Heart Failure

Multimarker Approach for the Prediction of Heart Failure Incidence in the Community

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Background—Several biological pathways are activated in ventricular remodeling and in overt heart failure (HF). There are no data, however, on the incremental utility of a parsimonious set of biomarkers (reflecting pathways implicated in HF) for predicting HF risk in the community.

Methods and Results—We related a multimarker panel to the incidence of a first HF event in 2754 Framingham Heart Study participants (mean age, 58 years; 54% women) who were free of HF and underwent routine assays for 6 biomarkers (C-reactive protein, plasminogen activator inhibitor-1, homocysteine, aldosterone-to-renin ratio, B-type natriuretic peptide, and urinary albumin-to-creatinine ratio). We estimated model c statistic, calibration, and net reclassification improvement to assess the incremental predictive usefulness of biomarkers. We also related biomarkers to the incidence of nonischemic HF in participants without prevalent coronary heart disease. On follow-up (mean, 9.4 years), 95 first HF events occurred (54 in men). In multivariable-adjusted models, the biomarker panel was significantly related to HF risk (P=0.00005). On backward elimination, B-type natriuretic peptide and urine albumin-to-creatinine ratio emerged as key biomarkers predicting HF risk; hazards ratios per 1-SD increment in log marker were 1.52 (95% confidence interval, 1.24 to 1.87) and 1.35 (95% confidence interval, 1.11 to 1.66), respectively. B-type natriuretic peptide and urinary albumin-to-creatinine ratio significantly improved the model c statistic from 0.84 (95% confidence interval, 0.80 to 0.88) in standard models to 0.86 (95% confidence interval, 0.83 to 0.90), enhanced risk reclassification (net reclassification improvement=0.13; P=0.002), and were independently associated with nonischemic HF risk.

Conclusion—Using a multimarker strategy, we identified B-type natriuretic peptide and urine albumin-to-creatinine ratio as key risk factors for new-onset HF with incremental predictive utility over standard risk factors. (Circulation. 2010; 122:1700-1706.)

Key Words: biomarkers ■ epidemiology ■ heart failure ■ natriuretic peptides ■ risk ■ prediction

Heart failure (HF) is associated with high morbidity and mortality, making its prevention a public health priority.1 Identification of people who are at higher risk of developing HF is critical for targeting prevention strategies. Investigators from the Framingham Heart Study previously described an HF “risk profile”2 based on clinical, ECG, and x-ray features, but these clinical factors do not fully explain HF risk.3 Recently, numerous investigations have highlighted that several biological pathways are activated during left ventricular (LV) remodeling and HF evolution. Several reports focused on individual circulating and urinary biomarkers representing some of these key pathways,4 but few have assessed the incremental predictive utility of multiple biomarkers considered together.

Clinical Perspective on p 1706

We recently applied a multimarker strategy to identify key biomarkers associated with indexes of LV remodeling5 and vascular stiffness.6 In the present investigation, we extend the multimarker strategy to overt HF by relating the panel of...
biomarkers to the incidence of a first HF event in a large community-based sample. The biomarker panel included aldosterone-to-renin ratio (ARR; renin-angiotensin-aldosterone axis), C-reactive protein (CRP; inflammation), plasminogen activator inhibitor-1 (PAI-I; fibrinolysis), B-type natriuretic peptide (BNP; natriuretic peptide system), homocysteine (oxidative stress), and the urine albumin-to-creatinine ratio (UACR; endothelial function). We hypothesized that 1 or more of these circulating and urinary biomarkers will be associated with HF risk and will incrementally predict HF incidence beyond established risk factors.

Methods

Study Sample

Details of the Framingham Offspring Study have been published previously. In brief, 5124 individuals who were children (or spouses of children) of the original Framingham cohort participants were enrolled in 1971 in the Framingham Offspring Study, and these individuals have been examined approximately every 4 years. For the present investigation, we included attendees at the sixth examination cycle (1995 to 1998; n=3532), referred to as the baseline examination for our analysis. Of these, we excluded 737 participants because of unavailable biomarker information, 10 participants for missing covariate information, and another 31 participants who had prevalent HF. Thus, 2754 participants (54% women) remained eligible for this investigation. All participants provided written informed consent, and the Institutional Review Board of the Boston University Medical Center approved the study protocol.

Measurement of Biomarkers

Biosamples were obtained on the morning of the baseline examination (when covariate information was also collected and follow-up started) after an overnight fast, usually between 8 and 9 AM, and frozen at −80°C without any freeze-thaw cycles until assays were performed. Plasma PAI-1 was determined with an ELISA test for PAI-1 antigen (TintElize PAI-1, Biopool, Ventura, Calif). CRP was measured with the Dade-Behring BN100 nephelometer. Serum aldosterone was measured with a radioimmunoassay (Quest Diagnostics, Cambridge, Mass), and plasma renin concentrations were measured by an immunochemiluminometric assay (Nichols Assay, Quest Diagnostics). Plasma BNP was measured with a high-sensitivity immunodotometric assay (Shionogi, Osaka, Japan). We used high-performance liquid chromatography with fluorometric detection to measure total plasma homocysteine. We assessed UACR on a morning urine specimen using immunoturbidimetry (Tina-Quant Albumin Assay, Roche Diagnostics, Indianapolis, Ind) to measure urine albumin and the modified Jaffe method to measure urinary creatinine.

The following were the average interassay coefficients of variation for the biomarker measurements: PAI-1, 7.7%; CRP, 2.2%; renin, 2.0% (high concentrations) to 10% (low concentrations); aldosterone, 4.6% (high concentrations) to 9.8% (low concentrations); BNP, 12.2%; homocysteine, 9%; urine albumin, 7.2%; and urine creatinine, 2.3%.

HF Assessment

Follow-up for the present investigation extended from the baseline examination through December 2007. An end-points adjudication committee consisting of 3 physicians evaluated all suspected cardiovascular disease events (including HF) by reviewing Heart Study clinic charts and hospitalization and physician office records and ascertained the incidence of events according to criteria described previously. We used Framingham HF criteria to adjudicate HF incidence. In secondary analyses, we referred to participants who developed HF without an interim myocardial infarction (MI) or unstable angina (also known as coronary insufficiency) as the “nonischemic” HF group for simplicity.

Statistical Analyses

Biomarker values were natural logarithmically transformed (to account for skewed distributions) and standardized within sex to account for sex-related differences in biomarker distributions. We modeled aldosterone and renin together as a ratio, the ARR, because in our cohort such combined modeling has been most informative. We calculated age- and sex-adjusted Spearman coefficients to evaluate correlations between biomarkers.

To evaluate the predictive utility of biomarkers (with regard to HF risk), we performed the following analyses. First, after confirming that the assumption of proportionality of hazards was met, we fitted Cox models that incorporated age, sex, body mass index, systolic blood pressure, hypertension treatment, diabetes mellitus, ratio of total cholesterol to high-density lipoprotein cholesterol, smoking, prevalent MI, and valvular heart disease. Next, we tested whether the set of 6 biomarkers (denoted m1 through m6 in the equation) was associated with HF risk using a 6-degrees-of-freedom likelihood ratio test of the null hypothesis H0: βm1=βm2=...=βm6=0. The likelihood ratio test χ2 statistic was obtained by comparing likelihoods from 2 models: with covariates only and with covariates plus 6 biomarkers. Third, after determining that the set of biomarkers improved the model, we conducted backward elimination (P for retention in model=0.05) to identify the biomarker(s) with the strongest association with HF incidence, forcing in the 10 clinical covariates in the model. We also used stepwise selection to confirm the final model.

HF risk portended by a biomarker in any given individual is a function of the concentration of the biomarker and the relative risk associated with that concentration. In addition, biomarkers carry different relative risks and may vary in concentrations independently of each other. Therefore, to assess the composite HF risk associated with several biomarkers in any individual, we constructed a weighted biomarker score (including only biomarkers that emerged in backward elimination): Biomarker score=(β coefficient estimate of biomarker1×sex-standardized log-biomarker1 concentration)+(β coefficient estimate of biomarker2×sex-standardized log-biomarker2 concentration), etc.

We plotted the cumulative incidence of HF (accounting for competing risk of mortality) according to tertiles of the biomarker score, ascertained HF event proportions in each tertile, and evaluated whether participants in the second and third tertiles had higher HF risk compared with those in the first tertile in the multivariable-adjusted models described above. We also repeated these analyses in a subsample with Framingham Risk Score–predicted baseline 10-year coronary heart disease (CHD) risk ≥10%. In addition, we used the top tertile of the biomarker score as a threshold to calculate the sensitivity, specificity, positive predictive value, negative predictive value, likelihood ratio of positive test, and likelihood ratio of negative test to evaluate the performance characteristics of the score for possible HF risk screening.

To assess the utility of biomarkers associated with HF, we evaluated several metrics. First, we assessed model calibration (ie, concordance of observed risk and that predicted by the model with biomarkers) by calculating the Hosmer-Lemeshow χ2 statistic for Cox models. Second, we calculated the c statistic for the model with clinical covariates alone and compared it with that for the model with clinical covariates and biomarkers to estimate the increase in the c statistic in the latter.

Third, we classified participants into 3 categories of absolute 12-year HF risk (the maximum follow-up duration): low risk (<2%), intermediate risk (2% to 8%), and high risk (>8%). We evaluated whether inclusion of biomarkers improved risk classification of participants by calculating the net reclassification improvement (NRI).

The NRI is used to assess how well a new marker “reclassifies” people from 1 risk category to another (higher or lower). It is calculated as a sum of 2 separate components (1 for individuals with events and 1 for individuals without events) as follows: NRI=([events reclassified higher–events reclassified lower]/events)+([nonevents reclassified lower–nonevents reclassified higher]/nonevents).

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Results

Baseline clinical and biochemical characteristics of our sample are displayed in Table 1. Of the 2754 participants in our sample, 118 had a history of MI or unstable angina at baseline. Approximately half the participants in our sample had a baseline Framingham Risk Score—predicted 10-year CHD risk ≥10%, and a fifth had predicted 10-year CHD risk ≥20%. Of note, women made up ≈70% of the group with 10-year CHD risk <10%. Approximately 80% of the HF events were concentrated in the subgroup of participants with Framingham Risk Score—predicted 10-year CHD risk ≥10%.

Age- and sex-adjusted correlations among the biomarkers are presented in Table II in the online-only Data Supplement. The strongest positive and inverse correlations were between CRP and PAI-1 and between PAI-1 and BNP, respectively (Table 2). When BNP and UACR were modeled together as a biomarker score, had a baseline Framingham Risk Score—predicted 10-year CHD risk ≥10%, and a fifth had predicted 10-year CHD risk ≥20%. Of note, women made up ≈70% of the group with 10-year CHD risk <10%. Approximately 80% of the HF events were concentrated in the subgroup of participants with Framingham Risk Score—predicted 10-year CHD risk ≥10%. Age- and sex-adjusted correlations among the biomarkers are presented in Table II in the online-only Data Supplement. The strongest positive and inverse correlations were between CRP and PAI-1 and between PAI-1 and BNP, respectively (Table 2). When BNP and UACR were modeled together as a biomarker score, unadjusted HF proportions increased 10-fold across tertiles. Cumulative HF incidence curves by tertile of biomarker score are presented in the Figure. Participants in the second and third tertiles of biomarker score carried multivariable-adjusted HF hazards that were 3-fold and 4-fold higher, respectively, than those with a biomarker score in the first tertile (Table 3). Results were similar when we repeated these analyses in a subsample with Framingham Risk Score—predicted baseline 10-year CHD risk ≥10% (Table III in the
Table 3. Relations of Biomarker Score to HF Risk

<table>
<thead>
<tr>
<th>Tertile</th>
<th>Events/at Risk, n (%)</th>
<th>HF risk (95% CI)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6/918 (0.7)</td>
<td>2.9 (1.7–7.0)</td>
</tr>
<tr>
<td>2</td>
<td>24/918 (2.6)</td>
<td>4.2 (1.8–10.2)</td>
</tr>
<tr>
<td>3</td>
<td>65/918 (7.1)</td>
<td></td>
</tr>
</tbody>
</table>

*Event proportions by tertile of biomarker score based on BNP and UACR. †Multivariable-adjusted HF hazards compared with the referent group. Model adjusted for age, sex, body mass index, systolic blood pressure, hypertension treatment, diabetes mellitus, current smoking, ratio of total to high-density lipoprotein cholesterol, valvular heart disease, and prevalent MI.

Table 4. Classification of Participants Into HF Risk Groups Based on Multivariable Models With and Without Biomarkers

<table>
<thead>
<tr>
<th>Risk reclassification in participants without HF, n (row %)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2%†</td>
<td>1529 (93)</td>
</tr>
<tr>
<td>2%–8%†</td>
<td>176 (23)</td>
</tr>
<tr>
<td>&gt;8%†</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Total</td>
<td>1705</td>
</tr>
</tbody>
</table>

Risk reclassification in participants with HF, n (row %)

<table>
<thead>
<tr>
<th>Risk reclassification in participants with HF, n (row %)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2%†</td>
<td>26 (79)</td>
</tr>
<tr>
<td>2%–8%†</td>
<td>3 (8)</td>
</tr>
<tr>
<td>&gt;8%†</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
</tr>
</tbody>
</table>

NRI=[(7+8)–(3+3)]/95+[|(176+74)–(115+49)|]/2659=0.13; P=0.009.

*HF risk categories based on clinical covariates alone.
†HF risk categories based on clinical covariates plus biomarker score.

Figure. Cumulative incidence of HF according to tertiles of the biomarker score incorporating BNP and UACR.

Table 3. Relations of Biomarker Score to HF Risk

<table>
<thead>
<tr>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events/at risk, n (%)</td>
<td>6/918 (0.7)</td>
<td>24/918 (2.6)</td>
</tr>
<tr>
<td>HF risk (95% CI)†</td>
<td>Referent</td>
<td>2.9 (1.7–7.0)</td>
</tr>
</tbody>
</table>

*Event proportions by tertile of biomarker score based on BNP and UACR. †Multivariable-adjusted HF hazards compared with the referent group. Model adjusted for age, sex, body mass index, systolic blood pressure, hypertension treatment, diabetes mellitus, current smoking, ratio of total to high-density lipoprotein cholesterol, valvular heart disease, and prevalent MI.

Discussion

Principal Findings

In our large community-based sample, we identified BNP and UACR (from a multimarker panel) as key predictors of HF risk, emphasizing the importance of natriuretic peptide system activation and endothelial dysfunction as markers of disease progression. BNP and UACR were also indepen-
ently associated with nonischemic HF, suggesting that relations of biomarkers to HF risk are not mediated solely by interim occurrence of ischemic events, and were significantly associated with HF risk in the subgroup with normal LV systolic function, suggesting that our findings were not driven by individuals with LV systolic dysfunction in our sample. In addition, participants who were excluded because of intercurrent ischemic events as having “ischemic HF” may still have nonischemic HF (ie, the intervening event may not be causally related to HF occurrence). These 2 biomarkers improved HF risk prediction very modestly, as evidenced by improvements in model discrimination and risk reclassification. The biomarker score may have potential utility as a screening tool, a premise that would require additional studies; the high negative predictive value may be important to note in this context. We also demonstrate the robustness of the biomarkers in predicting HF risk in participants with high baseline CHD risk; however, we should be cautious in generalizing these findings to people with low baseline CHD risk (10-year risk <10%), and biomarker utility in the latter group needs further study.

Several previous investigations reported the relations of biomarkers from various biological domains to HF risk.7,11,28–30 However, our investigation is novel in several respects. Whereas earlier studies evaluated biomarkers individually, we used a multimarker strategy, which permitted a comparison of several biomarkers while limiting multiple statistical testing. We also assessed the potential incremental utility of biomarkers (and biomarker scores) for predicting HF risk (above and beyond standard clinical risk factors). An additional strength of our report is the demonstration that both BNP and UACR are associated with the risk of developing nonischemic HF in a large subgroup without history of MI or unstable angina, thereby avoiding potential confounding by preexisting and interim ischemic events, which can activate several of the pathways represented by the biomarkers we investigated.

Although the exact mechanisms underlying the predictive value of BNP and UACR cannot be conclusively determined from epidemiological data alone, the results from our investigation, if confirmed, can potentially be used in clinical settings to evaluate HF risk and to identify specific high-risk individuals. Analogous to the use of multivariable risk profiles in the assessment of CHD risk in people with dyslipidemia, with attendant determination of treatment targets, biomarker risk scores can be used to identify those who are at high risk for HF and may potentially benefit from treatment of currently established HF risk factors (hypertension, diabetes, obesity, etc) to targets that are lower than conventionally recommended to reduce HF incidence. However, this approach (using biomarker scores for risk stratification) has yet to be tested and need validation before use in clinical settings. Indeed, it may be argued that all patients at risk of developing HF warrant aggressive management of their risk factor burden.

Mechanisms Underlying the Relations of Biomarkers to HF Risk

BNP is a hormone with natriuretic, diuretic, and vasodilatory properties that is released in response to increased LV filling pressures31 and/or greater LV wall stress.32 BNP has been used in the diagnosis of clinical HF33 but is also elevated in people with asymptomatic LV dysfunction.34 Thus, one explanation for the relations of BNP to HF risk is that participants with elevated BNP concentrations are those with subclinical LV remodeling,35 systolic dysfunction,36 or diastolic dysfunction37 and therefore develop HF at higher rates. Another possibility is that relations of BNP to HF risk are mediated by its relations to incident ischemic cardiovascular events.9 BNP may be released in the setting of ischemic events other than MI or with subclinical ischemia and may therefore predict HF secondary to clinical or subclinical ischemia. In our investigation, a variety of adjustments for ischemic events (including adjustment for unrecognized MI) and exclusion of participants with MI and unstable angina did not alter the results. However, it is possible that BNP released in response to subclinical ischemia may be an explanation for the association between this biomarker and HF risk. Overall, it is likely that BNP is a marker for each of the mechanisms noted above.

Similarly, UACR is a risk marker for endothelial dysfunction,38 target organ damage,39 ischemic events,40 and an atherogenic risk profile,41 which may explain why it is related to HF risk. As with BNP, it is likely that UACR is a cumulative measure for all these mechanisms for HF risk.

The other biomarkers in our panel (CRP, PAI-1, ARR, and homocysteine) have previously been implicated in ventricular remodeling, alterations in LV function, and HF incidence.29,30,42–44 However, in our analysis, we did not observe an independent association between these biomarkers and HF risk. It is conceivable that the relations of these biomarkers to HF risk may be mediated through their relations to clinical risk factors that we adjusted for in our model. Indeed, previous reports have described the associations between CRP and hypertension45 and diabetes mellitus46 and between PAI-1 and hypertension47 and metabolic syndrome.48 Prior investigations also have noted the relations of ARR to hypertension23 and both ARR and homocysteine to vascular stiffness.6,49 Thus, our results do not imply that the pathways represented by these biomarkers do not contribute to HF risk.

Strengths and Limitations

Our study is strengthened by a large sample size, standardized measurements of biomarkers and clinical variables, a rigorous definition of HF events, and a conservative analysis strategy to minimize multiple testing. However, several limitations should be acknowledged. First, we tested only a small set of biomarkers that were available at a routine examination and that have previously been implicated in LV remodeling and/or HF risk; markers of other biological pathways (or other biomarkers of domains we evaluated) that were not tested may be important in influencing HF risk. Second, differences in the analytic precision of the assays for these biomarkers may have influenced the results of analysis. Third, we lack information on quantitative LV ejection fraction, measures of diastolic function, and measures of endothelial or vascular function at the baseline examination; therefore, we could not adjust for these measures in our multivariable models. Fourth, reclassification metrics and
performance characteristics of the biomarker score are susceptible to misclassification of participants (cases versus noncases) in whom follow-up information is not complete. Finally, our sample comprised middle-aged white individuals of European ancestry, and our results may not be generalizable to other age groups or ethnicities.

Conclusions

Refining HF prediction is a fundamental step for preventing the condition. In our prospective investigation of a large community-based sample of middle-aged whites, we identified BNP and UACR as key biomarkers associated with HF risk. However, the incremental usefulness of these biomarkers over standard clinical factors (as assessed by c statistics and NRI) is very modest. Additional investigations are therefore warranted both to replicate our findings and to assess their applicability to routine clinical settings.

Sources of Funding

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Disclosures

None.

References


Several biological remodeling have been individually implicated in left ventricular remodeling and/or heart failure (HF) development, but it is unclear whether biomarkers reflecting these pathways aid in the prediction and stratification of HF risk beyond standard risk factors. In a community-based sample, we prospectively related a panel of circulating biomarkers representing distinct biological pathways, viz., aldosterone-to-renin ratio (renin-angiotensin-aldosterone axis), C-reactive protein (inflammation), plasminogen activator inhibitor-1 (fibrinolysis), B-type natriuretic peptide (natriuretic peptide system), homocysteine (oxidative stress), and the urine albumin-to-creatinine ratio (endothelial function) to the risk of developing new-onset HF. We used a multimarker approach that permitted a comparison of the biomarkers in relation to their contributions to HF risk while limiting multiple testing. We also related a biomarker score (based on biomarkers associated with HF) to HF risk. After adjustment for conventional HF risk factors, B-type natriuretic peptide and urine albumin-to-creatinine ratio emerged as key HF risk predictors. When B-type natriuretic peptide and urine albumin-to-creatinine ratio were modeled as a biomarker score, we observed a striking 10-fold increase in HF incidence across tertiles of biomarker score. Biomarkers provided incremental information over clinical risk factors for predicting HF as assessed by significant improvements in c statistic and net reclassification. The predictive ability of biomarkers was maintained in subgroups with normal left ventricular function, those with renal function, and those without intervening ischemic events.

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SUPPLEMENTAL MATERIAL: A Multimarker Approach for Prediction of Heart Failure Incidence in the Community.

I. Definitions of covariates

II. Supplementary Table 1. Framingham heart failure criteria

III. Statistical methods for secondary analyses

IV. Supplementary Table 2. Correlations between biomarkers

V. Supplementary Table 3: Analyses confined to high-risk participants

VI. Supplementary Table 4: Analyses adjusting for all clinical ischemic events

VII. Supplementary Table 5: Analyses adjusting for unrecognized MI

VIII. Supplementary Table 6: Analyses modeling clinical risk factors as time-dependent covariates
I. Definitions of covariates

Covariates used for multivariable analyses were all defined at the baseline examination. We calculated body mass index (BMI) as the weight in kilograms divided by the square of height in meters. A physician measured blood pressure twice on the left arm of the seated participants using a mercury-column sphygmomanometer and a cuff of appropriate size; the average of two such readings was considered the examination blood pressure. Fasting lipids and glucose were measured using standardized assays. We defined diabetes as a fasting plasma glucose ≥126 mg/dl or receiving hypoglycemic therapy. We defined valve disease as ≥moderate stenosis or regurgitation of the mitral or the aortic valves on Doppler color flow imaging at the echocardiographic examination performed at the baseline examination. Interim MI or unstable angina was defined as occurrence of these events between baseline examination and time of HF occurrence.
## II. Supplementary Table 1. Framingham Criteria for HF Diagnosis

<table>
<thead>
<tr>
<th>Major Criteria</th>
<th>Minor Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paroxysmal nocturnal dyspnea or orthopnea</td>
<td>Dyspnea on ordinary exertion</td>
</tr>
<tr>
<td>Distended neck veins</td>
<td>Night cough</td>
</tr>
<tr>
<td>Hepatojugular reflux</td>
<td>Heart rate &gt; 120/minute</td>
</tr>
<tr>
<td>Rales</td>
<td>Hepatomegaly</td>
</tr>
<tr>
<td>S3 gallop</td>
<td>Ankle edema</td>
</tr>
<tr>
<td>Enlarged heart by X-ray</td>
<td>Decrease in vital capacity by 1/3rd</td>
</tr>
<tr>
<td>Acute pulmonary edema on chest X-ray</td>
<td>Pleural effusion by X-ray</td>
</tr>
<tr>
<td>Treatment induced weight loss &gt;10lbs/5 days</td>
<td>Pulmonary vascular engorgement by X-ray</td>
</tr>
<tr>
<td>Increased venous pressure &gt; 16 cm water</td>
<td></td>
</tr>
<tr>
<td>Pulmonary edema, visceral congestion or cardiomegaly on autopsy</td>
<td></td>
</tr>
</tbody>
</table>

HF is diagnosed when 1 major and 2 minor criteria or 2 major criteria are present without a competing explanation for findings.
III. Statistical Methods for Secondary Analyses

We performed several secondary analyses on the biomarkers identified in our primary analyses as predictors of HF risk. Several biomarkers in our panel have been previously related to CVD risk, and they may, therefore, influence HF risk via ischemic events during follow-up. We examined this possibility in four different ways. First, we included interim MI as a time-dependent covariate in our primary models relating the biomarkers to HF risk. Second, we related biomarkers to risk of developing non-ischemic HF in a subgroup of participants without history of major coronary disease (MI or unstable angina) at baseline; for these analyses, participants who developed an MI or unstable angina on follow-up were censored as non-events at the time of the ischemic event. Third, we repeated the analyses evaluating relations of the biomarker score to HF risk adjusting for all ischemic events (MI, unstable angina and angina pectoris), both incident and prevalent. Fourth, we also repeated the multivariable model with biomarker score additionally adjusting for incident and prevalent unrecognized MI.

The relations of biomarkers to HF risk may be mediated by their relations to underlying renal function, so we (a) additionally adjusted our primary model for estimated glomerular filtration rate (eGFR) as calculated by the “Modification of Diet in Renal Disease” formula, and (b) repeated our primary model in a sub-sample with eGFR ≥60 ml/min/1.73 m². As values for covariates (such as BMI) and proportions of participants with co-existing heart disease (such as valve disease) may change over time, we repeated the multivariable model with biomarker score treating all clinical risk factors as time-dependent covariates. Lastly, since BNP and UACR values vary with age, sex, and BMI we tested if relations of biomarkers to HF risk varied according to these covariates by incorporating first-order interaction terms (age dichotomized at
median; sex, men versus women; BMI dichotomized at <30 versus ≥30 kg/m²) in the multivariable models.
IV. Supplementary Table 2. Correlations among Biomarkers

<table>
<thead>
<tr>
<th></th>
<th>CRP</th>
<th>PAI-1</th>
<th>Homocysteine</th>
<th>ARR</th>
<th>BNP</th>
<th>UACR</th>
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</thead>
<tbody>
<tr>
<td>CRP</td>
<td>1.00</td>
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<td>0.03</td>
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<td>-0.05</td>
<td>0.02</td>
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<tr>
<td>PAI-1</td>
<td></td>
<td>1.00</td>
<td>0.06</td>
<td>0.00</td>
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<td>0.00</td>
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<tr>
<td>Homocysteine</td>
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<td>-0.06</td>
<td>0.06</td>
<td>0.04</td>
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<tr>
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<td>1.00</td>
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</tr>
<tr>
<td>BNP</td>
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<tr>
<td>UACR</td>
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<td></td>
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</tr>
</tbody>
</table>

Cells display age- and sex-adjusted Spearman partial correlation coefficients for natural log-transformed and sex-standardized mean biomarker values, calculated on a sample of 2754 individuals. Values in bold indicate correlations that are statistically significant at a p-value threshold of 0.05.

CRP = C-reactive protein; PAI-1 = plasminogen activator inhibitor-1; ARR = aldosterone-to-renin ratio; BNP = B-type natriuretic peptide; UACR = urinary albumin-to-creatinine ratio.
V. Supplementary Table 3. Relations of Biomarker Score to HF Risk in Participants with Predicted 10-year CHD Risk ≥ 10%

<table>
<thead>
<tr>
<th></th>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of events/no. at risk (%)*</td>
<td>5/367 (1.4)</td>
<td>18/449 (4.1)</td>
<td>56/540 (10.4)</td>
</tr>
<tr>
<td>HF risk†</td>
<td>Referent</td>
<td>2.36 (0.87 – 6.38)</td>
<td>3.91 (1.50 – 10.18)</td>
</tr>
</tbody>
</table>

Results based on sub-sample of participants with predicted 10-year CHD risk ≥ 10% as assessed by Framingham Risk Score.

* Event proportions by tertile of biomarker score based on BNP and UACR

† Multivariable-adjusted HF hazards (confidence intervals) compared to referent group. Model adjusted for age, sex, body mass index, systolic blood pressure, hypertension treatment, diabetes, current smoking, total/HDL cholesterol ratio, valvular heart disease and prevalent myocardial infarction.
VI. Supplementary Table 4. Relations of Biomarker Score to HF Risk: Adjustment for all Clinical Ischemic Events

<table>
<thead>
<tr>
<th></th>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of events/no. at risk (%)</strong>*</td>
<td>6/918 (0.7)</td>
<td>24/918 (2.6)</td>
<td>65/918 (7.1)</td>
</tr>
<tr>
<td><strong>HF risk†</strong></td>
<td>Referent</td>
<td>2.69 (1.09 – 6.61)</td>
<td>4.39 (1.84 – 10.48)</td>
</tr>
</tbody>
</table>

* Event proportions by tertile of biomarker score based on BNP and UACR
† Multivariable-adjusted HF hazards (confidence intervals) compared to referent group. Model adjusted for age, sex, body mass index, systolic blood pressure, hypertension treatment, diabetes, current smoking, total/HDL cholesterol ratio, valvular heart disease and both prevalent and incident ischemic events (MI, unstable angina and angina pectoris).
VII. Supplementary Table 5. Relations of Biomarker Score to HF Risk: Additional Adjustment for Unrecognized MI

<table>
<thead>
<tr>
<th></th>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of events/no. at risk (%)*</td>
<td>6/918 (0.7)</td>
<td>24/918 (2.6)</td>
<td>65/918 (7.1)</td>
</tr>
<tr>
<td>HF risk†</td>
<td>Referent</td>
<td>2.69 (1.10 – 6.62)</td>
<td>4.37 (1.83 – 10.44)</td>
</tr>
</tbody>
</table>

* Event proportions by tertile of biomarker score based on BNP and UACR

† Multivariable-adjusted HF hazards (confidence intervals) compared to referent group. Model adjusted for age, sex, body mass index, systolic blood pressure, hypertension treatment, diabetes, current smoking, total/HDL cholesterol ratio, valvular heart disease, prevalent recognized MI and prevalent and incident unrecognized MI.
VIII. Supplementary Table 6. Relations of Biomarker Score to HF Risk: Clinical Risk Factors Modeled as Time-Dependent Covariates

<table>
<thead>
<tr>
<th></th>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of events/no. at risk (%)</strong></td>
<td>6/918 (0.7)</td>
<td>24/918 (2.6)</td>
<td>65/918 (7.1)</td>
</tr>
<tr>
<td><strong>HF risk</strong></td>
<td>Referent</td>
<td>2.73 (1.11 – 6.71)</td>
<td>4.33 (1.81 – 10.34)</td>
</tr>
</tbody>
</table>

* Event proportions by tertile of biomarker score based on BNP and UACR

† Multivariable-adjusted HF hazards (confidence intervals) compared to referent group. Model adjusted for age, sex, body mass index, systolic blood pressure, hypertension treatment, diabetes, current smoking, total/HDL cholesterol ratio, valvular heart disease and prevalent MI. Body mass index, systolic blood pressure, hypertension treatment, diabetes, current smoking, total/HDL cholesterol ratio and valvular heart disease were modeled as time-dependent covariates.
Reference List


심부전 발생 예측을 위한 새로운 접근법: 다중 표지자 사용 전략

강석 민 교수 세포암생물학 실험실

Summary

배경

심혈관 사망률과 심부전 발생은 다양한 기전이 관여한다. 그러나 일반인들의 심부전 발생을 예측하는 데 있어 다양한 생활습관지표들은 동반 다중 표지자 접근 전략의 유용성이 대해서는 0.6 알려진 바가 없다.

방법 및 결과

Framingham Heart Study에 참여한 심부전 증상이 있는 2,754명(평균 연령 58세, 여성 54%)을 대상으로 6개의 생활습관 지표(C-reactive protein, plasminogen activator inhibitor-1, homocysteine, aldosterone to renin ratio, B-type natriuretic peptide and urinary albumin-to-creatinine ratio)를 이용해 심부전 발생을 예측하고자 하였다. 이러한 생활습관 지표들의 추가적인 유용성을 평가하고자 관련 통계적 기법을 사용하였다. 추적기간 동안(평균 9.4년) 95명의 심부전 (념성 54명)이 발생하였다. 다변량분석 결과, 다중 표지자 접근 전략이 심부전 발생과 유의한 상관관계를 가 있었다 (P=0.00005). 이 중에서 B-type natriuretic peptide (HR, 1.52; 95% CI, 1.24-1.87)와 urinary albumin-to-creatinine ratio (HR, 1.3; 95% CI, 1.11-1.66)가 심부전 발생을 예측하는 데 있어서 중요한 지표였다. 또한, 이 두 표지자는 심부전 발생 위험 예측 증가 모델을 유의하게 증가시켰으며 (net reclassification improvement=0.13; P=0.002). 비해혈성 심부전 발생과도 유의하게 관련이 있었다.

결론

다중 표지자 사용 전략을 이용하여 B-type natriuretic peptide와 urinary albumin-to-creatinine ratio가 새로운 심부전 발생을 예측하는 중요한 위험인자임을 알 수 있었고 추가적인 유용성을 확인할 수 있었다.
심부전의 발생과 관련이 다양한 기전이 관여한다고 알려져 있으나, 아직까지 어떤 기전이 심부전 발생에 결정적인 역할을 하는지에 대해서는 정확하게 밝혀져 있지 않다. 또한, 이러한 기전을 대비하는 생물학적 지표들이 현재 기존의 심부전 위험인자(혈압, 당뇨병, 심장 구조, 심부전 X-선 소견 등)보다 심부전 발생을 예측하는 데 있어 유용성이 보다는 악화되고 있다. 본 연구에서는 Framingham Heart Study에 참여한 일반인의 체적 검사를 통해 다양한 심부전 발생 기전을 대별하는 생물학적 지표를 이용하여 aldosterone-to-renin ratio(renin-angiotensin-aldosterone system), C-reactive protein(inflammation), plasminogen activator inhibitor-1(fibrinolysis), B-type natriuretic peptide(natriuretic peptide system), homocysteine(oxidative stress)와 urinary albumin-to-creatinine ratio(endothelial dysfunction)의 인자 표지자 접근 전략을 통해 심부전의 새로운 발생을 계획하고자 하였다. 즉, 각기 다른 표지자들은 여러 방향에서의 심장 성장의 대표자들 혹은 이들 표지자들의 조합이 심부전 발생 예측에 유용한지를 알아본 연구이다. 이 중에서 B-type natriuretic peptide와 urinary albumin-to-creatinine ratio는 심부전 발생을 예측하는 중요한 위험인자를 맡을 수 있었다. 또한, 가중치를 감안하여 전체적으로 개선된 biomarker score에 따라서 이 두 가지 생물학적 표지자들이 다른 표지자들에 비해 심부전 발생을 높이 예측할 수 있었다. 즉, 심부전 발생이 있어 natriuretic peptide system의 활성화와 endothelial dysfunction이 중요한다는 사실을 제시한다. 또한, 총산수소기능은 가정할 수 있다. 성장 단단한 기능은 가장 사람들의 예방에 기여하고 심부전 발생 예측에 주목해야 한다. 그래서 심부전 발생도이 환자들의 약 80% 정도에서 발생한 사실을 고려한다면, 심혈관 위험도가 높은 환자군에게 본 연구의 결과를 적용하기에는 무리가 있다고 본다. 본 연구에서 제시한 biomarker score의 유용성은 여러 연구에서 검증이 필요하다는 생각되지만, 심부전 환자들에 스크리닝하는 데 유용할 수 있으며, 심부전 발생을 예측하는 데 있어 negative predictive value로서 중요한 역할을 할 수 있다. 물론, 본 연구에서는 측정하지 않았지만 심부전 발생 기전에 관여하는 다른 생물학적 표지자들이 향후 필요한 연구가 진행되어야 할 연구 결과를 더욱 활발히 삽입할 수 있을 것이다.

결론적으로, 기존 검사항과 증가되는 심부전 환자들의 발생을 예측하는 방법 중에서 본 연구에서 제시한 B-type natriuretic peptide와 urinary albumin-to-creatinine ratio의 심부전 발생을 예측할 수 있는 결과에 사용하기 위해서는 정확한 테스트는 임상 연구들을 토대로 검증이 필요하다.
Résumés d’articles

Valeur prédictive d’une série de marqueurs à l’égard du risque d’insuffisance cardiaque en milieu communautaire

Raghava S. Velagaleti, MD ; Philimon Gona, PhD ; Martin G. Larson, ScD ; Thomas J. Wang, MD ; Daniel Levy, MD ; Emelia J. Benjamin, MD, ScM ; Jacob Selhub, PhD ; Paul F. Jacques, ScD ; James B. Meigs, MD, MPH ; Geoffrey H. Tofler, MD ; Ramachandran S. Vasan, MD

Contexte—On sait que plusieurs voies biologiques sont activées lors du remodelage ventriculaire et de l’insuffisance cardiaque (IC) avérée. Aucune donnée n’est toutefois disponible sur la valeur additive d’un ensemble réduit de biomarqueurs (reflétant les voies impliquées dans la survenue de la maladie) en termes de prédiction du risque d’IC en milieu communautaire.

Méthodes et résultats—Nous avons recherché les liens unissant divers biomarqueurs à la survenue d’un premier épisode d’IC chez 2 754 participants à l’étude cardiologique de Framingham (âge moyen : 58 ans ; 54 % de femmes) qui étaient initialement indemnes d’une telle affection et chez lesquels six marqueurs biologiques avaient été systématiquement mesurés (à savoir la C-réactive protéine, l’inhibiteur 1 de l’activateur du plasminogène, l’homocystéine, le rapport aldostérone/rénine, le peptide natriurétique de type B et le rapport albuminurie/créatininurie). Nous avons estimé la statistique c, la calibration et l’indice d’amélioration de la reclassification nette du modèle pour apprécier la contribution additionnelle de chacun de ces marqueurs à la prédiction du risque. Nous avons également recherché les liens existant entre ces marqueurs et l’incidence des cas d’IC non ischémiques chez les participants qui étaient indemnes de maladie coronaire à leur entrée dans l’étude. Au cours du suivi (durée moyenne : 9,4 ans), 95 premiers épisodes d’IC ont été enregistrés (dont 54 chez des hommes). Dans les modèles ajustés pour les variables multiples, notre série de biomarqueurs s’est montrée significativement corrélée avec le risque d’IC (p = 0,00005). A l’issue de la procédure d’éliminations rétrogardes successives, le peptide natriurétique de type B et le rapport albuminurie/créatininurie sont apparus comme des marqueurs prédictifs majeurs du risque d’IC : les risques relatifs par augmentation de 1 unité de l’indice de chaque biomarqueur sont de 1,66. Ces deux marqueurs ont significativement amélioré la statistique c des modèles standard de 0,84 (IC à 95 % : 0,80 à 0,88) à 0,86 (IC à 95 % : 0,83 à 0,90) ; ils ont également permis de donner une meilleure reclassification des niveaux de risque (indice d’amélioration de la reclassification nette : 0,13 ; p = 0,002) et ont été corrélés de façon indépendante avec le risque d’IC non ischémique.

Conclusion—Par l’évaluation d’une série prédéfinie de marqueurs, nous avons pu établir que le peptide natriurétique de type B et le rapport albuminurie/créatininurie sont deux facteurs clés du risque de survenue d’une IC de novo et qui s’ajoutent à la valeur prédictive des facteurs de risque classiques. (Traduit de l’anglais : Multimarker Approach for the Prediction of Heart Failure Incidence in the Community. Circulation. 2010;122:1700–1706.)

Mots clés : biomarqueurs ■ épidémiologie ■ insuffisance cardiaque ■ peptides natriurétiques ■ risque ■ prédiction

Influence du lasofoxifène sur l’incidence des événements cardiovasculaires chez la femme ménopausée ostéoporotique

Résultats à cinq ans de l’essai Postmenopausal Evaluation and Risk Reduction With Lasofoxifene (PEARL)

Kristine Ensrud, MD, MPH ; Andrea LaCroix, PhD ; John R. Thompson, PhD ; David D. Thompson, PhD ; Richard Eastell, MD ; David M. Reid, MD ; Slobodan Vukicevic, MD ; Jane Cauley, DrPH ; Elizabeth Barrett-Connor, MD ; Roisin Armstrong, PhD ; Francine Welty, MD, PhD ; Steven Cummings, MD

Contexte—Dans l’essai PEARL (Postmenopausal Evaluation and Risk Reduction With Lasofoxifene [Évaluation du lasofoxifène dans la réduction des risques encourus après la ménopause]), les femmes traitées par le lasofoxifène à la posologie de 0,5 mg/jour ont présenté un moindre risque d’événement coronarique majeur et d’accident vasculaire cérébral (AVC), alors que celles ayant reçu le médicament à raison de 0,25 mg/jour ont été exposées à un plus faible risque d’AVC. En revanche, les deux doses de lasofoxifène ont majoré le risque d’événement thromboembolique veineux. Dans la présente publication, nous présentons des données complètes sur les événements cibles cardiovasculaires en examinant notamment chacun des...