Role of Hepatic-Triglyceride Lipase Activity in the Association between Intra-abdominal Fat and Plasma HDL Cholesterol in Obese Women

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Intra-abdominal fat content is an important variable in the association between regional body fat distribution and plasma high density lipoprotein (HDL) cholesterol levels. In the present study, we report on the role of plasma postheparin lipases as well as abdominal and femoral adipose tissue lipoprotein lipase activities in the association between body fat distribution and plasma lipoprotein levels. Postheparin plasma lipoprotein lipase (LPL), hepatic-triglyceride lipase (H-TGL), abdominal and femoral adipose tissue (AT>LPL activities and plasma lipoprotein levels were measured after an overnight fast in a sample of 16 obese women (ages 36.0±6.1 years [mean±SD], percent body fat 46±6%). Computed axial tomography was used to assess body fat distribution. Plasma postheparin LPL activity was neither correlated with total adiposity nor with the level of Intra-abdominal fat. Intra-abdominal fat deposition was, however, positively correlated with H-TGL activity (r=0.66, p<0.005). Furthermore, covariance analysis showed that the association between intra-abdominal fat and H-TGL was independent from total adiposity. Plasma postheparin LPL and abdominal AT-LPL activities showed no significant correlation with plasma lipoprotein levels, whereas femoral AT-LPL activity was positively correlated with the HDL₃ cholesterol/HDL₂ cholesterol ratio (r=0.51, p<0.05). H-TGL activity was, however, negatively correlated with HDL₃ cholesterol (r=−0.60, p<0.05), but not with HDL₅ cholesterol (r=−0.28, NS). These results suggest that the high H-TGL activity in obese women with excess deep abdominal fat could be responsible for the reduction in plasma HDL₃ cholesterol levels. It should, however, be emphasized that these cross-sectional observations do not necessarily reflect a cause-effect relationship and that additional experimental studies are needed to substantiate the present findings. (Arteriosclerosis 9:485-492, July/August 1989)

Numerous studies have demonstrated that variations in plasma lipid and lipoprotein levels that are observed in obesity are related to the regional distribution of body fat.¹⁻¹¹ These changes in plasma lipid and lipoprotein levels could be partly responsible for the independent relation of body fat distribution to the incidence of coronary heart disease (CHD).¹²⁻¹⁷ Indeed, studies that have used skinfolds and the waist-to-hip circumference ratio to assess regional body fat distribution have shown that individuals with a high proportion of abdominal fat display significant changes in their plasma lipid and lipoprotein levels, such as an increase in plasma triglyceride concentration¹⁻¹¹ and a reduction in plasma high density lipoprotein (HDL) cholesterol levels.⁵⁻¹¹ Individuals with a peripheral accumulation of body fat, however, display a normal lipoprotein profile and a low risk of CHD.¹⁻¹¹ Recent advances in the assessment of adipose tissue distribution have allowed the accurate measurement of both deep and subcutaneous fat content, and with the use of computed-assisted tomography,¹⁸⁻²³ it has been possible to determine the respective associations between deep and subcutaneous fat deposits and plasma lipoprotein levels. We have recently reported that, in a sample of obese women, deep abdominal fat was the critical variable in the association between body fat distribution and plasma HDL cholesterol levels.²⁴ Multiple regression analyses also indicated that intra-abdominal fat was the variable of body fat distribution that explained the largest amount of variance of lipoprotein ratios (HDL cholesterol/low density lipoprotein [LDL] cholesterol; HDL apoprotein [apo] A-1/LDL apo B; and HDL₃ cholesterol/HDL₅ cholesterol) that are often used in the estimation of the risk of CHD.²⁴ We have, therefore, suggested that a high intra-abdominal fat content should be considered as a risk factor for CHD.²⁴ The mechanisms for the association between intra-abdominal fat and HDL cholesterol levels have not, however, been elucidated.

It is well known that the activity of triglyceride lipases, namely lipoprotein lipase (LPL) and hepatic triglyceride...
lipase (H-TGL), are important in the metabolism of lipoproteins and also in the regulation of plasma HDL levels.25-32 In numerous experimental conditions, it has been shown that subjects with high plasma LPL activity have high HDL levels,25-28 whereas subjects with high H-TGL activity have low HDL levels.29-32 Since HDL cholesterol, and particularly HDL₂ cholesterol concentrations, are decreased in relation to intra-abdominal fat content, we therefore investigated the potential role of triglyceride lipases as a potential mechanism for explaining these associations in a sample of obese women.

Methods

Subjects

The sample of 16 obese women studied in the present paper was part of a larger group of 52 premenopausal obese women who participated in a study designed to investigate the associations between body fat distribution measured by computed tomography25 and metabolic variables, such as glucose tolerance and plasma insulin levels,24 and plasma lipoprotein concentrations.24 The physical and metabolic characteristics of the original sample of 52 obese women have, therefore, been described in detail. At the time of the study, the subjects were solicited for further tests that required adipose tissue biopsies and collection of postheparin plasma for the measurement of adipose tissue and plasma lipase activities. Among the 52 women originally studied, 16 subjects volunteered to participate in the additional tests. The physical and metabolic characteristics of this subsample of 16 women, presented in Table 1, were not significantly different from those of the original sample.24 All subjects signed an informed consent document as required by the Laval University Medical Ethics Committee. A physician gave each subject a complete physical examination that included a medical history, and subjects with cardiovascular disease or endocrine disorders (such as hirsutism) or those on medication were excluded. Diabetic subjects were excluded from the study, but two women had plasma glucose values >140 but <200 mg/dl at 2 hours after an oral glucose tolerance test and were diagnosed by the classification of the National Diabetes Data Group as having impaired glucose tolerance.35 All participants were tested during the early follicular phase of their menstrual cycles and in weight-stable periods.

Computed Tomography

Computed tomography was performed on a Siemens Somatom DRH scanner (Erlangen, FRG) by using the procedures of Sjöström et al.20 as previously described.33 Briefly, we performed an abdominal scan using a radiograph of the skeleton as a reference to establish the position of the scan (between L4 and L5) to the nearest millimeter. The total and deep fat areas were calculated by delineating these areas with a graph pen and then computing the adipose tissue surfaces; an attenuation range of -30 to -190 HU was used.20,21 The intra-abdominal fat area was measured by drawing a line within the muscle wall surrounding the abdominal cavity. The subcutaneous fat was calculated by subtracting the amount of intra-abdominal fat from the total fat area.

Measurement of Total Body Fat

The total body fat was obtained from the body density measured by hydrostatic weighing as previously described,24 and the percent body fat was derived from body density using the equation of Siri.37 The fat mass was obtained by multiplying percent body fat by body weight. Pulmonary residual volume was measured by using the helium dilution technique of Meneely and Kaltreider.36 Waist and hip circumferences were also measured by following the procedures of the Airline Conference.39

Oral Glucose Tolerance Test

A 75 g oral glucose tolerance test (OGTT) was performed in the morning after an overnight fast. Blood samples were collected through a venous catheter from an antecubital vein at -15, 0, 15, 30, 45, 60, 90, 120, 150, and 180 minutes for the determination of plasma glucose and insulin concentrations. Plasma glucose was enzymatically measured,42 whereas plasma insulin was measured by radioimmunoassay with polyethylene glycol separation.41 The postglucose plasma glucose and insulin areas under the curve were determined by using the trapezoid method.

Adipose Tissue Biopsies and Measurement of Adipose Tissue Lipoprotein Lipase Activity

Adipose tissue was surgically removed under local anesthesia from the abdominal (lateral to the umbilicus) and the femoral (anterior midthigh) fat deposits. Approximately 500 mg of adipose tissue was obtained from each site. Samples of adipose tissue were immediately frozen for the measurement of heparin releasable LPL activity24 as previously described.43 Fat cells were also isolated by collagenase digestion,44 and the mean fat cell size was measured by using a microscope equipped with a graduated ocular as previously described.45 The density of triolein was used to transform adipose cell volume into fat cell weight. Adipose tissue (AT)-LPL activity was expressed in μmol free fatty acid (FFA)/h/10⁶ cells. Due to the

Table 1. Characteristics of Sample of 16 Premenopausal Obese Women

<table>
<thead>
<tr>
<th>Variable (unit)</th>
<th>Means±SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>36.0±6.1</td>
<td>25.1-49.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>89.7±14.4</td>
<td>67.2-120.6</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>35.0±4.7</td>
<td>28.0-44.8</td>
</tr>
<tr>
<td>% body fat</td>
<td>46.4±6.2</td>
<td>34.8-55.1</td>
</tr>
<tr>
<td>WHR</td>
<td>0.81±0.05</td>
<td>0.75-0.93</td>
</tr>
<tr>
<td>Fat cell weight (μg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal</td>
<td>0.79±0.22</td>
<td>0.52-1.23</td>
</tr>
<tr>
<td>Femoral</td>
<td>0.88±0.19</td>
<td>0.53-1.11</td>
</tr>
<tr>
<td>Plasma lipid and HDL cholesterol levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TG (mg/dl)</td>
<td>145±42</td>
<td>88-222</td>
</tr>
<tr>
<td>CHOL (mg/dl)</td>
<td>213±34</td>
<td>153-293</td>
</tr>
<tr>
<td>HDL-CHOL (mg/dl)</td>
<td>43±9</td>
<td>32-61</td>
</tr>
</tbody>
</table>

BMI = body mass index, WHR = waist-to-hip circumference ratio, TG = triglyceride, CHOL = cholesterol, HDL = high density lipoprotein.
well-known association between fat cell size and AT-LPL activity, we also expressed AT-LPL activity per unit of cell surface (nmol FFA/m²). We previously reported that the intraclass reliability of our LPL assay reached 0.81 under standardized conditions.

**Plasma Postheparin Triglyceride Lipase Activities**

LPL and H-TGL activities were measured in plasma obtained from subjects who had fasted for 12 hours at 10 and 20 minutes after an i.v. injection of heparin (10 IU/kg body weight). Selective assays for enzyme activities of LPL and H-TGL were performed by a modification of the method of Nilsson-Ehle and Ekman.44 These assays are in agreement with the results obtained by the selective inhibition of H-TGL with antihistamin lipase antibodies.47 Plasma was separated by low-speed centrifugation at 4°C, and a 0.5-ml aliquot was frozen and lyophilized overnight. Acetone-ether powders were then prepared from these lyophilized samples, were dried under nitrogen, and were stored at −20°C until assayed. The acetone-ether powders were dissolved in 2 ml of 0.9% NaCl and were used as an enzyme source for the measurements of both LPL and H-TGL activities. Two different substrates and selective assay conditions were used to measure the LPL and H-TGL activities.

The H-TGL activity was measured using as the substrate an artificial emulsion containing 0.2 M Tris-HCl buffer (pH 9.0), 4 mg/ml of FFA-free albumin, 0.17 mg/ml of egg lecithin, and 2.5 mg/ml of glycerol tri-14C-oleate (0.15 μCi/mg). The substrate was sonicated for 30 seconds three times at 1-minute intervals in an ice bath to avoid overheating; a Polytron (Brinkman Instruments Incorporated, Westbury, NY) was used. Two aliquots (0.2 ml each) of the enzyme extract were preincubated for 5 minutes at 37°C in a shaking water bath with an equal volume of 2.0 M NaCl to inhibit LPL activity; this was followed by a 20-minute incubation in the presence of 0.4 ml substrate. Incubations were terminated by addition of 2 ml mixture of isopropanol:3 N H2SO4 (40:1). Lipids were extracted by the addition of 1 ml H2O and 2.5 ml hexane. The hexane phase was removed, and the aqueous phase was re-extracted with 2.5 ml hexane. One milliliter of 0.1 N NaOH in ethylene glycol was added to the combined hexane phases; this was shaken and centrifuged. One milliliter of the ethylene glycol phase containing the FFA was removed and counted for 14C in 14 ml of Aquasol (New England Nuclear, Lachine, Quebec).

LPL activity was measured by using as substrate an artificial emulsion containing 0.2 M Tris-HCl buffer (pH 8.0), 1.7 mg/ml of FFA-free albumin, 5 mg/ml of glycerol tri-14C-oleate (0.15 μCi/mg), and acetone-ether extract corresponding to 1.2 ml of pooled normal human serum as a source of apo C-II. The substrate was emulsified as described above with 1% Triton X-100 (0.07% final concentration). Aliquots in duplicate (0.2 ml) of the enzyme extract were preincubated for 5 minutes at 30°C in a shaking water bath with an equal volume of 0.2 M Tris-HCl (pH 8.0) with or without 3% protamin. The assay mixture was further incubated for 20 minutes in the presence of 0.4 ml substrate. After the termination of the incubation, the radioactivity was counted as described above. LPL activity was calculated as the lipase activity sensitive to 3% protamin from the total lipase activity (without protamin). LPL and H-TGL activities represent the means of the two samples obtained 10 and 20 minutes after heparin injection and are expressed as nmol of oleic acid released per milliliter of plasma per minute. The linearity of both assays was standardized using acetone powders prepared from human milk (unpublished data).

**Plasma Lipoprotein Analyses**

Blood samples were obtained in the morning after an overnight 12-hour fast from an antecubital vein into Vacutainer tubes containing ethylenediaminetetraacetic acid (EDTA). Samples were collected while subjects were in the early follicular phase of their menstrual cycles. Cholesterol and triglyceride (TG) levels were determined in plasma and in lipoprotein fractions using an Auto-Analyzer II (Technicon Instruments Corporation, Tarrytown, NY) as previously described.44 Very low density lipoproteins (VLDL, d<1.006 g/ml) were isolated by ultracentrifugation, and the HDL fraction was obtained after precipitation of LDL in the infranatant (d>1.006 g/ml) with heparin and MnCl2.50 The cholesterol content of HDL2 and HDL3 was also determined after further precipitation of HDL2.51

**Results**

The characteristics of premenopausal women are summarized in Table 1. All subjects were younger than 50 years of age. The body fatness variables indicated that adiposity varied from moderate to massive obesity with large adipocytes as reflected by high abdominal and femoral fat cell weights.

Table 2 presents the associations between the waist-to-hip circumference ratio (WHR), abdominal adipose tissue areas measured by computed tomography, and plasma lipoprotein levels. The WHR was positively correlated with plasma VLDL cholesterol levels and negatively correlated with plasma HDL cholesterol, HDL2 cholesterol, and HDL3 cholesterol levels. Table 2 also shows that plasma VLDL concentration was not significantly correlated with the abdominal adipose tissue areas. The HDL2 cholesterol level was, however, negatively correlated with the deep abdominal fat area. Trends for associations between deep abdominal fat and HDL cholesterol, as well as HDL2 cholesterol/HDL3 cholesterol ratio, were also noted, but they did not reach statistical significance in this subsample (n=16) as compared to our recently reported data on a larger sample of obese women.24

Table 3 shows the correlations between adiposity, indices of body fat distribution and of carbohydrate metabolism, and postheparin plasma and adipose tissue AT lipolytic enzyme activities. The plasma postheparin LPL and AT-LPL activities showed no significant correlation with total adiposity, with regional body fat distribution, nor with indices of carbohydrate metabolism. Plasma postheparin H-TGL activity was, however, positively correlated with the degree of adiposity as reflected by the significant positive correlations with percent body fat as well as with abdominal and femoral fat cell weights. Trends for positive correlations between abdominal and
Table 2. Correlation Coefficients between Waist-to-Hip Ratio, Adipose Tissue Areas at Abdominal (L4–L5) Region Determined by Computed Tomography, and Plasma Lipoprotein Levels in Obese Women

<table>
<thead>
<tr>
<th>Variable</th>
<th>WHR</th>
<th>Total (0.08)</th>
<th>Deep (0.20)</th>
<th>Subc (0.02)</th>
<th>Deep/total (0.24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLDL-CHOL (Log 10)</td>
<td>0.59*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL-CHOL</td>
<td>-0.39</td>
<td>-0.20</td>
<td>-0.27</td>
<td>-0.16</td>
<td>-0.14</td>
</tr>
<tr>
<td>HDL-CHOL</td>
<td>-0.66†</td>
<td>-0.42</td>
<td>-0.44</td>
<td>-0.37</td>
<td>-0.03</td>
</tr>
<tr>
<td>HDL2-CHOL</td>
<td>-0.61*</td>
<td>-0.48†</td>
<td>-0.50*</td>
<td>-0.43</td>
<td>-0.06</td>
</tr>
<tr>
<td>HDL2-CHOL/LDL-CHOL</td>
<td>-0.64‡</td>
<td>-0.30</td>
<td>-0.32</td>
<td>-0.27</td>
<td>-0.01</td>
</tr>
<tr>
<td>HDL2-CHOL/HDL3-CHOL</td>
<td>-0.25</td>
<td>-0.22</td>
<td>-0.19</td>
<td>-0.20</td>
<td>0.07</td>
</tr>
<tr>
<td>Deep/total abdominal areas</td>
<td>-0.29</td>
<td>-0.42</td>
<td>-0.43</td>
<td>-0.38</td>
<td>-0.09</td>
</tr>
</tbody>
</table>

WHR = waist-to-hip ratio, Subc = subcutaneous, VLDL = very low density lipoprotein, LDL = low density lipoprotein, HDL = high density lipoprotein, CHOL = cholesterol.

Table 3. Correlation Coefficients between Total Adiposity, Indices of Body Fat Distribution and of Carbohydrate Metabolism, and Triglyceride Lipases in Obese Women

<table>
<thead>
<tr>
<th>Variable</th>
<th>Postheparin plasma LPL</th>
<th>LPL (10^6 cells)</th>
<th>H-TGL (nmol FFA/hr/10^6 cells)</th>
<th>Adipose tissue LPL</th>
<th>Abdominal (10^6 cells)</th>
<th>Femoral (10^6 cells)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI</td>
<td>-0.25</td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% body fat</td>
<td>-0.33</td>
<td>0.55*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat cell weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal</td>
<td>-0.14</td>
<td>0.51*</td>
<td>0.43</td>
<td>0.21</td>
<td>0.24</td>
<td>0.08</td>
</tr>
<tr>
<td>Femoral</td>
<td>-0.20</td>
<td>0.53*</td>
<td>0.32</td>
<td>0.21</td>
<td>0.44</td>
<td>0.22</td>
</tr>
<tr>
<td>WHR</td>
<td>-0.20</td>
<td>0.49†</td>
<td>0.13</td>
<td>0.19</td>
<td>-0.12</td>
<td>-0.20</td>
</tr>
<tr>
<td>OGTT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulin area</td>
<td>-0.16</td>
<td>0.32</td>
<td>0.62‡</td>
<td>0.49†</td>
<td>0.19</td>
<td>0.05</td>
</tr>
<tr>
<td>Glucose area</td>
<td>-0.13</td>
<td>0.05</td>
<td>-0.40</td>
<td>-0.39</td>
<td>-0.48†</td>
<td>-0.39</td>
</tr>
<tr>
<td>Ins/glu areas</td>
<td>-0.10</td>
<td>0.26</td>
<td>0.74‡</td>
<td>0.63‡</td>
<td>0.34</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Adipose tissue LPL: 10^6 cells = nmol FFA/hr/10^6 cells; nmol FFA/hr/μm²/10^6 cells.

†p<0.05, †p<0.06, †p<0.006, †p<0.001.

LPL = lipoprotein lipase, H-TGL = hepatic triglyceride lipase, BMI = body mass index, WHR = waist-to-hip circumference ratio, OGTT = oral glucose tolerance test, Ins/glu areas = ratio of insulin area/glucose area, FFA = free fatty acid.

femoral fat cell weights, on one hand, and abdominal and femoral AT-LPL activities expressed per 10^6 cells, on the other hand, were observed but they did not reach statistical significance. The plasma insulin area under the OGTT curve was, however, positively correlated with abdominal AT-LPL activity, and the correlation remained significant after control for fat cell surface. The insulinogenic index (ratio of insulin area/glucose area) displayed an even closer relationship with abdominal AT-LPL activity. These relationships were not observed, however, for femoral AT-LPL activity. In the femoral deposit, a trend for a negative correlation was observed between the glucose area and AT-LPL activity expressed on a per cell basis, suggesting that women with impaired glucose tolerance had a reduced femoral AT-LPL activity.

As shown in Figure 1, the plasma postheparin LPL activity was not significantly associated with the absolute amount of deep abdominal fat measured by computed tomography nor with the subcutaneous adipose tissue area measured in the same region. As illustrated in Figure 2, H-TGL activity was positively correlated with the absolute amount of deep abdominal fat, but it showed no significant relationship with subcutaneous abdominal fat.

Since both total adiposity and deep abdominal fat were significantly correlated with H-TGL activity, partial correlation coefficients were calculated to measure the independent contribution of deep abdominal fat and total adiposity to H-TGL activity. The results indicate that when we controlled for the effect of total adiposity on the H-TGL activity, deep abdominal fat remained significantly correlated with activity (r=0.48, p<0.05). On the contrary, when we adjusted percent body fat for the effect of deep abdominal fat, there was no significant residual correlation between total adiposity and H-TGL activity (r=0.22, NS). These results demonstrate that the association between deep abdominal fat content and H-TGL activity is entirely independent of the variation in total body fatness.

Table 4 shows data on the relationships between postheparin plasma triglyceride lipase activities, abdominal and femoral AT-LPL activities, and plasma lipoprotein levels. In this sample of obese women, both plasma and abdominal AT-LPL activities were not significantly corre-
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Discussion

Intra-abdominal Fat, Hepatic Triglyceride Lipase Activity, and HDL₂ Cholesterol

Our results clearly demonstrate that there is a significant association between intra-abdominal fat accumu-

lation with plasma lipoprotein levels. Trends for a negative association between femoral AT-LPL activity and plasma VLDL cholesterol levels and for a positive association between femoral AT-LPL and HDL₂ cholesterol levels were observed, but they did not reach statistical significance. The ratio of HDL₂ cholesterol/HDL₃ cholesterol was, however, positively correlated with femoral AT-LPL activity when expressed per unit of cell surface (r=0.51, p<0.05). Finally, the H-TGL activity was negatively correlated with the HDL₂ cholesterol levels and with the HDL₂ cholesterol/HDL₃ cholesterol ratio, but was not significantly correlated with HDL₃ cholesterol levels.

Discussion

Intra-abdominal Fat, Hepatic Triglyceride Lipase Activity, and HDL₂ Cholesterol

Our results clearly demonstrate that there is a significant association between intra-abdominal fat accumu-

lation and the activity of postheparin plasma H-TGL, and that this association is independent from the effect of obesity per se. A positive relationship between the level of obesity and plasma H-TGL activity was reported previously, and our results are concordant with these observations. However, in the covariance analysis with the inclusion of intra-abdominal fat as a covariate, no significant residual correlation could be found between obesity and plasma H-TGL activity, thereby suggesting that intra-abdominal fat accumulation is the best fatness correlate of H-TGL activity. The negative association that we found between postheparin plasma H-TGL activity and plasma HDL₂ cholesterol levels is concordant with the results of numerous studies that have suggested that H-TGL plays a role in the catabolism of HDL₂ or in the conversion of HDL₂ to HDL₃. In the present study, however, H-TGL activity was negatively correlated with the ratio of HDL₂ cholesterol/HDL₃ cholesterol, and this association was due to a reduction in HDL₂ cholesterol.
rather than to an increase in HDL₃ cholesterol levels. This finding is concordant with the observation of Applebaum-Bowden et al.⁵² who reported that an increase in H-TGL activity induced by administration of an anabolic steroid was associated with a reduction in plasma HDL₂ cholesterol but not with an increase in HDL₃ cholesterol.

To the best of our knowledge, it is the first time that significant associations between deep abdominal fat, plasma H-TGL activity, and plasma HDL₂ cholesterol levels have been reported. Although the association between plasma H-TGL activity and HDL₂ cholesterol levels appears to reflect a causal-effect relationship, the mechanism by which intra-abdominal fat accumulation is correlated with plasma H-TGL activity is not known. This association is perhaps not causal, and it may represent the influence of sex steroids that are significantly associated with the regional distribution of body fat (for a review, see reference 8). H-TGL activity, and plasma HDL₂ levels.⁵⁴ Evans et al.⁵ have shown that obese women with a high proportion of abdominal fat had higher plasma free testosterone levels (percent of total) and lower sex hormone binding globulin levels than did obese women with peripheral fat accumulation, suggesting that obese women with high androgenic activity could be at risk for the development of the metabolic disturbances associated with high abdominal fat content. In a recent review, Tikkanen and Nikkila⁵⁰ have reported that sex steroids affect plasma HDL₂ cholesterol levels by up- or down-regulating the H-TGL activity. Steroids with androgenic activity increase H-TGL activity and reduce plasma HDL₂ cholesterol levels.⁵⁰ Applebaum-Bowden et al.⁵² also recently reported that administration of stanozolol, an androgenic anabolic steroid, is associated with an increase in plasma H-TGL activity that precedes the decrease in plasma HDL₂ cholesterol levels, suggesting a clear causal relationship between H-TGL and plasma HDL₂ cholesterol. These data indicate that variations in sex steroids, which influence both plasma H-TGL and HDL₂ cholesterol levels, may also represent an important factor for the association between intra-abdominal fat and H-TGL activity; however, further work is required to substantiate this hypothesis.

**Intra-abdominal Fat and Plasma Lipoprotein Lipase Activity**

In the present study, no significant association was found between the amount of intra-abdominal fat, plasma postheparin LPL activity, and plasma lipoprotein levels. Such a lack of association must not be taken as an evidence against the role for LPL activity in regulating plasma lipoprotein levels. It may be argued that because we used low doses of heparin, a maximum release of the enzyme was not achieved. However, there is recent evidence indicating that although both LPL and H-TGL activities increased with increasing doses of heparin, subjects maintained their rank order despite the dose effects.⁵³ Furthermore, obese women in this study were rather homogeneous, and different results could have been obtained by using subjects with wider ranges of body fatness. Indeed, it has been shown that LPL plays an important role in the regulation of plasma HDL levels. A low LPL activity results in low plasma HDL levels²⁵-²⁶ and, conversely, a high plasma LPL activity is generally associated with high levels of HDL.²⁶-²⁸ The results of the present study indicate, however, that variations in plasma LPL activity are not, in obese premenopausal women, an important factor for the independent association between the level of intra-abdominal fat and plasma HDL cholesterol levels.

**Adipose Tissue Lipoprotein Lipase Activity**

Variation in abdominal AT-LPL activity was not associated with changes in plasma HDL-cholesterol levels. Femoral AT-LPL activity, when expressed by unit of cell surface, displayed a significant positive correlation with the ratio of HDL₂ cholesterol/HDL₃ cholesterol, and trends for associations with plasma VLDL cholesterol and HDL₃ cholesterol levels were noted. These results suggest that variations in abdominal and femoral AT-LPL activities will not necessarily have the same impact on the regulation of plasma HDL cholesterol levels.

Furthermore, it also appears that abdominal and femoral AT-LPL activities could display different responses to variation in plasma insulin levels. Whereas we observed a strong positive association between the insulin area under the curve measured during an OGTT and abdominal AT-LPL activity, such a relationship was not observed for femoral AT-LPL activity. The association between plasma insulin levels and AT-LPL activity has been well documented,⁵⁴,⁵⁵ and it is known that the enzyme is insulin-sensitive.⁵⁶,⁵⁷ The results of the present study further indicate, however, that regional variation is observed in the response of AT-LPL to changes in systemic insulin
levels. The lack of association between plasma insulin levels and femoral AT-LPL could be explained by two observations. First, women with a gluteal-femoral accumulation of body fat display a higher insulin sensitivity and lower plasma insulin levels, but they have a higher femoral AT-LPL activity than women with a high relative accumulation of abdominal fat. Secondly, regional variation in insulin responsiveness has been documented, and the antilipolytic effect of insulin has reportedly been higher in abdominal, than in femoral, adipocytes. It, therefore, appears reasonable to suggest that the response of AT-LPL to hyperinsulinemia displays regional variation and that further studies will be required to elucidate the mechanisms underlying these observations.

In conclusion, this study demonstrates that, in a sample of obese premenopausal women for which the level of intra-abdominal fat appears to be the critical variable in the association between regional body fat distribution and plasma HDL cholesterol levels, a high plasma H-TGL is associated with high levels of intra-abdominal fat and with low HDL2 cholesterol levels. This association between the amount of intra-abdominal fat and H-TGL activity was independent from the level of obesity. The mechanisms responsible for these relations will require further studies, but from present knowledge, it is suggested that variations in sex steroid levels are involved in this association. Since low HDL2 cholesterol levels are considered as a risk factor for CHD, a variation in H-TGL activity might play an important role in the disturbance in plasma lipoprotein transport observed in obese women with high levels of deep abdominal fat.

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