ORIGINAL INVESTIGATION

Profile for Estimating Risk of Heart Failure

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Context: We devised a risk appraisal function to assess the hazard of heart failure in persons who are predisposed by coronary disease, hypertension, or valvular heart disease.

Objective: To provide general practitioners and internists with a cost-effective method to select people at high risk who are likely to have impaired left ventricular systolic function and may therefore require further evaluation and aggressive preventive measures.

Methods: The routinely measured risk factors used in constructing the heart failure profile include age, electrocardiographic left ventricular hypertrophy, cardiomegaly on chest x-ray film, heart rate, systolic blood pressure, vital capacity, diabetes mellitus, evidence of myocardial infarction, and valvular disease or hypertension. Based on 486 heart failure cases during 38 years of follow-up, 4-year probabilities of failure were computed using the pooled logistic regression model for each sex; a simple point score system was employed. A multivariate profile was also produced without the vital capacity or chest x-ray film because these may not be readily available in some clinical settings.

Results: Using the risk factors that make up the multivariate risk formulation—derived from ordinary office procedures—the probability of developing heart failure can be estimated and compared with the average risk for persons of the same age and sex. Using this risk profile, 60% of events in men and 73% in women occurred in subjects in the top quintile of multivariate risk.

Conclusions: Using this multivariate risk formulation, it is possible to identify high-risk candidates for heart failure who are likely to have a substantial yield of positive findings when tested for objective evidence of presymptomatic left ventricular dysfunction. The risk profile may also identify candidates who are at high risk for heart failure because of multiple, marginal risk factor abnormalities that might otherwise be overlooked.

Arch Intern Med. 1999;159:1197-1204

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HEART FAILURE morbidity and mortality continue unabated despite declines in some cardiovascular events.[1] Heart failure is a progressive, often terminal stage of cardiac disease that, when symptomatic, curtails survival like many types of cancer.[2] In Framingham Study subjects with overt congestive heart failure, the median survival rate was only 1.7 years for men and 3.2 years for women.[3] This heart failure mortality rate is 4 to 8 times the death rate of the general population of comparable age and has not improved greatly despite major declines in coronary, hypertensive, and rheumatic heart disease mortality.[1] Furthermore, sudden death continues to be a prominent feature of heart failure.[1]

Effective prevention of heart failure requires the early detection and correction of predisposing conditions and risk factors in susceptible persons. Preventive measures must be implemented by general practitioners and internists for high-risk, asymptomatic persons with hypertension, coronary disease, left ventricular hypertrophy (LVH), diabetes, and valvular heart disease. High-risk candidates for heart failure need to be targeted for evaluation and treatment in a cost-effective manner. Their evaluation and treatment should be designed to delay the onset of heart failure, since treatment of asymptomatic persons with impaired left ventricular systolic function has been shown to delay the onset of overt heart failure.[4] Independent predictors of congestive heart failure have been identified by epidemiological research in the Framingham Study.[2] Using these risk factors, we constructed a multivariable risk profile that efficiently identifies prime candidates for heart failure from among those with predisposing conditions.

The purpose of this report is to provide a risk profile for general practitioners and internists that will enable them to estimate the risk of developing heart failure in predisposed persons with coronary disease, hypertension, or valvular

SUBJECTS AND METHODS

The Framingham Study is a prospective, epidemiological, population-based undertaking designed to investigate the prevalence, incidence, and determinants of cardiovascular disease. The study design, recruitment procedures, population sampling, response rates, and methodology have been reported in detail elsewhere.[5-8] Subjects were reexamined every 2 years for the appearance of cardiovascular events in relation to previous biennially measured risk factors. Each examination included a medical history, physical examination, several blood pressure measurements, a 12-lead electrocardiogram (ECG), and laboratory tests.

The probability of developing heart failure was determined in subjects aged 45 through 94 years who had coronary disease, hypertension, or valvular heart disease, but were free of the condition at baseline. Over the course of the 38-year study period, among those with these predisposing conditions, there were 6354 person-examinations with follow-up in men and 8913 in women. The independent risk factors used to predict heart failure included age, systolic blood pressure, LVH on ECG, vital capacity by spirometry, heart rate, coronary heart disease, murmurs signifying valvular heart disease, diabetes, radiographic cardiomegaly, and, in some models, body mass index. Definitions and criteria for the categorical risk factors and cardiac conditions have been reported in detail elsewhere.[5,6] Active surveillance for development of heart failure has been a feature of the Framingham Study since its inception. Using information from the Framingham Study clinic examinations, hospital admissions, and attending physicians' records, a diagnosis of congestive heart failure was designated when at least 2 major or 1 major and 2 minor criteria for heart failure were present (**Table 1**). Minor criteria were accepted only if they could not be attributed to another existing medical condition.

At each examination, interim cardiovascular events were ascertained from medical histories, physical examinations, ECGs, chest x-ray films, and review of interim medical records, including the hospital and attending physicians' records of those who failed to reappear for their scheduled biennial examination. All suspected cardiovascular events were reviewed by a panel of 3 physicians who applied established criteria for such events.[5] The coronary disease events included in this risk profile were recognized and unrecognized myocardial infarction and unstable angina. Valvular heart disease was considered present if there was a grade 3/6 or louder systolic murmur or a diastolic murmur of any intensity.

At each examination, subjects were seated and blood pressures were measured twice by the examining physician using a mercury sphygmomanometer. Hypertension was defined as the presence of either an elevated blood pressure or ongoing antihypertensive treatment of a previously elevated blood pressure. Based on 2 physicians' readings, elevated blood pressure was identified when blood pressure was 140/90 mm Hg or greater on both readings. Persons with an elevated fasting blood glucose level exceeding 7.8 mmol/L (140 mg/dL) or a casual blood glucose level over 11.1 mmol/L (200 mg/dL) were considered diabetic, as were persons using insulin or oral hypoglycemic agents. Electrocardiographic LVH was diagnosed when both increased voltage and repolarization abnormalities were present.[5] When the cardiothoracic ratio exceeded 0.5 on chest film, cardiomegaly was identified. Vital capacity was measured by spirometry using a Collins respirometer; the best of 3 efforts was recorded. Body mass index was defined as weight measured in kilograms divided by square of height in meters.

A pooled logistic regression model—$f(x) = 1/(1 + e - x)$—was used to generate the heart failure risk profile[9]; x was estimated by an equation with an intercept (a), and the sum of the β coefficients for each of the specific risk factors multiplied by their actual values. For example, $x = a + (\beta_1 \times \text{age}) + (\beta_2 \times \text{LVH}) + (\beta_3 \times \text{vital capacity}) + (\beta_4 \times \text{heart rate}) + (\beta_5 \times \text{systolic blood pressure}) + (\beta_6 \times \text{coronary disease}) + (\beta_7 \times \text{valve disease}) + (\beta_8 \times \text{diabetes}) + (\beta_9 \times \text{cardiomegaly})$. This model provides a simple formula for estimating the probabilities of heart failure when specific risk factors are present. Separate models were developed for each sex and for persons with coronary disease, hypertension, or valvular heart disease. Only variables with a .05 level of significance in the multivariate model for the development of heart failure in either sex were used in the risk functions. Specifically, the logistic model predicts the probability of developing heart failure within the next 4 years based on the presence of the relevant risk factors specified above. Four years of follow-up was chosen as the prediction intervention interval; consequently, every other interim biennial examination was used. Subjects missing more than 2 biennial examinations were excluded from the analysis. For those missing up to 2 examinations, data from the last attended examinations were carried forward.

Because vital capacity and chest x-ray film information is not readily obtainable in many physicians' offices, heart failure risk formulations were also devised excluding these variables. The regression coefficients for the ingredients of the profiles including and excluding these variables are displayed in **Table 2** and **Table 3**, respectively.

heart disease—the most common causes of the condition. The conditional probabilities of heart failure were estimated using a logistic function composed of age, systolic blood pressure, vital capacity, heart rate, electrocardiographic (ECG) LVH, radiographic cardiomegaly, diabetes, and murmurs signifying valvular heart disease.

RESULTS

During 38 years of follow-up of subjects with the specified predisposing conditions, 252 men and 234 women developed overt heart failure meeting the established criteria. The incidence of overt heart failure increased steeply with age and was greater in men than in women throughout the age range (**Table 4**). The risk of heart failure increased approximately 37% per decade of age in men and 24% per decade of age in women. The mean characteristics of the heart failure cases are presented in **Table 5**.

The multivariate regression coefficients and their corresponding odds ratios and *P* values are displayed in Table 2 and Table 3. Table 3 excludes the vital capacity and chest x-ray film variables. Body mass index is included in Table 3 but not Table 2 because it was statistically significant in

Table 1. Criteria for Congestive Heart Failure*

Major
Paroxysmal nocturnal dyspnea
Neck-vein distention
Rales
Radiographic cardiomegaly (increasing heart size on chest x-ray film)
Acute pulmonary edema
S_3 gallop
Increased central venous pressure (<16 cm water at right atrium)
Circulation time ≥25 seconds
Hepatojugular reflux
Pulmonary edema, visceral congestion, or cardiomegaly at autopsy
Minor
Bilateral ankle edema
Nocturnal cough
Dyspnea on ordinary exertion
Hepatomegaly
Pleural effusion
Decrease in vital capacity by one third from maximum value recorded
Tachycardia (rate ≥120 beats/min)
Both
Weight loss ≥4.5 kg in 5 days in response to treatment of congestive heart failure

**Diagnosis required that 2 major or 1 major and 2 minor criteria be present concurrently. Minor criteria were acceptable only if they could not be attributed to another medical condition.*

Table 2. Pooled Logistic Regression Model With Coefficients and Odds Ratios*

Variables	Units	Regression Coefficient	OR (95% CI)	*P*
		Men		
Intercept		–7.3611		
Age	10 y	0.0313	1.37 (1.17-1.60)	<.001
LVH	Yes/no	0.8428	2.32 (1.51-3.56)	<.001
Vital capacity	100 cL	–0.0030	0.74 (0.61-0.90)	.003
Heart rate	10 bpm	0.0144	1.15 (1.05-1.27)	.002
Systolic blood pressure	20 mm Hg	0.0067	1.14 (1.02-1.29)	.03
CHD	Yes/no	1.5333	4.63 (3.52-6.10)	<.001
Valve disease	Yes/no	0.8868	2.43 (1.73-3.41)	<.001
Diabetes	Yes/no	0.2383	1.27 (0.90-1.79)	.17
Cardiomegaly	Yes/no	0.7968	2.22 (1.63-3.01)	<.001
		Women		
Intercept		–5.4997		
Age	10 y	0.0216	1.24 (1.06-1.45)	.007
LVH	Yes/no	1.0072	2.74 (1.78-4.22)	<.001
Vital capacity	100 cL	–0.0087	0.42 (0.33-0.55)	<.001
Heart rate	10 bpm	0.0092	1.10 (0.99-1.21)	.07
Systolic blood pressure	20 mm Hg	0.0032	1.07 (0.96-1.20)	.24
CHD	Yes/no	1.5358	4.64 (3.42-6.31)	<.001
Valve disease	Yes/no	1.2454	3.47 (2.46-4.92)	<.001
Diabetes	Yes/no	1.4275	4.17 (2.91-5.97)	<.001
Cardiomegaly	Yes/no	0.4792	1.61 (1.21-2.16)	.001
Valve disease and diabetes	Yes/no	–0.9293	0.39 (0.19-0.83)	.01

**Includes vital capacity and chest x-ray information. OR indicates odds ratio; CI, confidence interval; LVH, left ventricular hypertrophy; and CHD, congenital heart disease.*

the multivariate case only when the vital capacity and chest x-ray film variables were excluded. Similar results were observed in men and women for LVH, coronary disease, and cardiomegaly on chest x-ray film, but results differed substantially for diabetes, vital capacity, blood pressure, and heart rate. Diabetes had a much more significant impact on women (odds ratio, 4.17 vs 1.27), as did the presence of valvular heart disease (odds ratio, 3.47 vs 2.43).

The probability of developing heart failure in those with predisposing conditions depended on the presence of the specified risk factors, each of which independently contributed to the level of risk in both sexes. In persons with elevated blood pressure, the risk of heart failure was greater than in normotensive persons at all levels of multivariate risk, but varied widely depending on the burden of the associated risk factors that often accompany hypertension (**Figure 1** and **Figure 2**). The same applies for coronary or valvular heart disease.

The probability of patients with the specified predisposing conditions developing heart failure can be estimated using a simple point score system based on information readily obtained by a practitioner in the office (**Table 6** through **Table 9**). For example, a 60-year-old man with documented coronary disease who has a vital capacity of 2.5 L, a systolic blood pressure of 160 mm Hg, heart rate of 85 beats/min, ECG LVH, and heart enlargement on chest x-ray film receives a total score of 31 points. This sum is calculated by adding 3 points for age, 9 points for coronary disease, 4 points for vital capacity, 2 points for systolic blood pressure, 3 points for heart rate, 5 points for ECG LVH, and 5 points for heart enlargement. In this instance, no additional points are added for heart murmurs or diabetes, since neither condition is present in this subject. A score of 31 points indicates a 4-year probability of heart failure of 34% (Table 6). The average man of this age with hypertension, valvular disease, or coronary disease has a heart failure probability of 3% (Table 3). Comparing the two indicates an 11-fold increased risk of heart failure in the former because of the associated risk factors.

Another way of calculating this conditional probability is by using the coefficients from the model as follows:

$$f(x) = 1/(1 + e - x)$$

$$\begin{aligned} x &= -7.3611 + (0.0313 \times \text{Age}) + (0.8428 \times \text{LVH}) \\ &\quad + (-0.0030 \times \text{Vital Capacity}) + (0.0144 \times \text{Heart Rate}) \\ &\quad + (0.0067 \times \text{Systolic Blood Pressure}) \\ &\quad + (1.5333 \times \text{Myocardial Infarction}) \\ &\quad + (0.8868 \times \text{Heart Murmur}) \\ &\quad + (0.2383 \times \text{Diabetes}) + (0.7968 \times \text{Heart Enlargement}) \\ &= -7.3611 + (0.0313 \times 60) + (0.8428 \times 1) + (-0.0030 \times 250) \\ &\quad + (0.0144 \times 85) + (0.0067 \times 160) + (1.5333 \times 1) \\ &\quad + (0.8868 \times 0) + (0.2383 \times 0) + (0.7968 \times 1) \\ &= -7.3611 + 1.878 + 0.8428 - 0.75 \\ &\quad + 1.224 + 1.072 + 1.5333 + 0.7968 \\ &= -0.7642 \end{aligned}$$

$$f = 1/[1 + \exp(0.7642)] = 1/3.1473 = 0.3177$$

This indicates a 4-year probability of heart failure of 32%, an estimate quite close to that obtained using the point score system. The same assessment of the conditional

Table 3. Pooled Logistic Regression Model With Coefficients and Odds Ratios*

Variables	Units	Regression Coefficient	OR (95% CI)	P
		Men		
Intercept		−9.2087		
Age	10 y	0.0412	1.51 (1.31-1.74)	<.001
LVH	Yes/no	0.9026	2.47 (1.31-3.77)	<.001
Heart rate	10 bpm	0.0166	1.18 (1.08-1.29)	<.001
Systolic blood pressure	20 mm Hg	0.00804	1.17 (1.04-1.32)	.007
CHD	Yes/no	1.6079	4.99 (3.80-6.55)	<.001
Valve disease	Yes/no	0.9714	2.64 (1.89-3.69)	<.001
Diabetes	Yes/no	0.2244	1.25 (0.89-1.76)	.20
		Women		
Intercept		−10.7988		
Age	10 y	0.0503	1.65 (1.42-1.93)	<.001
LVH	Yes/no	1.3402	3.82 (2.50-5.83)	<.001
Heart rate	10 bpm	0.0105	1.11 (1.01-1.23)	.03
Systolic blood pressure	20 mm Hg	0.00337	1.07 (0.96-1.20)	.24
CHD	Yes/no	1.5549	4.74 (3.49-6.42)	<.001
Valve disease	Yes/no	1.3929	4.03 (2.86-5.67)	<.001
Diabetes	Yes/no	1.3857	4.00 (2.78-5.74)	<.001
BMI	Yes/no	0.0578	1.06 (1.03-1.09)	<.001
Valve disease and diabetes	Yes/no	−0.9860	0.37 (0.18-0.78)	.009

*Excludes vital capacity and chest x-ray information. OR indicates odds ratio; CI, confidence interval; LVH, left ventricular hypertrophy; CHD, congenital heart disease; and BMI, body mass index.

Table 4. Incidence of Cardiac Failure in Persons With Coronary Attacks, Valvular Heart Disease, or Hypertension Aged 45 to 94 Years After 38-Year Follow-up in the Framingham Study

	Population at Risk, Person-Examinations		No. of Events		4-Year Rate, per 100 Person-Examinations	
Age, y	Men	Women	Men	Women	Men	Women
45-54	1573	1773	31	18	1.97	1.02
55-64	2260	3011	71	53	3.14	1.76
65-74	1856	2864	89	87	4.80	3.04
75-84	614	1153	58	61	9.45	5.29
85-94	51	152	3	15	12.95*	9.87
Total	**6354**	**8913**	**252**	**234**	3.97	2.63

*Estimated from age regression (37% increment per decade).

probability of developing heart failure can be made for women with coronary disease (Table 8). Similarly, congestive heart failure probabilities can be estimated for persons with valvular heart disease or hypertension. The relative risk of heart failure can be estimated by comparing persons free of predisposing conditions with the average for persons of the same age and sex with one of the predisposing conditions.

The vital capacity is a very useful predictor of heart failure, as is heart enlargement on a chest x-ray film.[2,3] However, many physicians do not have access in their offices to spirometers to measure the vital capacity or to chest x-ray films to detect cardiomegaly. For this contingency, we have developed a similar point score system based on models without the specified variables (Table 7 and Table 9). For the women's model, body mass index was added because it was found to have a significant effect. Valve disease and diabetes are handled differently in women than in men because of significant interactions between these variables.

Table 5. Characteristics of Heart Failure Cases*

Characteristics	Men (n = 6354)	Women (n = 8913)
Age, y†	62.0	63.8
LVH, %	5.8	4.8
Vital capacity, L†	3.3	2.2
Heart rate, bpm†	75.8	78.1
Systolic blood pressure, mm Hg†	149.8	154.5
CHD, %	23.1	8.3
Valve disease, %	10.0	13.1
Diabetes, %	11.3	8.3
Cardiomegaly, %	11.7	20.8

*LVH indicates left ventricular hypertrophy; CHD, congenital heart disease.
†Values are means.

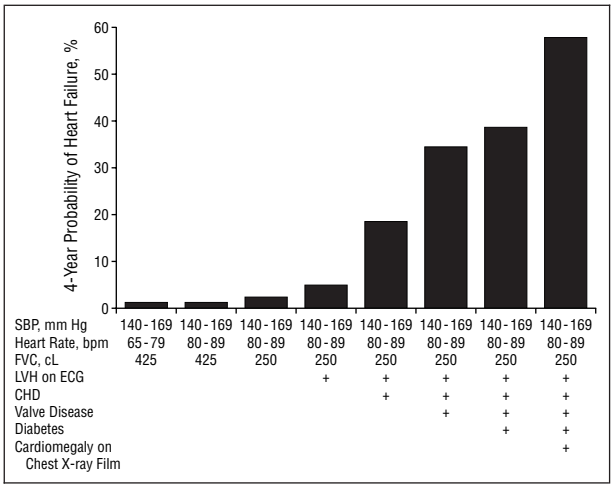

Figure 1. *Risk of heart failure in hypertensive men aged 60 to 64 years by burden of associated risk factors after 38-year follow-up in the Framingham Study. SBP indicates systolic blood pressure; FVC, forced vital capacity; LVH on ECG, left ventricular hypertrophy on electrocardiogram; and CHD, congenital heart disease. Plus sign indicates that patients in this category had this condition.*

COMMENT

Heart failure is a major and growing problem in the United States because of the aging of the population and because many cardiac patients are saved from an early death by more sophisticated treatment.[10,11] Because of the lethal nature of heart failure once it becomes clinically overt, there is a need to detect candidates for this condition well in advance of symptoms so that they can be tested for presymptomatic impairment of left ventricular systolic function and be given a treatment designed to slow progression to overt heart failure.[4] Using multivariate risk assessment, it is possible to identify persons at high risk of heart failure in whom asymptomatic left ventricular

dysfunction is likely to be present and in whom preventive measures may delay or prevent the onset of overt heart failure. Evidence from controlled trials suggests that use of angiotensin-converting enzyme inhibitors, aspirin, and β-blockers; treatment of dyslipidemia; and myocardial revascularization have the potential to delay the onset of heart failure in high-risk candidates for heart failure.[4,10,12-14]

Epidemiologic investigation in the Framingham Study has identified and quantified the influence of a number of predisposing risk factors for the development of heart failure in persons with coronary disease and hypertension.[1-3] Most of the risk factors included in the heart failure risk profile are well known to practicing physicians. This approach quantifies the impact of these risk factors and pulls the information together to provide a composite estimate of the hazard. In this report, we show that it is possible to construct from these identified independent risk factors a multivariate scoring system for estimating the conditional probability of developing heart failure. Among individuals predisposed to heart failure, those with a high probability of developing overt heart failure can be tested in a cost-effective manner for the presence of left ventricular systolic dysfunction with the expectation of a high yield of positive findings. If left ventricular systolic dyfunction is present, these people can then be targeted for appropriate preventive measures to arrest the progression to overt heart failure. Many individuals who have sustained a myocardial infarction or who have valvular heart disease routinely undergo echocardiography to assess left ventricular structure and function. However, the yield of positive findings when echocardiograms are performed indiscriminately can be low. Also, there are many hypertensive candidates for heart failure who do not receive such an evaluation and are at high risk by virtue of advanced age, concomitant diabetes, and LVH.

The Framingham Study provides an opportunity to investigate a sizable population-based sample of subjects with predisposing conditions for heart failure in which there is little referral bias. Since the sample size is substantial, it is possible to assess the independent contributions of a number of relevant predisposing risk factors for the on-

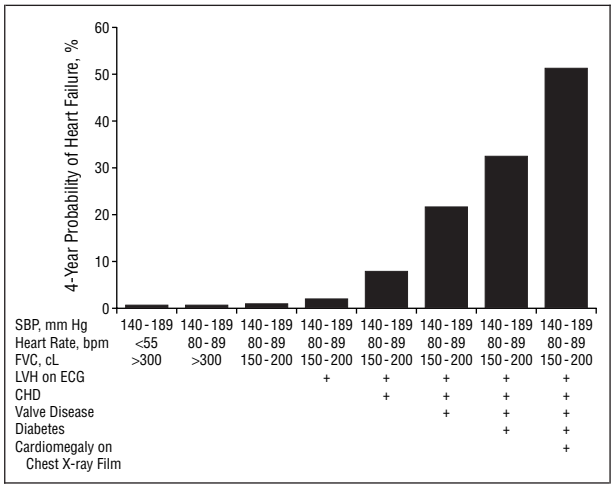

Figure 2. *Risk of heart failure in hypertensive women aged 60 to 64 years by burden of associated risk factors after 38-year follow-up in the Framingham Study. SBP indicates systolic blood pressure, FVC, forced vital capacity; LVH on ECG, left ventricular hypertrophy on electrocardiogram; and CHD, congenital heart disease. Plus sign indicates that patients in this category had this condition.*

Table 6. Probability of Congestive Heart Failure Within 4 Years for Men Aged 45 to 94 Years With Coronary Disease, Hypertension, or Valvular Disease*

	Points									
Variables	**0**	**+1**	**+2**	**+3**	**+4**	**+5**	**+6**	**+7**	**+8**	**+9**
Age, y	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-89	90-94	
Forced vital capacity, cL	≥425	375-424	325-374	275-324	200-274	150-199	≤149			
Systolic blood pressure, mm Hg	<120	120-139	140-169	170-189	190-219	>219				
Heart rate, bpm	<55	55-64	65-79	80-89	90-99	>99				
LVH on ECG	No					Yes				
Coronary heart disease	No									Yes
Valve disease	No					Yes				
Diabetes	No	Yes								
Cardiomegaly	No					Yes				

Points	4-Year Probability of Congestive Heart Failure, %	Points	4-Year Probability of Congestive Heart Failure, %
5	1	26	18
10	1	27	21
12	2	28	24
14	3	29	27
16	4	30	31
18	5	31	34
20	7	33	38
22	10	33	42
24	14	34	47
25	16	35	51

**LVH indicates left ventricular hypertrophy; ECG, electrocardiogram.*

Table 7. Probability of Congestive Heart Failure Within 4 Years for Men Aged 45 to 94 Years With Coronary Disease, Hypertension, or Valvular Disease*

	Points									
Variables	**0**	**+1**	**+2**	**+3**	**+4**	**+5**	**+6**	**+7**	**+8**	**+9**
Age, y	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94
Systolic blood pressure, mm Hg	<120	120-139	140-169	170-189	190-219	>219				
Heart rate, bpm	<55	55-64	65-79	80-89	90-104	>104				
LVH on ECG	No				Yes					
Coronary heart disease	No								Yes	
Valve disease	No					Yes				
Diabetes	No	Yes								

Points	4-Year Probability of Congestive Heart Failure, %	Points	4-Year Probability of Congestive Heart Failure, %
5	1	24	30
10	2	25	34
12	3	26	39
14	5	27	44
16	8	28	49
18	11	29	54
20	16	30	59
22	22		

*Excludes forced vital capacity and cardiomegaly. LVH indicates left ventricular hypertrophy; ECG, electrocardiogram.

Table 8. Probability of Congestive Heart Failure Within 4 Years for Women Aged 45 to 94 Years With Coronary Disease, Hypertension, or Valvular Disease*

	Points									
Variables	**0**	**+1**	**+2**	**+3**	**+4**	**+5**	**+6**	**+7**	**+8**	**+9**
Age, y	45-49	50-59	60-69	70-79	80-89	90-94				
Forced vital capacity, cL	>299	250-299	200-249	150-199	<150					
Systolic blood pressure, mm Hg	<130	130-189	>189							
Heart rate, bpm	<55	55-79	80-99	>99						
LVH on ECG	No					Yes				
Coronary heart disease	No								Yes	
Cardiomegaly	No		Yes							
Valve disease	No						Yes			
Diabetes (no valve disease)	No						Yes			
Diabetes (valve disease)	No			Yes						

Points	4-Year Probability of Congestive Heart Failure, %	Points	4-Year Probability of Congestive Heart Failure, %
5	<1	26	18
10	1	27	21
12	1	28	24
14	2	29	28
16	3	30	32
18	4	31	37
20	6	32	42
22	9	33	46
24	13	34	51
25	15	35	56

*LVH indicates left ventricular hypertrophy; ECG, electrocardiogram.

set of heart failure in those with the specified predisposing conditions, with less selection bias than is possible in clinical studies or intervention trials. The multivariate risk estimates are based on 15 267 individual examinations and the occurrence of 486 heart failure events. With comparable numbers of men and women, the independent and joint contributions of the risk factors for subsequent occurrence of heart failure could be accurately estimated and multivariate risk profiles for predicting heart failure for both sexes could be formulated.

However, because the study sample is almost exclusively white and virtually non-Hispanic and non-Asian,

Table 9. Probability of Congestive Heart Failure Within 4 Years for Women Aged 45 to 94 Years With Coronary Disease, Hypertension, or Valvular Disease*

	Points									
Variables	**0**	**+1**	**+2**	**+3**	**+4**	**+5**	**+6**	**+7**	**+8**	**+9**
Age, y	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94
BMI, kg/m^2	<21	21-25	26-29	>29						
Systolic blood pressure, mm Hg	<140	140-209	>209							
Heart rate, bpm	≤59	60-79	80-104	>104						
LVH on ECG	No					Yes				
Coronary heart disease	No						Yes			
Valvular disease	No						Yes			
Diabetes (no valve disease)	No						Yes			
Diabetes (valve disease)	No		Yes							

Points	4-Year Probability of Congestive Heart Failure, %	Points	4-Year Probability of Congestive Heart Failure, %
5	<1	19	14
10	2	20	17
11	2	21	21
12	3	22	25
13	3	23	30
14	4	24	36
15	5	25	42
16	7	26	48
17	9	27	54
18	11	28	60

**Excludes forced vital capacity and cardiomegaly. BMI indicates body mass index; LVH, left ventricular hypertrophy; and ECG, electrocardiogram.*

the multivariate risk profiles may not apply as accurately to other racial or ethnic samples. Also, the criteria used for heart failure are clinical and quite stringent. Many heart failure events were diagnosed prior to the introduction of routine echocardiography into the study, so that milder cases of failure with reduced ejection fractions but only minimal symptoms could have been missed. Assessment of left ventricular systolic dysfunction by echocardiography is now widely available, but this procedure cannot be routinely ordered for all patients with hypertension, coronary disease, or heart murmurs.

Furthermore, while the multivariate risk formulation describes the probability of developing congestive heart failure in relation to the risk factors in this cohort quite well, its utility for accurately predicting heart failure in other cohorts will have to be confirmed by applying it to other population samples. The detection of a heart murmur does not identify valvular heart disease as sensitively or specifically as echocardiogram. Nevertheless, clinically significant heart murmurs can carry a substantial independent risk of heart failure (Table 2 and Table 3).

This multivariate risk profile cannot distinguish between candidates for systolic and diastolic heart failure. A substantial proportion of patients with overt heart failure have normal systolic left ventricular systolic function.

The mortality rate observed for heart failure in the Framingham Study is greater than that reported in many clinical trials. This is to be expected, as the criteria used were rather rigorous, requiring severe and overtly manifest disease. Moreover, the population at risk (62 years) was slightly older on average than that in most heart failure trials (60 years). The trial data are not population-based and often exclude persons with other conditions that contribute to mortality. Furthermore, many of the events occurred in an era when there were few remedies available that could prolong the life of patients with heart failure.

Multivariate profiles derived from the Framingham Study data on conditions and risk factors that predispose people to the development of heart failure can enable general practitioners and internists to conveniently estimate the likelihood that heart failure will occur in individuals with predisposing conditions, such as coronary disease, valvular heart disease, and hypertension. This can be done using variables readily obtained in office practice. When subjects were stratified using the more complete multivariate risk profile assessment for cardiomegaly (including chest x-ray and pulmonary function testing for forced vital capacity), 60% of events in men and 73% in women occurred in those falling into the top quintile of risk.

Accepted for publication August 23, 1998.

Framingham Study research is supported by contract N01-HC-38038 from the National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, Md, and by the Visiting Scientist Program, supported by ASTRA USA, Framingham, Mass; Hoechst Marion Roussel, Kansas City, Mo; and Servier Amerique Inc, Neuilly-sur-Seine, France.

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