Hyperuricemia and Incident Heart Failure

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Background—Hyperuricemia, a known correlate of oxidative stress, is a marker for adverse prognosis among individuals with heart failure. However, the relationship between hyperuricemia and the risk for incidence of heart failure in a community-based population has not been studied.

Methods and Results—We prospectively analyzed the relationship between serum uric acid concentration at baseline and subsequent heart failure among the participants of the Framingham Offspring cohort (n=4912; mean baseline age, 36 years; 52% women). By using Cox regressions, we calculated the risk of heart failure with increasing serum uric acid after adjusting for sex, age, smoking, body mass index, renal dysfunction, diuretics, systolic blood pressure, valvular heart disease, diabetes, alcohol, and use of antihypertensive medications. The incidence rates of heart failure were 6-fold higher among those at the highest quartile of serum uric acid (>6.3 mg/dL) compared with those at the lowest quartile (<3.4 mg/dL). The adjusted hazard ratio for the highest quartile of serum uric acid compared with the lowest was 2.1 (1.04 to 4.22). The relationship between hyperuricemia and heart failure was found in participants without metabolic syndrome and other subgroups as well.

Conclusions—Hyperuricemia is a novel, independent risk factor for heart failure in a group of young general community dwellers. This has implications for development of preventive strategies for heart failure. (Circ Heart Fail. 2009;2:556-562.)

Key Words: heart failure ■ risk ■ uric acid ■ incidence ■ hyperuricemia ■ prospective studies ■ biological markers

Nearly 5 million Americans currently suffer from heart failure, and ~550,000 new cases of heart failure are now diagnosed each year. Heart failure is associated with high risk of morbidity, mortality, and hospital utilization in the United States. The established risk factors for heart failure include male sex, hypertension, valvular heart disease, coronary artery disease, and obesity. Despite the progress made in its management, the mortality from heart failure remains high, underlining the need for identification of novel risk factors that may be amenable to intervention.

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Earlier studies have shown that heart failure is often associated with hyperuricemia. Hyperuricemia is associated with worse hemodynamic measures such as increased left atrial pressure and decreased cardiac index among patients with primary pulmonary hypertension, cor pulmonale, and dilated cardiomyopathy in a small case series. Among those with established heart failure, hyperuricemia is a risk factor for adverse outcomes, including mortality.

Serum uric acid may be useful for prognostication among those with preexisting heart failure. Hyperuricemia can predict heart failure among those with preexisting hypertension. There have not been any studies that examined hyperuricemia as an independent risk factor for heart failure risk among the general population. The single available study from Austria did not account for confounders such as valvular heart disease and diuretics, and renal disease suggested that highest quantiles of serum uric acid was associated with increased risk for death from heart failure.

Hyperuricemia can be easily detected in routine medical care. If indeed presence of hyperuricemia provides additional information on future heart failure risk (over and above other risk factors), it has the potential to be a screening tool. Accordingly, we hypothesized that hyperuricemia is a risk factor for heart failure independent of other known risk factors.

Methods

Study Cohort and Data Source

We used data from the Framingham Offspring Study, a longitudinal observational study of children of the original Framingham Heart Study cohort and their spouses. All participants of the Framingham Offspring cohort that began in 1971 were eligible to be included in this study. The data for our analyses were obtained from the National Heart, Lung, and Blood Institute limited access dataset program. This analysis protocol was approved by the Stanford University institutional review board. We excluded all the subjects who did not have uric acid measurement.

Follow-Up and Observation Period

Participants were under surveillance for cardiovascular events and were followed up approximately every 4 years by study visits that included medical review, physical examination, and laboratory testing. In the current analyses, we used data collected from the first through seventh study visit. The exact number of days from baseline to each study visit or outcome event was used in our analyses. The
median follow-up of this cohort was 29 years, and the cumulative observation time was 135,991 person-years.

For analyses of the effects of serum uric acid, each observation started in the first (baseline) visit and ended at the day of outcome event, death, or last contact with the study. In using such a definition, we acknowledge that the duration of hyperuricemia for each individual in the observation period is an underestimation of the true duration of hyperuricemia. In all analyses, the observation ended at the time of death, last contact, or the outcome event.

Measurement of Covariates
Exercise, diet, drugs, and state of hydration may result in transient fluctuations of uric acid levels, and one measurement of uric acid may not be an accurate metric of the hyperuricemic “trait.” We examined this possibility in our data by calculating the probability of an individual participant changing the quartile of uric acid during the time interval between the first and second visit (ie, transition probability) for each of the uric acid stratum. Because this estimate was ~20%, we deemed the variability to be too high, and serum uric acid was measured at the first and the second visits and averaged to arrive at a mean value that replaced the single baseline measurement. Serum uric acid was assayed using the uricase method. Information on renal dysfunction, obesity measures, blood pressure, serum lipids, serum glucose, smoking, alcohol, aspirin, antihypertensive, and anti-diabetic medication use was available at all visits. Detailed information on individuals’ diabetes and hypertension medications such as name, dosage, and duration of treatment were not available. For the purpose of this study, participants with a cardiac murmur at the time of the first study visit was assessed to have valvular heart disease, a risk factor for heart failure. Participants were evaluated for coronary artery disease at baseline and at subsequent visits by medical history, clinician assessment, and ECG. The determination of renal dysfunction at baseline was made by the study physician. Serum creatinine or other laboratory measures of renal function was not available for this analysis. Gout was defined as a diagnosis of definite gouty arthritis by the study physician.

Outcome Assessment
Heart Failure
Heart failure events (both hospitalized and nonhospitalized) were adjudicated by a study physician panel according to the predetermined Framingham criteria shown in Table 1.20,21 Heart failure was considered to be present if 2 major or 1 major and 2 minor criteria were present in the absence of alternative explanation for the clinical picture (please see Table 1 for further details). There were no participants with heart failure at baseline.

Statistical Analysis
Risk Factors for Heart Failure
Our primary analyses addressed the following question: Does elevated serum uric acid independently predict the risk for incident heart failure? We used Cox proportional hazards regression model to study the relationship between baseline serum uric acid level and heart failure. In these regressions, the time variable was defined as the period (number of days) from the baseline date to the date of incidence of heart failure or the date of last study visit. Observations of patients who did not die or develop heart failure were censored at the time of last observation. In the primary analyses, the baseline values of the covariates were used to adjust for confounding. However, the relationship between hyperuricemia and other cardiovascular risk factors is complex (Figure 1) because hyperuricemia is a risk factor for kidney disease, hypertension, and atherosclerotic cardiovascular diseases.22–27 Changes in health conditions over time, such as increased blood pressure and worse renal function, can potentially be a cause and a consequence of hyperuricemia. Thus, using time varying measures of these covariates may be problematic. Therefore, in addition to Cox regressions with time-varying values of covariates, we preformed extensive stratified analyses for those who did not meet the adult treatment panel criteria for metabolic syndrome baseline,28 who died of any cause during the follow-up, and those who survived until the cutoff date for observation (visit 7).

Results
Overall, of the 4989 participants in the Offspring study, there were 4912 eligible participants with 196 incident cases of heart failure. Participants who developed heart failure were more likely to be older, men, and with a worse traditional risk factor profile, have gout and currently used allopurinol, a uric acid-reducing medication. These individuals had a greater prevalence of gout and higher serum uric acid concentration. Increasing serum concentrations of serum uric acid was associated with worse cardiovascular risk (Table 2).

During the follow-up period, the cumulative incidence of gout was 12.6% (n=171) and 4.5% (n=192) among heart failure and no heart failure groups, respectively (P<0.001). Overall, 155 participants with gout reported using allopurinol during the follow-up. Only 2 participants without gout reported using allopurinol.

Figure 2 shows the heart failure-free survival curve. Those in the higher quartiles of serum uric acid had greater incidence of heart failure (Table 3). Proportional hazards assumptions were met in all the Cox regression models. In these models, increasing level of serum uric acid was associated with increased risk for heart failure in unadjusted and age-sex–adjusted models (Table 3). In multivariable regres-
sions, the increased risk relationship between uric acid level and heart failure was most evident in the highest quartile.

In this cohort of relatively young adults (median baseline age 36 years, interquartile range 28 to 44), the prevalence of documented coronary artery disease at baseline was infrequent (n=6), and exclusion of these individuals did not change our overall risk estimate. There were no participants with renal dysfunction at the baseline. Multivariable Cox regressions were performed for each of the following subgroups: participants who did not use diuretics, any blood pressure medications, nondiabetics; those who did not develop renal dysfunction anytime during follow-up; and those who did not develop the metabolic syndrome (Table 4). The link between hyperuricemia and heart failure was consistent across all these analyses.

Analyses for Survivor Effect
When the multivariable analyses were repeated separately among the 892 participants who died during follow-up from any cause and those who survived until the seventh visit, each

Table 2. Baseline Characteristics of Framingham Offspring Study Participants According to Serum Uric Acid Concentrations (n=4912)

<table>
<thead>
<tr>
<th>Quartile 1 (1.2 to 4.34 mg/dL)</th>
<th>Quartile 2 (4.35 to 5.2 mg/dL)</th>
<th>Quartile 3 (5.3 to 6.2 mg/dL)</th>
<th>Quartile 4 (6.3 to 13.7 mg/dL)</th>
<th>P (for Trend)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of participants</td>
<td>1164</td>
<td>1194</td>
<td>1227</td>
<td>1329</td>
</tr>
<tr>
<td>Age, y</td>
<td>34±10</td>
<td>36±10</td>
<td>36±11</td>
<td>38±11</td>
</tr>
<tr>
<td>Proportion of men</td>
<td>5</td>
<td>30</td>
<td>65</td>
<td>88</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>23±3</td>
<td>25±4</td>
<td>26±4</td>
<td>28±4</td>
</tr>
<tr>
<td>Alcohol use</td>
<td>81</td>
<td>84</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>Proportion of current smokers</td>
<td>60</td>
<td>65</td>
<td>62</td>
<td>68</td>
</tr>
<tr>
<td>Diuretic users</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>114±13</td>
<td>119±15</td>
<td>123±15</td>
<td>129±17</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>73±9</td>
<td>77±10</td>
<td>79±10</td>
<td>84±11</td>
</tr>
<tr>
<td>Fasting glucose, mg/dL</td>
<td>93±17</td>
<td>99±23</td>
<td>104±33</td>
<td>108±32</td>
</tr>
<tr>
<td>Total cholesterol, mg/dL</td>
<td>187±37</td>
<td>191±38</td>
<td>199±41</td>
<td>205±40</td>
</tr>
<tr>
<td>LDL cholesterol, mg/dL</td>
<td>115±33</td>
<td>121±35</td>
<td>130±36</td>
<td>131±35</td>
</tr>
<tr>
<td>HDL cholesterol, mg/dL</td>
<td>57±14</td>
<td>53±15</td>
<td>48±13</td>
<td>45±13</td>
</tr>
<tr>
<td>Triglycerides, mg/dL</td>
<td>101±69</td>
<td>112±73</td>
<td>131±107</td>
<td>163±162</td>
</tr>
<tr>
<td>Serum uric acid, mg/dL</td>
<td>3.7±0.5</td>
<td>4.8±0.3</td>
<td>5.7±0.3</td>
<td>7.2±0.8</td>
</tr>
<tr>
<td>Valvular heart disease</td>
<td>8.3</td>
<td>7.7</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>History of gout at baseline</td>
<td>0.1</td>
<td>0.6</td>
<td>0.3</td>
<td>6.9</td>
</tr>
<tr>
<td>History of diabetes at baseline</td>
<td>0.9</td>
<td>1.8</td>
<td>2.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Data are presented as mean±SD or %. Valvular heart disease was defined for this study as presence of cardiac murmur at baseline. Gout was determined based on physician diagnosis. Diabetes was defined using the American Diabetes Association criteria or use of antidiabetes medications. LDL indicates low-density lipoprotein; HDL, high-density lipoprotein.
unit increase in serum uric acid increased the risk for incident heart failure for the deceased (n=125; hazard ratio, 1.2 [0.9 to 1.5]) and survivors (n=76; hazard ratio, 1.1 [0.9 to 1.5]), although neither reached statistical significance.

**Gender Effects**
In multivariable regressions, the impact of such statistical interaction was tested for but was found to be statistically insignificant (P=0.21). Furthermore, when data were analyzed for men and women separately, the risk estimates were greater than unity but not statistically significant in both groups because of small number of events in each.

**Discussion**
We report for the first time that hyperuricemia is a risk factor for heart failure in a large prospective study of a community-dwelling population. Similar to the Vorarlberg study, this risk was most evident at serum uric acid levels greater than ~6 mg/dL—a cutoff point close to the solubility of urate in the normal human body.17

Our observation is not unexpected given the knowledge about the significance of hyperuricemia as a marker of abnormal oxidative metabolism.20 Serum uric acid level is an index of oxidative stress in the human body.20 Serum uric acid is known to contribute to endothelial dysfunction by impairing nitric oxide production.31 Serum uric acid has also been shown to be inversely correlated with the measures of functional capacity and maximal oxygen intake.5 Among patients with chronic heart failure, serum uric acid concentrations are associated with greater activity of superoxide dismutase and endothelium-dependent vasodilatation.32

Another potential pathophysiological link between hyperuricemia and heart failure might be through inflammation. Asymptomatic hyperuricemia is a proinflammatory state

### Table 3. Incident Heart Failure According to Baseline Uric Acid Quartiles in Framingham Offspring Cohort (n=4912)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1.2 to 4.34 mg/dL (n=1164)</th>
<th>4.35 to 5.2 mg/dL (n=1193)</th>
<th>5.3 to 6.2 mg/dL (n=1227)</th>
<th>6.3 to 13.7 mg/dL (n=1328)</th>
<th>P (for Trend)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of incident heart failure</td>
<td>13</td>
<td>36</td>
<td>57</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Rate per 10 000 person-years (95% CI)</td>
<td>3.9 (2.3 to 6.8)</td>
<td>10.8 (1.8 to 15.0)</td>
<td>17.3 (13.4 to 22.4)</td>
<td>25.8 (21.0 to 31.7)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Unadjusted hazard ratio</td>
<td>1.00</td>
<td>2.8 (1.5 to 5.3)</td>
<td>4.5 (2.5 to 8.3)</td>
<td>7.0 (3.9 to 12.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age-sex–adjusted hazard ratio</td>
<td>1.00</td>
<td>1.9 (1.0 to 3.7)</td>
<td>2.6 (1.3 to 4.9)</td>
<td>3.3 (1.7 to 6.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Model 1: multivariable-adjusted hazard ratio with baseline values of covariates</td>
<td>1.00</td>
<td>1.6 (0.8 to 3.2)</td>
<td>1.7 (0.9 to 3.3)</td>
<td>2.1 (1.0 to 4.2)</td>
<td>0.007</td>
</tr>
<tr>
<td>Model 2: multivariable-adjusted hazard ratio with time-varying values of covariates</td>
<td>1.00</td>
<td>1.6 (0.7 to 3.5)</td>
<td>2.1 (0.9 to 4.0)</td>
<td>2.3 (1.0 to 5.1)†</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Model 3: multivariable-adjusted hazard ratio with time-varying values of covariates among the subgroup without metabolic syndrome</td>
<td>1.00</td>
<td>1.5 (0.6 to 3.5)</td>
<td>2.0 (0.8 to 4.8)</td>
<td>2.5 (1.0 to 6.2)‡</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Multivariable models were adjusted for sex, baseline values of age, smoking, systolic blood pressure, serum total cholesterol:high-density lipoprotein ratio, alcohol use, renal dysfunction, coronary artery disease, valvular heart disease, diuretic use, and nondiuretic blood pressure medications. CI indicates confidence interval.

*Age-sex–adjusted trend.

†95% CI, 1.01 to 5.10.

‡95% CI, 1.04 to 6.18.
associated with higher levels of serum markers of inflammation, such as C-reactive protein, interleukin-6, and neutrophil count. Among patients with heart failure, hyperuricemia is associated with higher levels of markers of endothelial activation, such as the soluble intercellular adhesion molecule-1, and inflammatory markers such as interleukin-6, tumor necrosis factor-α, and its receptors. Similar observations have been made in other population-based studies and hospital-based studies. The risk of heart failure was proportionate to the degree of elevation of serum uric acid among patients with gout. Locally, even when there is no active arthritis, the synovial fluid of patients with gout shows low-grade inflammatory activity.

Increased levels of serum uric acid among normal individuals predict hypertension, renal dysfunction, and coronary artery disease and portend reduced life expectancy. Lowering of serum uric acid with allopurinol can reduce blood pressure among hypertensives. This raises the possibility of the hyperuricemia-heart failure link being mediated by hypertension, a hypothesis that cannot be directly tested in observational studies such as ours. Nevertheless, other studies have shown that hyperuricemia is an independent risk factor for heart failure among those who already have hypertension. In our study, this link was consistently observed (a) in time-varying Cox models in which incident hypertension was adjusted for and (b) in stratified analyses of participants who did not develop hypertension.

The significance of our observation lies in its use for developing a risk prediction rule for heart failure. Although observations we have made raise the possibility of the hyperuricemia-heart failure link being mediated by hypertension, a hypothesis that cannot be directly tested in observational studies such as ours. Nevertheless, other studies have shown that hyperuricemia is an independent risk factor for heart failure among those who already have hypertension. In our study, this link was consistently observed (a) in time-varying Cox models in which incident hypertension was adjusted for and (b) in stratified analyses of participants who did not develop hypertension.

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### Table 4. Multivariable Adjusted Risk of Heart Failure Among Various Subgroups of the Framingham Offspring Cohort

<table>
<thead>
<tr>
<th>No. of Participants in Model</th>
<th>Hazard Ratio for Each 1-mg/dL Increase in Serum Uric Acid</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of renal dysfunction anytime during the observation</td>
<td>3587</td>
<td>1.3</td>
</tr>
<tr>
<td>Nonusers of any nondiuretic blood pressure medications</td>
<td>3677</td>
<td>1.20</td>
</tr>
<tr>
<td>Nonusers of diuretics</td>
<td>3639</td>
<td>1.20</td>
</tr>
<tr>
<td>Nondiabetics</td>
<td>3517</td>
<td>1.28</td>
</tr>
<tr>
<td>No metabolic syndrome at study end date</td>
<td>3765</td>
<td>1.26</td>
</tr>
</tbody>
</table>

Unless specified otherwise, multivariable models were adjusted for sex, time-varying measures of age, smoking, systolic blood pressure, serum total cholesterol, high-density lipoprotein ratio, alcohol use, renal dysfunction, coronary artery disease, valvular heart disease, diuretic use, and nondiuretic blood pressure medications.

*P=0.048.

Sources of Funding

The Framingham Offspring Study is conducted and supported by the National Heart, Lung, and Blood Institute in collaboration with the Framingham Offspring Study Investigators. This research was supported in part by grant KL2 RR024154-01 from the National Center for Research Resources, a component of the National Institutes of Health.
Disclosures

Dr Krishnan has received grant support from Takeda Pharmaceuticals of North America, Inc, Deerfield, Ill (formerly TAP Pharmaceuticals Products, Inc) and has held stock in Savient Pharmaceuticals. He has served as an advisor/consultant for both these companies. Proprietary products manufactured by these companies are not named or discussed in this manuscript. This manuscript was prepared using a limited access dataset that Dr Krishnan obtained from the National Heart, Lung, and Blood Institute and does not necessarily reflect the opinions or views of the Framingham Offspring Study or the National Heart, Lung, and Blood Institute. He conceived the manuscript idea, designed the analysis plan, performed statistical analysis, interpreted the results, drafted the manuscript, and will serve as the guarantor.

References

Heart failure is an incurable condition that is responsible for at least 287,000 deaths annually. Heart failure is the most common reason for hospitalization among people on Medicare, and the number of hospitalizations has been increasing over time. We propose that hyperuricemia is a useful biomarker for estimating risk for heart failure and tested this hypothesis using the data from Framingham Offspring Study. We observed that the incidence of heart failure among those with serum uric acid concentrations >6.3 mg/dL was 6-fold higher than that among participants with serum uric acid <3.4 mg/dL. The adjusted risk for heart failure was double among those with hyperuricemia. Our findings have implications for early identification of those at risk for heart failure and put forward a new target for intervention.
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The online version of this article, along with updated information and services, is located on the World Wide Web at:
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