Levels of Three Hemostatic Factors in Relation to Serum Lipids
Monocyte Procoagulant Activity, Tissue Plasminogen Activator, and Type-1 Plasminogen Activator Inhibitor

David J. Crutchley, Gizelle V. McPhee, Martin F. Terris, and Maria A. Canossa-Terris

To explore the relationship between blood lipid levels and a predisposition to thrombosis, levels of three hemostatic factors were measured in 41 human subjects and correlated with serum lipids. Procoagulant activity associated with peripheral blood monocytes isolated and purified after a 2-hour incubation in whole blood was not significantly related to lipid levels. However, activity in monocytes incubated with 100 ng/ml of bacterial endotoxin was significantly correlated with high density lipoprotein (HDL) cholesterol \( r=0.55, p<0.005 \), while net procoagulant activity (endotoxin-challenged minus basal) was significantly correlated with both HDL cholesterol \( r=0.61, p<0.005 \) and total cholesterol \( r=0.50, p<0.01 \). Plasma levels of the fibrinolytic factor, tissue plasminogen activator, were significantly correlated with total cholesterol \( r=0.41, p<0.01 \), while those of the type-1 plasminogen activator inhibitor were significantly correlated with both total cholesterol \( r=0.46, p<0.01 \) and total triglycerides \( r=0.31, p<0.05 \). The balance between the fibrinolytic factors was not significantly related to serum lipids. These results suggest that the expression of procoagulant activity by peripheral blood monocytes exposed to endotoxin may be enhanced in cases where HDL cholesterol levels are high. In addition, these results suggest that hypertriglyceridemia may be associated with a decreased fibrinolytic capacity due to elevated secretion of plasminogen activator inhibitor. (Arteriosclerosis 9:934–939, November/December 1989)

Hyperlipidemia is an established risk factor for coronary artery disease. The importance of thromboembolism in the development of myocardial infarction is also well recognized. These observations suggest that prolonged hyperlipidemia may adversely affect the hemostatic system, leading eventually to occlusive thrombosis. However, the precise relationship between blood lipids and thrombosis is not yet clear. For example, the effects of differing types or severities of hyperlipidemia on the expression of blood coagulation or fibrinolytic factors are not fully known.

In the present study, we explored the relationship between serum lipids and several potentially important hemostatic factors. First, we investigated the effects of lipid levels on the ability of peripheral blood monocytes to generate procoagulant activity. Previous studies indicated that the role of these cells in the blood coagulation process is complex.\(^1\) The majority of monocyte-associated procoagulant activity appears to be due to tissue factor (thromboplastin), which functions as the cofactor for the Factor VIIa-catalyzed activation of Factors IX and X.\(^2\) Tissue factor-initiated coagulation by monocytes is augmented by the ability of these cells to bind Factor VIIa\(^3\) and to express Factor VIIa activity.\(^4\) Although monocyte procoagulant activity appears to be lower under normal conditions, it can be markedly stimulated by exposure of the cells to agents such as bacterial endotoxin. Enhanced procoagulant activity by peripheral blood monocytes may then serve as a trigger for disseminated intravascular coagulation by causing the cells to function as circulating thrombotic foci.

An important defense of the body against intravascular coagulation is the fibrinolytic system. The major physiological inhibitor of this system appears to be tissue plasminogen activator (tPA), a fibrin-dependent serine protease that converts the plasma zymogen, plasminogen, to the fibrinolytic enzyme, plasmin.\(^5\) The fibrinolytic potential of tPA is, in turn, offset by the presence of the type-1 plasminogen activator inhibitor (PAI-1), whose levels appear to be regulated independently.\(^6\) Since the balance between tPA and PAI-1 may, to a large extent, determine the capability of the fibrinolytic defense system, we also investigated the relationship between lipids and the plasma levels of these factors.

**Methods**

**Human Subjects**

A total of 41 healthy human volunteers participated in the study. None were taking medication on a routine basis.
Serum Lipids and Hemostatic Factors

Crutchley et al.

Informed consent was obtained. A total of 40 ml of blood was drawn by standard forearm venipuncture into sterile, evacuated tubes containing the appropriate anticoagulants: 20 ml was anticoagulated with heparin, 10 ml was anticoagulated with ethylene-diaminetetraacetic acid (EDTA), and the remaining 10 ml was used to prepare the serum. All persons were requested to fast overnight, and blood was drawn between 8:30 and 10:00 a.m. to minimize diurnal variations in TPA and PAI-1.

Monocyte Preparation

Heparinized blood was immediately divided into eight 2-ml portions. Four portions were mixed with 100 ng/ml endotoxin (lipopolysaccharide w, E. coli 0111:B4; Difco Labs, Detroit, MI), and the remainder was mixed with an equal volume of sterile saline. The blood was incubated for 2 hours at 37°C with frequent mixing. Mononuclear cells were collected by density gradient centrifugation on Ficoll-Hypaque cushions and were further purified by selective adherence to gelatin-coated dishes. The resulting cells were washed and resuspended in buffer (110 mM NaCl, 50 mM Tris, pH 7.4) before assay of procoagulant activity. Portions were taken for determination of cell count by standard hemocytometric techniques. Cell preparations obtained by these techniques routinely contained more than 95% monocytes, as determined by Wright-Giemsa staining and nonspecific esterase staining and were routinely greater than 90% viable, as determined by trypan blue exclusion.

Monocyte Procoagulant Activity

A modification of the method of Bolhuis et al. was used. In this method, monocytes activate Factor X in the presence of Ca++, phospholipid, and trace amounts of plasma as a source of Factor VII. The Factor Xa generated is then measured by its ability to cleave a specific chromogenic substrate, N-benzoyl-Glu-Gly-Arg-p-nitroanilide (Kabi S-2222; Helena Labs; Beaumont, TX). Assay mixtures contained: 25 μl of a suspension containing approximately 5 × 10⁶ cells/ml of purified monocytes, plus 65 μl of a mixture consisting of 32 μl of buffer (110 mM NaCl, 50 mM Tris, pH 7.4), 32 μl of 25 mM CaCl₂, 1 μl phospholipid (rabbit brain cephalin, Sigma, St. Louis, MO), 2.5 μl of a solution containing 10 units/ml of purified human Factor X (Sigma), and 0.25 μl of normal human plasma. The mixtures were incubated for 30 minutes at 37°C to allow the formation of Factor Xa. The reaction was stopped by the addition of 45 μl of 10 mM EDTA; then, 100-μl subsamples were transferred into 96-well flat-bottomed plates. An aliquot of 20 μl of a 3 mM solution of substrate was then added, and absorbance at 405 nm was read every 10 minutes with an automatic plate reader (EIA Reader model 2550, Bio-Rad, Richmond, CA). The assay was calibrated with a standard rabbit brain thromboplastin preparation (Ortho Diagnostics, Raritan, NJ), which was prepared by dissolving the contents of one 25-test vial in 5 ml of sterile water. The resulting solution was assigned a value of 100 000 units/ml. In place of the monocyte suspension, 25 μl of diluted standard, containing 1 to 250 units, was used. Assay specificity was determined as follows. Omission of Factor X from the assay mixtures abolished monocyte Factor Xa generating activity, indicating that substrate cleavage was not due to proteases other than Factor Xa. In 21 subjects, parallel assays in which normal plasma was substituted by plasma congenitally deficient in Factor VII (Helena) were run. This maneuver markedly reduced the generation of Factor Xa in these samples, indicating that a significant portion of the monocyte procoagulant activity was dependent on exogenous Factor VII.

Plasma Fibrinolytic Factors

Blood anticoagulated with EDTA was immediately centrifuged at 4°C to prepare platelet-poor plasma, which was then stored in 250-μl portions at −40°C until assayed. The tPA was measured by an enzyme-linked immunosorbent assay (ELISA), according to the double sandwich technique of Bergsdorf et al., which was made more specific by the modification of Ranby et al. Briefly, 96-well plates were incubated for 3 hours at 25°C with 200 μl per well of a solution of goat anti-IPA antibody (American Diagnostica, New York, NY), containing 2.5 μg/ml of immunoglobulin G (IgG) in 0.1 M NaHCO₃ (pH 8.5). After washing, residual binding sites were blocked by incubating the wells for 2 hours with buffer (150 mM NaCl, 10 mM sodium phosphate, 0.5 mg/ml Tween 20, 1 mg/ml bovine serum albumin, pH 7.4). The wells were then incubated for 18 hours with 200 μl of the same buffer containing 30 μl of suitably diluted, acidified plasma, 0 to 1.6 ng/ml tPA, and 2 μg/ml of either goat anti-IPA IgG or nonimmune goat IgG. The addition of IgG improves the accuracy of the technique by allowing simultaneous estimation of nonspecific and antigen-specific binding. After further washing, the wells were incubated for 3 hours with 200 μl peroxidase-labeled anti-IPA antibody, and peroxidase activity was measured after the addition of 200 μl of 0.04% o-phenylenediamine, 0.03% H₂O₂, in 0.1 M citrate-phosphate buffer (pH 5.0). The reaction was stopped after 30 minutes by the addition of 50 μl of 4.5 M sulfuric acid, and the absorbance at 492 nm was measured. This assay uses antibodies that recognize both free and inhibitor-bound tPA and so provides a measure of total plasma tPA.

PAI-1 was measured by a similar ELISA technique, according to the double antibody sandwich method of Declerck et al. A kit (IMUBIND, American Diagnostica) was used according to the manufacturer’s instructions. The assay was made more specific by first incubating plasma samples for 1 hour at 37°C with 20 μg/ml of a mouse polyclonal anti-human PAI-1 IgG (American Diagnostica) or nonimmune mouse IgG (Sigma). Immune complexes were then removed by the addition of 10 μl of a suspension of protein A (Sigma), followed by a brief centrifugation. The difference between the results obtained with normal plasma and with plasma immunodepleted of PAI-1 were taken as the true level of PAI-1.

Serum Lipid Measurement

A portion of the freshly prepared serum was analyzed immediately for total cholesterol and triglycerides. The assays were performed on an automatic analyzer (Olympus AU 5061), which was calibrated by standards trace-
Table 1. Clinical Profiles of Human Subjects

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Range</th>
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<tbody>
<tr>
<td>Age</td>
<td>55</td>
<td>58</td>
<td>11</td>
<td>26–69</td>
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<tr>
<td>Serum lipids (mg/dl)</td>
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<tr>
<td>Total cholesterol</td>
<td>254</td>
<td>243</td>
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<tr>
<td>HDL cholesterol</td>
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<td>61</td>
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<td>69–294</td>
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<tr>
<td>LDL cholesterol, calculated</td>
<td>144</td>
<td>143</td>
<td>58</td>
<td>0–263</td>
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<tr>
<td>Total triglycerides</td>
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<td>165</td>
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<td>47–1735</td>
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<td></td>
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<td></td>
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<td>Control</td>
<td>67</td>
<td>40</td>
<td>70</td>
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<td>+Endotoxin</td>
<td>163</td>
<td>128</td>
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<td>105</td>
<td>64</td>
<td>135</td>
<td>0–640</td>
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<td>Fibrinolytic factors (ng/ml)</td>
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<tr>
<td>tPA antigen</td>
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<td>18.7</td>
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<tr>
<td>PAI-1 antigen</td>
<td>41.0</td>
<td>38.4</td>
<td>17.2</td>
<td>17.4–109.4</td>
</tr>
</tbody>
</table>

There were 15 women and 26 men in the study.

HDL=high density lipoprotein cholesterol, LDL=low density lipoprotein cholesterol, tPA=tissue plasminogen activator, PAI-1=plasminogen activator inhibitor.

Lipid Profile

A total of 41 persons were studied, 15 women and 26 men, with ages ranging from 26 to 69 years. As shown in Table 1, total serum cholesterol in the persons studied ranged from 133 to 363 mg/dl, and total serum triglycerides ranged from 47 to 1735 mg/dl. Affinity chromatography of thawed serum samples on heparin-agarose columns gave alpha fraction (HDL) cholesterol values in the range of 32 to 139 mg/dl, and beta fraction (LDL) cholesterol values in the range of 69 to 294 mg/dl. When LDL cholesterol was estimated according to the Friedewald equation, values in the range 0 to 263 mg/dl were obtained. The apparent lack of LDL in one patient and the extremely low value (8 mg/dl) observed in another reflect the inaccuracy of this calculation due to the extremely high triglyceride levels in these patients (1735 and 618 mg/dl, respectively).

Monocyte Procoagulant Activity

Monocytes were incubated with whole blood to expose the cells to their native lipid milieu and to approximate in vivo conditions. Monocytes were also incubated in the presence or absence of bacterial endotoxin to assess the effects of lipids on basal and on stimulated activity.

As shown in Table 1, the monocyte-associated procoagulant activity in the persons studied was extremely variable. This has been noted by other workers. Exposure of blood to endotoxin led to an increased procoagulant activity in most persons (30 of 41). In the remainder, procoagulant activity was unchanged (one subject) or declined (nine subjects) after endotoxin treatment. The reasons for the decline are unclear. The monocytes from one person were lost during preparation. The overall stimulation of procoagulant activity in the 40 persons studied was two- to threefold.

Results

Statistical Analysis

Stepwise linear multiple regression analyses were performed to determine the significance of the observed correlations and to determine the degree of independence of the significant factors. To facilitate these analyses, an RS/1 statistical package (BBN Software Products Corporation, Cockeysville, MD) was used in conjunction with an AT-type personal computer.
Figure 1. The relationship between monocyte procoagulant activity (units [U]/10^6 cells) and high density lipoprotein (HDL) cholesterol (mg/dl). A. No significant relationship was found between basal procoagulant activity and HDL cholesterol. B. Procoagulant activity in endotoxin-challenged monocytes was positively and significantly correlated with HDL cholesterol (r=0.55, p<0.005). C. Net procoagulant activity (challenged minus basal) was similarly correlated with HDL cholesterol (r=0.61, p<0.005).

Monocyte procoagulant activity was not significantly related to age, gender, LDL cholesterol, or serum triglycerides. However, significant relationships were observed between procoagulant activity and HDL cholesterol. Thus, although basal procoagulant activity was unrelated to HDL cholesterol (Figure 1A), a moderate, positive, and highly significant correlation was found between endotoxin-stimulated activity and HDL cholesterol (r=0.55, p<0.005; Figure 1B). A stronger and equally significant correlation was found between the net increase in procoagulant activity (i.e., endotoxin-stimulated minus basal) and HDL cholesterol (r=0.61, p<0.005; Figure 1C). An additional correlation was found between the net increase in procoagulant activity and total cholesterol (r=0.50, p<0.01), although multivariate analysis indicated that total cholesterol was not an independent variable.

**Fibrinolytic Factors**

Table 1 shows that plasma tPA antigen levels ranged from 5.3 to 34.7 ng/ml, and plasma PAI-1 antigen levels ranged from 17.4 to 109.4 ng/ml. Normal values for plasma tPA antigen have generally been reported to be in the range of 1 to 13 ng/ml, while those for PAI-1 antigen are in the range of 4 to 77 ng/ml. Since the antibodies used in the ELISA for tPA recognize both free and inhibitor-bound tPA while those used in the ELISA for PAI-1 recognize only free PAI-1, these data indicate that in most cases an excess of PAI-1 is present. Similar observations have been made by others, and are consistent with the finding that most of the tPA in plasma is catalytically inactive.

An analysis of the relationship between the levels of the fibrinolytic factors and serum lipids showed weak but significant correlations. Thus, tPA was positively correlated with total cholesterol (r=0.41, p<0.01; Figure 2A) and with cholesterol associated with the unadjusted beta (LDL) fraction (r=0.39, p<0.01), although multivariate analysis indicated that the latter was not an independent variable. Moreover, when the values for calculated LDL cholesterol were used, the correlation was lost (r=0.23, p>0.05). Finally, a moderate but significant correlation was observed between PAI-1 and total cholesterol (r=0.46, p<0.01; Figure 2B), and a weak correlation was found between PAI-1 and total triglycerides (r=0.31, p<0.05; Figure 3). No correlation was found between PAI-1 and
It is noteworthy that exposure of isolated human monocytes to bacterial endotoxin, suggest- ing that elevated HDL cholesterol is associated with a "sensitization" of these cells to endotoxin. If this observation extends to other stimuli, the increased monocyte-initiated blood coagulation that is associated with elevated HDL cholesterol may be observed only when such stimuli are present.

The mechanisms underlying the relationship between HDL cholesterol and endotoxin-induced monocyte procoagulant activity are presently unclear. Since it has been shown that lipoproteins bind and transport endotoxin,22 the simplest explanation is that alterations in lipoprotein content may have facilitated the delivery of endotoxin to peripheral blood monocytes. Alternatively, exposure of monocytes to elevated HDL cholesterol may have altered the lipid composition of their plasma membranes, leading in turn to changes in the phospholipid moiety of tissue factor, in the binding of Factor VII/Villa to the monocyte surface, or in the assembly of the tissue factor-Factor Villa complex. In this context, it is noteworthy that exposure of isolated human peripheral blood monocytes to purified HDL enhanced the development of procoagulant activity via a prothrombinase,23 which was later shown to be Factor Villa.4 In contrast, however, Carson24,25 has reported that HDL and apoprotein A-II inhibit the activation of Factor Xa by purified tissue factor and Factor Villa. Whatever the mechanisms involved, the apparent positive relationship between HDL cholesterol and the development of monocyte procoagulant activity requires independent confirmation, in view of the fact that HDL, a negative risk factor for coronary heart disease,26 is generally regarded as a "good" cholesterol. Studies identifying the subclass of HDL most closely associated with increased monocyte procoagulant activity would also seem to be warranted.

The present results also indicate weak but significant correlations between total cholesterol and the fibrinolytic factors, tPA and PAI-1. In the case of tPA, the association appeared to be with the LDL fraction. However, the clinical effects of hypercholesterolemia on the fibrinolytic system are difficult to predict, since both factors increased in concert. Thus, no significant changes were seen in the balance between tPA and PAI-1 with respect to cholesterol or LDL levels. In contrast, a weak but significant correlation was found between PAI-1 and any of the lipid classes.

Figure 3. The relationship between plasma fibrinolytic inhibitor and serum triglycerides (mg/dl). Plasminogen activator inhibitor (PAI-1) (ng/ml) was weakly but significantly correlated with serum triglycerides (r=0.31, p<0.05).

**Discussion**

In the present study, we provide evidence that the expression of three potentially important hemostatic factors appears to be correlated with the lipid profile of the persons studied. These results suggest that a direct relationship may exist between serum lipids and the blood coagulation and fibrinolytic systems.

The results linking the expression of monocyte procoagulant activity to levels of HDL cholesterol are interesting. A significant positive relationship was observed only after exposure of the cells to bacterial endotoxin, suggesting that elevated HDL cholesterol is associated with a "sensitization" of these cells to endotoxin. If this observation extends to other stimuli, the increased monocyte-initiated blood coagulation that is associated with elevated HDL cholesterol may be observed only when such stimuli are present.

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**Acknowledgment**

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**References**


Index Terms: blood coagulation • fibrinolysis • monocyte procoagulant activity • tissue factor • tissue plasminogen activator • plasminogen activator inhibitor • serum cholesterol • serum triglycerides • hyperlipidemia
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