A Quantitative Evaluation of Heart Size Measurements from Chest Roentgenograms

By LESTER GLOVER, M.D., WILLIAM A. BAXLEY, M.D., and HAROLD T. DODGE, M.D.

SUMMARY

In order to assess the accuracy of radiographic parameters of left heart enlargement, quantitative biplane angiographic data was compared to chest X-ray data in 254 adults with various heart diseases. Cardiac silhouette volume measured from PA and lateral chest roentgenograms compared most favorably to the sum of the left ventricular mass, end-diastolic volume, and left atrial maximal volume (r = 0.78, P < 0.01; 79% accuracy). The cardiothoracic ratio gave 70% accuracy (r = 0.64, P < 0.01). Subgrouping of patients according to specific left ventricular hemodynamic alterations did not improve correlations. The roentgenographic relationship of the left ventricle and inferior vena cava correlated poorly with left ventricular size. Of 90 patients with increased left atrial maximal volumes, 81 had visible posterior displacement of the barium-outlined esophagus by the left atrium.

Additional Indexing Words:
Left ventricular volume
Left ventricular mass
Left ventricular hypertrophy

ONE of the most common clinical methods for assessing cardiac enlargement is the use of chest roentgenograms. Overall heart size has been evaluated from chest films in a variety of ways, two of the most popular of which are calculation of the cardiothoracic ratio from posteroantero (PA) films alone,1 and determination of the total cardiac silhouette volume utilizing both PA and lateral projections.2 In addition to overall heart size, interest has also focused on methods of evaluating specific left-sided cardiac chamber enlargement. Thus, left ventricular enlargement has been shown to alter the relationships between the left leaf of the diaphragm, the inferior vena cava, and the posterior margin of the left ventricle as viewed in the lateral film.3–5 Likewise, left atrial dilatation may displace posteriorly the barium-outlined esophagus seen in the lateral film.6

A number of earlier studies have attempted to establish the validity of the various radiologic parameters for assessing cardiac enlargement, but these have not been fully quantitative and have usually involved the X-ray features in groups of normals and groups with known cardiac disease.4–8 More recently Lewis et al.9 have quantitatively compared left ventricular end-diastolic volumes determined by thermo-dilution methods with measurements from chest radiographs in patients with pure aortic valve lesions. They found a relatively high correlation (r = 0.85) between X-ray frontal heart area and left ventricular end-diastolic volume in patients with pure aortic valve insufficiency, but no significant correlation in patients with valvular or subvalvular aortic stenosis. This discrepancy was thought to result from selectively increased ventricular muscle mass in the latter lesions.

With the use of quantitative biplane angiography, it is possible to determine in vivo left atrial and left ventricular chamber volumes and left ventricular muscle mass in patients with various cardiac lesions and differing degrees and types of left heart enlargement.10–13 Normal values have been established for these parameters,14–16 thus allowing more meaningful assessment of degree of enlargement.
In this investigation, left ventricular mass and end-diastolic volume and left atrial maximal volume determined from quantitative biplane angiography were compared with various indicators of cardiac enlargement obtained from plain chest roentgenograms in a series of adults with a spectrum of heart diseases. The results help quantitate the accuracy of assessment of heart enlargement from standard chest films.

Methods

The subjects of this study were 254 adults who had diagnostic heart catheterizations for a variety of cardiac conditions. None had pericardial disease or effusion. Each patient had biplane angiography at six or 12 exposures/sec with power injection of contrast material into a left heart chamber. Left ventricular end-diastolic volumes were calculated from the films.10 In 205 patients, left ventricular mass was also calculated;12 in 106 patients left atrial maximal volume was calculated;11 and in 89 patients combined left ventricular volume and mass and left atrial maximal volume was determined.

Patients were listed as having abnormally large values if they exceeded 2.5 SD above the normal means as previously reported.14,15 Thus the upper normal values corrected for body surface area are: (1) left ventricular end-diastolic volume, 110 ml/m²; (2) left ventricular mass, 124 g/m²; (3) left ventricular end-diastolic volume plus mass, 234 ml/m²; (4) left atrial maximal volume, 53 ml/m² (95 ml uncorrected for body surface area); (5) combined left ventricular end-diastolic volume, mass, and left atrial maximal volume, 287 ml/m².

Each patient had standard 6-ft posteroanterior (PA) and lateral chest roentgenograms after swallowing barium, taken during the same hospitalization as the angiography. No change in clinical status intervened between the two types of radiographic studies. From the chest films, the following measurements were made as shown in figures 1–3 and compared to the normal values:

*Mass is expressed as myocardial volume in ml.

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**Figure 1**

The cardiothoracic ratio was calculated utilizing the maximal cardiac diameter, and the intrathoracic diameter at the level of the right costocaradic border. The cardiac silhouette volume parameters are: L, from the junction of the right atrium and superior vena cava to the apex; B, from the right cardiophrenic angle to the base of the main pulmonary artery segment; and D, the greatest cardiac diameter on the lateral film.2

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EVALUATION OF ROENTGENOGRAM MEASUREMENTS

1. Cardiothoracic ratio. The upper normal is 0.50.
2. Cardiac silhouette volume. The upper normal is 490 ml/m² for females, 540 ml/m² for males.
   This measurement was made in all patients.
3. Distance of the left ventricle posterior to the inferior vena cava. The upper normal is 1.8 cm.
   This was visible and measurable in 103 patients.
4. Height of the left ventricular-inferior vena caval intersection above the left diaphragm. This value decreases with ventricular enlargement; the lower limit of normal is 0.75 cm. This measurement could be made in 101 patients.
5. Left atrial index. This product of height and posterior displacement of the barium-outlined esophagus caused by the left atrium is an attempt at quantitative measurement of left atrial enlargement from the roentgenogram. Normally there is no such displacement (zero product). This measurement could be made in all 106 patients who had atrial volume determinations.

In order to determine if specific hemodynamic alterations influence the relationships between left heart enlargement as revealed by the two radiographic studies, the patients were subdivided into categories according to major diagnoses. These diagnostic categories are left ventricular pressure overload (aortic valvular or subvalvular stenosis or arterial hypertension), volume overload (aortic and/or mitral insufficiency), combined pressure and volume load, and myocardial disease.

Finally, the data from the angiographic studies and that from the chest roentgenograms were compared statistically.

Results

Table 1 shows the results of the total cardiac silhouette volume and the cardiothoracic ratio compared statistically to the quantitative angiographic measurements. The correlations are significant but not close; the coefficients become larger as more components of the left heart are included.

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Figure 2
Method of determining relationships between the left leaf of the diaphragm, posterior margin of the left ventricle (LV), and inferior vena cava (IVC) as seen in the lateral roentgenogram. The four essential anatomic points are marked by dots on the film (left); the schematic drawing (right) reveals the method of measuring the vertical height of the LV-IVC intersection above the left diaphragm, and of measuring the horizontal distance of the posterior extent of the LV outline from the IVC at an arbitrary level 2 cm above the intersection.
closest correlation, $r = 0.78$, is noted with the total silhouette volume compared to left ventricular end-diastolic volume plus mass plus left atrial volume. This relationship is further displayed in figure 4. The scatter of the differing symbols reveals that no particular hemodynamic abnormality results in any unique relationship between the two parameters. This is further seen in figure 5, comparing cardiothoracic ratio to the three combined components of the left heart.

Table 2 reveals the percentage of patients whose heart size was correctly evaluated from the plain chest X-rays. Again, cardiac silhouette volume gives the greatest diagnostic accuracy, 79%, when compared with left atrial plus left ventricular size. There were 5% false positive radiographic diagnoses.

Figure 3

*Method of determining the left atrial (LA) index from the lateral roentgenogram with barium swallow.*

*A and B represent the longitudinal and transverse dimensions of the left atrial displacement of the esophagus.*
Table 1

<table>
<thead>
<tr>
<th>Angio variables</th>
<th>Total volume*</th>
<th>C:T ratio</th>
<th>X-ray variables*</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV mass</td>
<td>205</td>
<td>0.53</td>
<td>205</td>
</tr>
<tr>
<td>LV EDV</td>
<td>254</td>
<td>0.57</td>
<td>254</td>
</tr>
<tr>
<td>Mass + EDV</td>
<td>205</td>
<td>0.64</td>
<td>205</td>
</tr>
<tr>
<td>Mass + EDV + LA volume</td>
<td>89</td>
<td>0.78</td>
<td>89</td>
</tr>
</tbody>
</table>

Abbreviations: C:T = cardiothoracic; LV = left ventricular; EDV = end-diastolic volume.

*P < 0.01 for all.
†Total volume is the total cardiac silhouette volume.

and 16% false negatives. The cardiothoracic ratio was 70% accurate with more false positives, 19%. When 0.6 is used as the upper normal for this ratio all patients with increased cardiothoracic ratio had enlarged total end-diastolic volume, mass, and left atrial volume.

Table 3 gives the comparison between the left ventricle-vena cava relationships and the angio graphic measure of total left ventricular size (end-diastolic volume plus mass). Although the correlations are poor, the 9% false positive value for the ventricular distance posterior to the cava may indicate a useful degree of specificity for this measurement.

Figure 6 reveals the relationship between the roentgenographic left atrial size index and maximal left atrial volume. The correlation is significant but not close, with r = 0.66. Of the 99 patients with abnormally enlarged maximal left atrial volumes, 81 (82%) had abnormal left atrial indexes (values greater than 0).

Discussion

The results of this investigation help to establish quantitatively the accuracy with which left heart enlargement may be ascertained from standard chest roentgenograms. The calculation of total
cardiac silhouette volume from both PA and lateral films as described by Keats and Enge² is seen to correlate more closely with left heart size and to more often correctly indicate an enlarged heart than does the cardiothoracic ratio. This may be due to the fact that an anteroposterior measure of heart size is included in the former but not the latter calculation. Furthermore, the cardiothoracic ratio includes a measure of chest wall size, which may vary independently of heart size. These two

Cardiothoracic (C:T) ratio determined from the PA roentgenogram compared to three anatomic components of the left heart, with subgrouping according to the major left ventricular abnormality as shown by the different symbols. The dashed lines are the upper normal values and the solid line is the line of best fit.

**Figure 5**

The Accuracy of the Chest X-Ray Parameters in Correctly Diagnosing Enlargement of Specific Portions and Combination of Portions of the Left Heart

**Table 2**

<table>
<thead>
<tr>
<th>Angio data</th>
<th>Chest X-ray data</th>
<th>Cardiac silhouette volume (%)</th>
<th>C/T ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV mass</td>
<td>False positive</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Correct</td>
<td>71</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>False negative</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>LV EDV</td>
<td>74</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>Mass + EDV</td>
<td>71</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Mass + EDV</td>
<td>71</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>LA volume</td>
<td>79</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>70</td>
<td>11</td>
</tr>
</tbody>
</table>

**Table 3**

Statistical Data and Accuracy Data of the Inferior Vena Cava-Left Ventricular Measurements from Lateral Chest X-Rays Compared to the Combined Left Ventricular End-Diastolic Volume Plus Mass

<table>
<thead>
<tr>
<th>Angio data</th>
<th>Distance LV posterior to IVC</th>
<th>Height of IVC-LV intersection above diaphragm</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV mass</td>
<td>n = 103</td>
<td>n = 101</td>
</tr>
<tr>
<td></td>
<td>r = 0.37</td>
<td>r = −0.31</td>
</tr>
<tr>
<td>EDV</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>62 Correct (%)</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>9 False positive (%)</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>29 False negative (%)</td>
<td>29</td>
</tr>
</tbody>
</table>

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methods of assessment of left heart enlargement are most accurate when all three components of the left heart (left ventricular end-diastolic volume, mass, and left atrial maximal volume) are utilized for the comparison. This might be expected due to individual variation in wall thickness and volume of the left ventricle and volume of the left atrium. Thus, silhouette volume correctly indicates normal or abnormal total left heart volume in 79% of cases ($r = 0.78, P < 0.01$) while the cardiothoracic ratio is correct in 70% ($r = 0.64, P < 0.01$). The other major components of the cardiac silhouette in patients without pericardial disease are the right atrium and right ventricle; these were not evaluated in this investigation and their variation is an obvious reason for lack of a greater correlation between the variables studied. Furthermore, it is common for plain chest films to be taken in deep inspiration; this may result in a Valsalva maneuver which can alter hemodynamics and heart size. The angiograms are made during normal breathing. Also, plain chest films are taken in the upright position whereas angiography is performed in the recumbent position. An additional factor tending to decrease these correlations is that the left ventricle might not be at end-diastole nor the left atrium at maximal volume at the instant of chest roentgenography. Furthermore, it might have been suspected that differing hemodynamic abnormalities involving the left ventricle might produce unique relationships between the variables studied, but as reflected by the scatter of the different symbols in figures 4 and 5, this is not the case. Thus, the particular left ventricular abnormality present in an individual patient does not seem to alter the accuracy of the roentgenographic diagnosis of left heart enlargement.

The relationships of the posterior aspect of the left ventricular wall, the left leaf of the diaphragm, and the inferior vena cava do not appear to be additionally useful in the assessment of left heart enlargement from the roentgenograms; the correlation coefficients obtained are 0.37 and −0.31. One possible exception to this conclusion, however, is that there were only 9% false positives in utilizing the criteria that the maximum normal displacement of the left ventricular margin posterior to the inferior vena cava (shown in fig. 2) is 1.8 cm. Thus the relative specificity of this measurement may be a useful adjunct in diagnosing left ventricular enlargement.

The assessment of left atrial enlargement by noting posterior displacement of the barium-outlined esophagus in the lateral roentgenogram is usually a subjective interpretation. Utilization of the left atrial index (fig. 3), in an attempt to quantify this radiographic feature, reveals significant but not close correlation with maximal left atrial volumes ($r = 0.66, P < 0.01$). However, of the 99 patients with enlarged left atrial maximal volumes, 82% had indentations of the barium-filled esophagus by the left atrium. Thus it appears that this index may have some useful clinical value in assessing left atrial enlargement.

It is of interest that the accuracy of roentgenographic diagnosis of left heart enlargement is generally about the same as the electrocardiogram when compared to quantitative angiocardiographic data. Thus, previous studies have shown that 67–68% of patients with increased left ventricular mass had ECG hypervoltage by commonly used criteria. This compares to 71% and 67% correct diagnoses of increased left ventricular mass, utilizing the roentgenographic calculation of total cardiac silhouette volume and cardiothoracic ratio as shown in table 2. However, Kuzman and Yuskis, utilizing less quantitative methods, compared the relative value of the ECG and roentgenography in assessing selective ventricular enlargement and concluded the ECG to be more reliable. Assessment of P-wave duration on the ECG provided the correct diagnosis of normal or enlarged left atrial maximal volumes determined by quantitative angiocardiography in 68% of patients as reported by Kasser and Kennedy. This figure compares with the 82% of patients in the present investigation whose enlarged left atrial maximal volumes were reflected by an
indented barium-filled esophagus in the lateral film.

References
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