Effect of exercise and medium-chain fatty acids on postprandial lipemia

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Received 2 November 2000; accepted in final form 10 November 2000

PROLONGED POSTPRANDIAL LIPEMIA (PPL) has been associated with changes in the lipoprotein profile and increased risk for atherosclerosis (24). The type of fat eaten in the meal also may affect the PPL; for example, ω-3 fatty acids have been shown to decrease the PPL (11, 34). Medium-chain fatty acids (MCT) are metabolized more rapidly than long-chain fatty acids (LCT) and thus may be cleared from the blood more quickly after a fat meal (2). The mechanisms of these effects on PPL are unknown but could relate to the exercise or diet-induced modification of fat-handling enzymes such as lipoprotein lipase (LPL), hepatic lipase (HL), and cholesterol ester transfer protein (CETP).

The fatty acid composition of cholesteryl esters is an important determinant of CETP activity. Data from Richelle and others (25) suggest that the transfer of MCT from emulsion particles to human low-density lipoprotein (LDL) was greater than LCT but that MCT also decreased the transfer of cholesteryl ester-rich particles to triglyceride (TG)-rich particles. The evidence on lipases consistently demonstrates that MCT serves as a better substrate for LPL and HL than does LCT (20, 26). In addition, LPL (but not HL) was shown to be increased with a MCT-LCT infusion mixture vs. a LCT infusion in humans (22). Mixtures of MCT and LCT are used frequently in parenteral and sports nutrition. The use of MCT-LCT mixtures also may be advantageous because ingestion of MCT alone has been associated with gastric distress in humans (4).

Like the fatty acid composition of a meal, exercise also impacts postprandial lipemia. Research in our laboratory previously has reported that PPL is attenuated by exercise training (40) or a single exercise session (38). However, the effect of exercise in combination with fat ingestion on the enzymes of lipoprotein metabolism has received little attention in the scientific literature.

Therefore, the purpose of this study was to examine the effects of MCT with and without exercise on PPL and associated enzyme activity in trained and sedentary individuals. We hypothesized the following: 1) substituting MCT in the meal would cause a reduction in the PPL and associated changes in lipoprotein enzymes and 2) MCT plus exercise would have an additive effect on attenuating the PPL response.

METHODS

Twenty-five healthy (age 20–45 yr), nonsmoking men (n = 12) and women (n = 13) were recruited as subjects for the study (Table I). All subjects were normolipidemic, i.e., fasting cholesterol <250 mg/dl and fasting TG <160 mg/dl, except one subject whose fasting TG was 260 mg/dl. Subjects

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were classified as either trained \((n = 13)\) or sedentary \((n = 12)\) on the basis of their previous 2-yr exercise habits, yielding six to seven subjects per cell. Subjects classified as trained had participated in 45 min of endurance activity four to six times per week for at least the past 2 yr; trained subjects expended 1,400–2,500 kcal/wk in exercise. Those classified as sedentary had participated in no more than one routine exercise session per week over the past 2 yr.

On the first visit to the laboratory, the subject was informed of the risks associated with participation in the study and completed an informed consent approved by the University of Missouri Health Sciences Institutional Review Board. Each subject also completed a health history questionnaire, physical activity questionnaire, 3-day diet record, and a bleeding-disorders questionnaire. Female subjects completed an additional questionnaire intended to assess the regularity and timing of their menstrual cycle. All female subjects were premenopausal and not on estrogen therapy. Any subject and timing of their menstrual cycle. All female subjects were premenopausal and not on estrogen therapy. Any subject and any disease symptom was eliminated from the study \((1)\).

No subject used a nutritional supplement beyond a daily multivitamin. The composition of the diet was estimated by the Food Processor software (version 7.4) and is shown in Table 2.

### Preliminary testing.
Each subject also underwent under-water weighing for estimation of body composition, with residual volume measured by helium dilution \((33)\) and a maximal oxygen consumption running test as previously described \((38)\). The data obtained from the latter test were used to determine the target intensity for each subject in the exercise trial.

### Trials.
Subjects underwent three fat-meal challenge trials, and, on 2 separate days, baseline samples also were collected after heparin injection to measure LPL and HL. Each subject logged his or her diet for the 24 h before the first trial or baseline and was instructed to eat and drink these same items during the 24-h period before the second and third trials and the separate baseline blood collection. Before each trial or baseline, subjects abstained from exercise for 48 h and fasted and abstained from caffeine intake for 12 h before the trials. The fast was continued during the trial except for the test meal. All subjects were instructed to maintain their normal diet and exercise routine between trials of the study. Each baseline and challenge trial was performed at the same time of day for a given subject.

Each subject underwent three fat-meal challenges: 1) LCT meal, 2) MCT meal, and 3) MCT meal plus exercise (MCT + Ex) (Fig. 1). The order of the challenges was assigned according to a counterbalanced design over an 8-wk (men) or 16-wk (women) period. Consecutive trials were spaced ~2 wk apart in men to allow adequate recovery and 4 wk apart in women to allow testing during the proliferative phase of the menstrual cycle in female subjects. The two baseline blood collections usually occurred before the first fat-meal challenge trial and were separated by at least 1 wk from each other or a trial.

### Meal composition.
The LCT high-fat test meal consisted of a mixture of whipping cream and premium ice cream served as a milkshake. The shake was individually formulated to contain \(1.5 \text{ g fat/kg subject body wt.}\) The shake was 88% fat, with 60% of fat calories from saturated long-chain fatty acids \((35)\). For a 70-kg individual, this yielded a meal that contained 28 g carbohydrate, 5 g protein, 106 g fat, 1,087 kcal, and 400 mg cholesterol. For the MCT high-fat test meal, MCT oil (Mead Johnson Pharmaceuticals) was substituted for the whipping cream in the LCT shake formulation; the shake also contained 1.5 g fat/kg subject body wt. The shake was 99% fat, with 70% of fat calories from MCT and 30% from saturated fatty acids \((35)\). For a 70-kg individual, this yielded a meal that contained 28 g carbohydrate, 5 g protein, 106 g fat, 32 g MCT, 1,017 kcal, and 270 mg cholesterol. The MCT oil contained 67% octanoic acid \((C_{10})\), 23% deconoic acid \((C_{12})\), and <6% fatty acids shorter than \(C_{8}\).

### Table 1. Subject characteristics

<table>
<thead>
<tr>
<th></th>
<th>Men ((n = 12))</th>
<th>Women ((n = 13))</th>
<th>Sedentary ((n = 12))</th>
<th>Trained ((n = 13))</th>
<th>All ((n = 25))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>31.4 ± 10.4</td>
<td>29.5 ± 7.3</td>
<td>29.1 ± 8.9</td>
<td>31.7 ± 8.8</td>
<td>30.4 ± 8.8</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>77.0 ± 6.6</td>
<td>61.3 ± 9.3*</td>
<td>70.2 ± 10.2</td>
<td>67.5 ± 12.4</td>
<td>68.8 ± 11.3</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>16.1 ± 7.9</td>
<td>17.6 ± 10.6</td>
<td>23.2 ± 9.8</td>
<td>13.2 ± 4.8*</td>
<td>17.9 ± 9.0</td>
</tr>
<tr>
<td>V̇O₂max, ml·kg⁻¹·min⁻¹</td>
<td>44.9 ± 7.0</td>
<td>40.8 ± 13.8</td>
<td>34.6 ± 8.1</td>
<td>50.3 ± 7.5*</td>
<td>42.8 ± 11.0</td>
</tr>
<tr>
<td>HRmax, beats/min</td>
<td>186 ± 17</td>
<td>183 ± 22</td>
<td>185 ± 22</td>
<td>185 ± 17</td>
<td>185 ± 20</td>
</tr>
<tr>
<td>RERmax</td>
<td>1.15 ± 0.04</td>
<td>1.16 ± 0.08</td>
<td>1.16 ± 0.05</td>
<td>1.15 ± 0.07</td>
<td>1.15 ± 0.06</td>
</tr>
<tr>
<td>Fasting TG, mg/dl</td>
<td>84.9 ± 37.3</td>
<td>92.4 ± 64.2</td>
<td>99.1 ± 63.3</td>
<td>79.3 ± 39.3</td>
<td>88.8 ± 52.1</td>
</tr>
<tr>
<td>Fasting cholesterol, mg/dl</td>
<td>170 ± 36</td>
<td>145 ± 24</td>
<td>151 ± 30</td>
<td>162 ± 37</td>
<td>157 ± 32</td>
</tr>
<tr>
<td>HDL-C, mg/dl</td>
<td>49.8 ± 8.3</td>
<td>62.0 ± 9.6*</td>
<td>52.9 ± 12.4</td>
<td>59.2 ± 11.6</td>
<td>55.6 ± 13.3</td>
</tr>
</tbody>
</table>

Values are means ± SD; \(n\), no. of subjects; V̇O₂max, maximal \(\text{O}_2\) consumption; HRmax, maximal heart rate; RERmax, maximal respiratory exchange ratio; TG, triglycerides; HDL-C, total high-density-lipoprotein cholesterol. Factors for conversion to mmol/l: TG = 0.0113, cholesterol = 0.0259. *Statistically significant difference between sedentary and trained subjects, \(P < 0.05\).

### Table 2. Composition of background diet from diet records

<table>
<thead>
<tr>
<th></th>
<th>Men ((n = 12))</th>
<th>Women ((n = 13))</th>
<th>Sedentary ((n = 12))</th>
<th>Trained ((n = 13))</th>
<th>All ((n = 25))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dietary fat</td>
<td>27.9 ± 8.9</td>
<td>28.9 ± 9.4</td>
<td>32.8 ± 8.0</td>
<td>23.9 ± 7.9*</td>
<td>28.4 ± 9.0</td>
</tr>
<tr>
<td>SFA</td>
<td>9.0 ± 3.0</td>
<td>10.1 ± 3.7</td>
<td>10.6 ± 3.0</td>
<td>8.5 ± 3.4</td>
<td>9.5 ± 3.3</td>
</tr>
<tr>
<td>MUFA</td>
<td>8.0 ± 4.2</td>
<td>7.7 ± 4.0</td>
<td>9.6 ± 4.3</td>
<td>6.1 ± 3.0*</td>
<td>7.8 ± 4.0</td>
</tr>
<tr>
<td>PUFA</td>
<td>4.4 ± 3.7</td>
<td>4.3 ± 2.6</td>
<td>5.2 ± 2.8</td>
<td>3.5 ± 3.3</td>
<td>4.3 ± 3.1</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>56.4 ± 9.1</td>
<td>57.3 ± 11.5</td>
<td>51.6 ± 8.6</td>
<td>62.1 ± 9.0*</td>
<td>56.8 ± 10.1</td>
</tr>
<tr>
<td>Protein</td>
<td>15.9 ± 3.7</td>
<td>15.9 ± 4.8</td>
<td>15.7 ± 3.5</td>
<td>14.2 ± 5.0</td>
<td>14.9 ± 4.1</td>
</tr>
</tbody>
</table>

Values are means ± SD given in %. SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids. *Statistically significant difference between sedentary subjects and trained subjects, \(P < 0.05\).
Aerobic exercise session. In the MCT trial, each subject performed 60 min of aerobic exercise on a treadmill at 60% of the measured maximal oxygen consumption 12 h before the consumption of the fat meal. Researchers in our laboratory had previously determined that this timing of the exercise produced a substantial attenuation of the PPL (38). The subject was allowed a 5-min warm-up period to adjust the treadmill speed and to achieve target intensity. Subjects fasted after the exercise bout until the fat-meal challenge was ingested 12 h later, i.e., the next morning.

Blood collection and analyses. Blood was collected into vacutainers containing 0.117 ml of 15% EDTA at 0 h (pre-meal) and at 2, 4, 6, and 8 h after the meal ingestion (Fig. 1), and centrifuged in the cold at 4°C for 15 min at 3,750 rpm in a Beckman TJ-6R centrifuge (Palo Alto, CA) and frozen at −70°C. Postheparin samples also were collected at 8 h after the meal challenge. Plasma was analyzed for TG at all time points, and for (HDL-C), HDL-C subfractions, and CETP mass at 0, 4, and 8 h. Postheparin LPL and HL were measured at baseline and 8 h postmeal.

For each plasma analysis, all samples for a given subject were analyzed in a single run. Plasma TGs were measured enzymatically (no. 339, Sigma Chemical, St. Louis, MO). The area under the TG curve (TG score) was calculated according to the trapezoidal rule (40). Total HDL-cholesterol (HDL\textsubscript{tot}-C) was measured by precipitating apolipoprotein B-containing lipoproteins with heparin-MnCl\textsubscript{2}. The supernatant was used to precipitate HDL\textsubscript{2}-C with dextran sulfate (38). Cholesterol content of the resulting solutions was measured enzymatically (no. 353, Sigma Chemical). The average intra-assay coefficient of variation was 2.5% for TG, 0.3% for HDL-C, and 2.8% for HDL\textsubscript{2}-C.

Fatty acids were analyzed in the treatment meals according to the method of Sun (29). The mean coefficient of variation was 3.2%

Postheparin LPL and HL were assayed in triplicate using modifications of the procedure described by Illingworth et al. (13). In this procedure, radioactive TG ([14C]triolein, NEN Life Science Products, Boston, MA) was used, and the lipase activity was determined as the ability of samples to hydrolyze [14C]triolein. Total lipase activity was measured in the reaction tubes containing Tris, whereas HL was measured in reaction tubes containing NaCl in Tris. Radioactivity was determined as the difference between total lipase activity and HL.

There was no significant difference between the two baseline values (1.8 ± 1.1 vs. 1.7 ± 1.0 μmol·ml\textsuperscript{-1}·h\textsuperscript{-1}), and so they were averaged and used as the baseline value in the statistical analyses. The mean intra-assay coefficient of variation was 5.6% for LPL and 6.1% for HL.

CETP concentrations were quantified by a sandwich ELISA as described below. Pure recombinant human CETP (rhCETP) was obtained as described previously (6). Dr. Alan Tall (Columbia University, New York) provided the mouse hybridoma cell line producing anti-human CETP monoclonal antibody (MAb) TP2 to Monsanto. Ninety-six-well Nunc MaxiSorp certified microtiter plates were coated with a purified anti-human CETP MAb, 5B2, generated at Monsanto according to protocols described in Connolly et al. (6). MAb 5B2 was added to the wells at room temperature overnight at a concentration of 10 μg/ml in 15 mM Na\textsubscript{2}CO\textsubscript{3}, 3.5 mM NaHCO\textsubscript{3}, and 0.02% sodium azide. Microtiter wells were then washed four times with wash buffer (5 mM Tris, 0.15 M NaCl, 0.05% Tween 20) and nonspecific sites on the wells were blocked for 1 h at 37°C using 3% BSA in wash buffer. Immediately after the plates were washed four times with wash buffer, dilutions of pure rhCETP or samples in

### Table 3. Fatty acid composition of challenge meals

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>LCT Meal (No MCT Oil)</th>
<th>LCT Meal + MCT Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PL</td>
<td>TG</td>
</tr>
<tr>
<td>8:0</td>
<td>0.0</td>
<td>0.9</td>
</tr>
<tr>
<td>10:0</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>12:0</td>
<td>3.7</td>
<td>4.9</td>
</tr>
<tr>
<td>14:0</td>
<td>11.0</td>
<td>15.3</td>
</tr>
<tr>
<td>14:1</td>
<td>0.7</td>
<td>1.9</td>
</tr>
<tr>
<td>15:0</td>
<td>0.6</td>
<td>1.3</td>
</tr>
<tr>
<td>16:0</td>
<td>31.7</td>
<td>33.5</td>
</tr>
<tr>
<td>16:1</td>
<td>0.8</td>
<td>2.4</td>
</tr>
<tr>
<td>18:0</td>
<td>14.7</td>
<td>12.7</td>
</tr>
<tr>
<td>18:1</td>
<td>30.6</td>
<td>20.7</td>
</tr>
<tr>
<td>18:2</td>
<td>8.2</td>
<td>3.4</td>
</tr>
<tr>
<td>18:3-1</td>
<td>0.0</td>
<td>0.4</td>
</tr>
<tr>
<td>18:3-2</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>20:3</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>20:4</td>
<td>0.0</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Values are % of total fatty acids. FFA, free fatty acids; PL, phospholipid fraction; TG, triglyceride fraction.
assay buffer (1% BSA in wash buffer) were added to the wells. Dilutions of samples and rhCETP were made in siliconized tubes. Plates were incubated for 2 h at 37°C. Wells were washed four times with wash buffer and alkaline phosphatase-conjugated anti-human CETP MAb TP2 in assay buffer was added. Plates were incubated for 1 h at 37°C. After four washes, phosphatase substrate (p-nitrophenol phosphate, Kirkegaard & Perry Laboratories, Gaithersburg, MD) was added and plates were incubated at room temperature until the absorbance of the highest standard concentration of rhCETP reached 0.5–1.0 (~15 min). Absorbance was read at 405 nm with a reference wavelength of 630 nm on a Powerwave 200 microplate reader (BioTek Instruments, Winooski, VT). Concentrations of CETP used as standards in the assay were initially determined by absorbance at 280 nm by using a specific absorption coefficient of 0.83 l·g⁻¹·cm⁻¹ (6). Values for CETP concentrations in standards and samples were converted to Bradford protein equivalents by using the conversion factor of 3.93 determined by Bradford protein assay using BSA as reference standard. The mean coefficient of variation for the assay was 5.2%.

**Statistical analyses.** A four-way ANOVA (training×gender×trial×time) with repeated measures on trial and time was used for all plasma variables. The TG area score was analyzed using a three-way ANOVA (without the time factor). Significant F ratios (\( P < 0.05 \)) were followed with post hoc contrast comparisons with specifically designated error terms.

**RESULTS**

Male and female responses to the treatments were not significantly different for any of the variables. Therefore, to simplify the presentation of the data, genders were combined. The average heart rate and oxygen consumption for the 60-min exercise session in the MCT + Ex trial was 132 ± 12 beats/min and 1.7 ± 0.1 l/min, respectively. This corresponded to exercise intensities of 72 ± 6% maximal heart rate and 59 ± 2% maximal \( \text{O}_2 \) consumption. The mean energy expenditure for the exercise session was 606 ± 30 kcal.

The TG curve was not different for the LCT vs. the MCT meals (Fig. 2). On the other hand, the measurement of TGs over time was lower for MCT + Ex, and the TG score for the MCT + Ex trial was significantly lower than the other two trials (Fig. 2). The TG scores between trained and untrained groups were not different across trials, nor was there a significant training × trial interaction (Fig. 3).

HDL\(_{\text{tot}-C}\) concentrations were significantly different between men and women and borderline significantly different (\( P = 0.12 \)) between sedentary and trained individuals at 0 h (baseline; Table 1), but the response to the trials was similar between groups. In addition, the response of HDL\(_{\text{tot}-C}\) was not significantly different for the three trials. Similarly, HDL\(_{\text{Ld}-C}\) response was not different between groups or among the three trials (HDL\(_{\text{C}}\) response data not shown).

LPL at baseline was significantly higher in trained (2.0 ± 0.8 \( \mu \text{mol} \cdot \text{ml}^{-1} \cdot \text{h}^{-1} \)) vs. sedentary subjects (1.5 ± 1.0 \( \mu \text{mol} \cdot \text{ml}^{-1} \cdot \text{h}^{-1} \)). However, the training factor was not significant in the response to the three trials. LPL was significantly higher at 8 h in all trials vs. the baseline concentration, but the three fat-meal challenge trials were not different (Table 4). The baseline value rather than 0 h is used for the lipases because a fasting value was taken on 2 days separate from the trial as a result of heparin injection. The values for HL at baseline were similar between trained (1.2 ± 0.4 \( \mu \text{mol} \cdot \text{ml}^{-1} \cdot \text{h}^{-1} \)) and sedentary (1.4 ± 0.5...
microMol·ml⁻¹·h⁻¹). The MCT + Ex trial was significantly lower than the separate baseline and the other trials, and the LCT vs. MCT trials were not significantly different (Table 4).

CETP mass at baseline was not different between trained (2.7 ± 0.6 μg/ml) and sedentary subjects (2.6 ± 0.6 μg/ml), nor was training status a factor in the response to the three trials. However, the CETP concentration was lower at 4 and 8 h vs. 0 h for all trials, with the MCT + Ex trial significantly higher than the other trials because of the elevated baseline (Fig. 4).

DISCUSSION

Compared with LCT, MCT is more quickly digested in the mouth and stomach, more rapidly absorbed in the portal system, and more easily oxidized in liver and muscle (4). These characteristics have led investigators to examine MCT as an aid in improving weight loss (37), exercise performance (36), and the postprandial response (2, 3, 30). To our knowledge, this is the first study to examine the enzymatic response to acute ingestion of high-fat meal with MCTs.

A major discovery of this study was that substituting a substantial quantity of MCT for LCT in the fat load did not diminish the PPL response to the meal. This result is surprising because of the purported faster metabolic fate of MCT. Barr et al. (3) found that infusion of ~40 g of MCT in an emulsion caused a reduction in TGs in both normal subjects and patients with hypertriglyceridemia compared with infusing an emulsion with a similar quantity of corn oil. Similarly, Swift et al. (30) gave a high-fat test meal after 6 days on a diet containing soybean or MCT oil as the sole fat source. The MCT diet caused a significant elevation in resting TG and decreased HDL-C concentration from day 1 to day 6 of the diet. However, the PPL was reduced compared with the LCT diet. Asakura et al. (2) confirmed the lower PPL after acute MCT ingestion vs. corn oil ingestion but also observed elevated baseline cholesterol and TGs after 2 wk of MCT ingestion. Other investigators have observed a flatter PPL curve after MCT ingestion but at a much higher baseline level (12). We could not confirm the lower PPL after MCT ingestion probably because, unlike the homogeneous fat test meals of previous studies, our meal was more heterogeneous in fat content with ~30% of the fat as MCT and the remainder of the fat LCT. It is possible that our MCT and LCT meals were not distinct enough to cause a difference in the PPL. In addition, we compared our MCT trial to an LCT trial rather than corn or soy oil.

When exercise was added to the MCT treatment, the PPL was predictably decreased. This finding agrees with several previous reports using standard LCT meals (35, 38). Thus it appears that exercise attenuates the PPL response to a fat meal whether the fat source is LCT or MCT.

The addition of MCT to a high-fat meal did not affect CETP mass response to the fat load. Both meals caused a small but significant reduction in CETP mass (Fig. 4). However, the exercise treatment was associated with a relatively higher CETP concentration than with the fat meals alone. The reason for this relative elevation appears to relate to the increased 0-h (premeal) value, which occurred 12 h after the exercise session (Fig. 4). This increase in CETP 12 h after exercise may be related to the parallel increase in LPL. The stimulatory effect of LPL on CETP has been reported previously (32). Furthermore, Jiang et al. (14) have demonstrated a coordinated regulation of LPL and CETP mRNA in muscle and adipose. Only one study was uncovered that assessed the effect of a single exercise session on CETP, and these authors reported decreased CETP mass and activity for 2–3 days after a 230-km cycle marathon (9). Values for the 8 h immediately after the exercise were not reported, and the quantity of exercise in this study is not comparable to that in ours.

Our results did not demonstrate an association between training status and resting CETP mass or the response to a single aerobic exercise session. Other researchers have reported that chronic exercise train-

<table>
<thead>
<tr>
<th>Trial</th>
<th>LCT</th>
<th>MCT</th>
<th>MCT + Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPL, μmol·ml⁻¹·h⁻¹</td>
<td>1.75 ± 0.93</td>
<td>2.90 ± 1.20*</td>
<td>2.98 ± 1.00*</td>
</tr>
<tr>
<td>HL, μmol·ml⁻¹·h⁻¹</td>
<td>1.31 ± 0.46</td>
<td>1.25 ± 0.45</td>
<td>1.30 ± 0.43</td>
</tr>
</tbody>
</table>

Values are means ± SD. MCT + Ex, MCT plus aerobic exercise; LPL, lipoprotein lipase; HL, hepatic lipase. *Statistically significant difference between each trial and baseline, P < 0.05. †Statistically significant differences between MCT + Ex and all other trials, P < 0.05.
ing is associated with a decrease (28) or increase (10) in CETP mass or activity. CETP is believed to decrease the cholesterol content of HDL and thus is often considered atherogenic. However, the protein also has been shown to increase reverse cholesterol transport (31) and remove cholesterol from foam cells (21). Thus the potential health benefit of the diet and exercise effects on CETP mass must await further research.

A major finding of the present study is that fat loading causes an increase in postheparin LPL. The validity of this result depends on the accuracy of the baseline LPL in representing the 0 h (premeal) for the LCT and MCT trials. Because we found good agreement between the two separate baseline analyses, we believe that this is a reasonable assumption. The increase in LPL was similar with both the LCT and MCT meal. We are aware of only two other studies in which LPL was assessed after a meal, and, in both cases, endogenous LPL was measured without heparin injection (7, 18). Karpe et al. (18) reported that a mixed meal containing 50 g/m² of soybean oil caused a significant increase in LPL peaked at 6 h postmeal but was still elevated at 12 h. Our results seem to confirm the observations of previous investigators that LPL is stimulated by fat feeding. We have extended these results with the finding that LCT or MCT composition of the meal results in similar LPL increases. Others have reported that much of the MCTs are oxidized or converted to LCTs by de novo synthesis or chain elongation in the liver (23). Even when MCT was supplemented at a dose of 40% energy for 6 days, the amount of 8:0 and 10:0 measured in blood was 5% of total fat or less (12). These results could explain why the enzyme and lipoprotein responses to MCTs and LCTs were similar in the present study.

HL was the only enzyme activity that changed differently in the MCT + Ex condition vs. the other trials. Other investigators have reported no change in plasma HL as a result of LCT or MCT loading (7, 18, 22). Our results agree with these data in that LCT or MCT meals did not have a significant effect on postheparin HL. Thus, even if the MCTs are being elongated to LCTs in the liver, this process apparently is not affecting HL. However, when exercise was added to the treatment, the HL was reduced. Other investigators have reported that a session of exercise caused a reduction in postheparin HL (8, 16). Thus it was likely the exercise component of the trial rather than the MCT meal that induced the decrease in HL. We are not aware of any other study that assessed the combination of fat ingestion and exercise on LPL or HL.

The stimulation of LPL by fat ingestion or exercise is an interesting finding. It is likely that the two different stimuli operate at different tissues. That is, fat ingestion has been shown to stimulate adipose tissue LPL activity (7), whereas exercise has been shown to stimulate muscular LPL activity (27). Our analysis of postheparin plasma activity does not allow differentiation of these tissues. However, if the LPL is being stimulated in different tissues, it is surprising that, when both fat ingestion and exercise are administered together, the postheparin LPL is not additive. It is possible that the exercise session used in this study was not intense enough to maximally stimulate LPL in muscle. Ferguson et al. (8) recently reported that there was a threshold of ~1,100-kcal expenditure for exercise to increase postheparin LPL. Others have reported increases in LPL after more moderate exercise sessions (16). The energy expenditure of our exercise session averaged ~600 kcal; therefore, this exercise quantity may not have been sufficient to stimulate LPL above that induced by the fat meal.

In addition, the timing of the blood sampling for lipase measurement may not have caught the peak LPL. Ferguson et al. (8) showed elevated LPL and HL at 24 h after an aerobic exercise session. However, no activities were measured between the exercise session and 24 h postexercise. Kiens and Richter (19) reported that muscle LPL was elevated at 6 h and peaked at 18 h after the exercise session. Our blood samples were collected at 20 h, which should have been associated with near-peak LPL. It is not possible to perform serial blood sampling for LPL analysis because of the injection of heparin, which causes disturbances in fat metabolism for future sampling and creates a bleeding risk for subjects.

Taken together, the change in lipase activities with the exercise trial suggests a benefit to cardiovascular health through lipoprotein handling. Elevation in LPL due to exercise is associated with decreased plasma TG and increased HDL-C concentrations, changes that are believed to lower disease risk (16). In addition, lower HL may decrease the conversion of HDL₃ to HDL₂ and thus enhance reverse cholesterol transport (15).
It is possible that changes in plasma volume induced by the aerobic exercise may have affected the interpretation of the plasma data. Aerobic exercise has been shown to decrease plasma volume immediately after exercise, and this is followed by an expansion in recovery that may persist to some degree for several hours postexercise, thus potentially decreasing concentration measurements in blood (17). In a previous study (39), researchers in our laboratory observed only small changes in plasma volume (<5%) caused by moderate-intensity exercise for 60 min. Regardless, blood was collected at least 12 h after exercise, and the potential hemodilution by this time would cause at most small decreases in the concentrations of the enzymes in recovery. These alterations could not account for both the exercise-associated relative decrease in TG as well as the relative increase in CETP. However, we did not assess plasma volume changes and cannot rule out the possibility that hemodilution affected the plasma parameters.

Another possible explanation for the nonsignificant differences between LCT and MCT treatments was insufficient power as a result of a small sample size. We calculated the number of subjects required at a power of 0.80 to achieve statistical significance for some of the major comparisons (5). For example, for LCT vs. MCT treatments on TG score, the number of subjects required for significance would be over 3,000 and for the CETP comparison, 1,100. None of the other power calculations yielded required sample sizes that would be feasible in such studies. The closest nonsignificant difference to achieving significance was the trained vs. sedentary main effect for LPL ($P = 0.06$). In this case, a sample size of 45 in each group (power = 0.80) would be necessary to achieve statistical significance ($P = 0.05$). Thus it appears unlikely that the insignificant results in this study were due to small sample size.

**Conclusions.** These results suggest that substituting MCT in a fat meal does not alter the PPL response, but exercise with MCT reduces the PPL. In addition, LPL and CETP are affected by a fat meal with or without exercise, but HL is affected only when exercise is included.

Thus the amount of MCT used in the test meal in the present study did not affect the PPL response, but exercise with MCT reduces the PPL. In addition, LPL and CETP are affected by a fat meal with or without exercise, but HL is affected only when exercise is included.

### REFERENCES


