The Relationship of Increased Left Atrial Volume and Pressure to Abnormal P Waves on the Electrocardiogram

By IRWIN KASSER, M.D., AND J. WARD KENNEDY, M.D.

SUMMARY
Left atrial volume and pressure measurements in 23 normal subjects and 117 cardiac patients were compared with several electrocardiographic criteria for left atrial disease. Both P duration in lead II and V₁ terminal force (the area inscribed by the terminal portion of the P in lead V₁) showed a highly significant correlation with changes in left atrial volume but related less well to increases in left atrial pressure. Diagnostically, both criteria accurately predicted normal or increased left atrial size in two thirds of all patients. The V₁ terminal force was more accurate in predicting left atrial pressure abnormalities in all subjects and particularly reliable in detecting increased pressure and volume in mitral stenosis. The P/PR segment ratio was less helpful in the detection of left atrial disease.

Additional Indexing Words: Quantitative angiocardiography Atrial hypertrophy

CLINICIANS HAVE long appreciated the usefulness of the electrocardiogram in detecting left atrial disease. Berliner and Master¹ as well as Fraser and Turner² noted a high prevalence of broad or notched P waves, or both, in mitral valve disease. However, a significant number of patients with left atrial disease do not show abnormal P waves in the standard limb leads. To improve the reliability of the electrocardiogram for the recognition of left atrial disease, investigators have proposed other criteria, most notably the P/PR segment ratio and the product of the magnitude and duration of the terminal force of the P wave in lead V₁.³ ⁴ Despite these additional criteria, doubt remains concerning the specificity of the electrocardiogram in predicting increased left atrial volume or pressure.⁵ ⁶

The relationship of left atrial disease to the genesis of abnormal electrical forces is complex, involving the interplay of several factors. These include (1) myocardial changes with intra-atrial conduction abnormalities; (2) left atrial hypertension; (3) left atrial distention; and (4) chronicity of disease. In this study two of these factors, left atrial volume and pressure, have been determined in normal individuals and in patients with various types of heart disease and compared with several electrocardiographic criteria of left atrial enlargement on the standard 12-lead electrocardiogram. Attention has been directed to two specific points: (1) the correlation of increasingly severe abnormalities in left atrial volume and pressure with P wave changes; and (2) the ability of various electrocardiographic parameters to predict elevations in either left atrial volume or pressure or in both.

Methods
One hundred forty patients were studied by use of right and left heart catheterization and biplane angiocardiography. The clinical diagnoses

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of these patients are shown in Table 1. Satisfactory opacification of the left atrium was obtained in all subjects by the injection of contrast material into either the left atrium or pulmonary artery. Left atrial volumes were calculated from the ellipsoidal reference figure as previously described by Sauter and associates.\(^7\) Left atrial or pulmonary wedge pressures were recorded in 134 patients, using Statham 23Db strain-gauge transducers and a photographic recorder. The left atrial \(v\) wave was measured from the \(v\) peak to the \(y\) trough.

Standard 12-lead electrocardiograms were taken at 25 mm/sec and at a sensitivity of 1 mv/cm. P-wave measurements were made with calipers and a magnifying lens. The duration and amplitude of the P wave were measured in leads I, II, and V\(_1\). The Macr\(z\) index (P/PR segment ratio) was measured in lead II.\(^3\) Finally, the \(V_1\) terminal force was calculated as the algebraic product of the amplitude and duration of the terminal portion of the P wave in lead \(V_1\) as described by Morris and associates.\(^4\) This force was negative in 120 patients, isoelectric in 16, and positive in three.

### Results

The comparison of left atrial volume with atrial forces on the electrocardiogram yielded a highly significant correlation in all patients \((P < 0.001)\). Both P duration in lead II and \(V_1\) terminal force (the area inscribed by the terminal portion of the P in lead \(V_1\)) correlated equally well with left atrial volume. The correlation between P duration in lead II and left atrial maximal volume was \(r = 0.56\) (fig. 1). The \(V_1\) terminal force correlated best with left atrial maximal volume corrected for the body surface area, \(r = -0.55\) (fig. 2). The ratio of the P/PR segment related less well to the left atrial maximal volume \((r = 0.43)\) (fig. 3), and the P-
Table 2

Correlation of Left Atrial Volume and Pressure with Electrocardiographic Criteria in All Patients

<table>
<thead>
<tr>
<th>Criteria</th>
<th>LA max volume ml</th>
<th>LA max volume ml/m²</th>
<th>Pressure × volume mm/ml</th>
<th>Pressure × volume mm ml/m²</th>
<th>LA voltage (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 terminal force</td>
<td>-0.48</td>
<td>-0.55</td>
<td>-0.36</td>
<td>-0.29</td>
<td>-0.35</td>
</tr>
<tr>
<td>P duration in lead II</td>
<td>0.56</td>
<td>0.46</td>
<td>0.24</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>P/PR segment ratio</td>
<td>0.43</td>
<td>0.36</td>
<td>0.22</td>
<td>0.29</td>
<td>0.25</td>
</tr>
<tr>
<td>P duration in lead I</td>
<td>0.37</td>
<td>0.28</td>
<td>0.02</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>P amplitude in lead II</td>
<td>0.07</td>
<td>0.14</td>
<td>0.17</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>P amplitude in lead I</td>
<td>0.02</td>
<td>0.02</td>
<td>-0.08</td>
<td>-0.15</td>
<td>-0.23</td>
</tr>
</tbody>
</table>

Table 3

Accuracy of Electrocardiographic Criteria for Predicting Normal or Increased Left Atrial Volume or Pressure

<table>
<thead>
<tr>
<th>Criteria</th>
<th>LA maximal volume (normal: up to 88 ml)</th>
<th>LA mean pressure (normal: up to 12 mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correct diagnosis (%)</td>
<td>False positive abnormal ECG normal vol (%)</td>
</tr>
<tr>
<td>All patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V1 terminal force (normal: up to -0.03 mm/sec)⁴</td>
<td>66</td>
<td>6</td>
</tr>
<tr>
<td>P duration in lead II (normal: up to 0.11 sec)⁹</td>
<td>68</td>
<td>6</td>
</tr>
<tr>
<td>P/PR segment ratio (normal: 1.0 to 1.6)³</td>
<td>53</td>
<td>12</td>
</tr>
<tr>
<td>Mitral stenosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V1 terminal force</td>
<td>90</td>
<td>5</td>
</tr>
<tr>
<td>P duration in lead II</td>
<td>48</td>
<td>5</td>
</tr>
<tr>
<td>P/PR segment</td>
<td>62</td>
<td>5</td>
</tr>
</tbody>
</table>

wave amplitude in lead I or II or the P-wave duration in lead I showed poor correlation with left atrial volume (table 2).

Comparison of left atrial pressure with the previously stated electrocardiographic measurements yielded a less significant correlation than did the comparison with volume. Furthermore, comparison of the electrocardiogram with the product of left atrial maximal volume and mean pressure did not significantly improve the correlation seen with pressure alone. Finally, a poor correlation existed between left atrial v waves and measurements of the P wave in patients with mitral regurgitation as well as in all subjects when compared as a group (table 2).

The diagnostic accuracy of various electrocardiographic criteria were compared with the normal values indicated in table 3. Both the V1 terminal force and P duration in lead II correctly diagnosed left atrial size in two thirds of all patients, while the P/PR segment ratio was accurate in slightly more than half. Nevertheless, one quarter of all subjects demonstrated an enlarged left atrium in the presence of either a normal P wave or V1 terminal force on the electrocardiogram. Whereas the V1 terminal force and the P/PR segment ratio each predicted pressure with the same accuracy as they did volume abnormalities, the P duration in lead II predicted left atrial pressure less accurately than left atrial volume (table 3). In contrast, errors in diagnosing elevated left atrial pressure usually occurred in individuals who had large compliant left atria with pressures in the normal range.

In the analysis of several patient subgroups, all but those with mitral stenosis exhibited electrocardiographic-hemodynamic...
relationships similar to the whole population. In mitral stenosis, the V1 terminal force accurately diagnosed increased left atrial size and pressure in 90% and 70% of the patients, respectively. The P/PR segment ratio in these patients proved to be more reliable than P duration in lead II in detecting increased left atrial pressure and volume (table 3).

Discussion

Increased left atrial volume appears to be a more important determinant of abnormal atrial forces on the electrocardiogram than does elevated left atrial pressure. Several studies have reported poor correlation between left atrial pressure and volume, particularly in mitral valve disease. These authors have suggested that other factors, such as changes in the elasticity of the left atrial wall and duration of disease, may account for left atrial distention.

That increased left atrial volume is more closely associated with prolonged disease can be seen from the comparison of acute and chronic mitral regurgitation. In acute mitral regurgitation, high left atrial pressure is accompanied by a relatively small left atrial volume, while in chronic mitral regurgitation left atrial pressure tends to be lower and left atrial volume increased. Elevated left atrial pressure presumably causes progressive left atrial distention and increased compliance which act to lower pressure. This relationship is evident in table 2 in which the left atrial v wave in mitral regurgitation correlates inversely with P-wave abnormalities in contrast to the positive relationship of left atrial volume and the electrocardiogram.

Postmortem investigation has indicated that left atrial hypertrophy does not change the electrocardiogram. Mazzoleni and co-workers have reported that left atrial weight compares poorly with either P-wave duration or amplitude. However, the role of myocardial changes in the atrial wall has not yet been fully elucidated. Recent studies point to myocardial fibrosis as an important element in the development of atrial fibrillation associated with mitral valve disease. These factors may be equally significant in the formation of P-mitral.

To evaluate the accuracy of various electrocardiographic parameters, more rigid criteria for left atrial disease must be employed. While many patients with aortic valve disease or hypertension have left atrial involvement, some do not. Conversely, in many patients a mildly distended left atrium cannot be diagnosed by use of any technic short of quantitative angiocardiology. The present study indicates that the P duration in lead II and the V1 terminal force are equally accurate in reflecting abnormalities of left atrial size in all patients, while the latter parameter is more reliable for predicting elevations in left atrial pressure. Nevertheless, a quarter of all persons examined demonstrated a normal electrocardiogram in the presence of an enlarged left atrium. In fact, 19 of these patients had left atrial distention in excess of 120 ml, a size nearly twice the mean normal value of 63 ml reported by Murray and his associates. The diagnostic accuracy of the V1 terminal force in the present series is less than that reported by Morris and co-authors, who found that 86% (75 of 87) of their patients with left-sided valvular disease displayed an abnormal V1 terminal force. On the other hand, the data from the current study agree with the findings of other investigators concerning the helpfulness of the P/PR segment ratio in predicting left atrial disease.

Finally, it is interesting to note that correlation between left atrial volume and the P wave is similar to that of other studies comparing angiocardiology with electrocardiography. Baxley and associates reported a similar comparison (r = 0.55) between elevated left ventricular mass and QRS criteria for left ventricular hypertrophy.

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References


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