Inflammatory Plasma Markers and Pancreatic Cancer Risk: a Prospective Study of 5 U.S. Cohorts

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No conflicts of interest exist.
ABSTRACT

Chronic inflammation may play a role in the development of pancreatic cancer. However, few prospective studies have examined the association between plasma inflammatory markers and pancreatic cancer risk. Therefore, we investigated the association of prediagnostic circulating C-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor-α-receptor II (TNF-αR2) with subsequent pancreatic cancer risk in a prospective, nested case-control study of 470 cases and 1094 controls from Health Professionals Follow-up Study, Nurses’ Health Study, Physicians’ Health Study, Women’s Health Initiative, and Women’s Health Study. The median follow-up time of cases was 7.2 years (range 1-26 years). No association was observed between plasma CRP, IL6, and TNF-αR2 and risk of pancreatic cancer. Comparing extreme quintiles, the multivariate ORs were 1.10 (95% CI, 0.74-1.63; \( P_{\text{trend}} = 0.81 \)) for CRP, 1.19 (95% CI, 0.81-1.76; \( P_{\text{trend}} = 0.08 \)) for IL6, and 0.88 (95% CI, 0.58-1.33; \( P_{\text{trend}} = 0.57 \)) for TNF-αR2. In conclusion, pre-diagnostic levels of circulating CRP, IL6, and TNF-αR2 were not associated with risk of pancreatic cancer, suggesting that systemic inflammation as measured by circulating inflammatory factors is unlikely to play a major role in the development of pancreatic cancer.
INTRODUCTION

Chronic inflammation may promote cancer development through several mechanisms, including enhanced cellular proliferation and mutagenesis, poor adaptability to oxidative stress, promotion of angiogenesis, and inhibition of apoptosis (1, 2). Certain chronic inflammatory conditions, such as chronic pancreatitis, obesity, and type-2 diabetes, predispose to pancreatic cancer (3-5). In addition, pancreatic cancer induces a strong desmoplastic reaction that provides inflammatory mediators and growth factors to support tumor growth and metastases (6-8). However, the inflammatory mediators that promote pancreatic cancer development remain poorly defined.

Several inflammatory markers may play a direct pathogenic role in the development of pancreatic cancer or act as surrogate biomarkers, including C-reactive protein (CRP), interleukin-6 (IL6), and tumor necrosis factor-\(\alpha\) (TNF-\(\alpha\)). CRP is a biomarker increasingly used in cardiovascular screening (9, 10), and plasma CRP levels are increased in obesity, impaired glucose tolerance, and metabolic syndrome (11). IL6 and TNF-\(\alpha\) are cytokines that play important roles in triggering the inflammatory response, and are associated with risk factors for pancreatic cancer, such as obesity, insulin resistance and diabetes mellitus (12-15). Interestingly, these inflammatory cytokines are expressed by pancreatic cancer cells and surrounding stroma, and have been noted to facilitate tumor cell growth and metastases (6-8, 16-18). Prospective studies have demonstrated that elevated levels of CRP, IL6, and TNF-\(\alpha\) may be linked to higher risk of cancer (19-21).

Several small, hospital-based case-control studies showed that pancreatic cancer cases had higher levels of CRP, IL6, and TNF-\(\alpha\)/receptors than controls (22-25). Although a strong rationale exists to suspect a role for inflammatory cytokines in pancreatic cancer pathogenesis,
few prospective epidemiologic studies have examined the association of pancreatic cancer risk with CRP (21, 26, 27), IL6 (27), or TNF-α receptors (27). We therefore examined the association between pre-diagnostic plasma CRP, IL6, and TNF-α receptor 2 (TNF-αR2, TNFRSF1B) and subsequent risk of pancreatic cancer in five U.S. prospective cohorts with up to 26 years of follow-up.

**MATERIALS AND METHODS**

**Study Participants**

We pooled the primary data from five U.S. prospective cohorts. The Health Professionals Follow-up Study (HPFS) enrolled 51,529 male health professionals aged 40-75 years in 1986. The Nurses’ Health Study (NHS) enrolled 121,700 female nurses aged 30-55 years in 1976. The Physicians’ Health Study I (PHS I) is a randomized clinical trial of aspirin and β-carotene and enrolled 22,071 healthy male physicians aged 40-84 years in 1982. The aspirin component of the trial ended in 1988, while the β-carotene component ended in 1995, and participants are followed as an observational cohort. The Women’s Health Initiative (WHI)-Observational Study enrolled 93,676 postmenopausal women aged 50-79 years between 1994 and 1998. The Women’s Health Study (WHS) is a randomized clinical trial of low-dose aspirin and vitamin E and enrolled 39,876 healthy female health professionals aged ≥45 years between 1992 and 1995. The trial was completed in 2004 and participants are followed as an observational cohort.

Individual characteristics and habits, including age at blood draw, sex, race/ethnicity, weight, height, smoking status, physical activity, history of diabetes, and current multivitamin use, were obtained from the baseline questionnaires at enrollment in PHS I, WHI, and WHS and from the questionnaires preceding the date of blood draw in HPFS and NHS. Details of these
cohorts have been described previously (28-32). The current study was approved by the Human
Research Committee at the Brigham and Women’s Hospital, Boston, MA, and participants
provided informed consent.

**Blood Collection and Plasma Assays**

Blood samples were collected from 18,225 men in HPFS from 1993-1995, 32,826
women in NHS from 1989-1990, 14,916 men in PHS from 1982-1984, 93,676 women in WHI
transportation, and storage of plasma samples have been described previously (33-37).

Plasma CRP, IL6, and TNF-αR2 were measured in the laboratory of Dr. Nader Rifai
(Children’s Hospital, Boston, MA), using reagents from Roche Diagnostics (Indianapolis, IN).
Of note, we measured TNF-αR2 because TNF-αR2 has greater stability in plasma than TNF-α,
and acts as a comprehensive measure of TNF-α pathway activation (38). In previous studies, we
demonstrated that TNF-αR2 levels were correlated with adiposity (39) and predicted the risk of
diabetes (40) and coronary heart disease.(41)

All samples for CRP, IL6, and TNF-αR2 were handled identically in a single batch.
Laboratory personnel were blinded to case, control, or quality control status. The mean intra-
assay coefficients of variance for each assay were ≤10% for blinded, replicate, quality control
samples.

**Pancreatic cancer cases and matched controls**

We included cases of pancreatic adenocarcinoma diagnosed through 2008 among
participants who had provided blood samples and no prior history of cancer, except non-
melanoma skin cancer. Incident cases were identified by self-report or during follow-up of a participant’s death. Deaths were ascertained from next-of-kin or the U.S. postal service and by searching the National Death Index. This method has been shown to capture >98% of deaths.(42) Medical records of the cases were requested and reviewed by study physicians blinded to exposure data. Over 99% of cases in this study were confirmed by review of medical records, tumor registry data, or death certificates.

Eligible controls were cohort participants who provided a blood sample and were alive and free of cancer at the date of the case’s diagnosis. We randomly selected up to 3 controls for each case, matching on year of birth, prospective cohort (which concurrently matched on sex), smoking status (never, past, current), fasting status (fasting, non-fasting), and month of blood draw.

For the present analysis, 491 pancreatic cancer cases and 1137 matched controls were available. For the analyses of CRP and TNF-αR2, 2 cases and 1 control were removed due to failure of the assay, and for those 2 cases, we also removed their matched controls (n=4). For the analysis of IL6, 10 cases and 23 control were removed due to failure of the assay, and for those 10 cases, we removed their matched controls (n=17). Due to concern regarding the possible influence of subclinical malignancy on body-mass index, lifestyle choices and plasma markers levels, we further excluded pancreatic cancer cases diagnosed within 1 year of blood draw (n=19) and their matched controls (n=38). Therefore, for the analyses of CRP and TNF-αR2, we had a total of 470 cases (HPFS: 74; NHS: 103; PHS: 70; WHI: 194; WHS: 29) and 1094 controls (HPFS, 180; NHS, 307; PHS I, 173; WHI, 380; WHS, 54); for the analysis of IL6, we had a total of 462 cases (HPFS: 74; NHS: 95; PHS: 70; WHI: 194; WHS: 29) and 1059 controls (HPFS, 180; NHS, 275; PHS I, 170; WHI, 380; WHS, 54). The median follow-up time of cases
was 7.2 years (range 1-26 years).

Statistical Analysis

We pooled the primary data from five cohorts. Participants were categorized into quintiles based on the distributions among all controls. We additionally performed separate analyses in men and women using gender-specific quintiles. For analysis of CRP and pancreatic cancer risk, we also used the cutoff points proposed in clinical guidelines for cardiovascular disease, and categorized participants into CRP levels of less than 1, 1 to 3, and greater than 3 mg/L.\(^{(43)}\)

To compute odds ratios (ORs) and 95% confidence intervals (CIs), we used conditional logistic regression conditioned on the matching factors including year of birth, prospective cohort (HPFS, NHS, PHS I, WHI, WHS, which concurrently matched on sex), smoking status (never, past, current), fasting status (fasting, non-fasting), and month of blood draw. In multivariate models, we adjusted for established or suspected risk factors of pancreatic cancer including race (White, Black, other), history of diabetes mellitus (yes, no), body mass index (BMI, <18.5, 18.5–24.9, 25–29.9, ≥30 kg/m\(^2\)), physical activity (quartiles), current multivitamin use (yes, no), plasma 25(OH)D levels (quartiles), and plasma C-peptide levels (quartiles). In no instance did including any of these covariates change the estimate by more than 10%. \(P\) values for trend were calculated by the Wald test of a score variable that contained median values of quintiles.

To evaluate whether the associations between inflammatory markers and pancreatic cancer risk were linear, we compared the model fit including linear and cubic spline terms selected by a stepwise regression procedure to the model fit with only the linear term using the
likelihood ratio test. Additional analyses in which plasma markers were modeled as a continuous variable were conducted if the nonparametric regression curves showed that the associations of pancreatic cancer risk with plasma markers were consistent with linear associations.

We also conducted a meta-analysis of individual study data. We calculated ORs for each cohort and then pooled these cohort-specific ORs to compute a summary OR using the DerSimonian and Laird random effects model. Heterogeneity across studies was tested using the Q statistic.

To examine whether the associations between inflammatory markers and risk of pancreatic cancer were modified by other risk factors of pancreatic cancer, we conducted preplanned subgroup analyses using unconditional logistic regression adjusted for the matching factors and other relevant covariates. We examined the association in subgroups defined by sex, age at blood draw, follow-up time of cases, smoking status, BMI, and physical activity. Tests for interaction were performed by the Wald test of cross-product terms. To test the robustness of our results, we conducted a sensitivity analysis excluding individuals with diabetes. To further mitigate any effect of subclinical pancreatic cancer on plasma biomarker levels, we did additional analyses excluding pancreatic cancer cases diagnosed within 2 or 4 years from the date of blood draw. Finally, we repeated the analyses after inflammatory biomarkers were log-transformed to improve normality. All statistical analyses were performed with the SAS 9.1 statistical package (SAS Institute, Cary, North Carolina) and all $P$ values are two sided.

RESULTS

Median plasma level was higher in cases versus controls for IL6 (1.5 vs 1.2 pg/mL,
and not as apparent for CRP (1.8 vs 1.6 mg/L, \( P = 0.15 \)) and TNF-αR2 (2.7 vs 2.6 mg/mL, \( P = 0.23 \)). Among controls, CRP levels and IL6 levels were highly correlated (Spearman’s rank correlation coefficient \( r = 0.47 \)); we observed moderate correlations between CRP levels and TNF-αR2 levels \( (r = 0.24) \) and between IL6 levels and TNF-αR2 levels \( (r = 0.26) \).

Individuals in the upper quintiles of these inflammatory markers were older; more likely to be female, current smokers, or have diabetes; less likely to exercise; and had higher BMI and C-peptide levels (Table 1).

No association was observed between plasma CRP, IL6, and TNF-αR2 and risk of pancreatic cancer. Comparing extreme quintiles, the multivariate ORs were 1.10 (95% CI, 0.74-1.63; \( P_{\text{trend}} = 0.81 \)) for CRP, 1.19 (95% CI, 0.81-1.76; \( P_{\text{trend}} = 0.08 \)) for IL6, and 0.88 (95% CI, 0.58-1.33; \( P_{\text{trend}} = 0.57 \)) for TNF-αR2 (Table 2). There was no statistically significant heterogeneity due to sex (for the multivariate ORs of quintile 5, men vs women, \( P_{\text{heterogeneity}} = 0.40 \) for CRP, 0.09 for IL6, and 0.49 for TNF-αR2) and no association was observed between any of these inflammatory markers and pancreatic cancer risk among men and among women (Supplemental Table 1). The results were virtually unchanged when we excluded cases diagnosed within 2 years or 4 years from the date of blood draw, or limited to non-diabetics (Supplemental Table 2).

Spline analyses showed that the associations of pancreatic cancer risk with CRP, IL6, and TNF-αR2 were consistent with linear associations \( (P_{\text{nonlinear}} = 0.28 \) for CRP, 0.19 for IL6, and 0.57 for TNF-αR2). In additional analyses with plasma markers modeled as continuous variables, the multivariate ORs for an increment of one unit was 0.99 (95% CI, 0.98-1.01) for CRP, 1.01 (95% CI, 0.99-1.04) for IL6, and 0.92 (95% CI, 0.82-1.04) for TNF-αR2 (Table 2).

We observed similar odds ratios when analyzing each cohort separately (Supplemental
Table 3), with no statistically significant heterogeneity across studies ($P = 0.42$ for CRP, $0.23$ for IL6, and $0.40$ for TNF-$\alpha$R2). In a meta-analysis pooling the cohort-specific ORs, an increment of one unit for CRP had an OR of 0.99 (95% CI, 0.97-1.02); for IL-6, 1.00 (95% CI, 0.96-1.04); and for TNF-$\alpha$R2, 0.95 (95% CI, 0.82-1.09).

For analysis of CRP, we further categorized participants using the cutoff points proposed in clinical guidelines for cardiovascular disease (43). Comparing to CRP level less than 1 mg/L, the multivariate ORs of pancreatic cancer were 0.92 (95% CI, 0.69-1.23) for CRP level of 1 to 3 mg/L, and 1.07 (95% CI, 0.78-1.45) for CRP level of greater than 3 mg/L. We also found no statistically significant interactions by sex, age at blood draw, follow-up time of cases, smoking status, BMI, and physical activity (Supplemental Table 4). We repeated all the analyses after inflammatory biomarkers were log-transformed, and observed similar results.

**DISCUSSION**

In this large prospective study of 5 U.S. cohorts, pre-diagnostic plasma CRP, IL6, and TNF-$\alpha$R2 were not associated with risk of pancreatic cancer. Furthermore, there were no associations between these biomarkers and pancreatic cancer risk in any of the subgroups evaluated.

The prospective design and high follow-up rates in this study minimize the possibility that our null findings are due to selection bias or differential case ascertainment. Because we excluded cases diagnosed within 1 year of blood draw, it is unlikely that disease status or treatment may influence the biomarker levels (reverse causation). This concern was further minimized by analyses that excluded cases diagnosed within 2 and 4 years after blood collection. Our results are also unlikely to be explained by the cutoff points chosen because we consistently
found no associations by using quintile distribution of biomarkers among controls, by using the
cutoff points in clinical guidelines (for CRP), or by using biomarkers as a continuous variable.

Confounding might be of minor importance in the present study as we matched cases and
contROLS on important risk factors of pancreatic cancer such as age and smoking, and then
adjusted for risk factors such as BMI, physical activity, and diabetes for a more complete control
for confounding.

Measurement error could potentially explain the lack of associations in this study.
Inflammatory markers were measured only once at baseline, therefore may not represent long
term levels. However, CRP, IL6, and TNF-αR2 levels have been shown to be stable over time
(46). Subgroup analyses also showed that the results for less than 7.2 years of follow-up (median
follow-up time of cases) were similar to those for 7.2 or more years of follow-up. In addition, the
single measurement of baseline CRP, IL6, and TNF-αR2 has strongly predicted the risk for many
diseases including diabetes (36, 40). Furthermore, we attempted to reduce measurement error by
measuring CRP, IL6, and TNF-αR2 in a single laboratory as a single batch, and the coefficients
of variance were low for blinded, replicate quality control samples.

Our findings are consistent with previous studies examining plasma inflammatory
markers and pancreatic cancer risk. Three prospective studies examined pre-diagnostic CRP
levels in relation to pancreatic cancer risk (21, 26, 27). In the Alpha-Tocopherol, Beta-Carotene
Cancer Prevention Study (ATBC) cohort of male Finish smokers (26), a weak inverse
association was observed (OR, 0.94; 95% CI, 0.89–0.99), whereas no association was observed
in a small Greek prospective study (21), the Prostate, Lung, Colorectal and Ovarian Cancer
Screening Trial (PLCO) (26), or the European Prospective Investigation into Cancer and
Nutrition (EPIC) study (27). Only one prospective study has examined pre-diagnostic IL6 and
TNF-α receptors in relation to pancreatic cancer risk, and neither biomarker was significantly associated with overall risk of pancreatic cancer (27), although an inverse association was observed for TNF-αR1 among women.

In conclusion, our findings do not appear to support a positive association of pancreatic cancer risk with pre-diagnostic plasma CRP, IL6 and TNF-αR2. Although local inflammatory pathway activation appears play an important role in pancreatic carcinogenesis (6-8), systemic inflammation as measured by circulating inflammatory factors does not appear to represent a material predictor of risk.
Acknowledgements:

The authors would like to thank the participants and staff of the Health Professionals Follow-up Study, Nurses’ Health Study, Physicians’ Health Study, Women’s Health Initiative and Women’s Health Study, for their valuable contributions as well as the following state cancer registries for their help: AL, AZ, AR, CA, CO, CT, DE, FL, GA, ID, IL, IN, IA, KY, LA, ME, MD, MA, MI, NE, NH, NJ, NY, NC, ND, OH, OK, OR, PA, RI, SC, TN, TX, VA, WA, WY.

Funding/Support:

The NHS and HPFS are supported by the National Cancer Institute, National Institutes of Health (Grants No. P01 CA87969, P01 CA55075, P50 CA127003, R01 CA124908). Brian Wolpin, MD, MPH is supported by NCI K07 CA140790, an American Society of Clinical Oncology Career Development Award, a Howard Hughes Medical Institute Early Career Physician-Scientist Award, and the Lustgarten Foundation.

The PHS I is supported by grants CA 97193, CA 34944, CA 40360, HL 26490, and HL 34595 from the National Institutes of Health (Bethesda, MD).

The WHI program is funded by the National Heart, Lung, and Blood Institute, National Institutes of Health, U.S. Department of Health and Human Services through contracts N01WH22110, 24152, 32100-2, 32105-6, 32108-9, 32111-13, 32115, 32118-32119, 32122, 42107-26, 42129-32, and 44221. The authors thank the WHI investigators and staff for their dedication, and the
study participants for making the program possible. A full listing of WHI investigators can be found at: http://www.whiscience.org/publications/WHI_investigators_shortlist.pdf.

The WHS is supported by grants CA047988, HL043851, and HL080467 from the National Institutes of Health (Bethesda, MD).
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10. Scirica BM, Morrow DA. Is C-reactive protein an innocent bystander or proatherogenic culprit? The verdict is still out. Circulation. 2006 May 2;113(17):2128-34; discussion 51.
Table 1. Age/study-standardized baseline characteristics according to quintiles of inflammatory plasma markers among controls

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>C-reactive protein, mg/L</th>
<th>Interleukin-6, pg/mL</th>
<th>Tumor necrosis factor-α-receptor II, mg/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
<td>Q3</td>
<td>Q5</td>
</tr>
<tr>
<td>Age at blood draw, years</td>
<td>60.9</td>
<td>62.6</td>
<td>63.3</td>
</tr>
<tr>
<td>Men, %</td>
<td>49.6</td>
<td>32.5</td>
<td>17.0</td>
</tr>
<tr>
<td>Race, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>88.5</td>
<td>94.0</td>
<td>94.7</td>
</tr>
<tr>
<td>Black</td>
<td>3.4</td>
<td>1.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Other</td>
<td>8.2</td>
<td>4.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Body-mass index, kg/m²</td>
<td>23.7</td>
<td>25.9</td>
<td>27.6</td>
</tr>
<tr>
<td>Physical activity, MET-hr/week</td>
<td>20.6</td>
<td>22.1</td>
<td>17.5</td>
</tr>
<tr>
<td>Cigarette smoking, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>47.4</td>
<td>42.3</td>
<td>42.9</td>
</tr>
<tr>
<td>Past</td>
<td>41.5</td>
<td>44.8</td>
<td>42.2</td>
</tr>
<tr>
<td>Current</td>
<td>10.0</td>
<td>12.5</td>
<td>14.3</td>
</tr>
<tr>
<td>Missing</td>
<td>1.1</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>History of diabetes mellitus, %</td>
<td>0.9</td>
<td>3.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Regular multivitamin use, %</td>
<td>38.3</td>
<td>42.2</td>
<td>35.4</td>
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<tr>
<td>Fasting time, hours</td>
<td>10.5</td>
<td>10.4</td>
<td>10.1</td>
</tr>
<tr>
<td>Plasma 25(OH)D, nmol/L</td>
<td>63.6</td>
<td>66.6</td>
<td>60.7</td>
</tr>
<tr>
<td>Plasma C-peptide, ng/mL</td>
<td>1.7</td>
<td>2.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Table 2. Odds ratios (ORs) and 95% confidence intervals (CIs) for pancreatic cancer according to inflammatory plasma markers

<table>
<thead>
<tr>
<th>Quintiles of inflammatory plasma markers</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>( P_{\text{trend}}^{*} ) One-unit increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-reactive protein</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levels, mg/L</td>
<td>&lt;0.5</td>
<td>0.5-1.1</td>
<td>1.2-2.1</td>
<td>2.2-4.2</td>
<td>≥4.3</td>
<td></td>
</tr>
<tr>
<td>No. of cases</td>
<td>79</td>
<td>101</td>
<td>86</td>
<td>95</td>
<td>109</td>
<td>470</td>
</tr>
<tr>
<td>No. of controls</td>
<td>215</td>
<td>219</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>1094</td>
</tr>
<tr>
<td>Base model †</td>
<td>1.0</td>
<td>1.23 (0.85-1.76)</td>
<td>1.00 (0.69-1.45)</td>
<td>1.16 (0.80-1.68)</td>
<td>1.27 (0.88-1.83)</td>
<td>0.31 1.00 (0.98-1.02)</td>
</tr>
<tr>
<td>Multivariate ‡</td>
<td>1.0</td>
<td>1.18 (0.81-1.71)</td>
<td>0.97 (0.65-1.42)</td>
<td>1.09 (0.73-1.62)</td>
<td>1.10 (0.74-1.63)</td>
<td>0.81 0.99 (0.98-1.01)</td>
</tr>
<tr>
<td>Interleukin-6</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Levels, pg/mL</td>
<td>&lt;0.7</td>
<td>0.7-1.0</td>
<td>1.1-1.4</td>
<td>1.5-2.1</td>
<td>≥2.2</td>
<td></td>
</tr>
<tr>
<td>No. of cases</td>
<td>83</td>
<td>68</td>
<td>77</td>
<td>109</td>
<td>125</td>
<td>462</td>
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<td>No. of controls</td>
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<td>211</td>
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<td>212</td>
<td>213</td>
<td>1059</td>
</tr>
<tr>
<td>Base model †</td>
<td>1.0</td>
<td>0.81 (0.56-1.19)</td>
<td>0.88 (0.60-1.28)</td>
<td>1.24 (0.85-1.80)</td>
<td>1.38 (0.96-1.98)</td>
<td>0.01 1.02 (1.00-1.05)</td>
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<tr>
<td>Multivariate ‡</td>
<td>1.0</td>
<td>0.82 (0.56-1.21)</td>
<td>0.81 (0.55-1.21)</td>
<td>1.14 (0.77-1.69)</td>
<td>1.19 (0.81-1.76)</td>
<td>0.08 1.01 (0.99-1.04)</td>
</tr>
<tr>
<td>Tumor necrosis factor- ( \alpha )-receptor II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levels, mg/mL</td>
<td>&lt;2.1</td>
<td>2.1-2.4</td>
<td>2.5-2.8</td>
<td>2.9-3.4</td>
<td>≥3.5</td>
<td></td>
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<tr>
<td>No. of cases</td>
<td>89</td>
<td>95</td>
<td>82</td>
<td>101</td>
<td>103</td>
<td>470</td>
</tr>
<tr>
<td>No. of controls</td>
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<td>219</td>
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</tr>
<tr>
<td>Base model †</td>
<td>1.0</td>
<td>1.05 (0.74-1.49)</td>
<td>0.89 (0.61-1.29)</td>
<td>1.03 (0.72-1.48)</td>
<td>1.02 (0.69-1.49)</td>
<td>0.93 0.98 (0.88-1.10)</td>
</tr>
<tr>
<td>Multivariate ‡</td>
<td>1.0</td>
<td>0.96 (0.67-1.39)</td>
<td>0.79 (0.54-1.17)</td>
<td>0.92 (0.63-1.34)</td>
<td>0.88 (0.58-1.33)</td>
<td>0.57 0.92 (0.82-1.04)</td>
</tr>
</tbody>
</table>

*P values were calculated by the Wald test of a score variable that contained median values of quintiles.
†ORs and 95% CI were estimated by conditional logistic regression conditioned on the matching factors including year of birth, prospective cohort (HPFS, NHS, PHS I, WHI, WHS, which concurrently matched on sex), smoking status (never, past, current), fasting status (fasting, non-fasting), and month of blood draw.
‡Base model further adjusted for race (White, Black, other), history of diabetes mellitus (yes, no), BMI (<18.5, 18.5–24.9, 25–29.9, ≥30 kg/m²), physical activity (quartiles), current multivitamin use (yes, no), plasma 25(OH)D levels (quartiles), and plasma C-peptide levels (quartiles).