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B. K. Pedersen and L. Hoffman-Goetz

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Hormonal responses to consecutive days of heavy-resistance exercise with or without nutritional supplementation

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Testosterone and cortisol in relationship to dietary nutrients and resistance exercise

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Volek, Jeff S., William J. Kraemer, Jill A. Bush, Thomas Incledon, and Mark Boetes. Testosterone and cortisol in relationship to dietary nutrients and resistance exercise. *J. Appl. Physiol.* 82(1): 49–54, 1997.—Manipulation of resistance exercise variables (i.e., intensity, volume, and rest periods) affects the endocrine response to exercise; however, the influence of dietary nutrients on basal and exercise-induced concentrations of hormones is less understood. The present study examined the relationship between dietary nutrients and resting and exercise-induced blood concentrations of testosterone (T) and cortisol (C). Twelve men performed a bench press exercise protocol (5 sets to failure using a 10-repetitions maximum load) and a jump squat protocol (5 sets of 10 repetitions using 30% of each subject's 1-repetition maximum squat) with 2 min of rest between all sets. A blood sample was obtained at preexercise and 5 min postexercise for determination of serum T and C. Subjects also completed detailed dietary food records for a total of 17 days. There was a significant ($P \leq 0.05$) increase in postexercise T compared with preexercise values for both the bench press (7.4%) and jump squat (15.1%) protocols; however, C was not significantly different from preexercise concentrations. Significant correlations were observed between preexercise T and percent energy protein ($r = -0.71$), percent energy fat ($r = 0.72$), saturated fatty acids ($\text{g} \cdot 1,000 \text{ kcal}^{-1} \cdot \text{day}^{-1}$; $r = 0.77$), monounsaturated fatty acids ($\text{g} \cdot 1,000 \text{ kcal}^{-1} \cdot \text{day}^{-1}$; $r = 0.79$), the polyunsaturated fat-to-saturated fat ratio ($r = -0.63$), and the protein-to-carbohydrate ratio ($r = -0.59$). There were no significant correlations observed between any nutritional variables and preexercise C or the absolute increase in T and C after exercise. These data confirm that high-intensity resistance exercise results in elevated postexercise T concentrations. A more impressive finding was that dietary nutrients may be capable of modulating resting concentrations of T.

nutrition; carbohydrate; fat; protein; steroid hormones

TESTOSTERONE (T) is a steroid hormone secreted from the Leydig cells of the testes that has both anabolic and anticatabolic effects on muscle tissue (10, 22). Cortisol (C) is a steroid hormone released by the adrenal cortex that has catabolic effects on muscle tissue (10). Previous studies have demonstrated that several different resistance exercise protocols result in acute increases in serum concentrations of T and C (5, 8, 17–19, 29). The acute (exercise-induced) and chronic (resting) T and C responses to resistance exercise, although different, are determined by a complex interplay of several exercise program variables (e.g., intensity, volume, duration, rest periods, muscle mass involvement) and individual characteristics (e.g., age, health, fitness level) (6, 16). Dietary intake has been rarely documented in studies examining the hormonal response to resistance

exercise despite evidence indicating that specific nutrients may have the potential to alter the regulation and metabolism of T and C.

Previous studies have demonstrated that steroid hormone concentrations are subject to dietary regulation (2, 4, 24). Individuals consuming a diet containing ~20% fat compared with a diet containing ~40% fat (7, 9, 13, 25) have significantly lower concentrations of T. Also, replacement of dietary carbohydrate with protein has been shown to decrease T concentrations (2). These studies indicate that the energy supplied by the different macronutrients has a significant influence on T concentrations. Raben et al. (24) reported a significant decrease in resting T concentrations and an attenuation in the exercise-induced increase in T in male endurance athletes who switched from a meat-rich diet to a lacto-ovo vegetarian diet. Interestingly, both diets contained equal amounts of energy derived from protein, carbohydrate, and fat, indicating that the supply of energy from the different macronutrients was not responsible for the effect on T and that the composition of carbohydrate, protein, and fat may influence T concentrations. Thus both the amount and composition of the energy-providing macronutrients may modify T concentrations.

Few data exist regarding the relationship between nutrients and resting and exercise-induced increases in steroid hormones in young athletic men. Therefore, the primary purpose of this investigation was to examine the relationships among specific dietary nutrients and resting and resistance exercise-induced T and C concentrations.

METHODS

Subjects. Twelve healthy men with at least 1 yr of resistance training experience volunteered to participate in this investigation. Descriptive data for the 12 subjects are presented in Table 1. The subjects had been involved with resistance training ~5 yr, and they trained, on average, five sessions per week. Their workouts involved multiple sets (15–25 per workout) and moderate repetitions (6–15 per set) comprising exercises for two to three muscle groups per session. None of the subjects were coming off any type of high-volume and/or high-intensity cycles, and their workouts were characterized by relatively consistent training volumes 6–10 wk before the study. All subjects were informed as to the possible risks of the investigation before giving their written informed consent in accordance with The Pennsylvania State University Institutional Review Board for use of human subjects.

Exercise protocol. All subjects completed an identical bench press exercise protocol and a jump squat exercise protocol (performed on consecutive days) on two occasions separated by 1 wk. Both testing protocols were performed on a Plyomet-

Table 1. *Descriptive characteristics of experimental subjects*

Variable	
Age, yr	23.8 ± 1.1
Resistance training, yr	5.6 ± 0.9
Height, cm	172.3 ± 2.2
Weight, kg	75.6 ± 2.4
Body fat, %	13.3 ± 1.2
1-RM squat, kg	145.4 ± 11.3
10-RM bench press, kg	80.7 ± 4.2

Values are means ± SE for 12 subjects. RM, repetition maximum.

ric Power System (Lismore, New South Wales, Australia) interfaced to a computer on-line data-acquisition system previously described by Wilson et al. (30). Each subject refrained from alcohol and any strenuous weight training or other activity for a period of 48 h before any of the testing. Subjects also reported an adequate hydration status and sleep before the day of each exercise session. Each test was preceded by a thorough warm-up consisting of 5 min of low-intensity cycling on a stationary ergometer, static stretching, and one to two sets of movement-specific exercises performed with light resistances for a local warm-up. The bench press protocol consisted of five sets using a resistance equal to each subject's pretest 10-repetitions maximum (RM) bench press. The jump squat protocol involved performance of five sets of 10 continuous repetitions with a resistance equal to 30% of the subject's 1-RM squat. Thirty percent of the 1 RM was chosen as the resistance because mechanical power is maximized near this value (30). Starting in an upright position, subjects were instructed to jump repeatedly as high as possible without pausing between repetitions within a set. There was an exactly 2-min rest period between all sets.

Dietary analyses. Before the first exercise session each subject was instructed by a registered dietitian and provided with specific verbal and written procedures for reporting detailed dietary intake, including how to record portions by using household measures, combination foods, preparation technique, nutrient-content descriptors (e.g., light, fat free, lean, reduced), etc. The 1st wk of food records was examined by a registered dietitian to ensure that all subjects were following the provided instructions accurately and that all relevant information was included on the dietary record forms. The 1st wk of food records was not used for analysis. After this period, subjects recorded 17 consecutive days of food records. This is a long enough time period to obtain reliable information regarding the nutritional variables investigated in this study (21). Food record forms were analyzed for total food energy, carbohydrate, protein, fat, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), cholesterol, and dietary fiber by using Nutritionist IV, version 4, nutrient-analysis software (N-Squared Computing, First Databank Division, Hearst, San Bruno, CA). This software contains a currently updated database of over 13,000 foods, including many brand-name manufacturers' items and products from national fast-food chains. The nutrient data are based primarily on all available US Department of Agriculture data and scientific journal and industry sources. If a nutrient value was missing, information from other food tables (23) or information provided by food manufacturers was obtained.

Blood collection and analyses. Before the warm-up at each of the four exercise testing sessions, subjects were seated for 10–15 min after which a blood sample was obtained from one of the forearm veins with a 20-gauge needle, syringe, and

vacutainer setup. Although we were unable to schedule all subjects at the same time of day, all testing for an individual subject was conducted at the same time of day to reduce the effects of any diurnal variations on the hormonal concentrations. Immediately after the exercise protocol the subject was seated, and a second blood sample was obtained at exactly 5 min postexercise. The blood was allowed to clot at room temperature before being centrifuged for 15 min at 1,500 *g* at 4°C. The serum was separated and stored at –88°C, and it was thawed only once at a later date for analysis of T and C by using radioimmunoassay procedures. Immunoreactivity values were determined with the use of a gamma counter (1272 Clinigamma, Pharmacia Wallac, Wallac Oy, Finland) and Silent 700 Data Terminal (Texas Instruments, Temple, TX). All samples were analyzed in the same assay in duplicate for total T and total C by using a single-antibody ¹²⁵I solid-phase radioimmunoassay (Diagnostic Products, Los Angeles, CA). Intra-assay variances for T and C were <5%, and sensitivities of the assays were 0.14 and 5.5 nmol/l, respectively.

Statistical analyses. Statistical analyses were accomplished by using paired *t*-tests with appropriate α -level corrections to determine differences between pre- and postexercise T and C concentrations. Simple regression was used to determine relationships between selected dietary components and hormonal concentrations. T and C concentrations used for simple regression were the mean values obtained at the four exercise testing sessions. All values presented in the text are means ± SE. The significance in this study was chosen at $P \leq 0.05$.

RESULTS

Figure 1 shows the pre- and postexercise serum T and C concentrations for the bench press and jump squat protocols. T concentrations were significantly elevated postexercise compared with preexercise concentrations after both the bench press and jump squat exercise protocols. Postexercise C concentrations after exercise were not significantly different from preexercise values for both exercise protocols.

Mean values and ranges for dietary energy and nutrient intake are presented in Table 2. Correlation coefficients obtained between preexercise T concentrations and dietary nutrients are presented in Table 3. Preexercise T was significantly positively correlated with percent energy fat, SFA ($\text{g} \cdot 1,000 \text{ kcal}^{-1} \cdot \text{day}^{-1}$), and MUFA ($\text{g} \cdot 1,000 \text{ kcal}^{-1} \cdot \text{day}^{-1}$) and was significantly negatively correlated with the percent energy protein, the PUFA/SFA ratio, and the protein-to-carbohydrate ratio (Fig. 2). There were no significant correlations observed between any nutritional variables and preexercise C or the absolute increase in T and C after exercise.

DISCUSSION

The primary finding from this investigation was that dietary nutrients may influence resting concentrations of T in young athletic men. However, the resistance exercise-induced increase in T does not appear to be affected by nutritional variables averaged over 17 days. Because of the variation in nutrient intake from day to day within individuals (especially dietary cholesterol and PUFA/SFA values), 2–3 wk of diet information appears to be required to obtain reliable data (21). Most

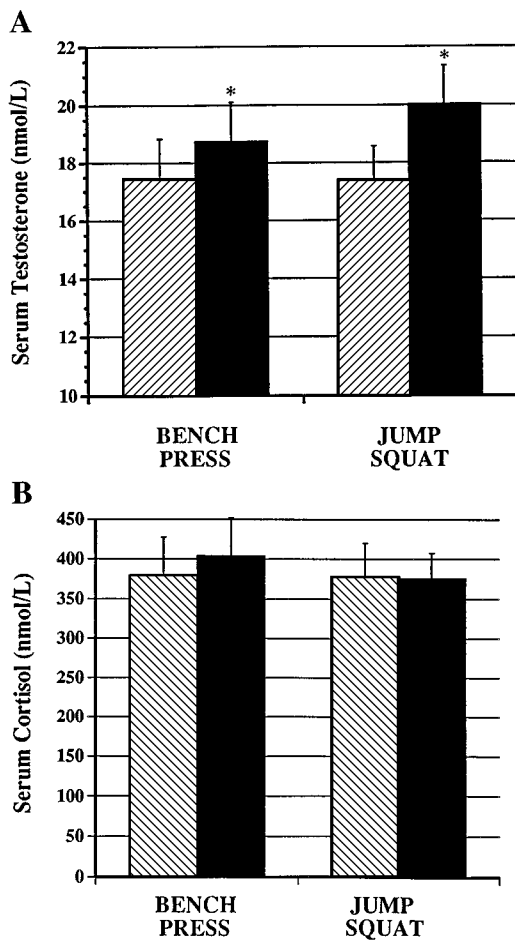


Fig. 1. Preexercise (hatched bars) and 5 min postexercise (solid bars) serum testosterone (A) and cortisol (B) concentrations during both the bench press and jump squat protocols. Values are means \pm SE. * $P \leq 0.05$ vs. corresponding preexercise value.

other studies have used much shorter time periods to obtain individual food intake information; thus their reliability and accuracy may be questionable. Our results demonstrated that dietary protein, fat, SFA,

Table 2. Calculated daily intake of dietary energy and nutrients

Nutrient	Mean	Minimum	Maximum
Energy, kJ	9,899	4,962	13,364
Protein, %	20	14	33
CHO, %	56	48	69
Fat, %	23	10	32
SFA, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	7.6	2.9	12.6
MUFA, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	8.3	3.1	12.6
PUFA, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	4.6	2.3	7.4
Cholesterol, mg \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	109	66	168
PUFA/SFA	0.65	0.32	0.99
Dietary fiber, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	9.0	4.0	27.5
Protein/CHO	0.36	0.26	0.59
Protein/fat	2.46	1.02	6.91
CHO/fat	6.47	3.36	15.89

Nutrient percent values are percentage of total energy per day. CHO, carbohydrate; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

Table 3. Correlation coefficients between preexercise testosterone concentration and selected nutritional variables

Nutrient	Correlation With Testosterone
Energy, kJ	-0.18
Protein, %	-0.71*
CHO, %	-0.30
Fat, %	0.72*
SFA, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	0.77†
MUFA, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	0.79†
PUFA, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	0.25
Cholesterol, mg \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	0.53
PUFA/SFA	-0.63‡
Dietary fiber, g \cdot 1,000 kcal $^{-1}$ \cdot day $^{-1}$	-0.19
Protein/CHO	-0.59‡
Protein/fat	0.16
CHO/fat	0.16

Correlation coefficients are Pearson product-moment correlation. Nutrient percent values are percentage of total energy per day. * $P \leq 0.01$. † $P \leq 0.005$. ‡ $P \leq 0.05$.

MUFA, PUFA/SFA ratio, and protein-to-carbohydrate ratio were all significantly correlated with preexercise T concentrations. However, none of these dietary variables were significantly correlated with C concentrations. These data are consistent with the findings of several other investigations that have reported a decrease in T in individuals consuming a diet containing \sim 20% fat compared with a diet containing \sim 40% fat (7, 9, 13, 25). Vegetarians also consume less fat, SFA, and a higher PUFA/SFA ratio compared with omnivores, and vegetarians exhibit lower concentrations of T compared with omnivores (3, 11, 12, 15, 24). These data suggest that alteration in dietary energy and/or dietary composition has the potential to modify T concentrations.

The results from several investigations strongly suggest that dietary fat has a significant impact on T concentrations; however, the influence of different types of lipids on T is not as clear. In the present investigation, dietary fat, SFA, and MUFA were the best predictors of resting T concentrations. Interestingly, Tegelman et al. (28) observed a significant positive correlation ($r = 0.76$) between percent energy fat and T in young athletic men, which is very similar to the correlation ($r = 0.72$) obtained in this study. Also, Adlercreutz et al. (1) reported significant positive correlations between T and dietary fat, SFA, MUFA, and cholesterol in postmenopausal women. The same nutrients were positively correlated with T in the present investigation except for cholesterol, which showed a correlation of $r = 0.53$ ($P = 0.07$) with T. In contrast to the results obtained in this study, Key et al. (15) reported a significant positive correlation ($r = 0.37$) between PUFA and T in male vegetarians and omnivores. Our results showed a nonsignificant correlation between PUFA and T and a significant negative correlation between the PUFA/SFA ratio and T. Thus dietary lipids appear to have a significant influence on resting T concentrations; however, the effect of different types of lipids on T regulation and metabolism is complicated and most likely influenced by a complex interaction of several

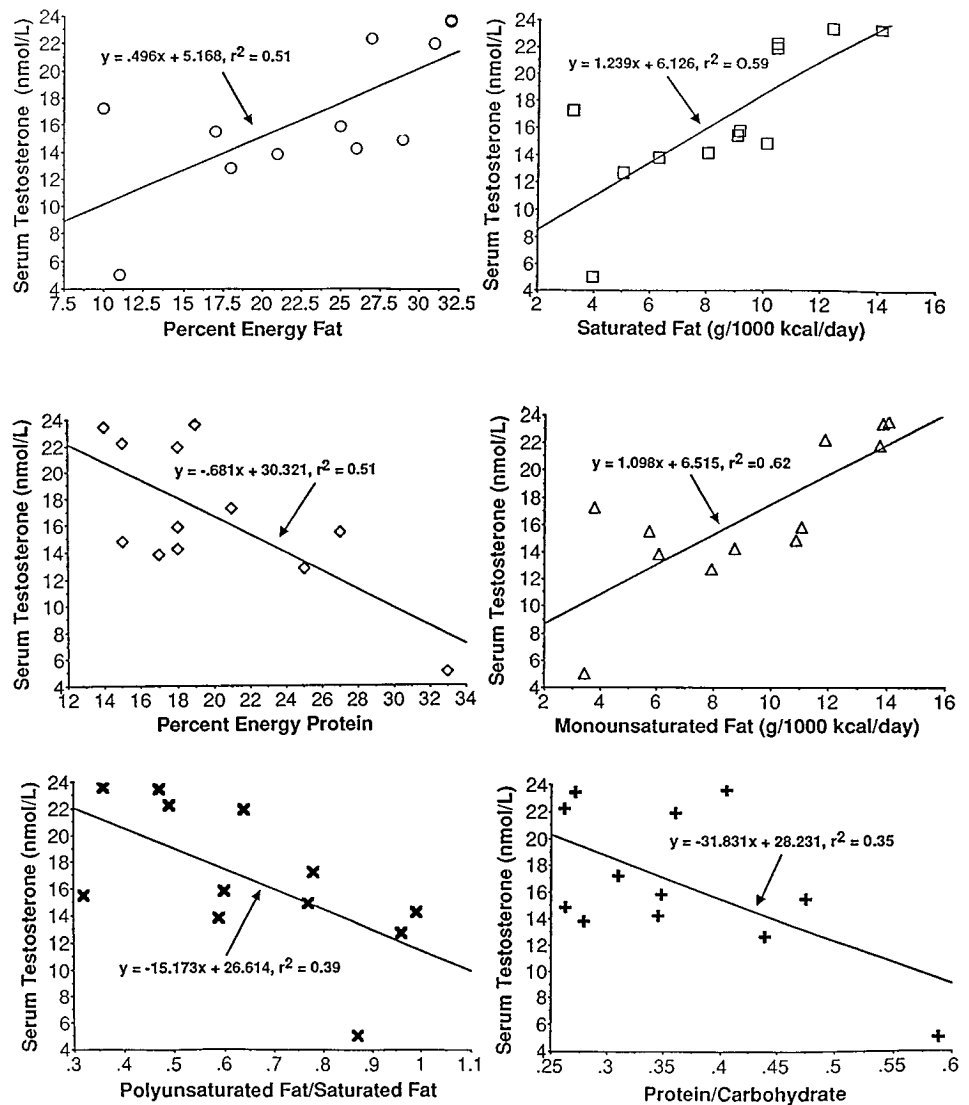


Fig. 2. Correlations between pre-exercise testosterone and selected nutritional variables.

nutritional and metabolic factors. This complexity is illustrated by the findings of Sebokova et al. (26, 27), who reported that alteration in the testicular plasma membrane and changes in the responsiveness of Leydig cells and subsequent T synthesis occur as a result of ingestion of different compositions of lipids.

The significant negative correlation between protein and resting T concentrations is consistent with the findings of Anderson et al. (2), who demonstrated that a low-protein diet (10% of total energy) was associated with higher levels of T compared with a diet higher in protein (44% of total energy). The authors postulated that it was the protein-to-carbohydrate ratio in the diet that influenced either T metabolism or the liver-derived protein sex hormone-binding globulin (2, 14). Interestingly, the protein-to-carbohydrate ratio in the present study was significantly negatively correlated with resting T concentrations. Also, the source from which the protein is derived may influence T concentrations. Raben et al. (24) compared the effects of two diets

differing only in the source of protein in male athletes. Results showed a reduced resting and postexercise increase in T concentrations in athletes consuming protein derived mainly from vegetable sources compared with a diet with protein derived mainly from animal sources. Thus not only the percent energy derived from protein in the diet but also the source of protein may influence T homeostasis.

The reason for a lack of a significant relationship between dietary nutrients and resting or resistance exercise-induced changes in C concentrations remains unknown. A number of factors related to the more dynamic nature of this hormone responding to stress and the differential storage, release, and synthesis mechanisms in glands along with differences in regulatory factors (e.g., blood flow) compared with T may partially explain our findings.

The fact that the absolute resistance exercise-induced increases in T and C concentrations were not significantly correlated with any nutritional variables

indicates that other mechanisms are responsible for the acute hormonal responses to exercise stress. The significant increase in T after both the bench press and jump squat exercise protocols confirms that high-intensity resistance exercise results in elevated concentrations of T (5, 8, 18, 19, 29). The fact that T was increased by ~15% after the jump squat exercise compared with ~7% after the bench press exercise was most likely due to the greater muscle mass used in the jump squat (16, 20). The lack of a significant C response to the resistance exercise protocols may have been due to the time of blood sampling or the amount of rest periods between sets (17). Finally, if blood samples had been obtained further into recovery, the possibility still exists that dietary nutrients may influence testosterone or cortisol concentrations.

In summary, the primary finding of this study was that resting concentrations of T may be partially explained by the amount and composition of dietary macronutrients. Our data suggest that the percentages of energy-providing macronutrients in the diet are important determinants of T homeostasis in healthy athletic men. Also, the type of lipid appears to influence circulating T concentrations. In this study, MUFA ($g \cdot 1,000 \text{ kcal}^{-1} \cdot \text{day}^{-1}$) and SFA ($g \cdot 1,000 \text{ kcal}^{-1} \cdot \text{day}^{-1}$) were the strongest predictors of T, accounting for 62 and 59% of the shared variance in T concentrations, respectively. These findings are particularly important for athletes training intensely who may experience a decline in T concentrations due to overtraining. Furthermore, this scenario may be exacerbated by a diet very low in fat, which many athletes (e.g., wrestlers, gymnasts, etc.) consume.

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