, sensitivity, the intraassay and interassay coefficients of variation for the ELISA are presented in Table 1.

Statistical Analysis

All values are given as the means ± SEM. Differences between the pre, during and post exercise values of the measured variables were tested for homogeneity by one-way ANOVA and the differences between specific means were tested for significance by the Duncan multiple range test (79). A difference between two means was considered statistically significant when P < 0.05.

Results

Changes of Plasma Levels of IL-2 before and after PRI Training

Traditional training significantly enhanced plasma concentrations of IL-2 during the recovery period (57.0 ± 10.8 pg/ml at post 0 D to 50.5 ± 11.3 pg/ml at post 7 D), reaching the highest level at post 0 D compared to pre-training (29.7 ± 5.8 pg/ml) (Fig. 1, upper panel). There was a significant gradual increase in plasma IL-2 level during the recovery period (21.5 ± 2.0 pg/ml at post 0 D to 35.1 ± 2.7 pg/ml at post
7 D) compared to the value of pre-training (17.3 ± 1.7 pg/ml) after low-intensity PRI training (0.5 Hz × 20 sec × 70% × 5 sets) and high-intensity PRI training (2.5 Hz × 20 sec × 70% × 5 sets) during the recovery period (43.5 ± 20.2 pg/ml at post 0 D to 60.2 ± 18.1 pg/ml at post 7 D) compared to the value of pre-training (23.6 ± 5.7 pg/ml) (Fig. 1, middle and lower panels). A lower plasma IL-2 concentration was found in the low-intensity PRI training compared to the plasma IL-2 concentration in traditional training.

**Changes of Plasma Interleukin-1β (IL-1β) Levels before and after PRI Training**

Fig. 2 shows the concentration of plasma IL-1β before and after PRI training. The highest level of plasma IL-1β was observed at week 6 (23.0 ± 6.2 pg/ml) for traditional training, but not significant compared to the pre-training (8.5 ± 2.4 pg/ml) (Fig. 2, upper panel). Then, the plasma IL-1β dropped to the lowest level at post 0 D (3.9 ± 0.4 pg/ml) and remained at low levels during the recovery period (post 1 D to post 7 D). In the low-intensity PRI training, the highest concentration of plasma IL-1β was observed at post 0 D (16.6 ± 4.5 pg/ml), then declined gradually to the significantly lower levels during the recovery period compared to the value of pre-training (13.5 ± 2.1 pg/ml) (Fig. 2, middle panel). The plasma IL-1β level reached the peak level (29.1 ± 8.0 pg/ml) at week 6 in the high-intensity PRI training period, then dropped to the level similar to that of pre-training (8.6 ± 2.6 pg/ml). The highest plasma IL-1β concentration, however, was observed at post 7 D (29.5 ± 4.4 pg/ml) after the high-intensity PRI training (Fig. 2, lower panel). Significantly low plasma IL-1β level in the low-intensity PRI training was observed at week 6, post 3, 5 and 7 D compared to the level of the traditional training. In contrast, higher plasma IL-1β level in high-intensity PRI training was found at post 3, 5 and 7 D compared to the level of the low-intensity PRI training.
Effect of PRI Training on the Concentration of IL-6 before and after Exercise

Gradually increased IL-6 level was observed after the traditional training (26.8 ± 9.9 pg/ml at post 0 D to 39.4 ± 16.6 pg/ml at post 7 D), however, the level was not significant compared to the value from pre-training (23.8 ± 10.4 pg/ml) (Fig. 3, upper panel). After the low-intensity PRI-training, the plasma IL-6 increased, but not significantly, during the recovery period (14.1 ± 2.7 pg/ml at post 0 D to 14.1 ± 1.8 pg/ml at post 7 D compared to 10.4 ± 1.3 pg/ml at pre-training) (Fig. 3, middle panel). Significant level of plasma IL-6 was found after high-intensity PRI-training (post 5 d, 46.5 ± 13.4 pg/ml, respectively) compared to the value from pre-training (17.8 ± 7.1 pg/ml) (Fig. 3, lower panel). In addition, significant difference was observed at post 3 and 5 D between low- and high-intensity PRI training. Higher plasma IL-6 level in high-intensity PRI training was found at post 3 and 5 D compared to the level of low-intensity PRI training.

Plasma Concentrations of IL-15 before and after PRI Training

After traditional training, the plasma IL-15 concentration decreased gradually to a lowest value at post 3 D (17.7 ± 2.0 pg/ml) (Fig. 4, upper panel). In contrast, gradually increased IL-15 level was observed during exercise and to a highest level at post 0 D after low-intensity PRI-training. In the recovery period, the plasma IL-15 level decreased gradually (Fig. 4, lower panel). There were differences between traditional training and low-intensity PRI training at post 0, 2, 3, and 5 D.

Plasma Concentrations of TNF-α before and after PRI Training

In the traditional training, the plasma TNF-α remained constant during and at recovery period until post 3 D (229.2 to 276.1 pg/ml), then declined gradually at post 5 and 7 D (218.6 ± 73.1 and 152.2 ± 62.3 pg/ml, respectively) (Fig. 5, upper panel). There was no significant change for the plasma TNF-α concentration after the low-intensity PRI training during exercise and in the recovery period, ranging

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Fig. 3. Plasma concentrations of interleukin-6 before and after PRI training. See legends to Figs. 1 and 2.

Fig. 4. Plasma concentrations of interleukin-15 before and after PRI training. See legend to Fig. 1.
from 66.8 ± 23.7 to 142.3 ± 80.3 pg/ml (Fig. 5, middle panel). In the high-intensity PRI training, an initial plasma TNF-α concentration of 117.6 ± 60.1 pg/ml decreased to 78.1 ± 35.8 pg/ml at post 1 D, then peaked to 515.8 ± 127.1 pg/ml (P < 0.05 compared to pre-training) (Fig. 5, lower panel). A lower plasma TNF-α concentration was found in low-intensity PRI training compared to the level in the traditional training. However, the plasma TNF-α concentration at post 7 D in high-intensity PRI training was significant higher than the plasma TNF-α levels in traditional and low-intensity PRI training.

**Plasma Concentrations of Cortisol before and after PRI Training**

In response to the traditional training, plasma cortisol reduced from 206.7 ± 13.9 at pre-training to 118.0 ± 17.3 ng/ml at post 1 D (P < 0.01). However, plasma cortisol levels rose up to 220.5 ± 19.1 ng/ml, then declined to 145.0 ± 12.1 (P < 0.01 vs. Pre) and 167.0 ± 14.7 ng/ml (P < 0.05 vs. Pre) at post 5 and 7 D, respectively (Fig. 6, upper panel). In the low-intensity PRI training, the highest values of plasma cortisol were found at post 5 D (217.3 ± 13.2 ng/ml) and the lowest value was observed at post 2 D (167.2 ± 15.3 ng/ml). No significant difference was found compared to the pre-training (185.3 ± 13.0 ng/ml) (Fig. 6, middle panel). After the high-intensity PRI training, the plasma cortisol level rose from 193.9 ± 1.07 at pre-training to 224.9 ± 25.8 ng/ml at post 0 D (P = 0.197), then decreased significantly (P < 0.01) to 123.2 ± 22.6 ng/ml at post 1 D, increased slowly to 157.0 ± 19.5 ng/ml at post 7 D (Fig. 6, lower panel). Significant difference in the plasma cortisol concentration between traditional and low-intensity PRI training was found at post 0 and 5 D. Between high-intensity PRI and traditional training, the significant difference was observed at post 0, 1, 2, and 3 D. Also, there was significant difference in the plasma cortisol concentration at post 1, 3, and 5 D between the low- and high-intensity PRI training.

**Plasma Concentrations of Testosterone before and after PRI Training**

In traditional training, significantly increased plasma concentrations of testosterone were found between post 0 D (10.7 ± 1.4 ng/ml) and post 3 D (6.0 ± 1.2 ng/ml) compared to pre-training (6.2 ± 0.7 ng/ml) (Fig. 7, upper panel). There was a gradual and significant increase in the plasma testosterone concentrations during and after the low-intensity PRI training (7.3 ± 1.2 and 9.8 ± 1.6 ng/ml, respectively) (Fig. 7, middle panel). After the high-intensity PRI
The recovery period had been extended to 7 days. Cytokines such as interleukin-1β (IL-1β), IL-2, IL-6, IL-15, tumor necrosis factor TNF-α, testosterone, and cortisol were measured before, during, and after PRI training. The present study provides information on changes in the plasma concentrations of IL-1β, IL-2, IL-6, IL-15, TNF-α, testosterone, and cortisol before, during, and after PRI training. The intensity and duration of physical activity may be related to the type, mode, intensity, and duration of physical activity. Additionally, the sensitivity and specificity of assays might be another important factor.

**Discussion**

The objective of this study was to determine if the plasma cytokine and hormone (testosterone and cortisol) levels would vary with different intensities of PRI training compared to traditional training with similar time and duration. The present study provides information on changes in the plasma concentrations of IL-1β, IL-2, IL-6, IL-15, TNF-α, testosterone and cortisol before, during, and after PRI training. The intensity of exercise could enhance the plasma IL-1β and TNF-α levels after exercise.

IL-2 is a cytokine produced primarily from activated T-lymphocytes. This cytokine plays important roles in immunoregulatory responses after stimulation, and enhances the function of T-cells for host defense. Results from previous studies indicated that the plasma concentration of IL-2 elevated, decreased, or unchanged after exercise. Suzuki et al. showed that the plasma IL-2 concentration was significantly reduced by 32% after the Marathon race (82). Espersen et al. found that, compared to the pre-exercise values, IL-2 was significantly decreased immediately after a five-kilometer race and significantly increased after 24 h (17). In contrast, Neiman

![Fig. 7. Plasma concentrations of testosterone before and after PRI training. See legends to Figs. 1 and 2.](image-url)
et al. showed unchanged plasma IL-2 concentrations after exercise compared to pre-exercise values (56). Also, there are many factors that affect the immune system during and after exercise. Early studies have documented different findings from immunosuppression to immunostimulation. Therefore, the IL-2 mRNA expression was detected in the PHA-stimulated CD4+CD8+ lymphocytes or peripheral blood mononuclear (PBMN) cells collected after exercise. Bacurau et al. reported that exercise induced a reduction by 35% in the production of IL-2 by cultured PBMN (1). In addition, the percentage of IL-2-reduction by 35% in the production of IL-2 by cultured Bacurau nucelar (PBMN) cells collected after exercise. This result indicates that the elevation of plasma IL-6 in low- and high-intensity PRI-training would not be so large compared to other studies.

IL-15 is a 14-kDa cytokine identified as a T-cell growth factor (70). Few studies are concerned with plasma IL-15 concentrations during and after exercise. Significantly increased plasma IL-15 protein levels were observed immediately after acute resistance exercise in young participants, including men and women (72). Another study showed unchanged plasma IL-15 protein during and after exercise in male people (52). In contrast, a recent study showed decreased circulating IL-15 levels in obese people with low energy diet and diet-induced weight-loss groups after aerobic exercise for 12 weeks (11). Also, evidences showed that increased expression of IL-15 mRNA was detected in the skeletal muscle (15, 52). Therefore, IL-15 is considered as a myokine; cytokines and other peptides that are produced, expressed and secreted from muscle fibres and exert paracrine or endocrine effects (61-63, 67). IL-15 exerts its effect on muscle protein dynamics, mainly on the decrease of muscle protein degradation induced by proteolysis factors, lipid oxidation stimulation and increase of glucose uptake (70). In our study, we found significantly increase of plasma IL-15 concentration at post 0 D in light-intensive PRI training, but not in traditional or in heavy-intensive PRI training. It is unknown whether these results indicate significant depression in muscle protein degradation, increased lipid oxidation, or glucose uptake. Further studies are needed to clarify this question.

Accumulated evidences show that the intensity and/or duration of exercise may be a form of stress which mediates cortisol secretion through the CRH and ACTH (33). Many studies have indicated that the plasma and salivary cortisol concentrations increase after prolonged exercise at high intensity (3, 24, 45, 53, 55, 87, 88). Therefore, short-duration and low-intensity physical training would not increase the plasma concentrations of cortisol (24). In addition, no change of serum cortisol concentrations was observed in a pilot study with 50 min of high intensity exercise (9). The augmentation of plasma cortisol after prolonged exercise with high intensity has been in relation to lipolysis, ketogenesis, proteolysis, and glucose homeostasis (12). Moreover, cortisol has been hypothesized as an important factor in maintaining lymphopenia and neutrophilia after high-intensity and prolonged exercise (64). Kanaley et al. reported that both baseline (pre-exercise) and peak cortisol concentrations were significantly higher at 7 AM that at 7 PM or midnight (35). In contrast, decreased cortisol concentrations overnight were observed after 90 min of exercise at 70% Vo2max (27). Although we did not collect blood samples at 7 AM, the schedule for the sample collection were the same.
In our study, increased plasma cortisol levels were, although not significantly, found after low and high intensity PRI training at post 0 D. However, significantly decreased cortisol level was observed from post 1 D to post 7 D after high intensity PRI training, not in low intensity PRI training. In contrast, in traditional training, the lowest cortisol was found at post 0 D. It is not known what factor(s) could affect the plasma cortisol levels in traditional training and PRI training; the training type, duration and intensity are considered possible factors to influence plasma hormone and cytokines levels (64).

As a potent anabolic hormone which stimulates muscle protein synthesis (40), testosterone is mainly synthesized and secreted from testicular Leydig cells in men and ovaries and adrenal cortex in women (44). Studies have indicated that exercise results in acute increases of plasma testosterone concentrations during and 5 minutes after training (23, 29, 37-39, 89). Then the elevated testosterone level returned to the basal level. In contrast, decreased plasma testosterone during exercise was found in other studies (14, 28). These studies indicate that the elevated or decreased plasma testosterone levels seem to be dependent on the training mode, duration of exercise bout and intensity of training. The physiological basis for these data (i.e. elevated or decreased testosterone levels) could be due to reduced metabolic clearance rate (6) and hemoconcentration (91) for increased testosterone concentration and blunted luteinizing hormone (LH) production rate (57) or reduced responsiveness of Leydig cells to LH for decreased testosterone concentration. Moreover, dietary nutrients employed by the trained people have been shown to affect hormonal changes during and after exercise (89). Low percentage of dietary fat (93) or high protein-to-carbohydrate ratio dietary (89) is associated with low plasma testosterone concentration in healthy active men. In this study, elevated plasma testosterone concentration was observed post-1 to 3 D in the three training modes. Although we did not measure the plasma LH, these increased testosterone levels might be due to the increased LH production from pituitary gland or elevated responsiveness of Leydig cells to LH. However, the exact physiological mechanisms responsible for the increased testosterone post-exercise in our study remain to be fully elucidated.

The relationship between cytokines (e.g. interleukins, interferons, and growth factors) and hormones (including steroid and protein hormones) has been well recognized (78). Exercise or training mainly enhances muscle strength and power. Numerous reviews have indicated that exercise could alter the immune and endocrine status during and after training period (44). In the past decade, muscle has been speculated and demonstrated to be the main source of IL-6 synthesis (63). Also, hormones, including growth hormone and insulin-like growth factors, have been associated with muscle strength and power during training period (78). Although we measured the plasma testosterone and cortisol concentrations before, during and after training, we did not find a relationship between cortisol and testosterone with interleukins.

In summary, the present study provides information on changes in the plasma concentrations of IL-1β, IL-2, IL-6, IL-15, TNF-α, testosterone and cortisol during different intensities of PRI training compared to traditional training with similar duration. Also, the recovery period had been extended to 7 days. Our result indicated that high-intensity PRI training could induce the proinflammatory cytokines, IL-1β and TNF-α, and decrease plasma cortisol levels in the recovery period.

Acknowledgments

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