Metabolic Factors, Adipose Tissue, and Plasminogen Activator Inhibitor-1 Levels in Type 2 Diabetes
Findings From the Look AHEAD Study

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Objective—Plasminogen activator inhibitor-1 (PAI-1) production by adipose tissue is increased in obesity, and its circulating levels are high in type 2 diabetes. PAI-1 increases cardiovascular risk by favoring clot stability, interfering with vascular remodeling, or both. We investigated in obese diabetic persons whether an intensive lifestyle intervention for weight loss (ILI) would decrease PAI-1 levels independently of weight loss and whether PAI-1 reduction would be associated with changes in fibrinogen, an acute phase reactant, or fibrin fragment D-dimer (D-dimer), a marker of ambient coagulation balance.

Methods and Results—We examined 1-year changes in PAI-1, D-dimer, and fibrinogen levels; adiposity; fitness; glucose; and lipid control with ILI in 1817 participants from Look AHEAD, a randomized trial investigating the effects of ILI, compared with usual care, on cardiovascular events in overweight or obese diabetic persons. Median PAI-1 levels decreased 29% with ILI and 2.5% with usual care (P<0.0001). Improvements in fitness, glucose control, and high-density lipoprotein cholesterol were associated with decreased PAI-1, independently of weight loss (P=0.03 for fitness, P<0.0001 for others). Fibrinogen and D-dimer remained unchanged.

Conclusion—Reductions in PAI-1 levels with ILI in obese diabetic individuals may reflect an improvement in adipose tissue health that could affect cardiovascular risk without changing fibrinogen or D-dimer levels.

Clinical Trial Registration—URL: http://clinicaltrials.gov/ct2/show/NCT00017953. Unique identifier: NCT00017953.

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Key Words: diabetes mellitus • fibrinolysis • obesity • adipokines • fitness
of changes in fitness and of improved glucose and lipid control on PAI-1 levels have not been evaluated in the setting of a clinical trial. The overall aim of this study was to investigate whether an intensive lifestyle intervention for weight loss (ILI) would, compared with usual care, decrease PAI-1 levels in obese persons with T2DM and whether an improvement in fitness and in metabolic factors known to affect adipose tissue function could contribute, independently of weight change, to the reduction in PAI-1 levels. Furthermore, to improve our understanding of the implications of PAI-1 reduction with ILI on cardiovascular risk in diabetic individuals and given the substantial epidemiological evidence supporting the association of fibrinogen and D-dimer with CVD (upper versus lower tertile risk of 1.8 for both),14,15 we also investigated whether the changes in PAI-1 with ILI were associated with changes in fibrinogen, an established acute phase reactant, changes in fibrin fragment D-dimer (D-dimer), a marker of ambient coagulation balance, or both. We hypothesized that despite the advanced degree of obesity and the metabolic disturbances commonly seen in T2DM, ILI would decrease PAI-1 levels to a greater extent than usual care. We also hypothesized that an improvement in metabolic factors and in fitness with ILI would, independently of adiposity changes, decrease PAI-1 levels. Our third and final hypothesis was that given that PAI-1 is a mild acute phase reactant and a major regulator of fibrinolysis, the reduction in PAI-1 levels with ILI would be associated with decreases in fibrinogen and D-dimer levels.

**Research Design and Methods**

**Study Design**

We evaluated 1817 individuals, generally corresponding to the first half of Look AHEAD (Action for Health in Diabetes) participants from 15 of 16 clinic sites, who had PAI-1 and fitness data at baseline and 1 year. Look AHEAD is a randomized clinical trial designed to examine whether a behavioral lifestyle intervention for weight loss will reduce cardiovascular events and overall mortality in overweight/obese subjects with T2DM. The Look AHEAD study design, subject characteristics, and lifestyle intervention components have been described.16 Briefly, subjects were randomized to ILI, aiming for a 7% weight loss from baseline, or to a diabetes support and education (DSE) arm, which served as the control. ILI participants attended 3 group sessions and 1 individual encounter per month during the first 6 months of the study, followed by 2 group sessions and 1 individual appointment per month thereafter, supporting behavioral change to increase physical activity to 175 weekly minutes of moderate-intensity exercise, reduce caloric and saturated fat intake, and change macronutrient composition to improve glycemic control. The activity program relied on at-home exercise, which for most participants consisted of brisk walking. The energy intake goal was 1200 to 1500 kcal/day for persons <114 kg and 1500 to 1800 kcal/day for those ≥114 kg. Liquid meal replacement for 2 daily meals was encouraged during the first 6 months to help with portion control. Subjects were asked to keep food and physical activity diaries, counting only bouts of ≥10-minute duration for the activity goal.16 DSE participants received 3 group health information sessions during the year. All participants continued care with their primary providers. The institutional review boards of the participating centers approved Look AHEAD and this ancillary study.

**Laboratory, Anthropometric, and Fitness Determinations**

PAI-1, D-dimer, and fibrinogen were measured in the University of Vermont Laboratory for Clinical Biochemistry Research as described.17 Briefly, PAI-1 was measured in duplicate in platelet-free plasma by ELISA (Asserachrom No. 00249, Stago, Parsippany, NJ). This assay is sensitive to all plasma forms of PAI-1 (average interassay coefficient of variation was 8.9% over 8 different controls). D-Dimer was measured by the STAR automated coagulation analyzer (Stago) using an immunoturbidimetric assay (Liaison D-Di) with 2 anti-human monoclonal antibodies specific to D-dimer and 4 controls (average interassay coefficients of variation for mean values of 2.18 and 0.24 μg/mL were 6.3% and 12.3%, respectively, and estimated at 23% for the 25th percentile [0.18 μg/mL]). Fibrinogen was quantified, by the STAR automated coagulation analyzer, using a clot-rate method (Stago; average interassay coefficient of variation was 5.9% over 10 different controls).

Determination of fitness using submaximal effort on a graded exercise stress test in metabolic equivalents and procedures for obtaining anthropometric measures, hemoglobin A1c (HbA1c), glucose, and lipids in Look AHEAD have been described.18

**Statistical Analysis**

Descriptive statistics, including median and interquartile range (IQR), were determined for PAI-1, D-dimer, and fibrinogen levels at baseline and for their 1-year changes from baseline. Differences between the ILI and DSE arms in variable 1-year changes were evaluated with the 2-sample t test or the Wilcoxon rank sum test. Bivariate associations of 1-year changes were evaluated with the Spearman correlation coefficients, adjusting for age and gender with partial correlation analyses, and tested for trend across quartiles of change by treatment arm.

In the multivariable regression analysis, log transformation was applied to PAI-1 to correct for its nonnormal distribution, and the difference between baseline and 1-year log-transformed PAI-1 values was calculated and treated as the outcome variable. Models were fitted to examine the effects of changes in metabolic variables of interest on PAI-1 change. Variables shown not to be significantly different between ILI and DSE in their 1-year changes were excluded. Changes in metabolic variables and in fitness were entered into separate regression models to evaluate their contribution to PAI-1 change, either alone or in combination, after adjusting for baseline PAI-1 level, demographics, clinic site, CVD history, diabetes duration, current smoking, and treatment with statins and thiazolidinediones. A dichotomous indicator for treatment group (ILI versus DSE) was included in all models to examine the significance of the treatment effect. Multicollinearity between related metabolic variables was excluded using Spearman correlation coefficients before inclusion in the regression models (all ≤0.4). Type I error rate was fixed at 0.05 for all analyses. Analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC).

**Results**

**Baseline Characteristics**

Participants were middle-aged, obese, and sedentary, with mean fitness values below the 20th percentile for their age (Table 1). PAI-1 levels (median [IQR]) were elevated at 45.42 ng/mL (25.26 to 75.46 ng/mL; reference range: 4 to 43 ng/mL). Median (IQR) fibrinogen levels were in the high normal range at 376.5 mg/dL (330 to 431 mg/dL; reference range: 203 to 404 mg/dL) and D-dimer median (IQR) levels were normal at 0.26 μg/mL (0.17 to 0.39 μg/mL; reference range: 0.06 to 0.77 μg/mL). The geometric means for PAI-1 and D-dimer levels were 42.46 ng/mL and 0.27 μg/mL, respectively. Baseline characteristics of 230 participants,
Table 1. Baseline Characteristics

<table>
<thead>
<tr>
<th></th>
<th>ILI (n=957)</th>
<th>DSE (n=860)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, mean (SD), y</strong></td>
<td>57.5 (7.1)</td>
<td>57.7 (7.2)</td>
</tr>
<tr>
<td><strong>Gender, No. (%)</strong></td>
<td></td>
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</tr>
<tr>
<td>Males</td>
<td>391 (40.9)</td>
<td>356 (41.4)</td>
</tr>
<tr>
<td>Females</td>
<td>566 (59.1)</td>
<td>504 (58.6)</td>
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<tr>
<td><strong>Ethnicity, No. (%)</strong></td>
<td></td>
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<tr>
<td>White</td>
<td>651 (68.1)</td>
<td>574 (66.7)</td>
</tr>
<tr>
<td>African American</td>
<td>124 (13.0)</td>
<td>115 (13.4)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>91 (9.5)</td>
<td>78 (9.1)</td>
</tr>
<tr>
<td>Native American</td>
<td>58 (6.1)</td>
<td>60 (7.0)</td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>8 (0.8)</td>
<td>8 (0.9)</td>
</tr>
<tr>
<td>Other/mixed</td>
<td>24 (2.5)</td>
<td>25 (2.9)</td>
</tr>
<tr>
<td><strong>Duration of diabetes,</strong> mean (SD), y</td>
<td>6.5 (6.3)</td>
<td>6.6 (6.2)</td>
</tr>
<tr>
<td><strong>History of CVD,</strong>† No. (%)</td>
<td>118 (12.3)</td>
<td>99 (11.5)</td>
</tr>
<tr>
<td><strong>Metabolic syndrome,</strong> No. (%)</td>
<td>890 (93.0)</td>
<td>797 (92.7)</td>
</tr>
<tr>
<td><strong>Current tobacco use,</strong> No. (%)</td>
<td>34 (3.6)</td>
<td>26 (3.0)</td>
</tr>
<tr>
<td><strong>Thiazolidinedione therapy,</strong> No. (%)</td>
<td>243 (25.4)</td>
<td>233 (27.1)</td>
</tr>
<tr>
<td><strong>Insulin therapy,</strong> No. (%)</td>
<td>146 (15.3)</td>
<td>122 (14.2)</td>
</tr>
<tr>
<td><strong>Estrogen replacement,</strong> No. (%)</td>
<td>168 (29.7)</td>
<td>146 (29.0)</td>
</tr>
<tr>
<td><strong>Weight, mean (SD), kg</strong></td>
<td>102.0 (20.1)</td>
<td>101.4 (18.7)</td>
</tr>
<tr>
<td><strong>BMI, mean (SD), kg/m²</strong></td>
<td>36.3 (6.3)</td>
<td>36.1 (5.9)</td>
</tr>
<tr>
<td><strong>Waist circumference, mean (SD), cm</strong></td>
<td>114.6 (14.8)</td>
<td>114.4 (14.2)</td>
</tr>
<tr>
<td><strong>Fitness (submaximal), mean (SD), MET</strong></td>
<td>5.2 (1.5)</td>
<td>5.1 (1.6)</td>
</tr>
<tr>
<td><strong>Fasting glucose,</strong> mean (SD), mmol/L</td>
<td>8.5 (2.4)</td>
<td>8.7 (2.7)</td>
</tr>
<tr>
<td><strong>HbA1c, mean (SD), %</strong></td>
<td>7.3 (1.2)</td>
<td>7.4 (1.2)</td>
</tr>
<tr>
<td><strong>Total cholesterol,</strong> mean (SD), mmol/L</td>
<td>5.0 (1.0)</td>
<td>4.9 (1.0)</td>
</tr>
<tr>
<td><strong>LDL-C, mean (SD), mmol/L</strong></td>
<td>2.9 (0.8)</td>
<td>2.9 (0.8)</td>
</tr>
<tr>
<td><strong>HDL-C, mean (SD), mmol/L</strong></td>
<td>1.1 (0.3)</td>
<td>1.1 (0.3)</td>
</tr>
<tr>
<td><strong>Triglycerides, mean (SD), mmol/L</strong></td>
<td>2.1 (1.5)</td>
<td>2.0 (1.4)</td>
</tr>
<tr>
<td><strong>Fibrinogen, median (IQR), µg/mL</strong></td>
<td>376.0 (326.0 to 431.0)</td>
<td>379.0 (334.0 to 431.0)</td>
</tr>
<tr>
<td><strong>D-Dimer median (IQR), ng/mL</strong></td>
<td>46.53 (26.20 to 75.63)</td>
<td>46.41 (24.33 to 75.14)</td>
</tr>
</tbody>
</table>

**MET** indicates metabolic equivalent; **LDL-C**; low-density lipoprotein cholesterol.

*Self-reported.
†Self-reported prior myocardial infarction, stroke, transient ischemic attack, angioplasty/stent, coronary artery bypass graft, carotid endarterectomy, abdominal aortic aneurysm, or heart failure.

Changes in Variables of Interest With ILI

ILI participants had significant improvements in adiposity, fitness, glucose, and lipid control at 1 year compared with those randomized to DSE, as observed for the overall Look AHEAD sample. There were no differences in low-density lipoprotein cholesterol between ILI and DSE at 1 year. One-year PAI-1 levels (median [IQR]) dropped 13.4% (−38.6 to 2.7) ng/mL from a baseline of 46.53 (26.2, 75.63) ng/mL in the ILI group (29% reduction) and 1.1% (−19.4 to 20.8) ng/mL from a baseline median (IQR) of 44.61 (24.33 to 75.14) ng/mL in the DSE group (2.5% reduction) (P<0.0001 for difference between groups). No change in D-dimer or decrease in fibrinogen levels was documented in either group.

Changes in PAI-1 levels were not associated with changes in D-dimer or fibrinogen levels (Spearman correlation coefficients, adjusted for gender and age, of −0.03 [P=0.22] and 0.03 [P=0.24], respectively). Greater improvements not only in adiposity but also in fitness, glucose control, high-density lipoprotein cholesterol (HDL-C) levels (Figure), and triglycerides (not shown) with ILI were found to be associated with greater decreases in PAI-1 levels (P for trend, <0.0001 for all). Separate analysis in the DSE arm showed progressive change in PAI-1 across quartiles of change only for body mass index (BMI) and HbA1c (P for trend, <0.001 for both).

These findings do not suggest important effect modification on the relationship between treatment arm and PAI-1.

Metabolic Predictors of 1-Year Change in PAI-1

Regression analyses showed that not only adiposity change (measured by BMI, weight, and waist changes) but also each of the changes in glucose (HbA1c and fasting glucose) and lipid (triglycerides and HDL-C) control and in fitness with ILI predicted a decrease in PAI-1 levels (log-transformed for analysis) at 1 year (P<0.001 for all) (Tables 3, models A to I). Change in waist accounted for 5% of the variance in PAI-1 change (33% with ILI), after adjusting for baseline PAI-1 level, demographics, medical history, and medication use, and was not a better predictor of PAI-1 change compared with change in BMI or change in weight, which explained 6% to 7% of the variance in PAI-1 change (models B and C, 34% and 35%, respectively, of the variance in PAI-1 change with ILI). Given that change in BMI was a stronger predictor of change in PAI-1 than change in waist was, we chose to include change in BMI in the remainder of our analyses.

Improvement in fitness with ILI, again in the presence of multiple covariates, explained 2% of the variance in PAI-1 change (model I, 30% of the variance in PAI-1 change with ILI) and remained associated with PAI-1 change after adjusting for changes in glucose control (model J, P<0.0001) and in adiposity (model K, P=0.026). Change in triglycerides with ILI was not associated with PAI-1 change when changes in glucose control and BMI were taken into account (model...
L, \(P=0.45\)). Change in glucose control, HDL-C, and fitness remained significantly associated with PAI-1 change in the full model after adjusting for adiposity change (model M, \(P<0.0001\) for HbA1c and HDL-C, \(P=0.04\) for fitness) and together accounted for 10% of the variance in PAI-1 change (38% of the variance in PAI-1 change with ILI) independently of baseline PAI-1 levels, individual demographic characteristics, history of CVD, diabetes duration, smoking, and thiazolidinedione use.

\[
\begin{array}{cccc}
\Delta \text{Weight, mean (SD), kg} & -8.9 (7.6) & -0.8 (5.0) & <0.0001 \\
\Delta \text{BMI, mean (SD), kg/m}^2 & -3.2 (2.6) & -0.3 (1.8) & <0.0001 \\
\Delta \text{Waist circumference, mean (SD), cm} & -7.7 (9.3) & -1.0 (7.7) & <0.0001 \\
\Delta \text{Fasting glucose, mean (SD), mmol/L} & -1.23 (2.45) & -0.39 (2.59) & <0.0001 \\
\Delta \text{HbA1c, mean (SD), %} & -0.7 (1.0) & -0.2 (0.9) & <0.0001 \\
\Delta \text{LDL-C, mean (SD), mmol/L} & -0.11 (0.67) & -0.13 (0.74) & 0.66 \\
\Delta \text{HDL-C, mean (SD), mmol/L} & 0.08 (0.18) & 0.04 (0.17) & <0.0001 \\
\Delta \text{Triglycerides, mean (SD), mmol/L} & -0.36 (1.29) & -0.15 (1.1) & 0.0001 \\
\Delta \text{Fitness (submaximal), mean (SD), MET} & 1.0 (1.4) & 0.2 (1.1) & <0.0001 \\
\Delta \text{PAI-1, median (IQR) ng/mL} & -13.4 (38.6 to 2.7) & -1.1 (19.4 to 20.8) & <0.0001† \\
\Delta \text{D-Dimer, median (IQR) mg/mL} & 0.0 (0.1 to 0.1) & 0.0 (0.1 to 0.1) & 0.57† \\
\Delta \text{Fibrinogen, median (IQR), mg/dL} & 5.0 (33.0 to 47.0) & 10.0 (25.0 to 42.0) & 0.21† \\
\end{array}
\]

\(\Delta\) indicates change scores using the raw scale; LDL-C, low-density lipoprotein cholesterol; MET, metabolic equivalent.

*P values are unadjusted and evaluate treatment differences on variable changes using the unpaired t test except where indicated.

†P values are unadjusted and evaluate treatment differences on variable changes using the Wilcoxon rank sum test.

### Discussion

Our study shows that in obese individuals with T2DM, moderate weight loss with ILI sustained over a 1-year period was sufficient to achieve significant reductions in PAI-1 levels compared with usual care and that improvements in fitness, glucose control, and HDL-C with ILI contributed, independently of adiposity change, to the lowering of PAI-1 levels. Finally, and contrary to our initial hypothesis, ILI did not change fibrinogen or d-dimer levels, pointing to complex physiological relationships between PAI-1 inflammation and coagulation balance.

PAI-1 levels are elevated in diabetes; in this study, they were more than twice those of healthy subjects in the Multi-Ethnic Study of Atherosclerosis (assays also performed at the University of Vermont Laboratory for Clinical Biochemistry Research)\(^{20}\) and higher than those seen in nondiabetic obese\(^{12}\) or prediabetic adults.\(^{13}\) In support of our main hypothesis, ILI effected a greater reduction in PAI-1 levels (29% from baseline) than did usual care (2.5% reduction) in our obese diabetic participants. The relatively large decline in PAI-1 levels seen in this study is similar to the reduction observed in less obese subjects without diabetes\(^{12,13}\) and was associated with a reduction in measures of adiposity. ILI participants reduced baseline weight by 8.7%, whereas DSE participants experienced less than a tenth of that change. Reductions in measures of both central and overall obesity were associated with the decrease in PAI-1 levels. Of interest, ILI was able to decrease PAI-1 to levels well within the normal range despite the presence of persisting obesity after the intervention (mean BMI at 1-year with ILI was 33.1 kg/m\(^2\), down from 36.3). In obesity, activated macrophages and T cells accumulate in adipose tissue, shifting adipokine secretion toward a proinflammatory pattern.\(^{21,22}\) Of these adipokines, tumor necrosis factor-\(\alpha\) and transforming growth factor-\(\beta\) appear to play an important role.\(^{9,11}\) It has been postulated that the adipocyte microenvironment acquires a proinflammatory phenotype when local angiogenesis cannot keep up with the expanding adipose tissue mass.\(^{23}\) It is
Table 3. Metabolic Variables as Predictors of PAI-1 Change With 1-Y ILI

<table>
<thead>
<tr>
<th>Model*</th>
<th>b-Coefficient</th>
<th>SE</th>
<th>R²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ILI vs DSE</td>
<td>-0.47</td>
<td>0.034</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model B</td>
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</tr>
<tr>
<td>ILI vs DSE</td>
<td>-0.20</td>
<td>0.038</td>
<td>&lt;0.0001</td>
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</tr>
<tr>
<td>Change in BMI</td>
<td>0.10</td>
<td>0.007</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model C</td>
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<td></td>
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<td></td>
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<tr>
<td>ILI vs DSE</td>
<td>-0.19</td>
<td>0.038</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td>Change in weight</td>
<td>0.03</td>
<td>0.003</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model D</td>
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<tr>
<td>ILI vs DSE</td>
<td>-0.32</td>
<td>0.035</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in waist circumference</td>
<td>0.02</td>
<td>0.002</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model E</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>ILI vs DSE</td>
<td>-0.41</td>
<td>0.033</td>
<td>&lt;0.0001</td>
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<tr>
<td>Change in fasting glucose</td>
<td>0.01</td>
<td>0.0004</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model F</td>
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<tr>
<td>ILI vs DSE</td>
<td>-0.39</td>
<td>0.034</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td>Change in HbA1c</td>
<td>0.17</td>
<td>0.018</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model G</td>
<td></td>
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</tr>
<tr>
<td>ILI vs DSE</td>
<td>-0.46</td>
<td>0.034</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td>Change in triglycerides</td>
<td>0.001</td>
<td>0.0002</td>
<td>0.0002</td>
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<tr>
<td>Model H</td>
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<tr>
<td>ILI vs DSE</td>
<td>-0.45</td>
<td>0.034</td>
<td>&lt;0.0001</td>
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<tr>
<td>Change in HDL-C</td>
<td>-0.02</td>
<td>0.003</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model I</td>
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<tr>
<td>ILI vs DSE</td>
<td>-0.40</td>
<td>0.035</td>
<td>&lt;0.0001</td>
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<tr>
<td>Change in fitness</td>
<td>-0.10</td>
<td>0.014</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model J</td>
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<tr>
<td>ILI vs DSE</td>
<td>-0.33</td>
<td>0.035</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in HbA1c</td>
<td>0.15</td>
<td>0.018</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in fitness</td>
<td>-0.08</td>
<td>0.014</td>
<td>&lt;0.0001</td>
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<tr>
<td>Model K</td>
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</tr>
<tr>
<td>ILI vs DSE</td>
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<td>0.038</td>
<td>&lt;0.0001</td>
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<tr>
<td>Change in BMI</td>
<td>0.08</td>
<td>0.008</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in HbA1c</td>
<td>0.13</td>
<td>0.017</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in fitness</td>
<td>-0.03</td>
<td>0.014</td>
<td>0.026</td>
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<tr>
<td>Model L</td>
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<tr>
<td>ILI vs DSE</td>
<td>-0.16</td>
<td>0.038</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in BMI</td>
<td>0.08</td>
<td>0.007</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in HbA1c</td>
<td>0.13</td>
<td>0.018</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in triglycerides</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Model M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILI vs DSE</td>
<td>-0.15</td>
<td>0.038</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td>Change in BMI</td>
<td>0.08</td>
<td>0.008</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in HbA1c</td>
<td>0.12</td>
<td>0.018</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in HDL-C</td>
<td>-0.012</td>
<td>0.002</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Change in triglycerides</td>
<td>-0.0001</td>
<td>0.0002</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Change in fitness</td>
<td>-0.03</td>
<td>0.014</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

*Each model (A to M) was analyzed independently and adjusted for baseline PAI-1 level, demographics, clinic site, history of CVD, diabetes duration, smoking, and thiazolidinedione and statin use, with difference between baseline and 1-y log-transformed PAI-1 values as outcome variable.
could have contributed to the change in PAI-1 levels with ILI in our study, studies investigating the origin of circulating
PAI-1 suggest that the source of PAI-1 may differ by age and
health status and that in obesity, adipose tissue is a major
source.8,9,40 Our results are also in agreement with a factor
analysis in healthy individuals that showed that PAI-1 clus-
tered with a body mass factor and not with an interleukin-6-
dependent inflammatory factor that included fibrinogen.41

The absence of associated changes in d-dimer with ILI,
despite the important reduction in PAI-1 levels, was unex-
pected. PAI-1 is a major regulator of fibrinolysis,9 and
d-dimer is a measure of ambient coagulation balance that
includes intraluminal fibrinolysis.42 Both coagulation (result-
ing in fibrin formation) and fibrinolysis (resulting in clot
dissolution) have to occur for d-dimer to be formed.42 Similar
findings have been observed with weight loss in younger, less
obese persons without diabetes.12 Our results may be ex-
plained by the relatively normal d-dimer levels found in our
stable ambulatory participants with T2DM, levels that indi-
cate that ongoing fibrin formation and dissolution were not
elevated. On the basis of these findings, one could hypothe-
size that elevated PAI-1 may exert an effect on clotting only
in the setting of a relatively large stimulation, such as that
occurring in the presence of a ruptured atherosclerotic plaque.

An alternative hypothesis would be that if there were a CVD
benefit associated with a decline in PAI-1 with ILI, it would
not be through regulation of ongoing, so-called ambient
coagulant balance and blood-based clot formation but rather
through its effect in the vessel wall. PAI-1 expression in the
vessel wall is increased in the presence of diabetes,43 and
Sobel et al have proposed a deleterious effect of elevated
tissue-based PAI-1 on vessel remodeling, leading to an
increased risk of plaque rupture.4

Our study has several limitations. First, our PAI-1 assay
measured total PAI-1 and was not specific for the active form.
However, preliminary experiments in our laboratory found
that it correlates highly with 2 frequently used assays: 1
measuring uncomplexed PAI-1 (active and latent free PAI-1;
in-house immunoassay; R = 0.82) and 1 commercial assay
measuring total PAI-1 (Biopool Tintelize immunoassay;
R = 0.80). Furthermore, PAI-1 antigen and activity are
strongly correlated (R = 0.77).44 Given the relatively stringent
blood collection requirements for an activity assay, coupled
with the multicenter nature of Look AHEAD, and the fact
that much of the epidemiological data linking PAI-1 to CVD was
assembled with assays for either uncomplexed or total PAI-1
(eg, Thogersen et al11), we chose the automated total PAI-1
assay. We also evaluated the use of citrate plasma compared
with a specialty collection tube (Biopool Statiblanye, Trinity
Biotech USA) and found excellent correlation (R = 0.99).
Second, Look AHEAD did not measure insulin levels, and the
effects of insulin on PAI-1 change could not be directly
assessed. It is possible that the association of hyperglycemia
and PAI-1 could be explained in part by the presence of
hyperinsulinemia. However, there is ample evidence that
hyperglycemia is able to increase PAI-1 secretion indepen-
dently of insulin change.26,45

In summary, our findings show that ILI decreases and
normalizes PAI-1 levels in stable obese diabetic persons
compared with usual care and that the decrease is associated
not only with moderate reductions in adiposity but also with
improvements in fitness, glucose, and HDL-C levels, factors
known to affect adipose tissue function and proinflammatory
adipokine production. The absence of effects on fibrinogen,
an acute phase reactant, supports the position that the de-
creases in PAI-1 levels with ILI result mainly from its effects
on adipose tissue inflammation rather than being a conse-
quently of systemic changes in inflammatory status. Finally,
we show that despite the large reduction in PAI-1 with ILI,
there were no changes in d-dimer, a marker of ambient
coaulation balance. These results support expanding the role
of PAI-1 to that of a marker of adipose tissue health. Future
results from Look AHEAD will determine whether decreases
in PAI-1 levels with ILI will reduce cardiovascular events.

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