Effects of a High-Fat Diet on Postabsorptive and Postprandial Testosterone Responses to a Fat-Rich Meal

Jeff S. Volek, Ana L. Gómez, Dawn M. Love, Neva G. Avery, M.J. Sharman, and William J. Kraemer

Postprandial testosterone concentrations have been shown to significantly decrease after a fat-rich meal, which may be due to inhibition of testosterone production by chylomicrons. We examined the effects of a high-fat diet known to reduce postprandial chylomicrons on the testosterone response to a fat-rich meal. Total testosterone (TT), free testosterone (FT), cortisol, and insulin responses to a high-fat test meal containing 5.44 MJ (1,300 kcal, 11% carbohydrate, 3% protein, 86% fat) were determined before (week 0) and after (week 8) an 8-week high-fat diet (64% fat) in 11 healthy men. The high-fat diet resulted in significant reductions in postabsorptive and postprandial serum triacylglycerols (55% and 50%, respectively). There were no significant changes in postabsorptive serum TT, FT, and cortisol, but insulin concentrations were significantly ($P \leq .05$) lower at week 8 (−28%). There was a significant reduction 1 hour after the fat-rich meal for TT (−22%) and FT (−23%), which remained significantly below baseline for 8 hours. Postprandial TT and FT responses were not significantly different after the 8-week high-fat diet. Postprandial serum cortisol concentrations were significantly reduced 1 hour after the meal. There were no significant differences before and after the high-fat diet. Insulin was significantly increased at the 0-, 1-, and 2-hour postprandial time points before and after the high-fat diet. Compared with week 0, insulin concentrations were significantly lower prior to and immediately after the fat-rich meal at week 8. These data indicate a fat-rich meal results in a prolonged reduction in TT and FT concentrations that is not altered by lowering postprandial chylomicrons. Alternative mechanisms (eg, higher uptake at the receptor level of cells) other than chylomicron-induced or insulin-induced inhibition of steroidogenesis are likely responsible for the reduction in TT and FT after a fat-rich meal.

DIET AFFECTS TESTOSTERONE concentrations depending on whether measurements are obtained in the postabsorptive (ie, absorption of nutrients from the gastrointestinal tract is complete) or postprandial (ie, time period between food ingestion and 6 to 8 hours thereafter) state. Cross-sectional studies comparing men who habitually consume different levels of fat[1,2] and diet intervention studies comparing testosterone responses after consuming diets low and high in fat[3-6] both indicate that higher intakes of fat are associated with significantly higher postabsorptive circulating testosterone concentrations. We previously demonstrated significant positive correlations between habitual consumption of dietary fat and postabsorptive testosterone concentrations in men.[7] Although many studies have been performed demonstrating chronic diets higher in fat are associated with higher postabsorptive testosterone concentrations, few studies have examined the acute postprandial testosterone response to a meal.[8]

Meikle et al[8] examined the testosterone responses to isocaloric high-fat and low-fat meals in men. Compared with the low-fat meal, postprandial total and free testosterone (FT) concentrations were approximately 30% lower for 4 hours after consumption of the high-fat meal. The mechanism(s) underlying the apparent paradox between acute and chronic fat intake on circulating testosterone concentrations (ie, chronic high-fat diets increase testosterone and acute fat intake decreases testosterone) are unclear. Meikle et al[8] hypothesized the lower postprandial testosterone response after the high-fat meal was a result of an acute increase in chylomicrons since chylomicrons have been shown to reduce luteinizing hormone (LH)-stimulated testosterone production in vitro.[9]

To test the hypothesis that chylomicrons inhibit the testosterone response to a fat-rich meal in vivo, we measured testosterone responses to a fat-rich meal before and after an 8-week diet intervention previously shown by our laboratory to result in dramatic decreases in postprandial chylomicrons.[10] Since other hormones may also interact with postprandial testosterone, such as cortisol and insulin,[11,12] we also measured these endocrine markers to examine if they might be associated with the testosterone response to a fat-rich meal. We hypothesized that the normal decrease in postprandial testosterone after a fat-rich meal would be blunted after a diet intervention that lowers postprandial chylomicrons.

MATERIALS AND METHODS

Experimental Design

All subjects participated in an 8-week free-living dietary intervention between the months of February and mid-April. Prior to the dietary intervention, each participant's habitual diet was determined via a 7-day food diary. Fasting blood samples were obtained from an antecubital vein with a 20-gauge needle and vacutainers between 7:00 AM and 9:00 AM after a 12-hour overnight fast and abstinence from alcohol and strenuous exercise for 24 hours prior to collection of blood. Blood samples were collected before and after 1 week of habitual diet and on 2 consecutive days after 2, 4, 6, and 8 weeks of the intervention diet. Postprandial triacylglycerol and hormone responses to a fat-rich test meal were measured prior to and after the intervention diet.

Subjects

Eleven Caucasian men free of metabolic and endocrine disorders volunteered to participate in this study. All subjects were informed of the purpose and possible risks of this investigation prior to signing an informed consent document approved by the Institutional Review Board at Ball State University. The physical characteristics of the subjects were mean ± SD, age, 27 ± 8 years; height, 178 ± 7 cm; and

From the Human Performance Laboratory, Ball State University, Muncie, IN.

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Address reprint requests to Jeff S. Volek, PhD, RD, Assistant Professor, The Human Performance Laboratory, Ball State University, Muncie, IN 47306.

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weight, 79.0 ± 11.9 kg. Subjects were not adhering to special diets or regular consumers of nutritional supplements and habitually consumed between 29% and 39% of energy as fat (assessed via a 7-day food diary). All subjects were nonsmokers and none were taking any medications. Subjects were moderately active and had been performing the same exercise routines for at least 6 months prior to the study and maintained their exercise program throughout the entire experimental period (assessed via activity records).

Dietary Intervention

The diet was designed so that fat comprised 65% to 70% of energy primarily from monounsaturated fat (30% to 35% of energy). Dietary cholesterol was also restricted to less than 500 mg · d^{-1}. The actual diets consumed were mainly comprised of lean beef (eg, hamburger, steak), poultry (eg, chicken, turkey), fish, canola and olive oils, various nuts/seeds and peanut butter, moderate amounts of vegetables, salads with low-carbohydrate dressing, moderate amounts of cheese, egg substitute (1 whole egg per day), protein powder, and water or low-carbohydrate diet drinks. Subjects were also provided with and required to consume 2.5 g · d^{-1} of a fiber supplement blend (Fibersol Capsules; Twin Laboratories, Hauppauge, NY), 2.5 g · d^{-1} of n-3 fatty acids (1.8 g eicosapentaenoic acid [EPA] and 0.7 g docosahexaenoic acid [DHA]) from fish oil concentrate (Dale Alexander TwinEPA; Twin Laboratories), and a daily multivitamin/mineral complex (Daily One Caps With Iron, Twin Laboratories). Adherence to the diet was assessed by monitoring urine ketones daily and serum ketones (β-hydroxybutyrate concentrations) biweekly. All subjects demonstrated elevated blood and urine ketones indicating a high degree of compliance to the dietary protocol.

Fat-rich meal. Before and after the 8-week high-fat diet, subjects reported to the laboratory after a 14-hour overnight fast between 6:00 AM and 8:00 AM and consumed a fat-rich meal containing 5.44 MJ (1,300 kcal), 11% carbohydrate, 3% protein, 86% fat, 52 g saturated fat, 59 g monounsaturated fat, 12 g polyunsaturated fat, and 276 mg cholesterol. Prior to the meal, a flexible cannula was inserted into a forearm vein, which was kept patent with a constant saline drip (60 mL · h^{-1}). Subjects rested in a seated position for 10 minutes to allow plasma volume changes to stabilize and 2 baseline blood samples were obtained 10 minutes apart with a 10-mL syringe. The first 3 mL of blood withdrawn was discarded to avoid dilution of the sample, and approximately 10 mL was subsequently withdrawn and processed. Postprandial blood samples were obtained immediately after the meal and hourly for a total of 8 hours to assess total and FT responses to the meal. Samples for cortisol and insulin were obtained for 1 and 3 hours after the meal, respectively. Subjects rested quietly in a seated position and consumed exactly 1 L of water only during the 8-hour postprandial period.

Blood Analyses

Fasting and postprandial whole blood samples were collected into 10 mL vacutainer tubes with a clot activator. Within 15 minutes, whole blood was centrifuged at 3,000 × *g* for 15 minutes at 10°C and the resultant serum stored frozen at −80°C. Serum total testosterone (TT), FT, cortisol, and insulin were assayed in duplicate using solid-phase ^{125}I radioimmunoassays (Diagnostic Systems Laboratory, Webster, TX) with detection limits of 0.3 nmol · L^{-1}, 0.6 pmol · L^{-1}, 8.3 nmol · L^{-1}, and 9.3 pmol · L^{-1}, respectively. All fasting and postprandial samples for each hormone were determined in the same assay to avoid interassay variance and were thawed only once for each assay procedure. Intra-assay variances for all hormones were less than 7%.

Statistical Analyses

Two fasting samples were obtained on different days for serum triacylglycerols and hormones. The mean of these 2 values was used for statistical analysis. A 1-way repeated-measures analysis of variance (ANOVA) was used to evaluate biweekly changes in triacylglycerols and hormones over the 8-week high-fat diet. A 2-way ANOVA with postprandial time point and diet condition (pre and postdiet) as main effects was used to evaluate changes in postprandial responses. When a significant F value was achieved the Fisher's LSD test was used to locate the pairwise differences between means. The total area (serum concentration × time) under the line connecting postprandial values was calculated using the trapezoidal method. Relationships between variables were examined using Pearson's product-moment correlation coefficient. The level of significance was set at $P \leq .05$.

RESULTS

Dietary intake and postabsorptive and postprandial triacylglycerol responses are described in detail in another report[10]; this report includes data from 1 additional subject. The percentage of total calories from carbohydrate, protein, and fat were 44% ± 6%, 16% ± 2%, and 37% ± 3% during the subject's habitual diet and 7% ± 2%, 28% ± 3%, and 64% ± 3% during the high-fat diet. Monounsaturated fat accounted for 9% of total calories during the habitual diet and 31% of total calories during the high-fat diet. Cholesterol intakes were not significantly different during the habitual and high-fat diets (312 ± 74 and 397 ± 78 mg, respectively. Postabsorptive serum triacylglycerols significantly decreased by –55%, and the integrated 8-hour area under the postprandial triacylglycerol curve was significantly decreased by –50% at week 8.

Biweekly postabsorptive hormone responses to the 8-week high-fat diet are presented in Table 1. There were no significant effects of the high-fat diet on serum TT, FT, or cortisol. Compared with week 0, serum insulin concentrations significantly decreased at week 8 (−28%).

There were main time effects for both total and FT responses to the fat-rich meal. Concentrations of both total and FT were highest before the meal (20.0 ± 1.0 nmol · L^{-1} and 96.6 ± 8.3 pmol · L^{-1}, respectively) and declined 22% and 23%, respectively, at the 1-hour postprandial time point (Fig 1). Total and FT remained significantly below the premeal values for the entire 8-hour postprandial period. Serum cortisol concentrations were significantly reduced at the 1-hour postprandial time point, but there were no significant differences between week 0 and week 8 (Fig 2). Postprandial serum insulin concentrations were significantly increased at the 0-, 1-, and 2- hour postprandial time points. Compared with week 0, insulin concentrations were significantly lower prior to and immediately after the fat-rich meal at week 8 (Fig 3).

Table 1. Serum TT and FT, Insulin, and Cortisol Responses to an 8-Week High-Fat Diet

Time Point	TT (nmol · L^{-1})	FT (pmol · L^{-1})	Insulin (pmol · L^{-1})	Cortisol (nmol · L^{-1})
Week 0	24.8 ± 2.6	119.7 ± 11.8	56.7 ± 7.8	738 ± 60
Week 2	24.1 ± 3.2	111.4 ± 13.3	48.5 ± 7.2	733 ± 64
Week 4	25.2 ± 2.6	110.9 ± 9.4	57.0 ± 8.3	671 ± 63
Week 6	22.3 ± 1.6	110.6 ± 13.1	49.5 ± 6.5	644 ± 72
Week 8	22.8 ± 1.9	108.1 ± 12.4	40.8 ± 6.5*	647 ± 64

NOTE. Values are mean ± SE.

Abbreviations: TT, total testosterone; FT, free testosterone.

*$P \leq .05$ from corresponding week 0 value.

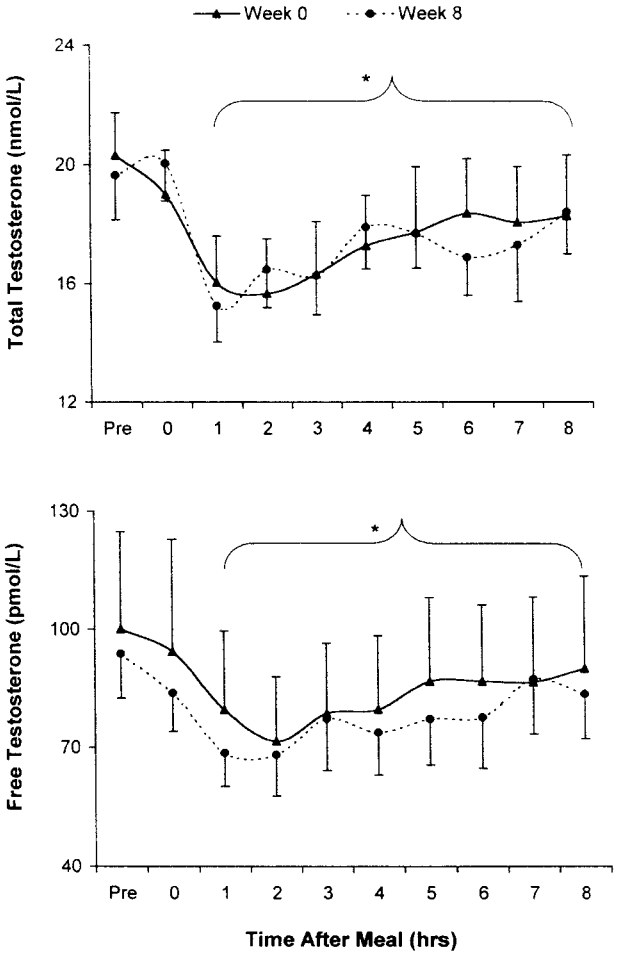

Fig 1. Postprandial serum TT (A) and FT (B) responses to a fat-rich meal before (week 0) and after (week 8) a high-fat diet. *$P \leq .05$ from corresponding pre value.

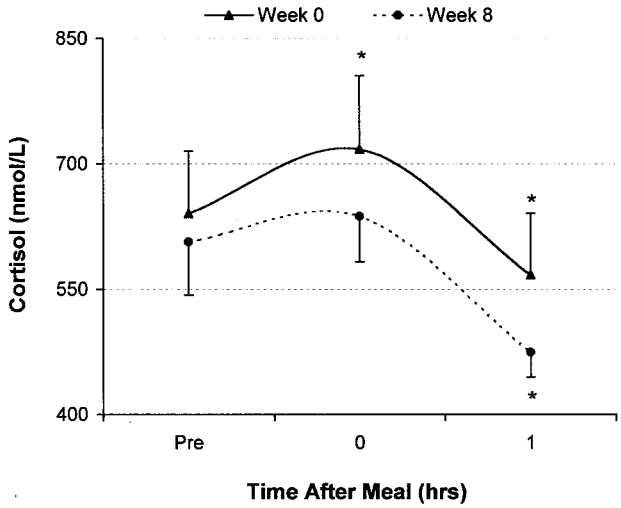

Fig 2. Postprandial serum cortisol responses to a fat-rich meal before (week 0) and after (week 8) a high-fat diet. *$P \leq .05$ from corresponding pre value.

Regression analyses were performed to examine relationships between postprandial triacylglycerols, insulin, and cortisol with the total and FT responses. There were no consistent correlations using individual time points and area under the curve estimates between postprandial serum triacylglycerol, insulin, or cortisol responses and the postprandial testosterone responses except for a relationship between the 3-hour insulin and the 3-hour TT area under the curves after the high-fat diet ($r = .677$; $P = .022$).

DISCUSSION

The significant decrease in serum testosterone concentrations observed after consumption of a meal in this study is consistent with our prior work[11] and the findings of other investigators.[8,12,14] The mechanism by which oral food intake, in particular fat-rich meals, decreases testosterone concentrations is unknown. Based on data from an in vitro model, it has been hypothesized that elevated chylomicrons after a fat-rich meal might inhibit testosterone production.[8,9] In this study, we examined the postprandial testosterone response before and after a diet intervention known to reduce chylomicrons by approximately one half. Despite a significant reduction in postprandial chylomicrons after the diet intervention, the total and FT responses to a standardized fat-rich meal were not significantly altered. This finding casts doubt on the hypothesis that postprandial chylomicrons are responsible for the reduction in testosterone typically observed after consumption of a fat-rich meal.

Dietary triacylglycerols are digested primarily in the lumen of the small intestines by pancreatic lipase into fatty acids and monoglycerols that enter the cytosol of the intestinal cell. Inside the intestinal cell the fatty acids and monoglycerol are reassembled into chylomicrons that enter the lymphatic system and eventually the systemic circulation. Chylomicrons are then hydrolyzed into nonesterfied fatty acids (NEFA) by various

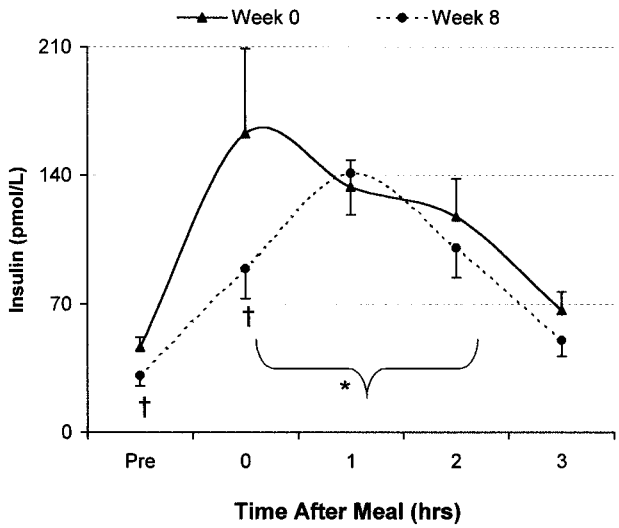

Fig 3. Postprandial serum insulin responses to a fat-rich meal before (week 0) and after (week 8) a high-fat diet. *$P \leq .05$ from corresponding pre value. †$P \leq .05$ from corresponding week 0 value.

lipases located on the endothelial surface of capillaries. NEFA then enter cells where they can be transported into the mitochondria and oxidized, stored as triglycerides, or exchange with membrane phospholipids. It has been suggested that NEFA can interfere with steroidogenesis through various mechanisms at the level of the Leydig cells in the testes.[9,15] Considering the temporal relationship between oral fat intake and an effect of chylomicrons on testosterone production at the Leydig cell, there would likely be a delay due to the time required for digestion and absorption of dietary lipid, transport to Leydig cells, and hydrolysis by lipases. Thus, the potential inhibitory effects of chylomicrons on testosterone production/secretion are probably not responsible for the normal reduction in testosterone concentrations after a fat-rich meal, but may impact postabsorptive testosterone concentrations.

In a prior study, we observed significant reductions in postresistance exercise circulating testosterone when a carbohydrate and protein beverage was consumed immediately after the workout, but not when a noncaloric placebo was consumed.[11] The findings from this study extend the inhibitory effect of a meal on postprandial testosterone concentrations to include consumption of carbohydrate and protein, as well as fat. Whether the lower testosterone concentrations after the protein and carbohydrate supplement were due to decreased testosterone production/secretion or greater uptake/clearance is unknown.

To our knowledge, this is the first study to examine the effects of a diet greater than 50% fat on postabsorptive testosterone concentrations. Based on findings from several studies, we had hypothesized that postabsorptive testosterone concentrations would increase after the high-fat diet. For example, Reed et al[3] reported a 21% decrease in FT after switching from 2 weeks of a high-fat diet (>100 g fat/d) to 2 weeks of a low-fat diet (<20 g fat/d). Hämäläinen et al[4] reported a 15% decrease in TT concentrations in healthy normal-weight men who switched from a diet consisting of 40% fat to a diet 25% in fat for 6 weeks. Tsai et al[5] reported 14% higher testosterone concentrations in healthy men after 3 days of a high-fat diet (60% fat) compared with 3 days of a low-fat diet (30%). Finally, Dorgan et al[6] reported 15% higher testosterone concentrations in healthy men who consumed a high-fat (41% fat) diet compared with a low-fat (19% fat) diet for 10 weeks. Our lack of a change in postabsorptive testosterone concentrations could be due to the higher fat content of the diet. It seems that switching from a diet about 20% fat to 40% fat is associated with an increase in testosterone. Subjects in this study habitually consumed a diet about 37% fat and switched to a diet about 67% fat. There may be a threshold of fat intake beyond which testosterone concentrations do not increase further.

An alternative explanation is that the type of fat influenced our results. Changing the fatty acid composition of the diet may alter the fatty acid composition of the testicular plasma membrane and subsequently influence receptors and the functional characteristics of the testes.[16] The high-fat diet in this study was rich in n-3 polyunsaturated fatty acids from fish oil and oleic acid from olive and canola oil, and relatively low in cholesterol. Rats fed high- and low-cholesterol diets rich in either linseed oil, fish oil, or beef tallow demonstrated a decrease in the binding capacity of the LH receptor in animals fed the linseed oil and fish oil diets, and the decrease was greater when fed low levels of cholesterol.[16] Oleic acid has also been shown to be a potent inhibitor of LH-stimulated testosterone production in vitro[9] by inhibiting cholesterol esterase and cholesterol utilization in Leydig cells.[17] Based on data from these in vitro studies, the fatty acid profile and cholesterol content of our chronic high-fat diet (ie, rich in fish oil and oleic acid and low in cholesterol) may have prevented us from observing an increase in postabsorptive testosterone concentrations that is typically observed when dietary fat is increased.

Studies have reported opposite responses of postprandial testosterone and insulin after a meal (ie, when testosterone is lowest, insulin is highest and vice versa).[11,13,14] The impact of insulin on testosterone is far from clear. Using the insulin clamp technique, infusions of insulin were shown to result in either no change or increases in testosterone.[18] Insulin has also been shown to increase the clearance of dehydroepiandrosterone (DHEA) in men,[19] although DHEA is probably quantitatively more important for testosterone synthesis in women.[20,21] In men, there is an inverse relationship between insulin and testosterone,[22] whereas in women, increased androgenicity is associated with insulin resistance.[23] Since we observed no consistent correlations between insulin and testosterone responses before the diet nor were the changes in insulin and testosterone related, our data indicate insulin is not associated with the reduction in testosterone after a meal.

We observed a significant decrease in fasting and postprandial insulin responses after the high-fat diet. Decreases in resting insulin concentrations have been reported in response to 3 to 4 days of a low-carbohydrate diet high in fat.[24-28] The mechanism for such a response probably resides in the greater reliance on fat oxidation induced by dietary carbohydrate restriction[29] and subsequent reduced requirement for insulin to assist in glucose uptake. To our knowledge, the reduced postprandial insulin response to a fat-rich meal observed after the high-fat diet has not been reported in the literature. Postprandial insulin concentrations after glucose ingestion ($1.5\ g \cdot kg^{-1}$) were significantly increased after 3 days of a high-fat diet.[30] The present study was much longer in duration (56 day *v* 3 days) and the meal lower in carbohydrate content (about 35 *v* more than 100 g), which confounds comparison of these 2 studies.

One limitation in our design was that we did not have a control condition where we measured testosterone concentrations without a meal. This would have controlled for the possible effects of a circadian rhythm of testosterone. However, postprandial trials were all performed at the same time of day for each subject between 6:00 and 8:00 AM. According to the typical circadian rhythm, testosterone concentrations should have been increasing between these morning hours[31] as opposed to the reduction we observed after the fat-rich meal. Thus, the reduction in testosterone is likely not an artifact of an underlying circadian rhythm.

The clinical significance of a decrease in circulating testosterone concentrations after a meal, especially a fat-rich meal, is difficult to predict, because it is unknown at this time whether the reduction in testosterone is due to increased uptake at the tissue level, decreased synthesis/secretion, or some other unknown mechanism. If, in fact, testosterone synthesis is inhibited, the known physiologic effects of hypogonadal function (eg, decreased protein synthesis, decreased sperm count, etc)

are well documented. The clinical ramifications of such a response, if truly representative of hypogonadal function, may well have long-term adverse metabolic and catabolic effects for the male. This may be underscored with aging or pathologic disease.

In summary, switching from a diet consisting of 37% fat to a diet 64% fat did not alter the postprandial reduction in testosterone concentrations observed after a fat-rich meal despite lowering postprandial triacylglycerols by more than 50%. These data indicate that the mechanism by which a fat-rich meal lowers testosterone concentrations is probably not mediated via chylomicron-induced inhibition of steroidogenesis as previously demonstrated in vitro.[9] While chylomicrons are probably not responsible for the reduction in postprandial testosterone concentrations, fatty acids derived via lipase action on chylomicrons may still be involved in inhibiting testosterone synthesis. Because fatty acids were not measured in this study, we cannot comment on the viability of this mechanism. Our lack of associations between insulin and testosterone suggests that insulin-induced inhibition of testosterone production/secretion is probably not a viable mechanism to explain the reduction in testosterone after a fat-rich meal either. Alternative theories to explain the mechanisms responsible for chronic diet and meal-induced alterations in testosterone should be explored.

REFERENCES

1. Howie BJ, Shultz TD: Dietary and hormonal interrelationships among Seventh-Day Adventists and nonvegetarian men. Am J Clin Nutr 42:127-134, 1985
2. Bélanger A, Locong A, Noel C, et al: Influence of diet on plasma steroid and sex plasma binding globulin levels in adult men. J Steroid Biochem Mol Biol 32:829-833, 1989
3. Reed MJ, Cheng RW, Simmonds M, et al: Dietary lipids: An additional regulator of plasma levels of sex hormone binding globulin. J Clin Endocrinol Metab 64:1083-1085, 1987
4. Hämäläinen E, Aldercreutz H, Puska P, et al: Diet and serum sex hormones in healthy men. J Steroid Biochem Mol Biol 20:459-464, 1984
5. Tsai L, Karpakka J, Aginger C, et al: Basal concentrations of anabolic and catabolic hormones in relation to endurance exercise after short-term changes in diet. Eur J Appl Physiol 66:304-308, 1993
6. Dorgan JF, Judd JT, Longcope C, et al: Effects of dietary fat and fiber on plasma and urine androgens and estrogens in men: A controlled feeding study. Am J Clin Nutr 64:850-855, 1996
7. Volek JS, Boetes M, Bush JA, et al: Testosterone and cortisol in relationship to dietary nutrients and heavy resistance exercise. J Appl Physiol 82:49-54, 1997
8. Meikle AW, Stringham JD, Woodard MG, et al: Effects of a fat-containing meal on hormones in men. Metabolism 39:943-946, 1990
9. Meikle AW, Benson SJ, Liu X, et al: Nonesterfied fatty acids modulate steroidogenesis in mouse Leydig cells. Am J Physiol 257: E937-E942, 1989
10. Volek JS, Gómez AL, Kraemer WJ: Fasting and postprandial lipoprotein responses to a low-carbohydrate diet supplemented with n-3 fatty acids. J Am Coll Nutr 19:383-391, 2000
11. Kraemer WJ, Volek JS, Bush JA, et al: Hormonal responses to consecutive days of heavy-resistance exercise with or without nutritional supplementation. J Appl Physiol 85:1544-1555, 1998
12. Chandler RM, Byrne HK, Patterson JG, et al: Dietary supplements affect the anabolic hormones after weight-training exercise. J Appl Physiol 76:839-845, 1994
13. Panidis D, Rousso D, Skiadopoulos S, et al: Does postprandial hyperinsulinemia contribute to hyperandrogenism in patients with polycystic ovary syndrome? Clin Exp Obstet Gynecol 24:88-91, 1997
14. Bloomer RJ, Sforzo GA, Keller BA: Effects of meal form and composition on plasma testosterone, cortisol, and insulin following resistance exercise. Int J Sport Nutr Exerc Metabolism 10:415-424, 2000
15. Sebokova E, Garg ML, Clandinin MT: Modulation of receptor-mediated gonadotropin action in rat testes by dietary fat. Am J Physiol 254:E708-E712, 1988
16. Sebokova E, Garg ML, Wierzbicki A, et al: Alteration of the lipid composition of rat testicular plasma membranes by dietary (n-3) fatty acids changes the responsiveness of Leydig cells and testosterone synthesis. J Nutr 120:610-618, 1990
17. Meikle AW, Cardoso de Sousa JC, Hanzalova J, et al: Oleic acid inhibits cholesteryl esterase and cholesterol utilization for testosterone synthesis in mouse Leydig cells. Metabolism 45:293-299, 1996
18. Pasquaili R, Macor C, Vicennati V, et al: Effects of acute hyperinsulinemia on testosterone serum concentrations in adult obese and normal-weight men. Metabolism 46:526-529, 1997
19. Lavallee B, Provost PR, Kahwash Z, et al: Effect of insulin on serum levels of dehydroepiandrosterone metabolites in men. Clin Endocrinol 46:93-100, 1997
20. Casson PR, Lindsay MS, Pisarka MD, et al: Dehydroepiandrosterone supplementation augments ovarian stimulation in poor responders: A case series. Hum Reprod 15:2129-2132, 2000
21. Villareal DT, Holloszy JO, Kohrt WM: Effects of DHEA replacement on bone mineral density and body composition in elderly women and men. Clin Endocrinol 53:561-568, 2000
22. Haffner SM, Valdez RA, Mykkanen L, et al: Decreased testosterone and dehydroepiandrosterone sulfate concentrations are associated with increased insulin and glucose concentrations in nondiabetic men. Metabolism 43:599-603, 1994
23. Phillips GB, Tuck CH, Jing TY, et al: Association of hyperandrogenemia and hyperestrogenemia with type 2 diabetes in Hispanic postmenopausal women. Diabetes Care 23:74-79, 2000
24. Fery F, Bourdoux P, Christophe J, et al: Hormonal and metabolic changes induced by an isocaloric isoproteinic ketogenic diet in healthy subjects. Diabetes Metab 8:299-305, 1982
25. Galbo H, Holst JJ, Christensen NJ: The effects of different diets and of insulin on the hormonal response to prolonged exercise. Acta Physiol Scand 107:19-32, 1979
26. Johannessen A, Hagen C, Galbo H: Prolactin, growth hormone, thyrotropin,3,5,3′-triiodothyronine, and thyroxine responses to exercise after fat- and carbohydrate-enriched diet. J Clin Endocrinol Metab 52:56-61, 1981
27. Langfort J, Zarzeczny R, Pills W, et al: The effect of a low-carbohydrate diet on performance, hormonal and metabolic responses to a 30-s bout of supramaximal exercise. Eur J Appl Physiol 76:128-133, 1997
28. Langfort J, Pilis W, Zarzecny R, et al: Effect of low-carbohydrate-ketogenic diet on metabolic and hormonal responses to graded exercise in men. J Physiol Pharmacol 47:361-371, 1996
29. Phinney SD, Bistrian BR, Wolfe RR, et al: The human metabolic response to chronic ketosis without caloric restriction: Physical and biochemical adaptations. Metabolism 32:757-768, 1983
30. Sidery MB, Gallen IW, MacDonald IA: The initial physiological responses to glucose ingestion in normal subjects are modified by a 3 d high-fat diet. Br J Nutr 64:705-713, 1990
31. Miyatake A, Morimoto Y, Oishi T, et al: Circadian rhythm of serum testosterone and its relation to sleep: Comparison with the variation in serum luteinizing hormone, prolactin, and cortisol in normal men. J Clin Endocrinol Metab 51:1365-1371, 1980