C-Reactive Protein, Interleukin 6, and Risk of Developing Type 2 Diabetes Mellitus

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Type 2 diabetes mellitus (DM) is estimated to affect 15 million Americans, is dramatically increasing in incidence, and is associated with an augmented risk for cardiovascular disease, especially among women. Because of the resultant macrovascular and microvascular injury typical of this disease, the economic and functional burdens are greatest during mid-to-late adulthood. Compounding these issues, as many as one third of individuals with type 2 DM are undiagnosed, and approximately 20% have diabetic retinopathy or evidence of systemic vasculopathy at clinical presentation.

Although the main physiological abnormalities are insulin resistance and impaired insulin secretion, the specific underlying determinants of these metabolic defects remain uncertain. An accumulating body of evidence suggests that inflammation may play a crucial intermediary role in pathogenesis, thereby linking diabetes with a number of commonly coexisting conditions thought to originate through inflammatory mechanisms. In this regard, substantial experimental evidence and more recent cross-sectional data suggest that interleukin 6 (IL-6) and C-reactive protein (CRP), 2 sensitive physiological markers of subclinical systemic inflammation, are associated with hyperglycemia, insulin resistance, and overt type 2 DM. Indeed, it recently has been postulated that type 2 DM may represent a disease of the innate immune system, a hypothesis of particular interest because both of these inflammatory biomarkers also are known to predict the development of cardiovascular disease in otherwise healthy populations.

Interleukin 6, a major proinflammatory cytokine, is produced in a variety of tissues, including activated leukocytes, adipocytes, and endothelial cells. C-Reactive protein is the principal downstream mediator of the acute phase response and is primarily derived via IL-6–dependent hepatic biosynthesis. In rodent models of glucose metabolism, the in vivo infusion of human recombinant IL-6 has been shown to induce gluconeogenesis, subsequent hyperglycemia, and compensatory hyperinsulinemia. Similar metabolic responses have been observed in humans after administration of subcutaneous recombinant IL-6. Cross-sectional investigations further support a role for inflammation in the etiology of diabetes;

Context  Inflammation is hypothesized to play a role in development of type 2 diabetes mellitus (DM); however, clinical data addressing this issue are limited.

Objective  To determine whether elevated levels of the inflammatory markers interleukin 6 (IL-6) and C-reactive protein (CRP) are associated with development of type 2 DM in healthy middle-aged women.

Design  Prospective, nested case-control study.


Participants  From a nationwide cohort of 27,628 women free of diagnosed DM, cardiovascular disease, and cancer at baseline, 188 women who developed diagnosed DM over a 4-year follow-up period were defined as cases and matched by age and fasting status with 362 disease-free controls.

Main Outcome Measures  Incidence of confirmed clinically diagnosed type 2 DM by baseline levels of IL-6 and CRP.

Results  Baseline levels of IL-6 (P<.001) and CRP (P<.001) were significantly higher among cases than among controls. The relative risks of future DM for women in the highest vs lowest quartile of these inflammatory markers were 7.5 for IL-6 (95% confidence interval [CI], 3.7-15.4) and 15.7 for CRP (95% CI, 6.5-37.9). Positive associations persisted after adjustment for body mass index, family history of diabetes, smoking, exercise, use of alcohol, and hormone replacement therapy; multivariate relative risks for the highest vs lowest quartiles were 2.3 for IL-6 (95% CI, 0.9-5.6; P for trend = .07) and 4.2 for CRP (95% CI, 1.5-12.0; P for trend =.001). Similar results were observed in analyses limited to women with a baseline hemoglobin A1c of 6.0% or less and after adjustment for fasting insulin level.

Conclusions  Elevated levels of CRP and IL-6 predict the development of type 2 DM. These data support a possible role for inflammation in diabetogenesis.
several studies have demonstrated elevated levels of IL-6 and CRP among individuals both with features of the insulin resistance syndrome and clinically overt type 2 DM.\(^{11-15}\)

Despite these observations, to our knowledge, there are no published prospective data evaluating the relationship between IL-6, CRP, and the development of type 2 DM. Therefore, we evaluated whether baseline plasma levels of these inflammatory markers might independently predict future risk for this disease among apparently healthy individuals.

METHODS

Study Participants

We designed a prospective, nested case-control study involving participants in the Women’s Health Study (WHS), an ongoing randomized clinical trial initiated in 1992 evaluating the use of low-dose aspirin and vitamin E in the primary prevention of cardiovascular disease and cancer among female health professionals aged 45 years and older.\(^{22}\)

Among participants in this primary prevention trial, 27,628 individuals (69% of the WHS cohort) also were free of baseline type 2 DM and provided whole blood samples at enrollment. These samples were centrifuged and then stored in liquid nitrogen until laboratory analysis. Plasma samples collected in EDTA were used for IL-6, CRP, and insulin level determination. Packed red blood cell samples were used for measurement of hemoglobin (Hb) A\(_{1c}\).

Case subjects were WHS participants who provided blood specimens, were free of reported diabetes at enrollment, and subsequently developed newly diagnosed diabetes during a 4-year observation period. Candidate cases were initially identified by self-report on yearly follow-up questionnaires and were subsequently verified through telephone interview conducted by a physician (A.D.P.).

Based on revised American Diabetes Association diagnostic criteria,\(^{23}\) cases were confirmed if 1 or more of the following conditions were met: (1) presence of more than 1 classic symptom of hyperglycemia (ie, polyuria, polydipsia, weight loss with or without polyphagia, and blurred vision) plus either a fasting plasma glucose of 126 mg/dL (7.0 mmol/L) or higher or random plasma glucose 200 mg/dL (11.1 mmol/L) or higher; (2) in the absence of symptoms, 2 or more elevated plasma glucose concentrations (fasting plasma glucose of ≥126 mg/dL [7.0 mmol/L], random plasma glucose ≥200 mg/dL [11.1 mmol/L], or 2-hour plasma glucose ≥200 mg/dL [11.1 mmol/L] during oral glucose tolerance testing); or (3) use of insulin or an oral hypoglycemic agent. The primary care physician’s office was contacted for supporting documentation as necessary. Candidate cases who did not meet the diagnostic criteria, who were found to have prevalent diabetes at enrollment, who died, or who were otherwise lost to follow-up were excluded. In addition, to reduce misclassification bias that might be due to undiagnosed diabetes at study entry, individuals diagnosed within the first year of follow-up (n=69) also were excluded.

For each woman who developed confirmed type 2 DM, 2 control subjects were chosen at random among individuals free of self-reported DM at the time the case subject reported her event. Control subjects were matched by age (within 1 year) and by fasting status of submitted blood specimens. Fasting was defined as 10 hours or longer since last meal prior to sample collection. The final study group undergoing laboratory investigation included 288 confirmed cases and 576 matched controls.

Because of the high prevalence of undiagnosed diabetes among middle-aged US population and because this study was designed to evaluate the role of inflammation as a determinant of future disease, we limited our sample to individuals with a baseline HbA\(_{1c}\) of 6.5% or less. Participants with missing values for baseline clinical covariates of interest also were eliminated from the analysis (body mass index [BMI; calculated as weight in kilograms divided by the square of height in meters], 3% of cases and 1.5% of controls; history of hypertension, 0.5% of cases and 0.7% of controls; history of hyperlipidemia, 0.5% of controls; and use of hormone replacement therapy [HRT], 0.3% of controls). The primary sample thus comprised 188 cases and 362 age-matched controls with HbA\(_{1c}\) of 6.5% or less on entry into the cohort. Based on available published data regarding the exposure rate for elevated CRP levels (≥0.22 mg/dL) among US women,\(^{24}\) we estimated our power to be approximately 87% for detecting a relative risk (RR) of 1.8. Exposure rates for elevated IL-6 levels were not available at the time of study design. The distribution of cases according to year of follow-up at time of diagnosis is as follows: 39 cases in year 2; 76 cases in year 3; and 73 cases in year 4. Among approximately two thirds of women who were fasting at the time of sample collection, we also measured specific insulin levels as an indicator of underlying insulin resistance.

Laboratory Procedures

Baseline plasma samples were thawed and assayed for IL-6, CRP, and specific insulin levels. Hemoglobin A\(_{1c}\) was measured by immunoassay (Hitachi 911 Analyzer; Roche Diagnostics, Indianapolis, Ind). The plasma concentration of IL-6 was measured by a commercially available enzyme-linked immunosorbent assay (R&D Systems, Minneapolis, Minn). C-Reactive protein was measured using a high-sensitivity latex-enhanced immunonephelometric assay on a BN II analyzer (Dade Behring, Newark, Del).\(^{25}\) Double antibody systems (Linco Research, St Louis, Mo), with less than 0.2% cross-reactivity between insulin and its precursors, were used to measure specific concentrations of plasma insulin. In addition, as insulin levels may be falsely lowered in the presence of hemolysis,\(^{26}\) samples with free hemoglobin values higher than 50 mg/dL (spectrophotometric method, Hitachi 911 Analyzer) were excluded from fasting subgroup investigations. Blood samples were analyzed in randomly ordered case-control triplets so as to reduce systematic bias and interassay variation. Blinded quality control specimens were analyzed...
and CRP in predicting diabetes after dividing the primary sample into 4 groups based on the 75th percentile cutpoints for each biomarker. Finally, to assess consistency of risk relationships among obese and nonobese individuals, the study sample was divided into 6 groups based on a BMI cutpoint value of 29 kg/m² (the upper tertile of BMI for our study population) and low, medium, and high tertiles of the inflammatory markers.

RESULTS
Baseline characteristics of women who were subsequently diagnosed with diabetes (case subjects) and those remaining free of diabetes (control subjects) are shown in Table 1. As would be predicted, women who subsequently developed diabetes had a higher mean BMI, were more likely to have a family history of diabetes in a first-degree relative, and were more likely to have a history of hypertension or hyperlipidemia. In addition, case subjects exercised less frequently and consumed less alcohol. There were no statistically significant differences in ethnicity, smoking, or HRT use.

Median baseline levels of IL-6 and CRP were significantly higher among cases than among controls (P<.001) (Table 1). Moreover, increasing levels

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cases (n = 188)</th>
<th>Controls (n = 362)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age, y</td>
<td>54.7</td>
<td>54.7</td>
<td>.001</td>
</tr>
<tr>
<td>Mean BMI, kg/m²†</td>
<td>31.8</td>
<td>25.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Race, %</td>
<td></td>
<td></td>
<td>.61</td>
</tr>
<tr>
<td>White</td>
<td>90.4</td>
<td>91.7</td>
<td></td>
</tr>
<tr>
<td>Nonwhite/unknown</td>
<td>9.6</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Family history of diabetes mellitus, %</td>
<td></td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>History of hypertension, %</td>
<td></td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>History of hyperlipidemia, %</td>
<td></td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Smoking status, %</td>
<td></td>
<td></td>
<td>.89</td>
</tr>
<tr>
<td>Nonsmoker</td>
<td>51.6</td>
<td>51.1</td>
<td></td>
</tr>
<tr>
<td>Former smoker</td>
<td>35.6</td>
<td>37.3</td>
<td></td>
</tr>
<tr>
<td>Current smoker</td>
<td>12.8</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>Frequency of exercise, times/week, %</td>
<td></td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Rarely or never</td>
<td>43.6</td>
<td>33.4</td>
<td></td>
</tr>
<tr>
<td>&lt;1</td>
<td>26.1</td>
<td>18.2</td>
<td></td>
</tr>
<tr>
<td>1-3</td>
<td>25.0</td>
<td>34.8</td>
<td></td>
</tr>
<tr>
<td>≥4</td>
<td>5.3</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>Frequency of alcohol consumption, %</td>
<td></td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Rarely or never</td>
<td>61.7</td>
<td>39.8</td>
<td></td>
</tr>
<tr>
<td>Monthly</td>
<td>14.9</td>
<td>14.4</td>
<td></td>
</tr>
<tr>
<td>Weekly</td>
<td>21.3</td>
<td>34.5</td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>2.1</td>
<td>11.3</td>
<td></td>
</tr>
<tr>
<td>Hormone replacement therapy use, %</td>
<td></td>
<td></td>
<td>.28</td>
</tr>
<tr>
<td>Never</td>
<td>43.1</td>
<td>45.0</td>
<td></td>
</tr>
<tr>
<td>Past only</td>
<td>13.8</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>43.1</td>
<td>45.6</td>
<td></td>
</tr>
<tr>
<td>Interleukin 6, pg/mL, median (interquartile range)</td>
<td>2.00 (1.43-2.78)</td>
<td>1.38 (0.91-2.05)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>C-Reactive protein, mg/dL, median (interquartile range)</td>
<td>0.69 (0.42-1.00)</td>
<td>0.26 (0.10-0.61)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Fasting insulin, pmol/L, median (interquartile range)</td>
<td>77.5 (52.5-98.5)</td>
<td>39.3 (28.8-56.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Hemoglobin A₁c, %, median (interquartile range)</td>
<td>6.0 (5.7-6.3)</td>
<td>5.5 (5.3-5.7)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*Limited to subjects (N = 550) with hemoglobin A₁c of 6.5% or less at baseline.
†BMI indicates body mass index.
‡Among subjects providing fasting blood samples: 126 cases and 225 controls.

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CRP, IL-6, AND RISK OF TYPE 2 DIABETES MELLITUS

Table 2. Crude and Adjusted Relative Risks of Type 2 Diabetes Mellitus, According to Baseline Plasma Concentration of Interleukin 6 and C-Reactive Protein*

<table>
<thead>
<tr>
<th>Inflammatory Marker</th>
<th>Quartile of Interleukin 6, Median (Interquartile Range), pg/mL</th>
<th>Quartile of C-Reactive Protein, Median (Interquartile Range), mg/dL</th>
<th>P for Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0.698</td>
<td>1.133</td>
<td>1.646</td>
</tr>
<tr>
<td></td>
<td>(0.909)</td>
<td>(0.91-1.382)</td>
<td>(1.383-2.050)</td>
</tr>
</tbody>
</table>

Crude analysis

Relative risk (95% CI) 1.0 2.5 (1.1-5.6) 4.1 (2.0-8.4) 7.5 (3.7-15.4) <.001 1.0 2.2 (0.8-6.0) 8.7 (3.6-21.0) 15.7 (6.5-37.9) <.001

P value .02 <.001 <.001 .13 <.001 <.001

BMI-adjusted analysis

Relative risk (95% CI) 1.0 1.8 (0.7-4.4) 1.9 (0.8-4.2) 2.9 (1.3-6.7) .008 1.0 1.2 (0.4-3.5) 4.1 (1.6-10.6) 4.4 (1.7-11.5) <.001

P value .19 .12 .01 .73 .004 .002

Adjusted for all risk factors†

Relative risk (95% CI) 1.0 1.4 (0.6-3.7) 1.3 (0.6-3.1) 2.3 (0.9-5.6) .07 1.0 1.3 (0.4-4.1) 4.1 (1.5-11.5) 4.2 (1.5-12.0) .001

P value .47 .51 .08 .61 .007 .007

*Limited to subjects with hemoglobin A₁c of 6.5% or less: 126 cases, 225 controls. CI indicates confidence interval; BMI, body mass index.
†Matched on age and fasting status, controlled for BMI, family history of diabetes, smoking, physical activity, alcohol consumption, and hormone replacement therapy. Limited to subjects providing fasting blood specimens, the relative risk (95% CI) for trend was the same across quartiles of IL-6 and CRP: 1.0, 1.8, 3.8, and 4.9, respectively (P=.02 for trend).

The subgroup of participants who provided fasting blood specimens, the median insulin level also was significantly higher in case subjects than control subjects (77.5 vs 39.3 pmol/L; P<.001). Therefore, we evaluated whether relationships between IL-6, CRP, and the future risk of diabetes were independent of fasting insulin level. As shown in Table 3, adjustment for baseline fasting insulin level further attenuated the effects of IL-6 levels. However, the risk relationship for CRP was not materially altered after adjustment for this factor. In addition, in this subgroup, Spearman partial correlation coefficients between inflammatory markers and both fasting insulin and BMI were statistically significant (P<.001) (Table 4). C-Reactive protein was more strongly correlated than IL-6 with each parameter tested. Hemoglobin A₁c of 6.5% or less was not strongly associated with either biomarker.

To assess potential joint effects, we computed the RR of DM after dividing the original sample into 4 groups based on the 75th percentile of control distributions for IL-6 and CRP (Figure 1). As shown, the RR of type 2 DM was highest among women with both high

Table 3. Relative Risks of Type 2 Diabetes Mellitus, According to Baseline Plasma Concentration of Interleukin 6 and C-Reactive Protein, Adjusted for Fasting Insulin Level in Addition to Clinical Risk Factors*

<table>
<thead>
<tr>
<th>Inflammatory Marker</th>
<th>Quartile of Plasma Biomarker Level</th>
<th>P for Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Interleukin 6</td>
<td>Relative risk (95% CI) 1.0 1.5 (0.5-4.8) .23</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>.56 .51</td>
<td></td>
</tr>
<tr>
<td>C-Reactive protein</td>
<td>Relative risk (95% CI) .91 .10 .04</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>.91 .10 .04</td>
<td></td>
</tr>
</tbody>
</table>

*Matched on age and fasting status, controlled for BMI, family history of diabetes, smoking, physical activity, alcohol consumption, and hormone replacement therapy. Limited to subjects providing fasting blood specimens with hemoglobin A₁c of 6.5% or less: 126 cases, 225 controls. CI indicates confidence interval.

Table 4. Spearman Partial Correlation Coefficients of Inflammatory Markers With Body Mass Index and Metabolic Parameters*

<table>
<thead>
<tr>
<th>Inflammatory Marker</th>
<th>Body Mass Index†</th>
<th>Hemoglobin A₁c‡</th>
<th>Fasting Insulin‡</th>
<th>Interleukin 6‡</th>
<th>C-Reactive Protein‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interleukin 6</td>
<td>0.45§</td>
<td>0.07</td>
<td>0.18§</td>
<td>. . .</td>
<td>0.39§</td>
</tr>
<tr>
<td>C-Reactive protein</td>
<td>0.57§</td>
<td>0.10</td>
<td>0.19§</td>
<td>0.39§</td>
<td>. . .</td>
</tr>
</tbody>
</table>

*Limited to subjects with hemoglobin A₁c of 6.5% or less: 126 cases, 225 controls.
†Adjusted for age.
‡Adjusted for age and body mass index.
§P<.001.

**of both inflammatory markers were associated with a higher risk of developing future diabetes; in age-matched analyses, the RRs of incident type 2 DM for increasing quartiles of IL-6 were 1.0, 2.5, 4.1, and 7.5, respectively (P<.001 for trend) and the RRs for increasing quartiles of CRP were 1.0, 2.2, 8.7, and 15.7, respectively (P<.001 for trend) (Table 2). Adjustment for BMI markedly attenuated these relationships, although persistent positive effects of IL-6 (P=.008 for trend) and CRP (P<.001 for trend) were observed. Indeed, CRP remained a significant predictor in fully-adjusted models that included BMI, family history of diabetes, smoking, physical activity, alcohol consumption, and HRT use. Overall, the RR for future diabetes increased 28% (95% confidence interval [CI], 1% to 65%; P=.07) per quartile increase in baseline IL-6 levels and 64% (95% CI, 22%-218%; P=.001) per quartile increase in baseline CRP levels. Similar findings were observed in analyses limited to those with an HbA₁c of 6.0% or less at baseline. For example, in this subset, fully adjusted RRs of incident diabetes across quartiles of CRP were 1.0, 1.8, 3.8, and 4.9, respectively (P=.02 for trend).

In the subgroup of participants who provided fasting blood specimens, the median insulin level also was significantly higher in case subjects than control subjects (77.5 vs 39.3 pmol/L; P<.001). Therefore, we evaluated whether relationships between IL-6, CRP, and the future risk of diabetes were independent of fasting insulin level. As shown in Table 3, adjustment for baseline fasting insulin level further attenuated the effects of IL-6 levels. However, the risk relationship for CRP was not materially altered after adjustment for this factor. In addition, in this subgroup, Spearman partial correlation coefficients between inflammatory markers and both fasting insulin and BMI were statistically significant (P<.001) (Table 4). C-Reactive protein was more strongly correlated than IL-6 with each parameter tested. Hemoglobin A₁c of 6.5% or less was not strongly associated with either biomarker.

To assess potential joint effects, we computed the RR of DM after dividing the original sample into 4 groups based on the 75th percentile of control distributions for IL-6 and CRP (Figure 1). As shown, the RR of type 2 DM was highest among women with both high

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IL-6 and CRP levels, suggesting a multiplicative effect above that seen for either high IL-6 or high CRP levels alone.

To investigate effect modification by BMI, we determined the RR of incident diabetes among women with a BMI less than 29 kg/m² or 29 kg/m² and greater (Figure 2). After controlling for BMI within strata, higher baseline plasma levels of IL-6 and CRP were associated with increased risk of incident disease. Notably, even among non-obese women, increasing IL-6 and CRP levels conferred an augmented step-wise elevation in risk.

Among individuals with a baseline HbA₁c of 6.5% or less, we performed secondary analyses to address the additional issues of potential surveillance bias, possible confounding by degree of baseline chronic hyperglycemia, and residual confounding by obesity. Case subjects were noted to have a higher baseline prevalence of diagnosed hypertension and hyperlipidemia and on this basis might have been screened more frequently for other major cardiovascular risk factors, including diabetes. We attempted to control for this potential surveillance bias by adjusting for history of hypertension and hyperlipidemia and found equivalent results; the BMI-adjusted RR in the highest vs the lowest quartile for IL-6 was 3.0 (95% CI, 1.3-7.0; P=.007 for trend) and for CRP was 4.0 (95% CI, 1.5-10.6; P=.001 for trend). To evaluate for confounding by chronic hyperglycemia, we controlled for baseline HbA₁c; in analyses simultaneously controlling for BMI, the adjusted RR for the highest compared with the lowest quartile of IL-6 was 2.0 (95% CI, 0.6-6.2; P=.77 for trend) and for CRP was 3.4 (95% CI, 0.9-12.1; P=.03 for trend). To assess residual confounding by obesity, we used waist-hip ratio (WHR) and waist circumference as alternate indices of adiposity among approximately two thirds of the study cohort for whom these parameters were available. The distribution of baseline characteristics in this subgroup was similar to those observed for the primary study sample. In statistical models controlling for WHR in addition to BMI, the RR in these analyses comparing the highest with the lowest quartile for IL-6 was 4.1 (95% CI, 1.4-11.8; P=.004 for trend) and for CRP was 3.1 (95% CI, 1.1-9.4; P=.001 for trend). Similar results were obtained after adjustment for waist circumference. In addition, after confining the study cohort to normal weight subjects (BMI ≤ 25 kg/m²), the median CRP level remained significantly elevated among case subjects vs control subjects (0.46 vs 0.15 mg/dL; P=.01). Finally, we found that randomized treatment assignment to vitamin E or low-dose aspirin did not affect the observed risk relationships during the 4-year observation period.

**COMMENT**

In this prospective study of apparently healthy middle-aged women, 2 markers of systemic inflammation, CRP and IL-6, were found to be determinants of risk for type 2 DM. In particular, CRP was a powerful independent predictor after adjustment for obesity, clinical risk factors, and fasting insulin levels. Parallel associations were found for IL-6, although lower in magnitude and of borderline statistical significance after multivariate adjustments. These findings were robust in sensitivity analyses limited to subjects with a baseline HbA₁c of 6.0% or less and were consistently noted in both obese and nonobese individuals.

To our knowledge, no prior epidemiological evidence has been available linking baseline CRP and IL-6 levels to incident DM. However, cross-sectional studies have reported increased concentrations of these inflammatory markers in both the insulin resistance syndrome and overt type 2 DM. Our data also extend prior work in which other inflammatory markers, such as white blood cell count, fibrinogen, and low serum albumin, and inflammation-associated hemostasis variables, such as factor VIII and von Willebrand factor, were associated with risk of diabetes; although in these latter investigations, risk relationships largely disappeared after adjustment for obesity.

The current prospective data support a possible role for inflammation in diabetogenesis and are in accord with previous hypotheses originated by Pickup and Crook, that type 2 DM may be a manifestation of an ongoing cytokine-mediated acute phase response initiated by the body’s innate immune system. Of particular relevance to the current findings, CRP is thought to exhibit several characteristics that imply a fundamental role in natural host defense. Specifically, CRP is a member of the pentraxin family of oligomeric proteins involved with pattern recognition in innate immunity. Reported immunoregulatory functions of CRP include enhancement of leukocyte reactivity, complement fixation, modulation of platelet activation, and clearance of cellular debris from sites of active inflammation. Although our data support etiological associations, at this time explicit mechanisms remain speculative and require further study.
Several alternative, perhaps coordinate, explanations for our results warrant further discussion. First, it is possible that the associations observed in this study of diabetes reflect underlying atherosclerosis among case subjects. However, it is worth noting that the 4-year cardiovascular event rate among our study cohort was low (1 case subject). Nevertheless observed in multivariate models controlling for obesity, the graded crude association between increasing concentrations of these inflammatory markers and risk for diabetes suggests a possible role in disease expression whether this process is obesity-driven or autonomously mediated.

Another potential mechanism that may explain our results is the relationship between inflammation and endothelial dysfunction. Altered endothelial permeability and diminished peripheral blood flow may limit insulin delivery and promote insulin resistance in metabolically active tissues. Furthermore, omental fat cells have been shown to secrete as much as 2 to 3 times more IL-6 in vitro than cells derived from subcutaneous stores, an intriguing finding as venous drainage from omental fat provides direct access to the portal system, and abdominal adiposity is strongly linked to insulin resistance. Although we found a stronger relationship between baseline elevations of CRP and incident diabetes than that seen for IL-6, this may partially reflect the considerably longer plasma half-life of CRP that thereby may provide a more stable indication of subclinical inflammation. Furthermore, because of diurnal variation in IL-6 release and because study specimens were obtained at different times of the day, random misclassification of both cases and controls may have biased our results for IL-6 toward the null. In this regard, plasma CRP levels may represent a more appropriate integrated measure of basal IL-6 activity.

In the present analysis, BMI was used as the principal measure of obesity, and as expected, significantly attenuated RR estimates for both IL-6 and CRP. Adjustment for WHR or waist circumference, indices of abdominal adiposity, similarly weakened the observed risk relationships. However, significant associations for both IL-6 and CRP were nonetheless observed in multivariate models adjusting for these factors. In addition, a stepwise RR gradient was evident even among nonobese individuals (Figure 2). Regardless of the apparent diminution of effects in statistical models controlling for obesity, the graded crude association between increasing concentrations of these inflammatory markers and risk for diabetes suggests a possible role in disease expression whether this process is obesity-driven or autonomously mediated.

IL-6 indicates interleukin 6; CRP, C-reactive protein; and BMI, body mass index. Risk estimates (relative risks, RRs) were matched on age and fasting status and controlled for continuous BMI within strata. The mean BMI within strata are <29 kg/m² (case subjects 25.7 kg/m² vs control subjects 23.6 kg/m²) and BMI ≥ 29 kg/m² (case subjects 35.4 kg/m² vs control subjects 33.6 kg/m²). The CRP tertile range (mg/dL) for low, middle, and high is ≤0.14, 0.15-0.48, and >0.48, respectively. The IL-6 tertile range (pg/mL) for low, middle, and high is ≤1.018, 1.019-1.757, and >1.757, respectively. Error bars indicate 95% confidence intervals. For high levels of IL-6, asterisk indicates P = .03 and P = .03 for RRs 2.6 and 3.0, respectively. For middle levels of CRP, the dagger indicates P = .005 and P = .01 for RRs 3.8 and 4.6, respectively, and for high levels of CRP, double dagger indicates P < .001 and P = .005 for RRs 5.6 and 5.3, respectively.

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strongly correlated with markers of endothelial activation and dysfunction.\(^{38}\) The increasingly recognized associations between endothelial dysfunction, inflammation, and insulin resistance provide an additional plausible physiologic basis for our findings.

Finally, it is possible that elevated IL-6 and CRP levels may largely reflect adipocyte activation. For instance, IL-6 and downstream CRP production may be associated with the corelease of other pathogenic substances arising from otherwise stimulated adipocytes. Other potential mediators of insulin resistance deriving from adipose stores include tumor necrosis factor \(\alpha\), leptin, free fatty acids, and resistin.\(^{54}\) Nonetheless, uncontrolled adipocytes and cachexia, as well as the corelease of other pathogenic substances, may not fully account for the metabolic consequences of obesity. In this regard, it is important to note adjusting for WHR and waist circumference in addition to BMI, we found consistent results statistically significant and undiminished in magnitude. Finally, we used a single baseline plasma measurement of each biomarker. We therefore could not evaluate the effects of changes in plasma levels of inflammatory markers over time. However, several longitudinal analyses have found that levels of CRP are stable during long-term follow-up, as long as measurements are not made within 2 weeks of an acute infection.\(^{35,36}\)

In conclusion, in this prospective evaluation of 2 markers of systemic inflammation in the prediction of incident diabetes, elevated CRP was found to be a powerful independent risk determinant. Interleukin 6 levels also were elevated among individuals at risk, although these associations were markedly attenuated after multivariate adjustment. Our epidemiological observations, coupled with emerging experimental evidence, support a possible role for inflammation in the pathogenesis of type 2 DM. Our data also raise the possibility that inflammatory markers, like CRP, might provide an adjunctive method for early detection of risk for this disease.

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