Postprandial Lipoprotein Metabolism in Normolipidemic Men With and Without Coronary Artery Disease


A delayed clearance of postprandial lipoproteins from the plasma may play a role in the etiology of premature coronary atherosclerosis. To address this hypothesis, we studied chylomicron (remnant) metabolism in two groups of 20 selected normolipidemic men aged 35-65 years, a group of coronary artery disease (CAD) patients, and a matched control group with documented minimal coronary atherosclerosis. Subjects received an oral fat load supplemented with cholesterol and retinyl palmitate. Plasma samples obtained during the next 24-hour period were analyzed for total as well as $d < 1.019$ g/ml and $d > 1.019$ g/ml triacylglycerol, cholesterol, and retinyl ester concentrations. Although both groups of patients responded identically in terms of the appearance of gut-derived lipids in the plasma, CAD patients showed a marked delay in the clearance of retinyl esters as well as in the normalization of plasma triacylglycerol concentrations. Postheparin plasma hepatic lipase activity was significantly lower in the CAD group. Apolipoprotein E phenotype measurements did not reveal marked differences in frequency between both groups. The frequency distribution was not unusual in comparison with the normal Dutch population. The magnitude of the postprandial responses of triacylglycerol and retinyl esters was correlated positively with the fasting levels of plasma triacylglycerol and negatively with high density lipoprotein subtraction cholesterol concentrations. These data indicate that the clearance of postprandial lipoproteins in normolipidemic CAD patients as selected in the present study is delayed as compared with that of controls without coronary atherosclerosis and suggest that postprandial lipoproteins may play a role in the etiology of their disease. (Arteriosclerosis and Thrombosis 1991;11:653-662)

Studies of experimental animals have revealed that cholesteryl ester-rich remnants of triacylglycerol-rich plasma lipoproteins may play a role in the deposition of lipids in the arterial wall.1-6 Most of these studies were performed with cholesterol-fed dogs or rabbits, and large concentrations of abnormal lipoproteins, derived from the catabolism of chylomicrons as well as hepatic very low density lipoprotein (VLDL),7,8 accumulated in these animals. High concentrations of gut- and liver-derived remnants of triacylglycerol-rich lipoprotein metabolism are also found in humans with a rare disorder of lipoprotein metabolism, familial dysbetalipoproteinemia,7 a disease that is associated with premature coronary atherosclerosis. It has been demonstrated that the clearance of chylomicron remnants from the plasma in these patients is seriously hampered.9,10 In normal humans, the presence of chylomicron remnants in the plasma is associated with the postprandial phase, and plasma residence times as low as 15-30 minutes have been measured.10,11 However, there is evidence that the removal of chylomicron remnants from the plasma is a saturable process, and plasma residence times of these lipoproteins can increase substantially if larger loads of lipids are consumed.12 Nevertheless, marked delays in the clearance of chylomicron remnants could remain undetected when the fasting plasma of individuals is screened for lipoprotein and lipid abnormalities. Zilversmit2-3 has advocated the concept that the
postprandial phase is critical in atherogenesis. Dis-
turbances in the removal of chylomicron remnants
from plasma would expose the vascular bed more
intensively to these atherogenic lipoproteins and fate
these subjects for premature coronary atherosclero-
sis. In this process, monocyte-derived macrophages
in the arterial wall are thought to play a central role,
and uptake of remnants of triacylglycerol-rich lipo-
proteins by these cells may lead to an intracellular
accumulation of cholesteryl esters and conversion of
these macrophages into foam cells. Consequently,
the importance of studies on the metabolism of
postprandial lipoproteins in humans has been
stressed, and recently, several studies have appeared
on this subject.9-11,17-19 In the present article, we
report on studies of postprandial lipoprotein metab-
olism in two groups of selected normolipidemic pa-
tients, a group with severe coronary atherosclerosis
(coronary bypass patients) and a matched control
group with normal coronary arteries at angiography.

Methods

Materials

Water-miscible emulsions of retinyl palmitate
(Arovit, 150,000 IU/ml) were from Roche, Basel,
Switzerland. Retinol, retinyl ester standards, and
other chemicals were from Sigma Chemical Co., St.
Louis, Mo. Organic solvents of high-performance
liquid chromatography (HPLC) grade and all other
chemicals of analytical grade were obtained from
Merck (Darmstadt, F.R.G.).

Patients

Coronary artery disease (CAD) patients and le-
son-free controls were selected from the data base of
the Cardiology Department of the Zuiderziekenhuis
Rotterdam by selection criteria as described below.
All patients were men between the ages of 35 and 65
years who underwent exploratory coronary angiogra-
phy in the 12-month period before entry into the
study. Controls underwent coronary angiography for
complaints of chest pain, but the angiograms showed
no or only minimal signs of coronary atherosclerosis
(i.e., stenosis in major vessels <20%). The CAD
group consisted of subjects suffering from severe
coronary atherosclerosis (at least three major coro-
nary vessels occluded by 70% or more) who under-
went coronary artery bypass surgery in the preceding
3-9 months. All had recovered well and were fit
enough to allow the cessation of medication that
could affect plasma lipoprotein metabolism (e.g.,
β-adrenergic antagonists, mainly metoprolol [stan-
dard dose, 50 mg b.i.d., regular preparation], used by
11 CAD and three control patients, and calcium
channel blockers, mainly nifedipine [standard dose,
10 mg t.i.d., regular preparation], used by one CAD
and six control patients) starting 3 days before the
study.

The frequency of physical activity of all subjects
was recorded in a questionnaire and found to be
rather low and not different between the groups (no
sport activity or less than once a week, 12 CAD and
11 control patients; once a week, five CAD and five
control patients; twice a week or more, three CAD
and four control patients). If anything, the intensity
of physical activity was higher in the CAD group, as
several of these patients still participated in rehabil-
itation programs.

CAD and control patients were selected according
to the following criteria: 1) plasma cholesterol less
than 260 mg/dl*, 2) low density lipoprotein (LDL)
cholesterol less than 200 mg/dl, 3) plasma triacylglyc-
erol concentration less than 200 mg/dl, 4) normal
blood pressure without medication, 5) absence of
obesity, liver disease, diabetes mellitus, thyroid dys-
fuction, kidney disease, or gastrointestinal disor-
ders, and 6) not smoking or only limited use of
cigarettes. (Two thirds were nonsmokers, the others
used only 1-15 cigarettes per day.) However, nearly
all subjects had been smokers in the past but had
stopped 9 months to 30 years earlier. The numbers of
current smokers in the CAD and control groups were
seven and four, respectively.) By excluding patients
with strong established risk factors for coronary
atherosclerosis or disturbed plasma lipoprotein met-
abolism, and subsequent patient matching (see be-
low), we aimed to exclude the confounding influence
of these factors in the interpretation of our data.

CAD and control patients were matched for age
difference <5 years), LDL cholesterol concentra-
tion (difference <50 mg/100 ml), and Quetelet index
difference <3). Only if a matched pair could be
formed were they entered into the study.

Patients were asked to participate after being in-
formed in a letter about the protocol and the objec-
tives of the study. More than 80% reacted positively.
The protocol for the study was approved by the ethical
committee of the Zuiderziekenhuis Rotterdam.

Protocol

Patients were hospitalized at the end of the after-
noon of the day preceding the study. In each session,
two subjects, a CAD patient and his matched control,
were studied. After a 6 PM evening meal, patients
were fasted overnight. At 8 AM the next morning,
blood samples were taken for various measurements
(see below), and patients received a liquid fat load
consisting of dairy cream (40% fat) supplemented
with egg yolk and retinyl palmitate. This mixture was
made into a milk shake after addition of a small
amount of milk powder. Each patient received a fat
load adjusted to his body composition (77.5 g fat, 0.5
g cholesterol, and 27,000 IU retinyl palmitate per
square meter of body surface area). The fat load was
consumed during a period of 15 minutes, and pa-
tients were deprived of any source of energy for the

*The present study started in 1984. According to current
concepts, the cutoff for "normal" (desired) plasma concentra-
tion of cholesterol for men aged 40-65 years is considered to be 200
mg/dl.
next 24 hours. Blood samples were taken during this period at 2, 4, 6, 8, 10, 12, 14, and 24 hours after consumption of the fat load. The fat load was well tolerated in all subjects. When asked, no one complained about gastrointestinal problems or steatorrhea. After 24 hours, patients received an intravenous injection of heparin (100 IU/kg body wt). Twenty minutes later, a blood sample was collected for postheparin plasma isolation, and patients received an intravenous injection of protamine sulfate (1 mg/kg body wt) to restore hemostasis.

**Analytical Methods**

**Lipoprotein fractionation.** Lipoproteins were fractionated from fasting serum samples (0.5 ml) by isopycnic density gradient ultracentrifugation essentially as described by Redgrave et al. Lipoprotein cholesterol profiles were obtained during elution of the gradients with an ISCO gradient fractionator (model 184, ISCO, Lincoln, Neb.) coupled to a Technicon autoanalyzer II, using specifications essentially as described by Boehringer for high density lipoprotein (HDL) cholesterol measurements on this instrument (Technicon autoanalyzer II, Boehringer-Mannheim, Mannheim, F.R.G., HDL cholesterol, cholesterol oxidase/phenol/4-amino-phenazone/peroxidase [CHOD-PAP] method, July 1983 edition, No. 783-6718-1217.1). This procedure resulted in total separation of VLDL, LDL, and HDL cholesterol peaks. Serum lipoprotein cholesterol concentrations were calculated by planimetry using sets of standard sera run before and after each gradient. Recoveries of cholesterol in this procedure were 100±8.6% (mean±SD).

HDL cholesterol subclass distributions were determined in a similar setup after fractionation of serum by rate zonal density gradient ultracentrifugation in an SW 40 rotor (Beckman Instruments, Palo Alto, Calif.) essentially as described previously. Cholesterol profiles in these gradients normally showed two HDL peaks and a large VLDL plus LDL peak “floating” on top of the gradient. A “shoulder” was often present on the “heavy” edge of the HDL3 peak and was designated HDL3b. Contributions of HDL2, HDL2 (“light” HDL3, the main HDL peak), and HDL3b were calculated by a newly developed deconvolution program run on an Olivetti M24 computer. Reproducible HDL subclass distributions could be calculated this way, and the resulting three-component profiles matched perfectly with measured cholesterol profiles after superimposition. Copies of the software can be obtained from the authors (P.H.E.G.).

Postprandial plasmas were fractionated in a VLDL plus intermediate density lipoprotein (IDL) fraction and an LDL plus HDL fraction by ultracentrifugation at d=1.019 g/ml and 4°C with a 40.3 rotor (Beckman), essentially as described previously. Plasma was kept at 0–4°C to inhibit lipid transfer activity during the ultracentrifugal procedure that could otherwise affect cholesteryl ester, retinyl ester, and triacylglycerol distributions.

**Apolipoprotein quantification and phenotyping.** Apolipoproteins A-I, A-II, and B were measured in samples of fasting serum by radial immunodiffusion as described earlier. Methods were standardized to give absolute protein values using pure apolipoprotein and LDL standards. Apolipoprotein E was also quantified by radial immunodiffusion using a pool of human sera as a standard. Consequently, for apolipoprotein E, data are expressed in relative units. Apolipoprotein E phenotyping was performed by isoelectric focusing of delipidated plasma, followed by immunoblotting, using apolipoprotein E antiserum as first antibodies, exactly as described by Havekes et al.

**Retinyl ester quantification.** Retinyl esters were determined in plasma and in the d<1.019 g/ml (VLDL plus IDL) and d=1.019 g/ml (LDL plus HDL) plasma fractions. Plasma samples for analyses were prepared at temperatures between 0°C and 4°C, shielded from light, and kept under N2 at –20°C until analysis (usually within 1 week). Lipid extractions were performed at temperatures below 4°C and were shielded from light. Plasma (0.8 ml), VLDL plus IDL fractions (0.8 ml), or LDL plus HDL fractions (1.6 ml) were extracted with a chloroform/methanol mixture containing 0.05% butylated hydroxytoluene according to Bligh and Dyer after addition of an internal retinyl acetate standard (16 μg). The chloroform phase of the extraction was removed, and 1.5 ml was dried under a stream of N2. Lipid residues were solubilized in 0.75 ml of a mixture of methanol and chloroform (3:1, vol/vol). Retinyl esters were separated and quantified by reverse-phase HPLC using a Radial-PAK C18 analytical column (Waters, Taunton, Mass.) equipped with a guard column (Guard-Pak precolumn, RClS C18) under isocratic conditions with a mixture of ethyl acetate and methanol (3:7, vol/vol) as the mobile phase (flow rate, 2 ml/min), essentially as described by Knook and de Leeuw. Retinol and the acetyl, lauryl, myristyl, palmityl, stearyl, oleyl, and linoleyl esters of retinol could be separated this way. The retinyl palmitate peak was by far the most prominent (~70% of the long-chain retinyl ester mass), and its relative contribution did not vary between patients and over time after fat ingestion. Therefore, we routinely measured this peak and calculated plasma concentrations using the internal retinyl acetate standard. Interassay variation was less than 2%, and plasma concentrations as low as 50 ng/ml could be measured accurately.

**Postheparin lipases and cholesteryl ester transfer activity measurements.** The activities of postheparin plasma lipoprotein lipase and hepatic lipase were determined as described previously. The amount of active cholesteryl ester transfer protein (CETP) was determined in samples of plasma delipidated by lipoprotein precipitation with dextran sulfate/MnCl2, by use of carbon-14–labeled cholesteryl oleate HDL as the donor and human LDL as the acceptor. The
assay contained human HDL (3 μg cholesteryl ester, 18,900 cpm), human LDL (150 μg cholesteryl ester), 25 mM sodium phosphate buffer, pH=7.4, 2 mM 5,5'-dithiobis-(2-nitrobenzoic acid), 150 mM NaCl, and 25 μl of delipidated plasma samples in a total volume of 250 μl. The assay mixture was incubated at 37°C for 4 hours, and radioactivity transferred to LDL was determined after LDL precipitation by dextran sulfate/MgCl2. Blanks in the assay contained 25 μl delipidated porcine plasma, a species lacking CETP activity. Samples were run in triplicate. Under the conditions employed, the transfer of radioactivity was linear over time. An evaluation of the assay has been published earlier.29

Data analysis. The mean and SEM of plasma parameters were calculated. As some of these parameters showed a non-Gaussian distribution, comparisons between CAD and control patients were performed by the Mann–Whitney U test. To evaluate changes in the distribution of lipids between the d<1.019 g/ml and d>1.019 g/ml density fractions before and after an oral lipid load, a Wilcoxon signed-rank test was used. Possible associations between several parameters were determined using linear regression as well as by Spearman’s rank correlation analysis. To quantify the magnitude of the postprandial responses in triacylglycerol and retinyl esters, the surface areas of those parts underneath the response peaks, defined by the connecting line between data points and a line originating at the t=0-hour value parallel to the* axis, were calculated for each person for several time intervals after ingestion of the lipid load. The resulting data sets were analyzed by the Mann–Whitney U test. Analyses were performed on a Digital VAX computer using BMDP or RS/E statistical packages.

Results
Characterization of Lipoprotein Parameters

Lipid and lipoprotein concentrations, determined in the plasmas of CAD patients and controls after an overnight fast, are given in Table 1. As a consequence of the selection protocol, plasma concentrations of total and LDL cholesterol are nearly identical in both groups of patients, as were age and Quetelet index. Plasma triacylglycerol concentrations were slightly different from those found in a normal Dutch population (see Reference 30).

Postprandial Triacylglycerol and Retinyl Ester Responses

CAD and control patients received the oral fat load at 8:30 AM. None of them complained about gastrointestinal problems or steatorrhea. During the day, patients moved freely throughout the ward and spent only limited time in bed. Complaints about hunger usually started in the beginning of the evening, but none of the patients had problems finishing the study. Results of the retinyl ester, cholesterol, and triacylglycerol analyses in the d<1.019 g/ml and d>1.019 g/ml fractions obtained by ultracentrifugation are shown in Figures 1–3. In response to the fat load, plasma triacylglycerol and retinyl ester concentrations rose sharply due to

<table>
<thead>
<tr>
<th>Parameter measured</th>
<th>CAD patients</th>
<th>Control patients</th>
<th>p&lt;0.05</th>
</tr>
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<tbody>
<tr>
<td>Cholesterol</td>
<td>220±8</td>
<td>215±6</td>
<td>NS</td>
</tr>
<tr>
<td>Triacylglycerol</td>
<td>145±8</td>
<td>126±8</td>
<td>NS</td>
</tr>
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<td>VLDL cholesterol</td>
<td>26±3</td>
<td>23±4</td>
<td>NS</td>
</tr>
<tr>
<td>LDL cholesterol</td>
<td>158±8</td>
<td>152±6</td>
<td>NS</td>
</tr>
<tr>
<td>HDL cholesterol</td>
<td>33±2</td>
<td>43±2</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>HDLc cholesterol</td>
<td>4.0±0.5</td>
<td>5.4±0.7</td>
<td>NS</td>
</tr>
<tr>
<td>HDLd cholesterol</td>
<td>24±1</td>
<td>31±2</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>Apolipoprotein A-I</td>
<td>129±3</td>
<td>154±5</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>Apolipoprotein A-II</td>
<td>51±2</td>
<td>59±2</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Apolipoprotein B</td>
<td>115±6</td>
<td>107±4</td>
<td>NS</td>
</tr>
<tr>
<td>Apolipoprotein E2</td>
<td>124±9</td>
<td>126±5</td>
<td>NS</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>52±1</td>
<td>51±1</td>
<td>NS</td>
</tr>
<tr>
<td>Quetelet index (kg/m2)</td>
<td>25±0.6</td>
<td>25±0.4</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values are mean±SEM.

CAD, coronary artery disease; VLDL, very low density lipoprotein; LDL, low density lipoprotein; HDL, high density lipoprotein; NS, not significant.

As chylomicron remnant uptake by the liver is known to be delayed in individuals with the apolipoprotein E2/E2 phenotype,10,19 all patients were phenotyped for apolipoprotein E. The data for these analyses are given in Table 2. Apolipoprotein E2 alleles were present in two CAD and four control patients, but only one of these CAD patients was found to be of the E2/E2 phenotype. Although groups were small, the observed frequencies are not very much different from those found in a normal Dutch population (see Reference 30).

Postprandial Triacylglycerol and Retinyl Ester Responses

CAD and control patients received the oral fat load at 8:30 AM. None of them complained about gastrointestinal problems or steatorrhea. During the day, patients moved freely throughout the ward and spent only limited time in bed. Complaints about hunger usually started in the beginning of the evening, but none of the patients had problems finishing the study. Results of the retinyl ester, cholesterol, and triacylglycerol analyses in the d<1.019 g/ml and d>1.019 g/ml fractions obtained by ultracentrifugation are shown in Figures 1–3. In response to the fat load, plasma triacylglycerol and retinyl ester concentrations rose sharply due to

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>CAD patients (n)</th>
<th>Control patients (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E3/E3</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>E3/E4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>E3/E2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>E2/E2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

CAD, coronary artery disease.
Postprandial Plasma Lipoproteins and CAD

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Increased concentrations in the \(d<1.019\) g/ml fraction. Peak levels were reached after about 6 hours (Figures 1 and 2), and no differences were found between the CAD and control patients in this ascending phase after ingestion of the fat load. In the time period between 6 and 12 hours after fat ingestion, plasma triacylglycerol concentrations returned to baseline, while retinyl esters showed a somewhat slower clearance from plasma. The magnitude of the triacylglycerol and retinyl ester responses were calculated for different time intervals as indicated in "Methods," and data are given in Tables 3 and 4. For all time intervals calculated, CAD patients showed larger responses to the oral fat load than did controls, the difference being particularly evident for the retinyl ester responses.

Plasma cholesterol concentrations were only minimally affected by consumption of the (cholesterol-rich) fat load (data not shown). Supposedly, as a consequence of increased concentration of acceptor lipoproteins (chylomicrons) and cholesteryl ester transfer activity,\(^{31}\) the cholesterol content of the \(d>1.019\) g/ml fraction decreases (Figure 3) while its triacylglycerol content increases (Figure 1). It is interesting to note that the triacylglycerol associated with the \(d>1.019\) g/ml fraction was higher in the CAD patient group than in controls, both before and after ingestion of the fat load (Figure 1). Cholesterol associated with the \(d<1.019\) g/ml fraction increased during the first 6 hours after ingestion of the fat load (Figure 3). No differences were evident between CAD and control patients in this phase. Eight hours after fat ingestion, cholesterol distributions started to return to prefeeding values. The profiles in Figure 3 indicate that this process takes more time in the CAD than in the control patient group. Cholesterol ester transfer activities in delipidated samples of plasmas of all CAD and control patients were determined in the fasted plasmas using an assay with \([^{14}\text{C}]\)cholesteryl ester–labeled donor HDL and unlabeled acceptor LDL.\(^{29}\) In this assay, which measures the amount of active CETP protein, no difference was observed between the two groups (145±2 versus 143±2 ng cholesteryl ester/hour/mg delipidated plasma protein, mean±SEM).

Measurement of Postheparin Plasma Lipase Activities

To investigate whether lipoprotein lipase and hepatic lipase activities are related to the observed difference in handling of plasma lipoproteins in the postprandial phase, patients received an intravenous
dose of heparin at the end of the 24-hour study period. The results of the lipase measurements are given in Table 5. Postheparin plasma lipoprotein lipase activities were only slightly lower in the CAD group as compared with control patients. Statistically significant differences were found for postheparin plasma hepatic lipase activities, which were lower in CAD patients.

Statistically significant positive associations were found between the level of fasting triacylglycerol and the magnitude of the triacylglycerol and retinyl ester responses in plasma (linear regression correlation coefficients as well as Spearman rank correlation coefficients between 0.52 and 0.6). Statistically significant negative associations were found between the levels of HDL₂ cholesterol and triacylglycerol responses and retinyl ester responses (linear regression correlation coefficients as well as Spearman's rank correlation coefficients between 0.34 and 0.40) but not with HDL₃₉ or HDL₃₉ cholesterol. No statistically significant associations were found between the magnitude of the triacylglycerol or retinyl ester responses over any of the time periods and activities of lipoprotein lipase or hepatic lipase, neither after linear regression nor after rank correlation analysis.

Discussion

It has been repeatedly suggested that a delayed clearance of postprandial lipoproteins from plasma may stimulate atherogenesis, but whether an abnormally high postprandial hyperlipemia is a risk factor is not well established. The present study was aimed at investigating the validity of these suggestions.

To overcome complications in interpretation of results due to the presence of multiple risk factors, stringent selection and entry criteria were used for patients, thereby allowing us to investigate postprandial plasma lipoprotein metabolism in groups of normolipidemic CAD and control patients with similar plasma total and LDL cholesterol concentration, Quetelet index, and age distributions. Bias toward history of medication was difficult to avoid. β-Adrenergic blockers (mainly metoprolol) were used by 11 CAD and three control patients, while calcium channel blockers (mainly nifedipine) were used by one CAD and six control patients. Metoprolol administration in humans has, in some studies, been associated with a mild hypertriglyceridemia and HDL-lowering effects, and although the use of this medication was stopped 3 days before the study, some effects of history of medication on the outcome of our study is at present difficult to exclude.

Challenging CAD and control patients with an oral fat load resulted in a marked and nearly identical increase of plasma triacylglycerol and retinyl ester concentrations in both groups due to the appearance of chylomicrons in plasma. The most significant finding in the present study is that the triacylglycerol and especially the retinyl ester concentrations in the plasma of CAD patients remained elevated for a prolonged period as compared with that of control patients, suggesting a delay in the clearance of postprandial lipoproteins. As postheparin lipoprotein lipase activities were not different between the two groups, a slower rate of chylomicron remnant removal could explain these findings. Differences in gastric emptying after the lipid load or efficiency of lipid absorption could also affect postprandial responses, but because we excluded patients with gastrointestinal disorders and had no indications for lipid malabsorption during our studies, an explanation of our findings at that level seems unlikely.

During the postprandial phase, transfer of cholesterol esters from HDL to triacylglycerol-rich lipoproteins and transport of triacylglycerol in the reverse direction has been found to be increased. It is of interest to note that in CAD patients, the triacylglycerol concentration associated with the d>1.019 g/ml fraction is increased compared with controls, both before as well as during the oral lipid load test.
TABLE 3. Plasma and d<1.019 g/ml Triacylglycerol Responses After Ingestion of Oral Fat Load

<table>
<thead>
<tr>
<th>Response interval (hr)</th>
<th>Plasma CAD patients (g/[lxhr])</th>
<th>Control CAD patients (g/[lxhr])</th>
<th>p*</th>
<th>Plasma Control patients (g/[lxhr])</th>
<th>Control CAD patients (g/[lxhr])</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-24</td>
<td>17.1±2.1</td>
<td>14.5±2.5</td>
<td>p&gt;0.05</td>
<td>15.1±1.9</td>
<td>12.1±1.9</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>6-24</td>
<td>13.8</td>
<td>12.1</td>
<td></td>
<td>11.6</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>8-24</td>
<td>7.6±1.1</td>
<td>4.9±1.3</td>
<td>p&lt;0.05</td>
<td>6.4±1.0</td>
<td>3.9±1.0</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>10-24</td>
<td>6.7</td>
<td>2.6</td>
<td></td>
<td>4.6</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>12-24</td>
<td>2.8±0.6</td>
<td>1.3±0.6</td>
<td>p&lt;0.01</td>
<td>2.4±0.5</td>
<td>0.9±0.2</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>14-24</td>
<td>0.7±0.2</td>
<td>0.2±0.1</td>
<td>p&lt;0.05</td>
<td>0.6±0.2</td>
<td>0.1±0.1</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>20-24</td>
<td>0.2</td>
<td>0</td>
<td></td>
<td>0.1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Plus-minus values are mean±SEM; single values are median. Magnitudes of the triacylglycerol responses were calculated as described in "Methods."

CAD, coronary artery disease.

*Probability value of CAD versus control patients by Mann–Whitney U test.

Triacylglycerol concentrations associated with the d<1.019 g/ml fractions before ingestion of the fat load were not different between the two groups (Figure 1). Speculating on the mechanism of these findings, it seems possible that the prolonged circulation of postprandial (triacylglycerol donor) lipoproteins favors transfer of triacylglycerol to the d>1.019 g/ml lipoproteins, thereby explaining these observations. Cholesterol concentrations associated with the d>1.019 g/ml fractions decreased during the postprandial phase (Figure 3), supposedly due to transfer of cholesterol ester from d>1.019 g/ml to postprandial lipoproteins as described earlier by others.31,34,35 The decrease in the d>1.019 g/ml cholesterol is slightly larger in the CAD patient group between 10 and 24 hours after the lipid load, in line with the previously mentioned concept of prolonged acceptor availability in CAD patients. CETP activity in delipidated, fasted plasma samples was found not to differ between CAD and control patients.

In the present study, postprandial lipoprotein metabolism was studied in normolipidemic CAD patients. A delayed removal of postprandial lipoproteins from plasma was described earlier by several investigators in patients with dyslipoproteinemia (type III) and endogenous hypertriglyceridemia (type IV)9,10,17-18 and was suggested to play a role in their premature atherosclerosis. Chylomicrons were found to accumulate in type IV and chylomicron remnants in type III hyperlipoproteinemic plasmas.18 Cortner et al10 reported recently that the delayed clearance of postprandial lipoproteins in type IV patients is secondary to overproduction of VLDL particles, whose remnants compete with chylomicron remnants for removal by the hepatic chylomicron remnant receptors. In this study and a second one by Brenninkmei-

TABLE 4. Plasma and d<1.019 g/ml Retinyl Palmitate Responses After Ingestion of Oral Fat Load

<table>
<thead>
<tr>
<th>Response interval (hr)</th>
<th>Plasma CAD patients (mg/[lxhr])</th>
<th>Control CAD patients (mg/[lxhr])</th>
<th>p*</th>
<th>Plasma Control patients (mg/[lxhr])</th>
<th>Control CAD patients (mg/[lxhr])</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-24</td>
<td>18.7±2</td>
<td>14.0±1.6</td>
<td>p&gt;0.05</td>
<td>14.7±1.9</td>
<td>10.7±1.5</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>6-24</td>
<td>17</td>
<td>11.5</td>
<td></td>
<td>12.4</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>8-24</td>
<td>13.3±1.6</td>
<td>8.7±1.1</td>
<td>p&lt;0.05</td>
<td>10.0±1.5</td>
<td>6.2±1.1</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>10-24</td>
<td>12.4</td>
<td>7.7</td>
<td></td>
<td>8.6</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>12-24</td>
<td>9.2±1.3</td>
<td>5.4±0.7</td>
<td>p&lt;0.01</td>
<td>5.5±0.7</td>
<td>2.5±0.7</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>14-24</td>
<td>6.1±0.9</td>
<td>3.5±0.4</td>
<td>p&lt;0.01</td>
<td>3.8±0.8</td>
<td>1.8±0.3</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>16-24</td>
<td>5.1</td>
<td>3</td>
<td></td>
<td>2.9</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>18-24</td>
<td>4.3±0.6</td>
<td>2.5±0.2</td>
<td>p&lt;0.01</td>
<td>2.4±0.5</td>
<td>1.2±0.2</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>20-24</td>
<td>3.7</td>
<td>2.2</td>
<td></td>
<td>1.7</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>22-24</td>
<td>3.2±0.4</td>
<td>1.9±0.2</td>
<td>p&lt;0.01</td>
<td>1.7±0.4</td>
<td>0.9±0.2</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>24-24</td>
<td>2.8</td>
<td>1.7</td>
<td></td>
<td>1.2</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

Plus-minus values are mean±SEM; single values are median. Magnitude of retinyl palmitate responses was calculated as described in "Methods."

CAD, coronary artery disease.

*Probability value of CAD versus control patients by Mann–Whitney U test.
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Table 5. Postheparin Plasma Lipase Activities in Coronary Artery Disease Patients and Controls

| Activity             | CAD patients | Control patients | p*  
|----------------------|--------------|------------------|------
| Lipoprotein lipase   | 97±7         | 114±11           | NS   
| Hepatic lipase       | 231±17       | 319±23           | <0.01

Activity in nmol fatty acid released per minute per milliliter of plasma; mean±SEM.

CAD, coronary artery disease.

*pProbability value of CAD versus control patients by Mann-Whitney U test.

It was shown that chylomicron remnant clearance is impaired in subjects with E2/E2 phenotype both in patients with type III dysbetalipoproteinemia as well as in normolipidemic subjects with this phenotype. Clearance of chylomicron remnants in heterozygous E2 subjects was found not to differ from controls.19

Although in our study the apolipoprotein E phenotype distribution varied slightly between CAD patients and controls, this did not have a major impact on the outcome of our experiments. Subgroup analysis (using only individuals with the E3/E3 phenotype) showed that the levels of both plasma triacylglycerol as well as retinyl esters measured after ingestion of the fat load remained significantly higher in the CAD patients at all time points found for the whole group, except for the 10-hour point, despite the smaller number of individuals (13 CAD and 12 control patients).

In conclusion, we think that our present studies support the hypothesis that slow removal of postprandial lipoproteins could play a role in atherogenesis and are unique, as we were able to demonstrate a relation between disturbed postprandial lipoprotein metabolism and the presence of coronary atherosclerosis in well-matched groups of normolipidemic CAD and control patients. It should, however, be stressed that our control group consisted of patients (with the advantage of having coronary angiography data available) and not normals, and at present, it cannot be excluded that this control group selection has biased our findings.

An important but still unresolved area of research is the relation between postprandial lipoprotein metabolism, HDL, and atherosclerosis. In the present study, it was found that plasma HDL parameters were lower in CAD patients as compared with controls. Low levels of plasma HDL have been associated with high risk for CAD in numerous epidemiological studies. Furthermore, it has been shown that high fasting levels of triacylglycerol are associated with low levels of plasma HDL and that subjects with low levels of plasma HDL or HDL show a marked postprandial hypertriglyceridemia. HDL may be directly implicated in counteracting atherosclerotic processes by functioning as a vehicle for reverse cholesterol transport, or alternatively, high levels of HDL may reflect an efficient handling of postprandial lipoproteins and VLDL and consequent minimal exposure of the vascular bed to potentially atherogenic lipoproteins. It is fair to say that the sequence of causes and consequences in the relation among HDL, postprandial responses, and CAD is still not very well defined. Therefore, our data and those of others on postprandial plasma lipoprotein metabolism indicate that chylomicron remnants could be implicated in atherogenesis but do not prove a direct causal relation.

Of interest is the present finding that activities of hepatic lipase are lower in CAD patients than in controls. Low hepatic lipase activities have been found earlier in groups of normolipidemic coronary angiography patients. Furthermore, it was found recently in the dietary Leiden Intervention Trial that hepatic lipase activities were significantly lower in the patient group that showed progression of atherosclerosis as compared with the group that showed no progression. Hepatic lipase activity has been associated with HDL cholesterol uptake by the liver, as well as chylomicron remnant and LDL catabolism. No statistically significant correlation was found in our present data between HDL and hepatic lipase activities. However, HDL cholesterol concentrations in our patients were low compared with those of normal healthy men analyzed by the same method (compare References 21 and 46), and the clustering of data points at the lower end of the normal HDL concentration range may explain our inability to find such an inverse relation.

Although postprandial lipoprotein clearance in the CAD group was delayed and hepatic lipase activities were low, no statistically significant association between retinyl ester responses (total or between 8 and 24 hours) and hepatic lipase activities could be demonstrated. This finding makes it difficult to speculate that low levels of hepatic lipase in CAD patients are implicated in the delayed clearance of postprandial lipoproteins in these patients. Other factors, that is, the activity of hepatic chylomicron remnant receptors and/or the apolipoprotein E phenotype, as well as the content of chylomicron remnants, may play a more prominent role in this process.

Identification of these factors will be critical in understanding disturbed postprandial lipoprotein metabolism and its implications for atherogenesis.

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**Key Words**  • chylomicrons  • chylomicron remnants  • postprandial lipoproteins  • oral fat load  • coronary artery disease
Postprandial lipoprotein metabolism in normolipidemic men with and without coronary artery disease.


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