Two-dimensional Echocardiographic Assessment of Electrocardiographic Criteria for Right Atrial Enlargement

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SUMMARY Right atrial (RA) size was determined with two-dimensional echocardiography using the apical four-chamber view in 45 adult patients with various echocardiographic criteria for RA enlargement and in 25 normal controls. RA size varied from 11.4-24.0 cm² (mean 16.1 cm²) in controls. RA enlargement (≥ 25 cm²) was found in only two of 11 patients with P pulmonale (predictive value [PV] = 18%) and one of five with prominent positive P-wave forces in lead V₁ (PV = 20%). However, RA enlargement was found in eight of eight patients with a qR pattern in lead V₁ in the absence of clinical indications of coronary artery disease (PV = 100%). RA enlargement was also found in 13 of 28 patients with a total QRS amplitude in lead V₁ of 6 mm or less and a threefold or greater ratio of total QRS amplitude in lead V₁ relative to that in V₂ (V₄/V₁ ≥ 3) (PV = 48%). A V₄/V₁ ratio of 4 or more detected 11 of 13 patients with RA enlargement, with six false-positive diagnoses (sensitivity = 85%, specificity = 60%, PV = 65%). The combination of total QRS amplitude in V₁ of 4 mm or less, together with a V₄/V₁ ratio of 5 or more, detected six of 11 with RA enlargement, with one false-positive diagnosis (sensitivity = 46%, specificity = 93%, PV = 86%). We conclude that ECG criteria for RA enlargement that primarily use increased P-wave amplitude have a limited PV. The qR pattern in lead V₁ appears to be extremely accurate in detecting RA enlargement. ECG criteria in leads V₁ and V₂ using decreased amplitude in leads V₁ and a V₄/V₁ ≥ 3 are of some value in detecting RA enlargement.

THE ABILITY OF the ECG to detect right atrial enlargement has been the subject of many investigations. In these studies, methods of validating right atrial dimensions included radiographic, autopsy, and hemodynamic data. In the latter instances, cases for study were chosen because of the presence of congenital cardiac lesions known to be associated with systolic or diastolic overloading of the right atrium. Recently, two-dimensional echocardiography has been shown to be an accurate technique for determining right atrial size and has been used to detect right atrial enlargement in patients with either mitral stenosis or atrial septal defect. In this investigation we determined two-dimensional echocardiographic estimates of right atrial size in patients who had various electrocardiographic criteria suggesting right atrial enlargement.

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Materials and Methods

During a 6-month period, 7160 routine 12-lead ECGs obtained by the heart station at the Milton S. Hershey Medical Center were scanned for the presence of electrocardiographic criteria for right atrial enlargement. The ECGs were recorded at 25 mm/sec on either a 1511A Hewlett Packard electrocardiograph or an Elema-Schonander Mingograph 61. The electrocardiographic signs of right atrial enlargement included (1) a peaked P wave with an amplitude in lead II greater than 0.25 mV and a P wave axis in the frontal plane to the right of +70°; (2) a QR, Qr, qR or qRS morphology in the right precordial leads in the absence of clinical evidence of coronary artery disease; and (3) decreased total QRS amplitude in lead V1 (6 mm or less) with at least a threefold greater total QRS amplitude in lead V2 (V2/V1 ≥ 3); and (4) an initial positive P wave force in lead V1 equal to or greater than 0.06 mm/sec.

Echocardiography

Sector-scan echocardiograms were obtained using a Picker 80-C cardiac imager with a 2.25-MHz transducer mechanically swept through a 60° arc at 30 sweeps/sec. The apical four-chamber view was obtained by placing the transducer near the apex of the heart and directing the examining plane to include both atrial cavities and the intervening atrial septum. With the usual upright transducer position this resulted in the right atrium being recorded on the right-hand portion of the viewing screen. Patients were placed in the left lateral decubitus position for this examination. This method has been described by Nanda and Gramiak.

Fifty-five hospitalized patients with electrocardiographic abnormalities agreed to undergo echocardiography. Forty-five of these patients had satisfactory echocardiograms for analysis of right atrial dimensions. There were 27 men and 18 women, ages 21–70 years (mean 42 years). Fourteen patients had predominant mitral valve disease, seven had congestive cardiomyopathy, five had mitral valve prostheses, two had mitral valve prolapse, one had congenital tricuspid insufficiency, two had cor pulmonale secondary to chronic obstructive lung disease, six had chronic obstructive lung disease without obvious cor pulmonale, four had coronary artery disease and four had no obvious cardiac disease. A normal control population with no clinical evidence of heart disease and normal ECGs also underwent two-dimensional echocardiography in an identical manner. There were 21 men and four women, ages 21–40 years (mean 30 years).

Analysis of Right Atrial Size

The videotape recording was replayed on a Precise Optics 12-inch television screen. After slow motion, frame-by-frame viewing, maximal right atrial size was determined. The videotape was stopped at this point and the right atrial dimensions and the calibration grid were drawn with a grease pen directly onto x-ray film from the television screen. The right atrial silhouette and calibration grid were traced onto paper and the area was planimetered by hand and converted to a square-centimeter area (fig. 1)

Statistics

The mean value for right atrial dimension in the normal control population was compared with that in each of the four groups with right atrial enlargement by electrocardiographic criteria using the unpaired t test. The standard deviation and 95% confidence intervals were calculated for the normal control population. In the electrocardiographic group with decreased total QRS amplitude in V1 relative to V2, the right atrial areas were compared with the total QRS amplitude in V1, the ratio of total QRS amplitude in V2 relative to that in V1, and the combination of these two independent factors using multiple linear regression.

In the appropriate setting, the relationship between prediction (electrocardiographic criteria for right atrial enlargement) and the presence of actual enlargement determined by two-dimensional echocardiography was given in terms of sensitivity, specificity, and predictive values: sensitivity = true positives/(true positives + false negatives); specificity = true negatives/(true negatives + false positives); and predictive value = true positives/(true positives + false positives).

Results

Controls

Right atrial sizes varied from 11.4–24.1 cm² (mean 16.1 ± 3.4 cm² [± SD]) in the normal control popula-

![Figure 1. Two-dimensional echocardiograms obtained at the same scale setting that show an enlarged right atrium (42 cm²) (upper panel) from a patient with a reduced QRS amplitude in lead V1, relative to lead V2 and a normal right atrial size (15 cm²) (lower panel) from a normal subject in the control population. RA = right atrium; TV = tricuspid valve; MV = mitral valve.](image-url)
TABLE 1. Predictive Value of ECG Criteria for Right Atrial Enlargement

<table>
<thead>
<tr>
<th></th>
<th>QR</th>
<th>P pulmonale</th>
<th>Reduced QRS</th>
<th>Increased P (V1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enlarged RA</td>
<td>8</td>
<td>2</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Normal RA</td>
<td>0</td>
<td>9</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>8/8</td>
<td>2/11</td>
<td>13/28</td>
<td>1/5</td>
</tr>
</tbody>
</table>

Predictive value (%)

100 18 46 20

Abbreviations: RA = right atrium; QR = qR pattern in the right precordial leads; reduced QRS = decreased total QRS amplitude in V1 (6 mm or less) with at least a threefold greater total QRS amplitude in V2; increased P (V1) = increased initial positive P-wave force in lead V1.

Position (figs. 1 and 2). The upper limit of normal from 95% confidence intervals was 23.3 cm².

P pulmonale

Only two of 11 patients with P pulmonale (peaked P wave and rightward frontal plane P-wave axis) had right atrial enlargement (36.4 and 38 cm²; predictive value 18%) (table 1, fig. 2). Right atrial size in the others ranged from 13.0-22.0 cm² (mean 17.3 cm²). This group was significantly different from the control group (p < 0.05).

Fig. 2. Right atrial size (cm²) in the normal control population and in the four groups with electrocardiographic criteria for right atrial enlargement. Increased P (V1) = increased initial positive P-wave force in lead V1; reduced QRS = decreased total QRS amplitude in V1 (6 mm or less); QR = qR pattern in the right precordial leads.

Reduced QRS Amplitude in Lead V1

All eight patients with QR pattern on the ECG had right atrial enlargement ranging from 28.0-50 cm² (mean 42.3 cm²; predictive value 100%) (table 1, fig. 2). This group varied significantly from the controls (p < 0.001). One patient had a significantly reduced total QRS amplitude in V1 relative to V2.

Reduced QRS Amplitude in Lead V1

Thirteen of 28 patients with 6 mm or less total QRS amplitude in lead V1 and at least threefold greater total QRS amplitude in lead V2 had right atrial enlargement (predictive value 46%) (figs. 1 and 2, table 1). One of these also had a QR pattern in lead V1. The abnormal values ranged from 25.0-57.7 cm² (mean 37.5 cm²). This group varied significantly from the control group (p < 0.001). Right atrial size correlated inversely with total QRS amplitude in V1 (p < 0.05). Right atrial size also correlated directly with the ratio of total QRS amplitude in V2 compared with V1 (V2/V1) (p < 0.005, r = 0.6) (fig. 3). Combining total QRS amplitude in V1 with the ratio of V2/V1 did not improve the correlation with right atrial size (p > 0.05). The V2/V1 ratio of 4 or more detected 11 of 13 patients with right atrial enlargement in this group, with six false-positive diagnoses (sensitivity 85%, specificity 60%, predictive value 65%) (table 2). The combination of total QRS amplitude in V1 of 4 mm or less together with a V2/V1 ratio of 5 or more

Fig. 3. Direct correlation of right atrial size (cm²) with the ratio of total QRS amplitude in lead V2 compared with lead V1 (p < 0.005, r = 0.6).
detected six of 11 with right atrial enlargement with one false-positive diagnosis (sensitivity 46%, specificity 93%, predictive value 86%) (table 2).

**Table 2. Reduced QRS Amplitude in Lead V1 Relative to Lead V2**

<table>
<thead>
<tr>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Predictive value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2/V1 ≥ 4</td>
<td>85</td>
<td>60</td>
</tr>
<tr>
<td>4 × 5</td>
<td>46</td>
<td>90</td>
</tr>
</tbody>
</table>

Abbreviations: V2/V1 ≥ 4 = at least a fourfold greater total QRS amplitude in V2 compared with V1; 4 × 5 = total QRS amplitude in V1 of 4 mm or less in combination with at least a fivefold greater total QRS amplitude in V2.

**Increased P Wave in Lead V1**

Only one of five patients with an increased P wave in lead V1 had right atrial enlargement (45 cm²), but he also had a qR pattern in V1 (predictive value 20%) (table 1, fig. 2). Three of the remaining four patients had P pulmonale and one had a significant reduction in total QRS amplitude in V1 relative to V2. Their right atrial sizes ranged from 15.3–22.0 cm² (mean 17.6 cm²).

**Discussion**

Various electrocardiographic abnormalities have been associated with right atrial enlargement.1-5, 7-9, 12-14 The most widely accepted criteria are based upon an increase in amplitude of the P wave in the limb leads, particularly leads II, III and aVF, in association with a peaked P-wave morphology and a rightward frontal plane P-wave axis.14 This pattern has been called P pulmonale.18 Berliner and Master, in a 1938 autopsy study,1 reported that subjects with isolated left atrial hypertrophy had normal P-wave amplitude, while those with biatrial hypertrophy had an increase in P-wave amplitude, although in four cases of isolated right atrial hypertrophy, no P-wave abnormalities were noted. In 1962 Caird and Wilcken7 found a right atrial abnormality at autopsy in 17 patients with obstructive lung disease. The P pulmonale electrocardiographic pattern was noted in seven of 11 with a dilated right atrium, three with a dilated and hypertrophied right atrium, and in none of four with a hypertrophied right atrium. However, in a 1965 autopsy series, Gordon and associates8 found no correlation between P-wave amplitude and right atrial volumes or weight in 98 patients. In children with congenital cardiac lesions resulting in increased flow or pressure in the right atrium, some correlation has been found between increased P-wave amplitude and the presence of these conditions.1-4 No firm conclusions can be drawn from these data regarding the value of an increase in P-wave amplitude in the detection of right atrial enlargement. Even so, in the recent 1978 electrocardiographic task force report,18 the criteria suggested for the detection of right atrial enlargement were based on an increase in P-wave amplitude and an altered P-wave axis resulting in the pattern known as P pulmonale. We rarely detected right atrial enlargement in the presence of P pulmonale and do not believe that it is a sensitive criterion for right atrial enlargement, as its predictive value was only 18%. An increase in the initial P-wave forces in lead V1 has also been suggested to indicate right atrial enlargement. In our small series this sign did not appear without other criteria for right atrial enlargement and did not prove to be an accurate indication of right atrial enlargement.

A QR complex in the right precordial leads in the absence of myocardial infarction has been suggested to indicate right ventricular hypertrophy.19, 20 right ventricular dilatation,19, 20 or right atrial enlargement.8, 13, 14 In our small group, two-dimensional echocardiograms were not technically adequate for determination of right ventricular size. However, significant right atrial enlargement was present in each instance. The reason for this electrocardiographic pattern has been suggested by Sodi-Pallares and associates,9 who observed that an intracardiac electrode oriented to the high basal region of the interventricular septum recorded a QR complex. They postulated that in some cases of right atrial enlargement, the heart is rotated so that the high basal portion of the interventricular septum becomes oriented toward lead V1.

A decrease in the total QRS amplitude in lead V1 with a marked discrepancy between the total QRS amplitude in leads V1 and V4 and normal rS morphology was originally described by Tranchesi1 to indicate right atrial enlargement. We found a negative correlation between total QRS amplitude in lead V1 and right atrial size and a positive correlation between the ratio of total QRS amplitudes in leads V2 and V1 and right atrial size. QRS patterns in lead V1 in this group included qR, rS, and rSr' morphologies. This electrocardiographic pattern has been attributed to the large volume of the right atrium that lies between the ventricular chambers and the precordial electrode (V1) and the rotation of the ventricular septum.12, 14 Thirteen of 28 patients with this electrocardiographic pattern had right atrial enlargement. Using the criterion of a fourfold or greater ratio of total QRS amplitude in lead V2 relative to total QRS amplitude in lead V1, we detected 11 of the 13 patients (sensitivity 85%) with right atrial enlargement, with six false-positive diagnoses (specificity 60%). If a total QRS amplitude in lead V1 of 4 mm or less and a fivefold or greater ratio of QRS amplitudes in leads V2 and V1 were used, six of the 11 patients with right atrial enlargement were detected, with only one false-positive diagnosis (sensitivity 46%, specificity 93%).

A potential limitation of this investigation is the absence of a longitudinal series of examinations in the same patient population. Without these data we cannot exclude the possibility that some patients with electrocardiographic criteria for right atrial enlargement have undergone significant right atrial enlargement from low normal baseline values and yet remain within the limits of our control population at the point of our examinations. Another potential limitation of this study is that two-dimensional echocardiography...
visualizes the right atrium in only a single plane and it is not generally possible to obtain tomographic views with this technique. However, measurements obtained from two-dimensional echocardiography have been found to correlate well with the actual volume of the right atrium.\textsuperscript{10}

We conclude that the QRS pattern in lead V\textsubscript{1} may be extremely accurate in detecting right atrial enlargements. Other electrocardiographic signs are much less useful in detecting right atrial enlargement, particularly those patterns that rely on an increase in P-wave voltage.

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