Lipoprotein-Associated Phospholipase A2 and Risk of Congestive Heart Failure in Older Adults

The Cardiovascular Health Study

Takeki Suzuki, MD, MPH; Cam Solomon, PhD; Nancy Swords Jenny, PhD; Russell Tracy, PhD; Jeanenne J. Nelson, PhD; Bruce M. Psaty, MD, PhD; Curt Furberg, MD, PhD; Mary Cushman, MD, MSc

Background—Inflammation may be a causative factor in congestive heart failure (CHF). Lipoprotein-associated phospholipase A₂ (Lp-PLA₂) is an inflammation marker associated with vascular risk. One previous study showed an association of Lp-PLA₂ activity with CHF risk, but there were only 94 CHF cases and Lp-PLA₂ antigen, which is available clinically in the United States, was not measured.

Methods and Results—We measured baseline Lp-PLA₂ antigen and activity in 3991 men and women without baseline CHF or cardiovascular disease who were participating in the Cardiovascular Health Study, a prospective observational study of adults 65 years or older. Cox proportional hazards models adjusted for age, sex, clinic site, race, low-density and high-density lipoprotein cholesterol, body mass index, systolic and diastolic blood pressure, hypertension, smoking status, pack-years, and diabetes were used to calculate hazard ratios and 95% CIs for incident CHF. Further models adjusted for coronary disease events during follow-up and C-reactive protein. Eight hundred twenty-nine participants developed CHF during 12.1 years. Adjusted hazard ratios for CHF with Lp-PLA₂ in the fourth compared with the first quartile were 1.44 (95% CI, 1.16 to 1.79) for Lp-PLA₂ antigen and 1.06 (95% CI, 0.84 to 1.32) for activity. Adjustment for incident coronary disease attenuated the hazard ratio for Lp-PLA₂ antigen to 1.26 (95% CI, 1.02 to 1.57), adjustment for C-reactive protein had minimal impact.

Conclusions—Lp-PLA₂ antigen was associated with risk of future CHF in older people, independent of CHF and coronary risk factors, and partly mediated by coronary disease events. Further clinical and basic research is needed to better understand the role of Lp-PLA₂ in CHF. (Circ Heart Fail. 2009;2:429-436.)

Key Words: epidemiology ■ heart failure

Congestive heart failure (CHF) is a major public health problem in the United States. Approximately 5 million patients have CHF and 550 000 are newly diagnosed each year.¹ Accumulating evidence supports that inflammation is an underlying pathophysiology of CHF.² ³ Various inflammation markers such as C-reactive protein (CRP) and interleukin (IL)-6 are increased in patients with CHF.⁴-⁶ CRP and IL-6 have been shown to be associated with incident CHF.⁷-⁹

Clinical Perspective on p 436

Lipoprotein-associated phospholipase A₂ (Lp-PLA₂), also known as platelet-activating factor acetylhydrolase, is an inflammation marker used for cardiovascular risk assessment.¹⁰ It is synthesized by monocytes and macrophages, and, in the circulation is bound to low-density lipoprotein (LDL).¹¹,¹² Lp-PLA₂ has proinflammatory properties through hydrolyzing oxidized phospholipids generating lysophosphatidylcholine and oxidized fatty acids.¹³,¹⁴ Lp-PLA₂ is strongly expressed in advanced coronary plaques suggesting a potential role in promoting plaque instability.¹⁵ However, Lp-PLA₂ may also play an anti-inflammatory role through inhibition of platelet-activating factor.¹⁶ Lp-PLA₂ can be measured using an activity assay or a commercially available antigenic (mass) assay,¹⁷ and the antigen and activity were measured in previous epidemiological studies.¹⁸,¹⁹ In a previous study
from the Cardiovascular Health Study (CHS), Lp-PLA₂ activity and antigen were correlated \((r=0.51)\), but this modest association points out the importance of considering both measures.\(^{20}\) Recently, a US expert panel published a document on the clinical use of Lp-PLA₂ in cardiovascular disease.\(^{21}\)

Several epidemiological studies reported that higher Lp-PLA₂ is a risk marker for coronary heart disease (CHD)\(^{22-28}\) and ischemic stroke.\(^{22,26}\) One study is available that reported an association of Lp-PLA₂ activity with risk of CHF,\(^{29}\) but there were <100 cases and Lp-PLA₂ antigen, which is available clinically in the United States, was not measured. Thus, whether Lp-PLA₂ antigen or activity are risk factors for CHF is not clear. We examined the association of both Lp-PLA₂ antigen and activity with risk of future CHF in the CHS.

**Methods**

**Subjects**

The CHS is a prospective population-based observational study of older adults aged 65 years or older at baseline to evaluate risk factors for the development and progression of cardiovascular disease (CVD). The design, rationale, and examination details have been described elsewhere.\(^{30}\) Briefly, participants were randomly selected from Medicare eligibility lists in 4 field centers: Forsyth County, NC; Sacramento County, Calif; Allegheny County, Pa; and Washington County, Md. An initial primarily white cohort of 5201 was recruited between 1989 and 1990, and an additional 687 blacks (minority cohort) were recruited in 1992 and 1993. Persons were ineligible for participation if they were receiving active treatment for cancer, were wheelchair bound or institutionalized, or were unable to participate in the examination. Comprehensive examinations and interviews were performed annually. The study was approved by institutional review boards at each site. Informed consent was obtained from all subjects.

Self-reported health behaviors, medical history, anthropometric measures, current medication use, seated blood pressure readings, electrocardiography recordings, and fasting blood chemistry measures were obtained at baseline for both cohorts. Common carotid intima-media thickness (IMT) was measured at baseline in a standard manner, as described previously.\(^{31}\) In previous CHS reports, IMT was an independent predictor of CHF.\(^{32}\) and Lp-PLA₂ was sig- nificantly higher in participants with higher IMT.\(^{33}\) Echocardiograms were obtained at baseline for the original cohort and again for members of both cohorts in 1994–1995. All participants in the original and minority cohorts were included in the primary analysis, except for 80 participants with baseline history of CHF, 115 with valvular heart disease by echocardiography (92 with aortic stenosis and 23 with severe mitral regurgitation), and 1190 with baseline CVD. Baseline CVD was defined as having one of the following at baseline: history of myocardial infarction, angina, stroke, transient ischemic attack, claudication, coronary artery bypass surgery, leg artery bypass, carotid endarterectomy, coronary angioplasty, or lower extremity angioplasty. Baseline CVD and CHF were adjudicated by the CHS Events Committee. Self report of a physician diagnosis of CHF was confirmed by review of medical records, with validation requiring a constellation of symptoms (shortness of breath, fatigue, orthopnea, and paroxysmal nocturnal dyspnea), physical signs (edema, pulmonary rales, gallop rhythm, and displaced left ventricular (LV) apical impulse), chest X-ray results (cardiomegaly and pulmonary edema), and treatment of CHF using diuretic agents, digitalis, or vasodilators (nitroglycerin, hydralazine, or angiotensin-converting enzyme inhibitors). The CHS Events Committee adjudicated the index event of CHF by reviewing all pertinent data on hospitalization or outpatient visits, including history, physical examination, report of chest x-ray, and medication use. This analysis includes validated events through June 30, 2003.

**Statistical Analysis**

Baseline characteristics were compared between those who developed CHF and those who did not by using \(\chi^2\) tests for discrete values and \(t\) tests for continuous data. Lp-PLA₂ antigen or activity was divided into quartiles (quartile 1 to 4, 1 being the lowest, 4 being the highest values) based on sex (men and women) and race (black and nonblack).

Kaplan-Meier curves with the end point of CHF were constructed based on Lp-PLA₂ antigen or activity quartiles. A log-rank test was performed to examine differences among the 4 groups. The associations of these categories of Lp-PLA₂ antigen or activity level with incident CHF were assessed using Cox proportional hazards models. Hazard ratios (HRs) and 95% CIs for incident CHF were calculated for each Lp-PLA₂ quartile compared with the 1st quartile. Models were first adjusted for age, sex, clinic site, and race. Additional adjustments included LDL and HDL cholesterol, body mass index, systolic and diastolic blood pressure, hypertension status, smoking status and pack-years, and diabetes status. Incident validated CHD was added to the model as a time-dependent covariate to assess mediation. Incident CHD was defined as incident myocardial infarction, angina, angioplasty, coronary artery bypass surgery, or CHD death. Additional variables were added individually to evaluate potential biological pathways of Lp-PLA₂ and incident CHF: baseline serum creatinine, statin and aspirin use, CRP, IL-6, LV mass by electrocardiography,\(^{34}\) and common carotid IMT. In secondary analysis, we replicated the earlier models among participants with baseline CVD. We did not adjust for incident CHD in secondary analysis because these participants had already had baseline CHD. Stratified analyses were subsequently performed on the basis of sex and race (black and nonblack). In addition, because it has been sensitivity ELISA.\(^{34}\) IL-6 was measured by high-sensitivity ELISA (R&D Systems, Minneapolis, Minn).\(^{35}\) The interassay coefficients of variation were 6% for CRP and 7% for IL-6. Elevated CRP was defined as >3.0 mg/L corresponding to the “high-risk category” in the American Heart Association/Centers for Disease Control consensus statement.\(^{36}\) Elevated IL-6 and fibrinogen were defined as values in the top tertile of the distribution (\(<2.04 \text{pg/mL and }>338 \text{mg/dL, respectively}\).

Plasma Lp-PLA₂ antigen (or mass) was determined at the Laboratory for Clinical Biochemistry Research (University of Vermont, Burlington, VT) using a commercially available ELISA kit (second generation PLAC Test; diaDexus Inc, South San Francisco, Calif). Plasma Lp-PLA₂ activity was measured at GlaxoSmithKline (Research Triangle Park, NC) by high-throughput radiometric assay using a tritium-labeled form of platelet activating factor as substrate in a 96-well microplate, as described previously.\(^{17}\) The interassay coefficients of variation were 6.3% for Lp-PLA₂ antigen and 7.5% for Lp-PLA₂ activity.

**Adjudication of Incident Congestive Heart Failure Events**

Our outcome was incident CHF, which was assessed and validated as reported previously.\(^{32,37}\) Subjects were interviewed every 6 months, and follow-up examinations were conducted annually at each study center until May 31, 1998, after which telephone follow-up continued. Self report of a physician diagnosis of CHF was confirmed by review of medical records, with validation requiring a constellation of symptoms (shortness of breath, fatigue, orthopnea, and paroxysmal nocturnal dyspnea), physical signs (edema, pulmonary rales, gallop rhythm, and displaced left ventricular (LV) apical impulse), chest X-ray results (cardiomegaly and pulmonary edema), and treatment of CHF using diuretic agents, digitalis, or vasodilators (nitroglycerin, hydralazine, or angiotensin-converting enzyme inhibitors). The CHS Events Committee adjudicated the index event of CHF by reviewing all pertinent data on hospitalization or outpatient visits, including history, physical examination, report of chest x-ray, and medication use. This analysis includes validated events through June 30, 2003.

**Laboratory Methods**

Phlebotomy was performed on the morning of enrollment after 8 to 12 hours of fasting.\(^{39}\) Fibrinogen, total and high-density lipoprotein (HDL) cholesterol, triglyceride, glucose, and creatinine were measured at the central laboratory, as reported previously.\(^{33}\) LDL cholesterol (LDL-C) was calculated for those with triglycerides <400 mg/dL. CRP was measured by an in-house validated high-sensitivity ELISA.\(^{34}\) IL-6 was measured by high-sensitivity ELISA (R&D Systems, Minneapolis, Minn).\(^{35}\) The interassay coefficients of variation were 6% for CRP and 7% for IL-6.\(^{34,35}\) Elevated CRP was defined as >3.0 mg/L corresponding to the “high-risk category” in the American Heart Association/Centers for Disease Control consensus statement.\(^{36}\) Elevated IL-6 and fibrinogen were defined as values in the top tertile of the distribution (\(<2.04 \text{pg/mL and }>338 \text{mg/dL, respectively}\).
reported that Lp-PLA2 was more strongly associated with vascular events in those with low LDL-C and in those with both elevated Lp-PLA2 and CRP,22 we evaluated incident CHF stratified by the levels of LDL (more or less than median), HDL (more or less than median), and CRP (more or less than 3 mg/L).

To evaluate the combined predictive value of Lp-PLA2 and other inflammation markers for incident CHF, participants were cross classified by Lp-PLA2 and inflammation markers (CRP >3 mg/L, and IL-6 and fibrinogen in tertiles) and interactions between Lp-PLA2 and these inflammation markers were assessed by calculating the relative excess risk due to interaction (RERI),39,40 and the RERI%, defined as the proportion of disease related to Lp-PLA2 and the inflammation marker, either singly or in combination, attributable to their interaction. The Delta method was used to calculate P values and 95% CIs used to assess significance of the relative excess risk due to interaction.

Statistical analyses were performed at the CHS Coordinating Center using Stata release 10 (Stata Corp, College Station, Tex).

**Table 1. Baseline Characteristics by Incident CHF Status**

<table>
<thead>
<tr>
<th></th>
<th>No CHF</th>
<th>Incident CHF</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>3162</td>
<td>829</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>71.8 (5.1)</td>
<td>73.8 (5.6)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Sex, male</td>
<td>1156 (36.6)</td>
<td>338 (40.8)</td>
<td>0.026</td>
</tr>
<tr>
<td>Race, black</td>
<td>486 (15.4)</td>
<td>122 (14.7)</td>
<td>0.64</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.4 (4.5)</td>
<td>27.5 (5.2)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Hypertension, %</td>
<td>1149 (36.4)</td>
<td>426 (51.4)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>134 (21)</td>
<td>142 (22)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>71 (11)</td>
<td>71 (12)</td>
<td>0.90</td>
</tr>
<tr>
<td>Current smoking, %</td>
<td>385 (12.2)</td>
<td>99 (12.0)</td>
<td>0.88</td>
</tr>
<tr>
<td>Diabetes mellitus, %</td>
<td>365 (11.6)</td>
<td>174 (21.0)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>LV mass by ECG</td>
<td>148 (30)</td>
<td>158 (34)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Cholesterol, mg/dL</td>
<td>213 (39)</td>
<td>210 (38)</td>
<td>0.015</td>
</tr>
<tr>
<td>Triglycerides, mg/dL</td>
<td>135 (73)</td>
<td>143 (74)</td>
<td>0.004</td>
</tr>
<tr>
<td>HDL, mg/dL</td>
<td>57 (16)</td>
<td>53 (15)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>LDL, mg/dL</td>
<td>131 (36)</td>
<td>129 (35)</td>
<td>0.24</td>
</tr>
<tr>
<td>CRP, mg/L</td>
<td>2.30 (1.18, 4.00)</td>
<td>2.90 (1.43, 6.05)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>IL-6, pg/mL</td>
<td>1.55 (1.09, 2.29)</td>
<td>1.84 (1.27, 2.79)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Fibrinogen, mg/dL</td>
<td>311 (274, 358)</td>
<td>326 (285, 362)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Creatinine, mg/dL</td>
<td>1.00 (0.26)</td>
<td>1.07 (0.46)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Common carotid IMT, mm</td>
<td>1.00 (0.90, 1.12)</td>
<td>1.05 (0.96, 1.20)</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Lp-PLA2 antigen, ng/mL</td>
<td>337.8 (117.3)</td>
<td>351.6 (113.7)</td>
<td>0.003</td>
</tr>
<tr>
<td>Lp-PLA2 activity, nmol/min/mL</td>
<td>38.6 (12.8)</td>
<td>39.6 (12.5)</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD), n (%), or median (interquartile range). BMI indicates body mass index.

Results

Baseline characteristics of the 3991 participants are shown in Table 1. There were 829 incident CHF cases during 12.1 years of follow-up (incidence rate of 19.1 per 1000 person-years). Those who developed CHF were older, more likely to be men, and to have diabetes, hypertension, and greater LV mass. Smoking was relatively uncommon and was similar between the 2 groups. Baseline Lp-PLA2 antigen and activity, along with other inflammation markers, were higher in those who developed CHF. There were 1190 participants with baseline CVD evaluated in secondary analyses. Patterns of association of baseline risk factors with CHF were similar to those without baseline CVD (data not shown).

**Associations Between Lp-PLA2 Antigen/Activity and Incident CHF**

Kaplan-Meier curves for time to CHF by Lp-PLA2 antigen (A) or activity (B) quartiles are shown in Figure 1. Those with the highest Lp-PLA2 antigen were more likely to develop CHF during follow-up, with the 10-year cumulative incidence rate ranging from 11.7 per 1000 person-years in the first quartile to 19.5 per 1000 person-years in the 4th quartile (P=0.0001) for difference among groups. There were no significant differences in CHF incidence among the quartiles of Lp-PLA2 activity.

The HRs of CHF for each quartile of Lp-PLA2 antigen and activity, compared with the first quartile, are shown in Table 2. Lp-PLA2 antigen in the top 3 quartiles, but not activity, were associated with increased risk of CHF, with gradually increasing risk by quartile for Lp-PLA2 antigen. The HR for Lp-PLA2 antigen in the top quartile was 1.44 (95% CI, 1.16 to 1.79) and that for Lp-PLA2 activity was 1.06 (0.84 to 1.32) after adjustment for LDL and HDL cholesterol, body mass.
index, systolic and diastolic blood pressure, hypertension status, smoking status and pack-years, and diabetes status. When incident CHD was added to the model as a time-dependent covariate, the HRs for Lp-PLA2 antigen in the top 3 quartiles were reduced but remained significant with about a 25% increased risk for values more than the median. Additional adjustment for other covariates, including common carotid IMT, had minimal impact on associations except IL-6 or LV mass, which slightly accentuated the HRs for Lp-PLA2 (Table 2).

### Stratified Analyses

Figure 2 shows results of stratified analyses for Lp-PLA2 antigen and risk of CHF. Lp-PLA2 antigen in the top quartile was associated with incident CHF in women (HR, 1.46; 95% CI, 1.10 to 1.94) but not men (HR, 1.08; 95% CI, 0.77 to 1.51). The association between Lp-PLA2 antigen and incident CHF was slightly larger in nonblacks (HR, 1.30; 95% CI, 1.03 to 1.65) than blacks (HR, 1.20; 95% CI, 0.68 to 2.14). Associations between Lp-PLA2 antigen and CHF were stronger in those with LDL less than the median and with HDL more than the median. The association was stronger in those with elevated CRP. However, none of these associations were significantly different between strata.

### Interaction Between Lp-PLA2 and Other Inflammation Markers

The joint associations of Lp-PLA2 antigen and inflammation markers, adjusted for risk factors and interval incident CHD, are shown in Table 3. In general, the inflammation markers had larger associations than Lp-PLA2 with incident CHF. The relative excess risks due to interaction between Lp-PLA2 antigen and inflammation markers were calculated. Considered jointly, the risk of CHF was 13% to 16% higher than expected by the separate additive effects of Lp-PLA2 antigen and other inflammation markers. For example, those with high-Lp-PLA2 antigen (top tertile) and high CRP (>3 mg/L) had a higher risk of CHF compared with those without either risk factor (HR, 2.05; 95% CI, 1.68 to 2.51). When considering interaction additively, a significant proportion of CHF risk, 13.9% (95% CI, 6.3% to 21.6%), was related to the combination of high levels of CRP and Lp-PLA2 antigen.

### Secondary Analysis in Participants With Baseline CVD

There were 440 incident CHF cases among 1190 participants with baseline CVD and no baseline CHF during 12.1 years of follow-up (incidence rate of 44.1 per 100 person-years). In these participants, the association of Lp-PLA2 antigen with incident CHF was similar to the association in those without baseline CVD after adjustment for risk factors (HR, 1.36; 95% CI, 1.02 to 1.83; Table 4). After adjusting individually for serum creatinine, CRP, IL-6, or LV mass, the association...
between Lp-PLA₂ antigen and incident CHF was modestly smaller and no longer statistically significant. The HR of incident CHF for Lp-PLA₂ activity was similar to that of Lp-PLA₂ antigen, with adjustment for age, sex, clinic site, and race.

### Discussion

The main finding of this study was that Lp-PLA₂ antigen, but not activity, was associated with increased 12-year risk of CHF in older people without CVD or CHF at baseline, even after adjustment for interval development of CHD, which seemed to mediate part of this association. Adjustment for other CHF risk factors, including CVD risk factors, creatinine, common carotid IMT, or other inflammation markers had minimal impact on this association. In contrast, Lp-PLA₂ activity was not associated with risk of incident CHF, except in participants with baseline CVD. There was modest complementary information in CHF risk prediction using combinations of elevated Lp-PLA₂ and other inflammation risk markers CRP, IL-6, and fibrinogen.

Previous epidemiological studies have demonstrated associations between Lp-PLA₂ and risk of CVD. For CHF, the Rotterdam Study reported a HR of 2.33 for Lp-PLA₂ activity in the 4th quartile versus 1st quartile with risk of CHF during 6.7 years (95% CI, 1.21 to 4.49), but there were <100 CHF cases and Lp-PLA₂ antigen, which is available clinically in the United States, was not measured. In our study, Lp-PLA₂ antigen, but not activity, was associated with incident CHF in an analysis involving 829 cases. The different findings between the studies could be due to differences in population characteristics and study design. Our cohort was older, had a higher CHF incidence rate, and a larger sample size and number of incident cases compared with the Rotterdam Study. Previous analyses in CHS showed that Lp-PLA₂ antigen and activity were associated with risk of myocardial infarction, whereas antigen but not activity was associated with stroke risk (Jenny et al, manuscript submitted). Disparate findings for antigen and activity assays may reflect assay design issues, preanalytical factors such as differences in biovariability, complex biology of Lp-PLA₂, and heterogeneity of CHF and stroke as clinical syndromes. These findings may also relate to the modest, not high, correlation between antigen and activity or nonlinear relationship between the two. In the CARDIA study, Lp-PLA₂ antigen was independently associated with calcified coronary plaque, whereas Lp-PLA₂ activity was not. Along with our findings, these results suggest Lp-PLA₂ antigen might be more associated with atherosclerosis than activity is. In contrast to our primary analysis involving participants without baseline CVD, analyses in those with baseline CVD showed associations of both Lp-PLA₂ antigen and activity with incident CHF. This is compatible with our previous observations of

### Table 3. Combined Association of Lp-PLA₂ Antigen and Inflammation Markers on Risk of CHF

<table>
<thead>
<tr>
<th>Lp-PLA₂ Antigen in Top Tertile, ≥316 ng/mL</th>
<th>Elevated Inflammation Marker</th>
<th>CRP &gt;3 mg/L</th>
<th>IL-6 &gt;2.04 pg/mL</th>
<th>Fibrinogen &gt;338 mg/dL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(−)</td>
<td>(−)</td>
<td>1 (reference)</td>
<td>1 (reference)</td>
<td>1 (reference)</td>
</tr>
<tr>
<td>(+)</td>
<td>(−)</td>
<td>1.26 (1.04, 1.54)</td>
<td>1.35 (1.11, 1.64)</td>
<td>1.30 (1.09, 1.55)</td>
</tr>
<tr>
<td>(−)</td>
<td>(+)</td>
<td>1.78 (1.49, 2.12)</td>
<td>1.74 (1.44, 2.09)</td>
<td>1.47 (1.22, 1.76)</td>
</tr>
<tr>
<td>(+)</td>
<td>(+)</td>
<td>2.05 (1.68, 2.51)</td>
<td>2.05 (1.64, 2.56)</td>
<td>1.65 (1.33, 2.05)</td>
</tr>
</tbody>
</table>

RERI% (95% CI) 13.9 (6.3, 21.6) 16.4 (9.7, 23.0) 12.7 (7.2, 18.3) Adjusted for LDL and HDL cholesterol, body mass index, systolic and diastolic blood pressure, hypertension status, smoking status and pack years, and diabetes status. Incident CHD is not included in this model.

### Table 4. HRs and 95% CIs for Incident CHF by Lp-PLA₂ Quartiles in Subjects With Baseline CVD and no CHF

<table>
<thead>
<tr>
<th>Model</th>
<th>Quartile 2</th>
<th>Quartile 3</th>
<th>Quartile 4</th>
<th>Quartile 2</th>
<th>Quartile 3</th>
<th>Quartile 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lp-PLA₂ Antigen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>1.21 (0.91, 1.62)</td>
<td>1.26 (0.95, 1.67)</td>
<td>1.43 (1.09, 1.87)</td>
<td>1.23 (0.93, 1.64)</td>
<td>1.13 (0.85, 1.51)</td>
<td>1.32 (1.01, 1.73)</td>
</tr>
<tr>
<td>Age, sex, clinic site, and race</td>
<td>1.24 (0.93, 1.65)</td>
<td>1.24 (0.94, 1.64)</td>
<td>1.40 (1.06, 1.84)</td>
<td>1.24 (0.93, 1.66)</td>
<td>1.14 (0.86, 1.53)</td>
<td>1.36 (1.03, 1.79)</td>
</tr>
<tr>
<td>Risk factors*</td>
<td>1.20 (0.90, 1.61)</td>
<td>1.20 (0.89, 1.60)</td>
<td>1.36 (1.02, 1.83)</td>
<td>1.29 (0.95, 1.74)</td>
<td>1.15 (0.84, 1.56)</td>
<td>1.35 (0.98, 1.84)</td>
</tr>
<tr>
<td>Incident CHD (model B)</td>
<td>1.20 (0.90, 1.61)</td>
<td>1.21 (0.90, 1.62)</td>
<td>1.38 (1.03, 1.84)</td>
<td>1.24 (0.92, 1.67)</td>
<td>1.11 (0.82, 1.51)</td>
<td>1.30 (0.95, 1.78)</td>
</tr>
<tr>
<td>Following parameters added to model B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creatinine</td>
<td>1.18 (0.88, 1.58)</td>
<td>1.18 (0.89, 1.58)</td>
<td>1.33 (0.99, 1.79)</td>
<td>1.29 (0.95, 1.74)</td>
<td>1.14 (0.84, 1.55)</td>
<td>1.34 (0.98, 1.83)</td>
</tr>
<tr>
<td>Statin and aspirin use</td>
<td>1.19 (0.89, 1.60)</td>
<td>1.19 (0.89, 1.59)</td>
<td>1.35 (1.01, 1.82)</td>
<td>1.29 (0.95, 1.74)</td>
<td>1.13 (0.83, 1.54)</td>
<td>1.33 (0.97, 1.83)</td>
</tr>
<tr>
<td>CRP</td>
<td>1.19 (0.89, 1.59)</td>
<td>1.19 (0.89, 1.59)</td>
<td>1.33 (0.99, 1.78)</td>
<td>1.32 (0.97, 1.78)</td>
<td>1.15 (0.85, 1.56)</td>
<td>1.37 (1.00, 1.87)</td>
</tr>
<tr>
<td>IL-6</td>
<td>1.07 (0.79, 1.46)</td>
<td>1.06 (0.78, 1.44)</td>
<td>1.23 (0.90, 1.67)</td>
<td>1.39 (1.00, 1.92)</td>
<td>1.28 (0.91, 1.78)</td>
<td>1.48 (1.05, 2.09)</td>
</tr>
<tr>
<td>LV mass by ECG</td>
<td>1.14 (0.85, 1.54)</td>
<td>1.16 (0.86, 1.56)</td>
<td>1.28 (0.95, 1.73)</td>
<td>1.25 (0.92, 1.70)</td>
<td>1.11 (0.81, 1.52)</td>
<td>1.28 (0.93, 1.77)</td>
</tr>
<tr>
<td>Common carotid IMT</td>
<td>1.18 (0.89, 1.60)</td>
<td>1.19 (0.89, 1.59)</td>
<td>1.36 (1.02, 1.82)</td>
<td>1.29 (0.96, 1.75)</td>
<td>1.14 (0.84, 1.55)</td>
<td>1.34 (0.98, 1.84)</td>
</tr>
</tbody>
</table>

Quartile 1 is the reference group.

*LDL and HDL cholesterol, body mass index, systolic and diastolic blood pressure, hypertension status, smoking status and pack years, and diabetes status.
associations of both analytes with myocardial infarction and suggests that both analytes reflect biologies related to CHF associated with atherosclerosis. This may suggest that both analytes represent biologies reflecting a similar role in those with baseline atherosclerosis.

In stratified analyses, associations between Lp-PLA₂ antigen and CHF were stronger in nonblacks, with LDL less than the median and HDL more than the median. Our results agree with a previous study, which showed that the association between Lp-PLA₂ and CHD risk was stronger in those with LDL less than the median, but this was not observed in CHS for vascular outcomes (Jenny et al, manuscript submitted). This difference could be due to differing results with different outcomes, different population characteristics, or that it is a chance finding. Inconsistent subgroup findings across studies require further evaluation and may be pursued using individual-level meta-analysis.

The pathophysiology explaining an association of Lp-PLA₂ with CHF may relate to Lp-PLA₂ as an inflammation marker. Lp-PLA₂, along with LDL particles, is proinflammatory by releasing lysophosphatidylcholine and oxidized nonesterified fatty acids. Our models evaluating biological pathways of Lp-PLA₂ and development of CHF suggested that adjustment for kidney function and other inflammation markers had minimal impact on the association between Lp-PLA₂ and CHF, consistent with the weak correlations of Lp-PLA₂ with renal function and inflammation markers. In previous studies, Lp-PLA₂ was related to different aspects of inflammation than CRP or IL-6. Our findings suggest a hypothesis that Lp-PLA₂ may represent a novel inflammatory pathway in the development of CHF. Furthermore, our study suggests that the association between Lp-PLA₂ antigen and incident CHF is minimally mediated by interval changes of CHD or baseline common carotid IMT. This could be because atherosclerotic burden was not fully accounted for by adjustment for these factors. However, this may mean that an inflammation pathway involving Lp-PLA₂ plays an important role in cardiac function independent of atherosclerosis. This may be supported by recent findings that Lp-PLA₂ was associated with mortality in a community-based cohort of patients with CHF. Finally, there is a Lp-PLA₂ inhibitor under investigation. Given the current findings, an Lp-PLA₂ inhibitor could be studied in relation to CHF and vascular outcomes.

The strengths of our study include measurement of both Lp-PLA₂ antigen and activity, its prospective population-based design, biennial sample, large sample size, long follow-up, and large number of incident CHF cases. Limitations of the study need to be considered. First, institutionalized individuals and those with short life expectancy were excluded. Thus, the sample was a relatively healthy community-dwelling elderly one and our results cannot be extrapolated to others. Second, the relatively low numbers of blacks resulted in less power for ethnic-specific analyses. Third, adjustment of interval development of CHD may not account fully for role of atherosclerosis in CHF cause. We added common carotid IMT to the model, and it did not change the association. Residual confounding could be invoked to suggest that the associations of Lp-PLA₂ with CHF are not independent of subclinical or clinical vascular disease. Finally, instability of proteins in long-term storage may lead to underestimates of risk in epidemiology studies, but we anticipate this to play a small role of this issue given the documented stability of other proteins in stored samples.

In conclusion, Lp-PLA₂ antigen was a risk factor for future CHF in older people, independent of CHF risk factors, other inflammation markers, and atherosclerosis measures. The association was partly mediated by occurrence of coronary vascular events. Further clinical and basic research is needed to better understand the pathophysiological role of Lp-PLA₂ in the development of CHF.

**Acknowledgments**

We thank the staff and participants in the CHS. A full list of participating CHS investigators and institutions is available at http://www.chs-nhlbi.org.

**Sources of Funding**

This research was supported by contracts N01-HC-35129, N01-HC-45133, N01-HC-75150, N01-HC-85079 through N01-HC-85086, N01-HC-15103, N01 HC-55222, and U01 HL080295 from the National Heart, Lung, and Blood Institute, with additional contribution from the National Institute of Neurological Disorders and Stroke. Measurement of Lp-PLA₂ was supported by GlaxoSmithKline. The sponsors were involved in the design and conduct of the study and approval of the final manuscript.

**Disclosures**

Dr Nelson is an employee of GlaxoSmithKline. Dr Cushman has received modest research support and consulting fees from GlaxoSmithKline.

**References**


Inflammation may be an etiologic factor in congestive heart failure (CHF). Lipoprotein-associated phospholipase A₂ (Lp-PLA₂) is an inflammation marker associated with vascular risk. We measured baseline Lp-PLA₂ antigen and activity in 3991 men and women without baseline CHF or cardiovascular disease who participated in the Cardiovascular Health Study, a prospective observational study of adults 65 years or older. Eight hundred twenty-nine participants developed CHF during 12.1 years. The main finding of this study was that Lp-PLA₂ antigen, but not activity, was associated with increased 12-year risk of CHF in older people without cardiovascular disease or CHF at baseline, even after adjustment for interval development of coronary heart disease, which seemed to mediate part of this association. Adjustment for other CHF risk factors, including cardiovascular disease risk factors, creatinine, common carotid intima-media thickness, or other inflammation markers had minimal impact on this association. In contrast, Lp-PLA₂ activity was not associated with risk of incident CHF, except in participants with baseline cardiovascular disease. There was modest complementary information in CHF risk prediction using combinations of elevated Lp-PLA₂ and other inflammation risk markers C-reactive protein, interleukin-6, and fibrinogen. Further clinical and basic research is needed to better understand the pathophysiological role of Lp-PLA₂ in the development of CHF.
Lipoprotein-Associated Phospholipase A2 and Risk of Congestive Heart Failure in Older Adults: The Cardiovascular Health Study
Takeki Suzuki, Cam Solomon, Nancy Swords Jenny, Russell Tracy, Jeanenne J. Nelson, Bruce M. Psaty, Curt Furberg and Mary Cushman

Circ Heart Fail. 2009;2:429-436; originally published online June 19, 2009; doi: 10.1161/CIRCHEARTFAILURE.108.839613

Circulation: Heart Failure is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2009 American Heart Association, Inc. All rights reserved.
Print ISSN: 1941-3289. Online ISSN: 1941-3297

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circheartfailure.ahajournals.org/content/2/5/429

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation: Heart Failure can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation: Heart Failure is online at:
http://circheartfailure.ahajournals.org/subscriptions/