Considerations in the Use of Echocardiography in Epidemiology

The Framingham Study

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SUMMARY To quantify potential biases in the use of echocardiography in epidemiologic studies, we assessed the relationship of sex, age, vital capacity, body fatness, and overt cardiovascular disease to prevalence of acceptable echocardiograms in 6148 Framingham men and women aged 17 to 90 years. Echocardiograms adequate to assess left ventricular chamber dimensions and wall thicknesses, aortic root, and left atrial dimensions as well as mitral and aortic valves were obtained in 4947 (80%) of the 6148 subjects. The prevalence of acceptable echocardiograms ranged from less than 50% for those more than 80 years of age to more than 96% for subjects under 30 years of age. A significant learning curve was apparent, particularly in the older subjects (more than 60 years of age) for whom prevalence of acceptable echocardiograms rose from a minimum of 28% during the first 5 months of studies to a maximum of 74 to 81% during studies 2 years later. The likelihood of unacceptable echocardiograms was slightly greater in men. Obesity (in subjects younger than 60 years of age), lower vital capacity, and overt cardiovascular disease were associated with unacceptable echocardiograms, independent of age. Consideration of these biases should aid in the interpretation and planning of epidemiologic and other studies using echocardiography. (Hypertension 9 [Suppl II]: II-40-II-44, 1987)

KEY WORDS • echocardiography • epidemiology • Framingham Study

DURING the past 20 years echocardiography has become an increasingly important diagnostic tool in clinical cardiology. During the last several years we have adapted echocardiography for use as an epidemiologic tool to assess various cardiac structural and functional findings including valvular,1-4 myocardial,5-6 pericardial,7 and other findings.8 Success in these studies and more recent preliminary data suggesting the independent prognostic significance of echocardiographic findings9 may stimulate increased use of the technique in other large population studies and clinical trials. Adequate echocardiograms can be obtained in most but not all subjects. This represents a limitation of the technique that should be considered in such applications. During the course of our experience, we have quantified several biases that help clarify this limitation. We assessed the relationship of sex, age, vital capacity, body fatness, and overt cardiovascular disease to prevalence of acceptable echocardiograms. Our findings are reviewed in this report.

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Methods

Subjects

Echocardiography was used routinely to evaluate 6148 Framingham men and women including 2291 subjects from the original Framingham cohort and 3857 offspring of the original cohort (and offspring's spouses) (Table 1). Subjects were studied from 1979 to 1983 during the 16th biennial examination of the original cohort and during the second examination cycle of the offspring. Echocardiographic studies were begun in the original cohort subjects in August 1979. Studies were initiated in the offspring subjects 2 months later (October 1979). All subjects gave informed consent prior to study. Lung capacity was measured using an Eagle I spirometer (W.E. Collins, Braintree, MA, USA) with digital display. The second of two maximal-effort expirations was used for analysis. Subscapular skinfold measurement (in millimeters) was obtained by two nurses 1 inch below the right scapula. This measurement was chosen as the best single available measure of body fat. Overt cardiovascular disease was evaluated through medical history, physical examination, and hospital records. All such records were routinely reviewed by a panel of physicians. Participants meeting established criteria for coronary heart disease, congestive heart failure, cerebral vascular accident, or intermittent claudication10 were considered to have overt cardiovascular disease.

Echocardiographic Methods

Subjects were studied using a standard M-mode echocardiographic technique with special attention to obtaining careful
just below the tips of these leaflets. Left atrial dimension was measured at the nadir of systolic T-scans. In more than 90% of the studies, M-mode studies were guided by two-dimensional echocardiography using conventional short- and long-axis views. A 2.25-MHz, 1.25-cm diameter, unfocused Aerotech transducer (K.B. Aerotech, Lewiston, PA, USA) and a Hoffrel 201 ultrasound receiver (Hoffrel Instruments, Norwalk, CT, USA) interfaced with a Honeywell 1856 strip chart recorder (Honeywell, Minneapolis, MN, USA) were used. A switch-gain circuit was used to simplify identification of the epicardium of the posterior left ventricular (LV) free wall. A Hoffrel mechanical sector scanner with a hand-held 2.25-MHz quarter-wave transducer was used for two-dimensional echocardiograms.

Measurements were first made according to the recommendations of the American Society of Echocardiography (ASE) using the leading edge to leading edge convention. The LV internal dimension at end diastole, interventricular septum, and LV free wall were measured at the onset of the QRS complex. The LV end-systolic dimension was measured at the nadir of systolic septal motion. The LV free wall thickness was measured when the ultrasound beam was at the level of the tips of the mitral valve leaflets. All other LV measurements were made at a level just below the tips of these leaflets. Left atrial dimension was measured as the maximal distance between the posterior aortic root wall and the posterior left atrial wall. Measurements were taken in the damped portion of the record when the ultrasonic beam passed through the aortic valve leaflets. Aortic root dimension was measured in the same portion of the recording (at the onset of the QRS complex). If each of these LV, aortic root, and left atrial measurements could be made and if the mitral and aortic valves could be assessed, the echocardiogram was considered to be acceptable.

T-tests were used to assess statistical significance. Multivariate associations between adequacy of the echocardiograms and attributes of the participants were tested by multiple logistic regression as described by Walker and Duncan.

Results

Echocardiograms were adequate for each of the measurements in 1349 (59%) of the 2291 original cohort subjects and 3598 (93%) of the 3857 offspring subjects, yielding an overall adequacy of 80% for the 6148 subjects studied (Figure 1; Tables 2 and 3). LV measurements could be made in only 3% of the echocardiograms that were considered inadequate. Put another way, very few of the echocardiograms were inadequate solely because of poor visualization of structures other than the left ventricle. Most of the subjects with adequate visualization of the LV walls and chamber dimensions had adequate visualization for assessment of the left atrium, aortic root, and valves. Thus only 28 of the 4975 subjects with adequate visualization of the LV structures had a poorly visualized aortic valve, aortic root and/or left atrium.

A significant learning curve was apparent when we plotted the acceptance rate (percentage of adequate echocardiograms) over time (Figures 2 and 3). This learning curve was more pronounced in the older sample (Figure 2), where the acceptance rate rose from a minimum of 28% during the first five months of echocardiographic studies to a maximum of 74% to 81% during studies 2 years later. The acceptance rate was consistently high in the younger offspring subjects, where it rose rapidly from 85% to a peak of 96% during the first year of studies (Figure 2).

The prevalence of adequate echocardiograms was slightly higher in women with a substantial drop in each sex occurring after age 60 years (Figure 4). The effects of age on adequacy of echocardiograms was progressive after age 60 years: for those more than 80 years of age, fewer than 50% had echocardiograms of adequate quality to make all of the readings described above (Figure 4). However, some potentially useful quantitative or qualitative information on at least one of the structures assessed was available on echocardiograms of more than 90% of

### Table 1. Characteristics of Framingham Study Subjects Who Had Echocardiograms

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Men (n = 2783)</th>
<th>Women (n = 3365)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>53.0 ± 15</td>
<td>55.0 ± 16</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.74 ± 0.08</td>
<td>1.60 ± 0.09</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>81.1 ± 14.8</td>
<td>64.4 ± 12.7</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.95 ± 0.17</td>
<td>1.66 ± 0.16</td>
</tr>
</tbody>
</table>

Values are means ± SD. Ranges are shown in parentheses.

### Table 2. Characteristics of Framingham Study Men With and Without Acceptable Echocardiograms

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Acceptable (n = 2218)</th>
<th>Not acceptable (n = 565)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>49.8 ± 13.9</td>
<td>64.9 ± 12.7</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.75 ± 0.07</td>
<td>1.72 ± 0.07</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>81.1 ± 12.0</td>
<td>81.2 ± 14.8</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.96 ± 0.16</td>
<td>1.93 ± 0.18</td>
</tr>
</tbody>
</table>

Values are means ± SD. Ranges are shown in parentheses.

### Table 3. Characteristics of Framingham Study Women With and Without Acceptable Echocardiograms

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Acceptable (n = 2729)</th>
<th>Not acceptable (n = 636)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>51.6 ± 15.0</td>
<td>68.4 ± 11.5</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.60 ± 0.07</td>
<td>1.56 ± 0.07</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.1 ± 12.3</td>
<td>65.7 ± 14.1</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.66 ± 0.56</td>
<td>1.65 ± 0.17</td>
</tr>
</tbody>
</table>

Values are means ± SD. Ranges are shown in parentheses.
even the oldest subjects (over 80 years old). Assessment of the relationship of forced vital capacity with quality of the echocardiograms in various age groups suggests a possible mechanism for at least part of the age effect on echocardiographic quality (Figure 5). While vital capacity decreased substantially with age, inadequate echocardiograms were associated with lower vital capacity in each of the age decades. Table 4 summarizes the independent contribution of sex, age, body fat, and vital capacity on the adequacy of echocardiograms. For this analysis, women were assigned a value of two and men a value of one. The statistically significant multiple regression coefficients suggest that male sex, age, and diminished vital capacity contribute independently to inadequate echocardiograms. The role for body fat is not as clear since the relationship between body fat measurement and adequacy of echocardiograms is only evident under the age of 60 years. While the relationship between body fat level and echocardiogram adequacy was statistically significant, acceptance rate was high even among study participants with the most body fat.

In participants over the age of 60 years, the probability of an acceptable echocardiogram was significantly lower in participants with overt cardiovascular disease (Figure 6). This relationship was stronger in men than in women and persisted after controlling for age, vital capacity and body fat (Table 5).

Discussion

The profile that emerges for subjects with poor quality echocardiograms is one of men and women over 60 years old with a lower forced vital capacity and a greater likelihood of overt cardiac disease. While men and obese participants were also slightly more likely to have inadequate echocardiograms, these relationships were relatively weak. For example, even the most obese young men had a high proportion (90%) of acceptable

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**Figure 2.** Learning curve indicating increased percentage of acceptable echocardiograms with each quintile of echocardiograms performed in the original Framingham cohort.

**Figure 3.** Learning curve indicating increased percentage of acceptable echocardiograms with each quintile of echocardiograms performed in the Framingham offspring subjects.

**Figure 4.** Percentage of acceptable echocardiograms in Framingham men and women by age.

**Figure 5.** Forced vital capacity in original Framingham cohort subjects with and without acceptable echocardiograms in three age decades.
The LV was similar to the findings of Valtder et al., who were able to assess the left ventricle in more than 90% of 196 apparently healthy Stanford University employees aged 26 to 64 years.15

The learning curves we noted were presumed to be due mainly to the ultrasonographer becoming more adept at rapidly finding the ultrasound "windows" (i.e., transducer locations on the chest wall) that yielded images of adequate quality. Despite considerable experience in clinical studies with smaller numbers of subjects, this learning curve appeared to be unavoidable in this setting where 15 to 30 studies were often performed daily by one ultrasonographer.

The greater prevalence of emphysematous changes (i.e., increased distention of alveolar sacs with destruction of alveolar seque) in the fifth through seventh decades of life16 at least partially explains the poorer quality of echocardiograms seen with advanced age and reduced forced vital capacity. This process would be expected to increase chances of lung tissue being interposed between the echocardiographic transducer on the chest wall and the heart. Attenuation of the ultrasound signal by air and scattering of the ultrasound signal due to multiple gas-tissue interfaces of the lungs would also reduce the signal and thus the clarity of images reflected from cardiac structures.

Increased body fat is associated with increased thickness of chest wall tissues interposed between the ultrasonoscope and the heart. Increased attenuation of the ultrasound signal associated with these increased tissues would be expected to contribute to the poorer quality of echocardiograms found with increased body fat. The full explanation for the association of overt cardiovascular disease with echocardiograms of poorer quality is unclear at present. This may be related to the other factors discussed above (i.e., pulmonary changes and increased fatness) that are associated with increased disease. These are not a sufficient explanation because the association of overt cardiovascular disease with echocardiograms of poorer quality was independent of both vital capacity and weight.

Despite the documented limitations of echocardiography, the technique appears to have a large potential role in epidemiologic studies and clinical trials. Expected refinements in the instrumentation and image processing should help expand this role and decrease some of the biases. In the meantime, consideration of these biases should aid in interpretation and planning of further studies using echocardiography.

References

8. Savage DD, Garrison RJ, Castelli WP, et al. Prevalence of subvalvular...


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