Glucose Tolerance and Insulin Sensitivity Following an One-Week Volleyball Competition

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Abstract

The purpose of the study was to compare glucose tolerance and insulin sensitivity between trained (TR) and competition (CP) states, in relation to cortisol and testosterone levels. Sixteen highly trained volleyball players voluntarily participated in this study. The first testing session (TR state) occurred 1 week before the start of national level volleyball CP, and the second testing session (CP state) occurred next morning after the 1-week CP. Fasted serum sample was used for measuring cortisol and testosterone. Subjects were then orally challenged with 75 g of glucose solution for determinations of oral glucose tolerance test (OGTT) and insulin response. Under both fasted and glucose challenged conditions, glucose levels of CP were not different from TR state, whereas insulin levels of CP were significantly elevated above TR (50 min: from 78.8 $\pm$ 8.7 to 96.6 $\pm$ 8.1 μU/ml, *P* < 0.05; 80 min: from 62.8 $\pm$ 7.0 to 82.0 $\pm$ 7.3; *P* < 0.05). Muscle creatine kinase (CK) level in blood was significantly increased above TR, suggesting greater muscle damage by CP. Serum leptin level, percent fat mass, and body weight were not different between two states. CP significantly increased serum cortisol level without significantly change in testosterone level. The new finding of the study was that volleyball CP reduced the whole-body insulin sensitivity significantly compared to TR state. The greater level of insulin concentration under CP state appears to be associated with elevated serum cortisol level. Despites the benefit of increased physical activity on metabolic function is widely recognized, physiological stress associated with CP can result in attenuation of systemic insulin sensitivity compared TR state.

Key Words: muscle damage, overuse, cortisol, testosterone, overtraining

Introduction

It is well established that both an acute bout of exercise and chronic endurance exercise training have beneficial effects on insulin action and glycemic control in normal and insulin-resistant individuals (13, 14). Since skeletal muscle is the main site for the postprandial whole-body glucose disposal (3, 6), the beneficial effect of exercise is thought to be associated, in part, with an improvement in skeletal muscle insulin sensitivity. On the contrary, early studies found that following marathon competition (2) and resistive type

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Received: August 10, 2005; Revised: December 4, 2005; Accepted: December 19, 2005.

of exercise (7, 16), which typically generates enormous muscle damage, reduces insulin action in skeletal muscle. This evidence brings about a hypothesis that the effect of CP, which normally performs in maximal physical effort leading to greater skeletal muscle damage, cannot be regarded as an equivalent physical activity in improving insulin sensitivity. Passelergue *et al*. (18, 19) has also showed that CP can result in increased catabolic tendency, as indicated by increased cortisol-to-testosterone ratio. It has been shown that an increase in the amounts of circulating plasma cortisol (20) or a decrease in testosterone (11, 21) can result in whole-body insulin resistance (17). In particular, volleyball competition consists of enormous high impact motions upon lower extremity compared to the most types of sports event, which may exacerbate the state of muscle damage and in turn affect insulin sensitivity. To test the hypothesis that whether effect of volleyball CP is different from TR on the whole-body glucose tolerance and insulin sensitivity, glucose and insulin levels were measured during TR state and following 1-week of volleyball CP. Variations in blood CK level (an indicator of muscle damage) and cortisol-to-testosterone ratio were also determined under two conditions.

Materials and Methods

Human Subjects

Sixteen highly trained volleyball players (aged 17.5±0.6 yr) voluntarily participated to this study. These volleyball players were trained on daily basis in preparation for an international-level volleyball competition, the daily training time was approximately 3 hours. The training goal for the latest 3 months before competition was focused on lower limb strength and skill. Aim and method were explained to all subjects, who then gave formal consent. Ethical approval for the study was obtained from the Human Subject Committee of Taipei Physical Education College. Blood sample was always withdrawn in the morning (8-9 AM) from all subjects under TR and CP states for biochemical and hormonal measurements. The first testing session (TR state) occurred 1 week before the start of national level volleyball CP, the second testing session (CP state) occurred next morning after the 1-week CP.

Blood CK

CK was directly measured on a Reflotron Plus Analyzer to determine the degree of muscle damage, according to its standard procedure provided by the manufacturer (Roche Diagnostic, Basel, Switzerland).

Oral Glucose Tolerance Test (OGTT) and Insulin Response

OGTT and insulin determination were performed under TR and CP states. The test procedure was according to the method as previously described (22). Briefly, 75 grams of glucose was orally delivered with 500 ml of pure water. Blood samples were collected from the fingertip at 0 (fasting value), 30, 50, and 80 min. Postprandial glucose and insulin levels were calculated by the mean value of 30^{th} min, 50^{th} min, and 80^{th} min of glucose and insulin, respectively. A glucose analyzer (Lifescan, CA, USA) was utilized for glucose concentration determination. Serum sample was collected from 200 µl of fingertip blood and used for insulin determination. The insulin was determined on the ELISA (Enzyme-Linked Immunosorbent Assay) analyzer (Tecan Genios, Salzburg, Austria) with the use of commercially available ELISA kits (Diagnostic Systems Laboratories, Inc., Webster, TX, USA), according to the manufacture’s instruction.

Cortisol, Testosterone, and Leptin

Serum samples for measuring hormones were always withdrawn from venous blood under morning fasted condition before OGTT. Total testosterone, cortisol, and leptin were also quantified on the ELISA analyzer with the use of commercially available ELISA kits (Diagnostic Systems Laboratories, Inc., Webster, TX, USA).

Body Composition

Circumference of the waist (umbilical level) and hip (maximum of buttocks) were measured to the centimeter and the waist-to-hip ratio (WHR) was calculated to estimate the degree of central fat distribution. BMI (body mass index) was calculated as kilogram per square meter. Body composition including muscle and fat masses was estimated by the segmental multi-frequency bioelectrical impedance analysis (SMFBIA) with the InBody 3.0 (Biospace Inc., USA). These measurements were used to determine whether the variation in insulin sensitivity under two states is due to change in body composition.

Statistical Analysis

A paired Student’s *t*-test was used to compare the significant mean differences of all measured values between TR and CP states. Pearson correlation was utilized to determine whether there was a significant correlation between pair of each variable. A level of $P < 0.05$ was set as significance on all tests, and all values are expressed as means ± SE.

Table 1. Subject characteristics and body composition. CP: 1-week volleyball competition; TR: trained state (1 week before CP); BMI: body mass index; %FM: percent fat mass; WHR: waist-to-hip ratio; α: probablility of type 1 error; NS: no significance

	Height	Weight	BMI	% FM	WHR	Leptin
CP	169.4 ± 1.1	63.2 ± 1.9	21.9 ± 0.4	24.5 ± 0.6	0.70 ± 0.01	0.45 ± 0.06
TR	169.4 ± 1.1	63.5 ± 1.9	22.0 ± 0.5	25.3 ± 0.6	0.70 ± 0.01	0.52 ± 0.08
α	NS	NS	NS	NS	NS	NS

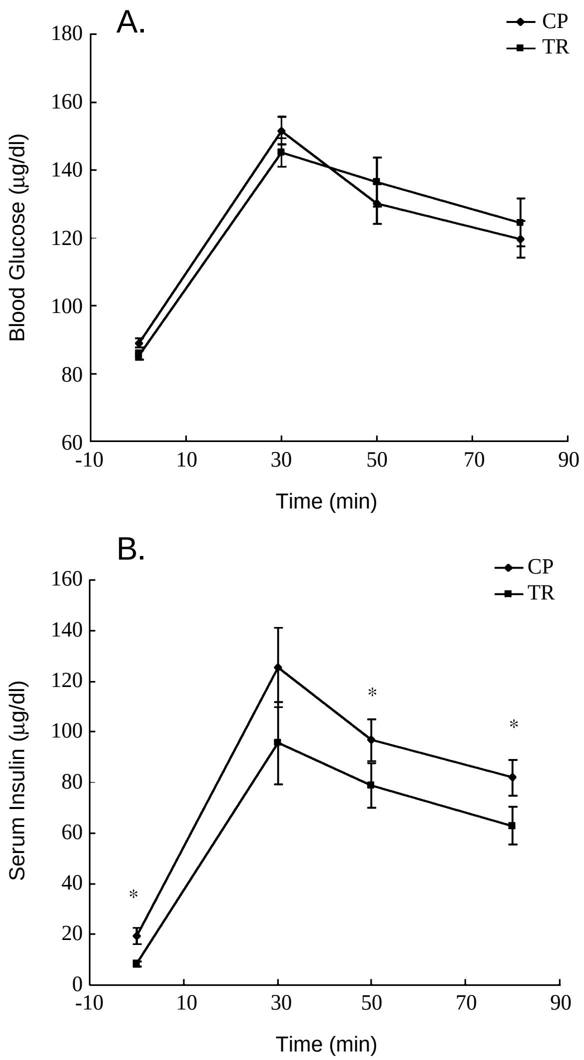

Fig. 1 Oral glucose tolerance test (A) and insulin response (B). *significant difference from the TR ($P < 0.05$).

Table 2. Hormones and blood creatine kinase (CK) levels. CP: 1-week volleyball competition; TR: trained state (1 week before CP); C/T: cortisol-to-testosterone ratio; α: probablility of type 1 error; NS: no significance.

	Testosterone (ng/ml)	Cortisol (µg/dl)	C/T	CK (U/l)
CP	0.91 ± 0.23	9.6 ± 1.1	10.0 ± 2.4	221 ± 21
TR	0.77 ± 0.07	6.0 ± 0.5	8.2 ± 1.6	160 ± 10
α	NS	< 0.05	NS	< 0.05

Results

Oral Glucose Tolerance Test (OGTT)

Fasted and postprandial glucose levels were not significantly different between TR and CP states (Fig. 1A), but fasted and postprandial insulin levels were significantly elevated by CP above TR (Fig. 1B). A significant correlation was observed between the plasma cortisol and fasted and postprandial insulin, respectively (r = 0.66, r = 0.60, Table 3).

Body Composition

Data for body composition is illustrated in Table 1. Body mass, BMI, % FM, WHR, and plasma leptin concentration were not significantly different between TR and CP states.

Testosterone, Cortisol, and Creatine Kinase (CK)

Stress hormone concentrations and blood CK of two states are shown in Table 2. Plasma cortisol and CK in the CP state were significantly elevated above TR state, while testosterone levels and C/T were not significantly different between two states.

Discussion

The main finding of the study was that volleyball CP significantly reduces the whole-body insulin sensitivity compared to TR, as evident by the fact that greater insulin response in the CP state above TR state to achieve the same glucose tolerance curve. Muscle CK in blood was significantly elevated by CP in paralleled with the increased insulin concentration suggesting that increased muscle damage could partly account for the deteriorated insulin sensitivity under CP state. The observation that increased muscle

Table 3. Correlation matrix of measured variables under CP states. C/T: cortisol-to-testosterone ratio. * significant correlation is reached between paired variables (*P* < 0.05).

	Fasted insulin	Postprandial insulin	Creatine kinase	Testosterone	Cortisol	C/T
Fasted insulin	1					
Postprandial insulin	0.47	1				
Creatine kinase	0.24	0.50*	1			
Testosterone	0.20	0.61*	0.37	1		
Cortisol	0.66*	0.60*	0.16	0.35	1	
C/T	0.48*	0.07	-0.14	-0.50	0.57	1

damage and enhanced fasted and postprandial insulin levels by CP could be explained by massive damage in recruited muscle leading to loss function in insulin action. Since skeletal muscle is responsible for approximately 85% of postprandial glucose uptake (3, 6), integrity of plasma membrane in skeletal muscle is undoubted important for normal insulin signaling and transmembrane glucose transport process. Yet we also note that the elevated fasting insulin levels in CP may also contribute to the higher postprandial insulin levels in CP than that in TR according to the insulin AUC curve. It appears that only fasting insulin levels, but not postprandial insulin levels, were associated with levels of cortisol, and the association between CK and insulin resistance in CP was very weak.

Additionally, reduction in insulin sensitivity by CP was not associated with alteration in body composition, which is another known factor influencing the whole-body insulin sensitivity (14). In this study, BMI and WHR were not changed from TR to CP state. Serum leptin level was not significantly increased by CP, which confirms that the possible confounding effect on insulin sensitivity due to increased adiposity can be precluded.

Another possible factor that might take part for the increased insulin level at CP state is the increased cortisol level. Cortisol was found to antagonize the insulin-mediated inhibition of hepatic glucose release (10), decrease glucose utilization in muscle (12), and reduce the binding affinity of insulin receptors (17). High serum cortisol levels could be linked to higher humoral inflammatory activity (5, 23) after CP. It has been frequently reported that CP induces high degree of inflammatory response in paralelled with muscle damage (15). Therefore, perturbation in the inflammation-related endocrine changes by CP might account for the CP-induced increase in serum insulin level.

A well-established adaptive response to exercise training is the improved glucose tolerance and enhanced skeletal muscle insulin sensitivity of glucose transport (14), but apparently CP cannot be considered as regular exercise training in this aspect. The normal training-induced enhancement in insulin action is found to associate with upregulation of specific components of the glucose transport system in skeletal muscle, including increased protein expression of GLUT-4 (9). It has been shown in the past that eccentric exercise (1) and marathon CP (2) causing severe muscle damage significantly impairs the normal training effect on increasing GLUT4 protein expression. In the current study, we speculate that attenuation in insulin sensitivity by CP could be related to impaired regulation of GLUT4 protein in skeletal muscle.

CP is different from TR in two major aspects. First, CP normally performs under maximal voluntary physical effort and pushes the body to the highest physiological limit for an athlete. Under this circumstance, this challenge could sometimes impair normal cellular function, particular in skeletal muscle. Second, unlike normal TR, time required for post-exercise recovery during CP season is limited due to uncontrollable day-to-day CP schedule. Accumulative damage due to insufficient recovery could lead to attenuated training effect in skeletal muscle, which might explain the reduced insulin sensitivity by CP compared to TR observed in this study. In this regard, CP may not be considered as an equivalent health-promoting physical activity as regular exercise training for the purpose of improving insulin sensitivity. Submaximal intensity of exercise training is normally recommended for health-promoting physical activity. But we must note that intensity of the exercise is critical for the generating the optimal benefit in glucose metabolism, since only recruited muscle fiber demonstrates increased insulin sensitivity for glucose uptake (4) and the number of the fiber recruited is dependent on exercise intensity (8).

The most important clinical implication of the study was that, unlike normal exercise training for health purpose, CP can generate more muscle damage due to the effort pushing to maximal physiological limit for winning. This result can lead to reduced whole-body insulin sensitivity for a period of time, while glucose tolerance appears normal. Most of coaches, players, physiologists, or physicians recognize that human body undergoing greater physical stress would required longer period of recovery, where both CK and insulin levels can be used for monitoring the physiological status ensuring metabolism of athletes back to normal. In addition, we must note that volleyball is a weight-bearing exercise that greater impact on connective tissue and skeletal muscle could be resulted during exercise. The conclusion of this study may not be applicable to those of non-weight bearing sports such as swimming. Furthermore, higher cortisol levels during CP could be due, in part, to psychological stress. Further evaluation on the influence of psychological factors on cortisol and insulin sensitivity is required in this aspect.

In conclusion, the new finding of the study was that CP significantly reduced the whole-body insulin sensitivity compared to TR, as evident by increased insulin levels without a change in glucose tolerance under both fasted and postprandial conditions. This reduction was occurred in parallel with increased blood levels of cortisol and CK. The result of the study suggests that CP could not be viewed as an optimal physical activity as normal exercise training for the purpose of improving insulin sensitivity.

Acknowledgment

This study was sponsored in part by National Science Council, Taipei, Taiwan, ROC, grant number 93-2413-H-154-009.

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