Exercise Plus n-3 Fatty Acids: Additive Effect on Postprandial Lipemia

Bryan K. Smith, Grace Y. Sun, Owen M. Donahue, and Tom R. Thomas

The purpose of this study was to examine changes in postprandial lipemia (PPL) in recreationally active males following aerobic exercise, omega-3 fatty acids (n-3FA) supplementation, and the combination of the two. PPL following a high-fat meal was measured in 10 recreationally active males (25 ±1.5 years) under each of the following conditions: no exercise and no n-3 FA supplementation (control); exercise and no n-3FA supplementation (exercise); n-3FA supplementation and no exercise (n-3FA); and exercise and n-3 FA supplementation (combined). Blood was collected before the high-fat meal and at 2, 4, 6, and 8 hours after the meal to assess the PPL response. Supplementation consisted of 4.0 g of n-3FA per day for 5 weeks. Triglyceride (TG) peak response, the total area under the TG curve (TG-AUC_T), and the incremental area under the TG curve (TG-AUC_I) were used to define the PPL response. TG peak response was significantly reduced 38% by n-3FA supplementation and 50% by the combination of exercise and n-3FA supplementation. N-3FAs significantly reduced the TG-AUC_T by 27% and by 42% when combined with exercise. When compared with the exercise trial, the TG-AUC_T during the combined trial was significantly lower. Exercise, n-3FAs, and the combination significantly reduced the TG-AUC_I by 40%, 42%, and 58%, respectively. These results suggest that the combination of exercise and n-3FA supplementation reduce PPL to a greater degree in recreationally active males when compared with the individual treatments.

POSTPRANDIAL LIPEMIA (PPL) is the sustained and elevated concentration of plasma triglycerides (TG) that occurs following a meal. Americans ingest approximately 33% of their daily calories from fat[1] and spend most of their day in a postprandial state. Elevated or exaggerated PPL is considered to be a major risk factor for cardiovascular disease (CVD) and has been observed in cardiac patients.[2] Two strategies shown to reduce PPL are aerobic exercise and omega-3 fatty acid (n-3FA) supplementation.[3-9]

An acute bout of aerobic exercise has been shown to significantly reduce PPL[3,6-9] and to significantly increase lipoprotein lipase (LPL) activity.[10,11] LPL is the enzyme responsible for hydrolyzing TG contained in chylomicrons and very–low-density-lipoproteins (VLDL). An increase in LPL activity may result in an increased rate of clearance of TG from chylomicrons and VLDLs. The end result of this process would be the reduction of plasma TG concentrations and a reduction in the PPL response. Increases in LPL activity following an acute bout of aerobic exercise have been associated with increased rates of TG clearance[12] and with reductions in PPL.[6]

Supplementation with n-3FA also can reduce PPL.[4,5,13] Eicosapentaenioic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) are the 2 long chain n-3FA primarily found in fish oil. Dietary supplementation with n-3FA has been shown to reduce PPL by decreasing hepatic TG secretion (VLDL) and/or decreasing intestinal TG secretion (chylomicrons and VLDL)[5,13-15] and by increasing LPL activity, which accelerates chylomicron TG clearance.[16]

Because both aerobic exercise and n-3FA supplementation can reduce PPL, it is possible that when combined they may have an additive effect on PPL. We have recently reported that when these 2 treatments were administered in combination, they produced no significant reductions in PPL.[17] Thus, when combined, either through a direct or an indirect mechanism, the individual effects of aerobic exercise and n-3FA supplementation on PPL appear to be negated. However, this finding occurred in sedentary subjects and therefore, it is necessary to determine if this same result occurs in a group of subjects who exercise on a regular basis. If this interference occurs in individuals who exercise regularly, then these individuals would be losing the beneficial effects of each treatment, which could have important health implications.

On the other hand, if there is no interference between the 2 treatments or if they have an additive effect on PPL, then this combination may have the potential to reduce the CVD risk that is associated with prolonged or exaggerated PPL. If the combined treatments reduce PPL, this would offer individuals an alternative to a pharmaceutical treatment, would require little if any medical supervision, and would be relatively inexpensive. In addition, individuals would gain all of the other health benefits that are associated with regular physical exercise and n-3FA supplementation instead of experiencing any of the potential side effects that are normally associated with pharmaceutical treatments.

The purpose of this study was to examine changes in PPL in recreationally active males following aerobic exercise, n-3FA supplementation, and the combination of the two. A secondary purpose of this study was to determine if changes in LPL activity were associated with the changes in PPL.

MATERIALS AND METHODS

Subjects

A total of 10 recreationally active male subjects participated in this study. Subject characteristics are shown in Table 1. Recreationally active was defined as no more than 5 hours of aerobic activity per week.

From the Center for Physical Activity and Weight Management, Schiefelbusch Life Span Institute, University of Kansas, Lawrence, KS; and the Departments of Biochemistry and Nutritional Sciences, University of Missouri-Columbia, Columbia, MO.

Submitted February 2, 2004; accepted May 11, 2004.

Supported by a grant from the American College of Sports Medicine, a grant from the Research Council of the University of Missouri-Columbia, and funding from the Elizabeth Hegarty Foundation.

Address reprint requests to Tom R. Thomas, MD, 106 McKee Gym, Dept. of Nutritional Sciences, University of Missouri, Columbia, MO 65211.

0026-0495/04/5310-0016$30.00/0

doi:10.1016/j.metabol.2004.05.012

Table 1. Subject Characteristics

Age (yr)	25.0 ± 1.5
Weight (kg)	76.6 ± 2.2
%BF (skinfolds)	9.8 ± 1.0
WHR	0.80 ± 0.01
BMI (kg/m^2)	23.2 ± 0.5
$\dot{V}O_2$max (L/min)	4.1 ± 0.2
$\dot{V}O_2$max (mL/kg/min)	53.1 ± 1.7
HR_{max} (bpm)	196.0 ± 2.0
RER_{max}	1.16 ± 0.03

NOTE. Values are means ± SE. Abbreviations: BF, body fat, WHR, waist-to-hip ratio; BMI, body mass index; $\dot{V}O_{2max}$, maximal oxygen consumption; HR, heart rate; RER, respiratory exchange ratio.

Prior to the initial screening, each subject was informed of the risks associated with this study and signed a consent form that had been approved by the University of Missouri Health Sciences Institutional Review Board.

Each subject completed a health questionnaire, a bleeding disorder questionnaire, a physical activity questionnaire, a daily supplement questionnaire, and a 1-day dietary record. Any subject having more than 1 major CVD risk factor (ie, known heart disease, high blood pressure, diabetes, etc), disease symptom,[18] bleeding disorder, or if currently taking n-3FA supplements was not allowed to participate. A 3-day dietary record was completed by each subject prior to supplementation and during the fourth week of supplementation. The 3-day dietary records were analyzed using the Food Processor IV software 7.9 (ESHA Research, Salem, OR) in order to characterize the diets of the participants and to track any changes in dietary habits during the experimental period.

Each subject completed a $\dot{V}O_2$max treadmill test prior to his first trial in order to characterize the subjects and to determine the appropriate exercise intensity during two 60-minute exercise sessions. The protocol that was used for the $\dot{V}O_2$max test has been used in multiple studies by our group.[6,9,17]

Body composition was estimated from the sum of 3 skinfold measurements (the abdomen, the chest, and the thigh). These measurements were used to estimate body density and percent body fat.[19]

In order to reduce intrasubject variability, each subject completed a 24-hour dietary record during the day immediately prior to the first trial. Each subject was required to repeat this diet during the 24 hours prior to each additional trial.

Experimental Design

The experimental design was a repeated measures crossover design. A timeline of the study is shown in Fig 1 and consisted of 2 measurements of fasting LPL activity and 4 postprandial trials. Fasting LPL activity was measured once at baseline and once after at least 3 weeks of n-3FA supplementation. The 4 postprandial trials consisted of the following: no exercise and no n-3 FA supplementation (control); exercise and no n-3FA supplementation (exercise); n-3FA supplementation and no exercise (n-3FA); and exercise and n-3 FA supplementation (combined).

The order of the presupplementation fasting LPL activity measurements and the 2 postprandial trials were randomized. Upon completion of the presupplementation testing, the subjects began 5 weeks of n-3FA supplementation (4 g n-3FA/d). Following supplementation, the order of the fasting postsupplementation LPL activity measurements and the 2 postprandial trials also were randomized. Postsupplementation testing began after the third week of n-3FA supplementation and ended after the fifth week of supplementation.

During each trial, subjects ingested a high-fat shake following a 12-hour overnight fast. Blood samples were collected prior to the exercise sessions, prior to the meal, and at 2, 4, 6, and 8 hours after the meal. A heparin injection was given immediately following the 8-hour blood collection in order to measure postprandial LPL activity (Fig 1). Each subject refrained from exercising for the 2 days prior to each trial.

A 60-minute aerobic exercise session was included in the 2 exercise trials. Each subject reported to the lab 13 hours prior to the high-fat shake to complete this aerobic exercise session. This session consisted of jogging on the treadmill at 60% of their previously determined $\dot{V}O_2$max. Metabolic data was collected during each exercise session and was used to monitor the intensity and to calculate the energy

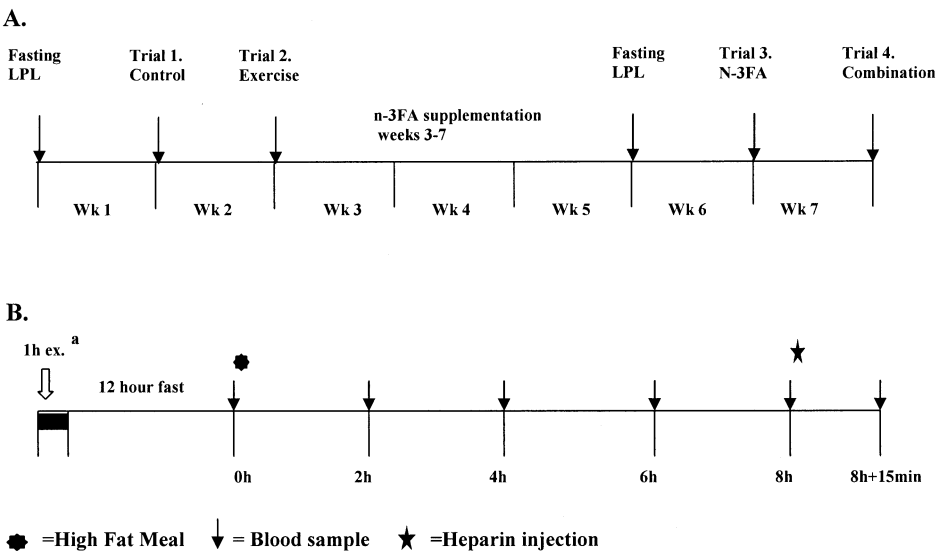

Fig 1. Timelines. (A) Study timeline. (B) PPL trial timeline. N-3FA, omega-3 fatty acid; LPL, lipoprotein lipase. [a]For exercise trials, each subject completed a 1-hour treadmill run at 60% of $\dot{V}O_{2max}$, 12 hours before the high-fat meal. Note: the order of trials 1 to 2 as well as trials 3 to 4 was randomized.

expenditure of the exercise session. Following the exercise session, each subject fasted until they reported to the lab the next morning.

High-Fat Meal

The test meal consisted of a high-fat shake. The shake was made from a combination of heavy whipping cream and specialty ice cream. The meal contained 1.3 g fat, 0.06 g protein, and 0.3 g of carbohydrate per kilogram of body weight. The average meal contained 1,007 kcal, of which 99.6 g or 896 kcal were from fat. The macronutrient composition of the shake was 88% fat, 1.8% protein, and 10.2% carbohydrate of total energy. This high-fat shake has been used in multiple studies from our group.[6,9,17,20]

N-3FA Supplementation

Following the completion of the second trial, each subject began 5 weeks of n-3FA supplementation (Fig 1). Each subject ingested 8 soft gel capsules (Super EPA-500, Bronson Pharmaceutical, St Louis, MO) containing 300 mg of EPA and 200 mg of DHA (500 mg n-3FA/capsule) for a total of 4 g of n-3FA per day. Each subject was instructed to take 2 capsules with each meal and 2 before bed. Weekly pill counts were used to track each subject's compliance in taking the supplements. Compliance also was checked by completing plasma free fatty acid (FFA) analysis on fasting plasma samples obtained pre- and postsupplementation to determine if EPA and DHA levels increased following the supplementation.

Blood Collection and Preparation

All blood samples were collected via a butterfly needle inserted into an antecubital vein. All nonheparinized blood samples were collected into 10 mL tubes containing EDTA. Heparinized blood was collected into 10 mL heparin tubes. All samples were immediately separated by centrifugation at 4°C for 15 minutes at 2,000*g* in a Marathon 22100R centrifuge (Fisher Scientific, Pittsburgh, PA). The separated plasma was transferred to cryogenic vials and stored at −70°C for later analysis.

Plasma TG Analysis

Plasma TG was measured enzymatically using a diagnostic kit (Infinity TG Reagent; Sigma Diagnostics, St Louis, MO). Plasma TG concentration was measured prior to and at 2, 4, 6, and 8 hours following the high-fat meal. The interassay coefficient of variation was 1.4%.

The PPL response was defined as the total area under the TG curve (TG-AUC_T), the incremental TG-AUC (TG-AUC_I), and the TG peak response. The TG-AUC_T was calculated using the trapezoidal method as previously described.[21] The TG-AUC_I also was calculated using the trapezoidal method, but the baseline TG values were subtracted from each TG value before completing the calculations. The TG peak response was defined as the difference between the largest increase in plasma TG concentration minus the 0 hour plasma TG value.

LPL Activity Analysis

LPL activity and hepatic lipase (HL) activity were measured as previously described.[22] Briefly, heparinized plasma (30 μL) was incubated with a [^{14}C] triolein emulsion at 37°C for 1 hour. Total lipase activity was measured by the liberation of labeled [^{14}C] oleic acid from the labeled triolein. HL activity was measured by inhibiting LPL activity with a 1.0 mol/L NaCl solution. LPL activity was calculated by taking the difference between the total activity and the HL activity. Activity levels were measured via a scintillation counter (Beckman LS5800, Fullerton, CA) and reported as micromole free fatty acids/mL plasma/h. The interassay coefficient of variation was 2.2% for total lipase activity and 17.8% for HL activity.

Table 2. Three-Day Dietary Record Data

	Presupplementation	Postsupplementation
Total kcal/d	3,077 ± 338	2,760 ± 342
Carbohydrate (%)	50.8 ± 2.0	52.6 ± 2.7
Protein (%)	18.2 ± 2.4	17.0 ± 2.1
Fat (%)	29.9 ± 2.5	28.5 ± 2.0
Saturated fat (%)	10.0 ± 1.0	9.7 ± 0.8
Monounsaturated fat (%)	5.7 ± 1.0	4.7 ± 1.1
Polyunsaturated fat (%)	2.7 ± 0.4	2.1 ± 0.4
Other/missing (%)	11.6 ± 2.1	12.0 ± 2.1

NOTE. Values are means ± SE. There were no significant differences between pre- and postsupplementation for any of the dietary measurements ($P > .05$).

FA Analysis

Plasma FA profiles of the TG and phospholipid (PL) subfractions were analyzed as previously described.[23] Briefly, lipids were extracted from the plasma, and the TG and PL subfractions were separated by high-performance thin-layer chromatography (HPTLC). Lipids were extracted from the HPTLC plate and converted to FA methyl esters. The FA methyl esters were analyzed by a Hewlett Packard Gas Chromatograph (Model 8590A; Andover, MA) with an attached Hewlett Packard Integrator (Model 3392A). The interassay coefficient of variation for this assay was 7.6%.

Statistical Analysis

Plasma TG concentrations were analyzed using a 2-way analysis of variance (ANOVA) (time × trial) with repeated measures on time and trial. The TG-AUC_T, TG-AUC_I, and TG peak response were analyzed using 1-way ANOVAs with repeated measures to detect differences among the 4 postprandial trials. LPL activity and HL activity were analyzed using a 1-way ANOVA with repeated measures to detect differences among the 6 measurements (2 fasting and 4 postprandial). Significant F ratios ($P < .05$) were followed up with Bonferroni *t* tests to identify differences between pairs of trials. All values are reported as means ± SE.

RESULTS

Comparisons between the pre- and postsupplementation 3-day dietary records indicated no significant changes in daily caloric intake in the subjects' diets over the course of the study (Table 2). There were no significant differences between the relative intensity (60.7% ± 0.5% *v* 60.6% ± 0.4% $\dot{V}O_2$max), the respiratory exchange ratio (0.92 ± 0.01 *v* 0.90 ± 0.01) or energy expenditure (734 ± 25 *v* 733 ± 27 kcal) during the pre- and postsupplementation exercise sessions, respectively.

Pill counts and the increases in n-3FA plasma concentrations suggest that subjects were following the supplementation protocol. On average, each subject ingested their supplements 96% ± 2% of the time. Changes (pre- and postsupplementation) in the fatty acid profiles of the plasma PLs and plasma TG fractions are shown in Table 3. Prior to supplementation, the percentage of EPA and DHA in the plasma PLs and TG fractions was 2.5% (of total FA). Following supplementation, this percentage had increased to 10.1%.

Plasma TG concentrations for each postprandial trial are shown in Fig 2. N-3FA supplementation did not significantly lower fasting (0 hour) TG concentrations. At 2 and 4 hours, the TG concentrations during both the n-3FA trial and the com-

Table 3. Percentages of Fatty Acids in Plasma pre and Postsupplementation

Fatty Acid	Phospholipid		Triglyceride	
	Pre	Post	Pre	Post
12:0	ND	ND	1.03 ± 0.91	1.03 ± 0.53
14:0	1.04 ± 0.12	0.79 ± 0.09	4.85 ± 0.86	5.74 ± 1.01
14:1	ND	ND	0.37 ± 0.12	0.44 ± 0.17
15:0	ND	ND	0.53 ± 0.10	0.54 ± 0.14
16:0	43.38 ± 0.50	44.08 ± 0.54	33.51 ± 0.93	33.34 ± 1.18
16:1	0.90 ± 0.10	0.56 ± 0.08*	4.43 ± 0.39	3.89 ± 0.42
18:0	12.43 ± 0.56	13.30 ± 0.26	3.09 ± 0.34	3.98 ± 0.25
18:1	11.20 ± 0.27	10.47 ± 0.29	33.51 ± 0.78	29.62 ± 1.16*
18:2	20.41 ± 0.91	17.37 ± 0.54*	16.08 ± 0.88	16.54 ± 1.25
18:3 n-6	0.06 ± 0.03	0.03 ± 0.02	0.68 ± 0.05	0.76 ± 0.10
18:3 n-3	0.21 ± 0.06	0.15 ± 0.04	0.60 ± 0.04	0.43 ± 0.06*
20:3	1.76 ± 0.12	1.04 ± 0.04*	0.07 ± 0.04	0.03 ± 0.02
20:4	6.71 ± 0.45	5.65 ± 0.42	0.70 ± 0.04	0.77 ± 0.13
20:5	0.78 ± 0.13	3.74 ± 0.25*	0.45 ± 0.17	1.72 ± 0.22*
22:6	1.14 ± 0.16	2.84 ± 0.24*	0.11 ± 0.04	1.18 ± 0.16*

NOTE. Values are means ± SE.

Abbreviation: ND, not detectable.

*Significantly different from pre value at $P < .05$.

bined trial were significantly lower than the control trial, and the combined trial was significantly lower than the exercise trial. At 6 hours, the TG concentrations during the exercise, the n-3FA, and the combined trials were all significantly lower than the control trial. By 8 hours, there were no significant differences among the 4 trials.

The TG peak response data is shown in Fig 3A. When compared with the control trial, the TG peak response was significantly lower for the n-3FA trial and the combined trial, but was not significantly different from the exercise trial. There were no significant differences among the exercise, the n-3FA, and the combined trials.

The TG-AUC_T data is shown in Fig 3B. When compared with the control trial, the TG-AUC_T for the n-3FA trial and the combined trial were significantly lower. When compared with the exercise trial, the TG-AUC_T for the combined trial was significantly lower.

The TG-AUC_I data is shown in Fig 3C. When compared with the control trial, the TG-AUC_I for the exercise, the n-3FA, and the combined trials all were significantly lower. There were no significant differences among the exercise, the n-3FA, and the combined trials.

LPL activity is reported in Table 4. There was a significant increase in fasting LPL activity when comparing pre- and postsupplementation values. Presupplementation fasting LPL activity was significantly lower than the 4 PPL trials. Postsupplementation fasting LPL activity was significantly lower than the exercise, the n-3FA, and the combined PPL trials, but was not significantly different from the control PPL trial. There were no significant differences among the 4 PPL trials. There were no significant differences in HL activity among any of the trials (Table 4).

DISCUSSION

The main finding of this study is that in recreationally active males, aerobic exercise, n-3FA supplementation, and the combination of the 2 significantly reduced the PPL response following a high-fat meal. A secondary finding of this study is that n-3FA supplementation increased fasting LPL activity in this population.

Compliance to the supplementation protocol was high as indicated by pill counts and the increase in plasma levels of EPA and DHA. The increases in plasma EPA and DHA were comparable to plasma changes reported by others.[24-26] Thus providing further evidence that the subjects followed the supplementation protocol.

The reduction in TG-AUC_I following exercise was similar in magnitude to previously reported reductions determined under similar experimental conditions.[6,9] The reduction in the TG peak response following exercise was similar to the reduction in the maximal TG response reported after a 90-minute bout of walking at 60% of $\dot{V}O_2$max.[7] Following the exercise only trial, the reduction in TG-AUC_T was less than previously reported.[7,8,27] Although the magnitude of the reduction in PPL in the current study may differ from previous studies, the current results do show that exercise is very effective at lowering the PPL response following a high-fat meal.

Observed reductions in TG-AUC_T, TG-ACU_I, and TG peak response following n-3FA supplementation were similar to previous reports.[5,13,28] There is abundant evidence indicating that the reduction in PPL following n-3FA supplementation is due to a decrease in chylomicron[5,13] and VLDL-TG[13-15] synthesis/secretion. On the other hand, there is limited evidence supporting the hypothesis that the reduction in PPL following n-3FA supplementation is due to an increased rate of TG clearance associated with increased endogenous (measured in nonheparinized plasma) LPL activity.[16,29] In both studies, it was concluded that this increase in endogenous LPL activity could lead to an increased lipolytic rate, which would help explain the TG lowering effects of n-3FA supplementation.

Others have reported increased LPL activity in nonfasting postheparin plasma following supplementation[30] and following

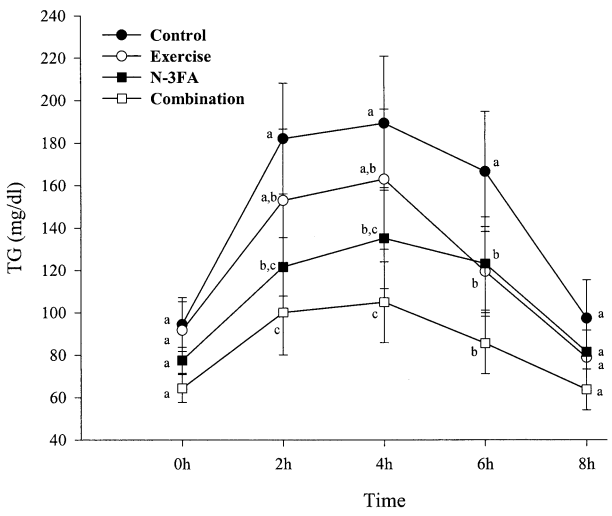

Fig 2. TG concentrations over time. Means at same time points with different letters are significantly different from each other ($P < .05$). TG, triglyceride.

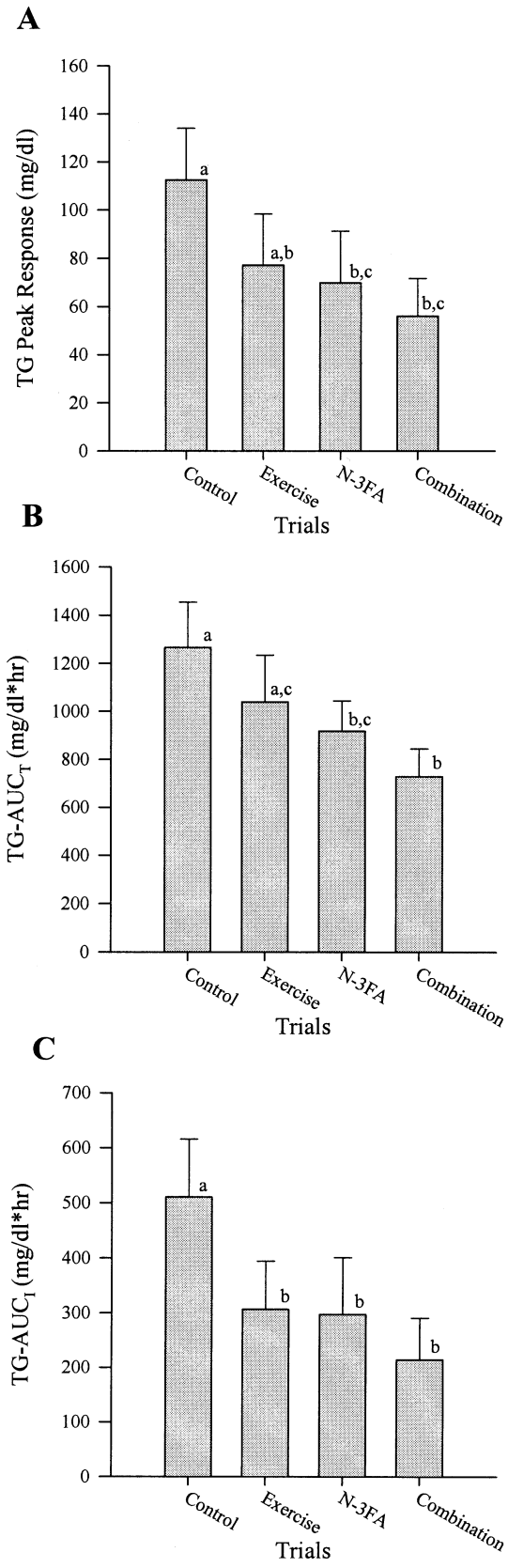

Fig 3. Postprandial responses. (A) TG peak response; (B) TG-AUC$_T$; (C) TG-AUC$_I$. Means with different letters are significantly different from each other at $P < .05$. TG, triglyceride.

meals enriched in n-3FAs.[31] Khan et al[30] reported an increase in postprandial postheparin LPL activity along with reductions in the PPL response, therefore supporting the idea that n-3FA supplementation may have the ability to increase TG clearance. Although TG clearance was not directly measured in the current study, the increase in fasting LPL activity combined with the reduction in PPL suggests that there could have been an increased rate of clearance following n-3FA supplementation. On the other hand, because chylomicron and VLDL-TG concentrations were not measured, it cannot be ruled out that a decrease in secretion/synthesis may have been totally responsible for the reductions in PPL. A more logical conclusion would be that both a decrease in chylomicron and VLDL-TG secretion/synthesis along with an increased clearance rate was responsible for the PPL reductions following n-3FA supplementation.

Only 1 other study has examined the PPL response to the combination of aerobic exercise and n-3FA supplementation. Thomas et al[17] examined this relationship in sedentary males using a similar experimental design. In sedentary males, the combined treatments negated the benefits of the individual treatments on the PPL response, which is contradictory to the current findings. The significance of this finding is that active individuals, unlike sedentary, are not at risk of losing the PPL reducing benefits of the individual treatments. These results suggest that active individuals may actually experience a greater PPL reducing benefit from the combined treatments than from the individual treatments.

Based upon the current results, recreationally trained males respond differently than sedentary males. The fact that the combined treatments result in no reduction in PPL in sedentary males presents a dilemma when making recommendations to this population. These results would indicate that if sedentary males become trained they would benefit from the combination of exercise and n-3FA supplementation. What is not known is how long these individuals must train before they too will experience the beneficial effects of the combined treatments. Warner et al[32] examined the combined effects of 12 weeks of

Table 4. Lipase Activity by Trial

Trial	LPL	Hepatic Lipase
Fasting, presupp	7.4 ± 0.9^a	3.6 ± 0.4
Fasting, postsupp	9.7 ± 0.7^b	3.9 ± 0.4
PPL, control	11.1 ± 0.9^{b,c}	3.5 ± 0.4
PPL, exercise	12.7 ± 0.6^c	3.3 ± 0.4
PPL, n-3FA	11.6 ± 0.6^c	3.5 ± 0.5
PPL, combination	12.6 ± 0.7^c	4.0 ± 0.5

NOTE. Values are mean ± SE (N = 9). Means in the same column with different letters are significantly different from each other at $P < .05$. LPL was significantly lower during the fasting, presupp trial when compared with the fasting, postsupp and the 4 PPL trials. Fasting, postsupp LPL was not significantly different from the PPL, control trial. There were no significant differences in LPL among the 4 PPL trials. There were no significant differences in hepatic lipase among the 6 trials. Units are micromoles free fatty acids/mL plasma/h.

Abbreviations: LPL, lipoprotein lipase; supp, supplementation; PPL, postprandial lipemia; n-3FA, omega-3 fatty acids.

aerobic exercise training and n-3FA supplementation on lipids in sedentary hyperlipidemic men and women. After 4 weeks of n-3FA supplementation and aerobic exercise, plasma TG was significantly lower than baseline and was still significantly lower than baseline at 12 weeks. Those results would indicate that beneficial effects of the combined treatments occur quite quickly, less than 4 weeks, in sedentary men and women.

The current results suggest that the combination of the exercise and n-3FA supplementation may have an additive effect on reducing PPL (Fig 3). This additive effect is evident when examining the statistical results of the TG-AUC_T calculations. There was an 18% reduction during the exercise trial and a 27% reduction during the n-3FA trial. The sum of the reductions of the 2 individual treatments is 45%, which is similar to the 42% reduction that was observed during the exercise and n-3FA trial. The most likely explanation for this additive effect is the independent effects of exercise and n-3FA supplementation on PPL reduction. Results from previous studies suggest that exercise increases LPL activity,[6,10] while N-3FA supplementation reduces TG synthesis[5,13-15] and possibly increases LPL activity.[16,29] Each of these changes would reduce PPL individually, but when combined, PPL could be reduced by several different mechanisms, thus resulting in an additive effect on attenuating the PPL response.

The results of this study represent only the short-term effects of the combination of exercise and n-3FA supplementation on PPL in a very specific population, recreationally trained males. Although these results are interesting, there are several additional questions that remain unanswered. What are the long-term effects of exercise and n-3FA supplementation on PPL, and maybe more importantly, what effect does this combination have on the prevention of CVD? How would different populations respond to the combined treatments? Obviously these questions have yet to be examined, but results of an earlier study by Warner et al[32] offers some insight to all of these questions. Following 12 weeks of n-3FA supplementation and aerobic exercise training in sedentary hyperlipidemic men and women, plasma TG were still significantly lower than baseline values.[32] Those results appear to indicate that there is reason to expect similar long-term results and to expect similar results in several different populations (ie, women and hyperlipidemic individuals).

At this point in time, it is difficult to say what effect this combination would have on the prevention of CVD. Because both treatments individually are recommended to help prevent or delay CVD, it could be hypothesized that the combined treatments also would aid in the prevention of CVD, but this question could only be answered by conducting long-term randomized trials. Current evidence would suggest that the only population that would not benefit from the combined treatments would be sedentary individuals, and with a short amount of training, they too would benefit from the combined treatments.

In conclusion, acute aerobic exercise or n-3FA supplementation significantly reduces TG-AUC and TG peak response following a high-fat meal in recreationally active males. In addition, these results suggest that the combination of exercise and n-3FA supplementation reduce PPL to a greater degree when compared with the individual treatments.

ACKNOWLEDGMENT

We thank Scott Rector and Pam Hinton, PhD for technical assistance and manuscript preparation.

REFERENCES

1. Allison DB, Egan SK, Barraj LM, et al: Estimated intakes of trans fatty and other fatty acids in the U.S. population. J Am Diet Assoc 99:166-174, 1999

2. Patsch JR, Miesenbock G, Hopferwieser T, et al: Relation of triglyceride metabolism and coronary artery disease. Studies in the postprandial state. Arterioscler Thromb Vasc Biol 12:1336-1345, 1992

3. Hardman AE, Aldred HE: Walking during the postprandial period decreases alimenetary lipaemia. J Cardiovasc Risk 2:71-78, 1995

4. Harris WS, Connor WE, Alam N, et al: Reduction of postprandial triglyceridemia in humans by dietary n-3 fatty acids. J Lipid Res 29:1451-1460, 1988

5. Harris WS, Muzio F: Fish oil reduces postprandial triglyceride concentrations without accelerating lipid-emulsion removal rates. Am J Clin Nutr 58:68-74, 1993

6. Thomas TR, Horner KE, Langdon MM, et al: Effect of exercise and medium-chain fatty acids on postprandial lipemia. J Appl Physiol 90:1239-1246, 2001

7. Tsetsonis NV, Hardman AE: Effect of low and moderate intensity treadmill walking on postprandial lipaemia in healthy young adults. Eur J Appl Physiol 73:419-426, 1996

8. Tsetsonis NV, Hardman AE: Reduction in postprandial lipemia after walking: Influence of exercise intensity. Med Sci Sports Exerc 28:1235-1242, 1996

9. Zhang JQ, Thomas TR, Ball SD: Effect of exercise timing on postprandial lipemia and HDL cholesterol subfractions. J Appl Physiol 85:1516-1522, 1998

10. Zhang JQ, Smith B, Langdon MM, et al: Changes in LPLa and reverse cholesterol transport variables during 24-h postexercise period. Am J Physiol 283:E267-274, 2002

11. Ferguson MA, Alderson NL, Trost SG, et al: Effects of four different single exercise sessions on lipids, lipoproteins, and lipoprotein lipase. J Appl Physiol 85:1169-1174, 1998

12. Sady SP, Thompson PD, Cullinane EM, et al: Prolonged exercise augments plasma triglyceride clearance. JAMA 256:2552-2555, 1986

13. Westphal S, Orth M, Ambrosch A, et al: Postprandial chylomicrons and VLDLs in severe hypertriacylglycerolemia are lowered more effectively than are chylomicron remnants after treatment with n-3 fatty acids. Am J Clin Nutr 71:914-920, 2000

14. Harris WS, Connor WE, Illingworth DR, et al: Effects of fish oil on VLDL triglyceride kinetics in humans. J Lipid Res 31:1549-1558, 1990

15. Nozaki S, Garg A, Vega GL, et al: Postheparin lipolytic activity and plasma lipoprotein response to w-3 polyunsaturated fatty acids in patients with primary hypertriglyceridemia. Am J Clin Nutr 53:638-642, 1991

16. Park Y, Harris WS: Omega-3 fatty acid supplementation accelerates chylomicron triglyceride clearance. J Lipid Res 44:455-463, 2003

17. Thomas TR, Fischer BA, Kist WB, et al: Effects of exercise and n-3 fatty acids on postprandial lipemia. J Appl Physiol 88:2199-2204, 2000

18. ASCM: ASCM's Guidelines for Testing and Prescription. Baltimore, MD, Lippincott, 2000

19. Jackson AS, Pollock ML: Generalized equations for predicting body density of man. Br J Nutr 40:497-504, 1978

20. Ziogas GG, Thomas TR, Harris WS: Exercise training, postprandial hypertriglyceridemia, and LDL subfraction distribution. Med Sci Sports Exerc 29:986-991, 1997

21. Tai MM: A mathematical model for the determination of total area under glucose tolerance and other metabolic curves. Diabetes Care 17:152-154, 1994

22. Nilsson-Ehle P, Schots MC: A stable radioactive substrate emulsion for assay of lipoprotein lipase. J Lipid Res 17:536-541, 1976

23. Sun GY: Preparation and analysis of acyl and alkenyl groups of glycerophospholipids from brain subcellular membranes, in Boulton AA, Baker GB, Horrocks LA (eds): Lipids and Related Compounds. Clifton, NJ, Humana, 1988, pp 63-82

24. Adler AJ, Holub BJ: Effect of garlic and fish-oil supplementation on serum lipid and lipoprotein concentrations in hypercholesterolemic men. Am J Clin Nutr 65:445-450, 1997

25. Rivellese AA, Maffettone A, Vessby B, et al: Effects of dietary saturated, monounsaturated and n-3 fatty acids on fasting lipoproteins, LDL size and post-prandial lipid metabolism in healthy subjects. Atherosclerosis 167:149-158, 2003

26. Finnegan YE, Minihane AM, Leigh-Firbank EC, et al: Plant- and marine-derived n-3 polyunsaturated fatty acids have differential effects on fasting and postprandial blood lipid concentrations and on the susceptibility of LDL to oxidative modification in moderately hyperlipidemic subjects. Am J Clin Nutr 77:783-795, 2003

27. Herd SL, Kiens B, Boobis LH, et al: Moderate exercise, postprandial lipemia, and skeletal muscle lipoprotein lipase activity. Metabolism 50:756-762, 2001

28. Minihane AM, Khan S, Leigh-Firbank EC, et al: ApoE polymorphism and fish oil supplementation in subjects with an atherogenic lipoprotein phenotype. Arterioscler Thromb Vasc Biol 20:1990-1997, 2000

29. Harris WS, Lu G, Rambjor GS, et al: Influence of n-3 fatty acid supplementation on the endogenous activities of plasma lipases. Am J Clin Nutr 66:254-260, 1997

30. Khan S, Minihane AM, Talmud PJ, et al: Dietary long-chain n-3 PUFAs increase LPL gene expression in adipose tissue of subjects with an atherogenic lipoprotein phenotype. J Lipid Res 43:979-985, 2002

31. Zampelas A, Peel AS, Gould BJ, et al: Polyunsaturated fatty acids of the n-6 and n-3 series: Effects on postprandial lipid and apolipoprotein levels in healthy men. Eur J Clin Nutr 48:842-848, 1994

32. Warner JG Jr, Ullrich IH, Albrink MJ, et al: Combined effects of aerobic exercise and omega-3 fatty acids in hyperlipidemic persons. Med Sci Sports Exerc 21:498-505, 1989