Left Atrial Enlargement

Echocardiographic Assessment of Electrocardiographic Criteria

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SUMMARY A comparison of electrocardiographic manifestations of left atrial enlargement (LAE) and left atrial size by echocardiography was made in 307 patients in sinus rhythm. Electrocardiographic criteria used were: 1) P wave duration in lead II equal to or greater than 0.12 sec; \( V_3 \); the ratio of the duration of negative terminal P in \( V_1 \), to the P-R segment equal to or greater than 1.0; \( V_5 \): a negative P terminal force in \( V_1 \), less than \(-0.03\) mm sec. The echocardiographic diagnosis of left atrial enlargement was based on 1) transverse dimension greater than 4.0 cm, or 2) a ratio of transverse atrial to transverse aortic root dimension greater than 1.17. In the presence of left atrial enlargement, a combination of criteria occurred more often than a single criterion. The overall predictive index of the electrocardiogram for left atrial enlargement was 63% (excluding criterion \( V_5 \); raised probability to 80%); and that for absence of left atrial enlargement was 78%. The index of coarse versus fine fibrillary waves was unreliable in predicting left atrial enlargement. Changes in P wave morphology may be used as a reasonably specific but less sensitive indicator of left atrial enlargement.

MANY ELECTROCARDIOGRAPHIC CRITERIA have been proposed for determining enlargement of the left atrium.\(^1\)\(^-\)\(^9\) Although much attention has been directed to changes in P wave morphology in left atrial enlargement, there has been no reliable noninvasive “standard” with which these abnormalities may be compared. The advent of echocardiography has provided such a standard. Previous investigators have found good correlation between echocardiographic left atrial dimension and left atrial angiographic area.\(^6\) \(^-\)\(^7\) Brown and associates found the ratio of left atrium to aortic root dimension improved sensitivity of the echocardiogram over measurements used previously.\(^8\) The reliability of the electrocardiogram in detecting left atrial enlargement was evaluated in our patient population using echocardiography as a standard for comparison. Two recognized electrocardiographic criteria for left atrial enlargement and a third frequently used at this institution were evaluated.

Materials and Methods

Echocardiograms and 12-lead electrocardiograms were obtained on 427 patients studied at the Ben Taub General Hospital between June 30, 1973 and June 30, 1974. Four patients in whom satisfactory echocardiographic measurements could not be obtained were excluded. Eighty-four additional patients were excluded, as the electrocardiograms and echocardiograms were done two or more months apart. The age range in this remaining group of 339 patients (200 females, 139 males) was 10–87, mean 42.3 years. There were 307 patients in normal sinus rhythm and 32 in atrial fibrillation.

Echocardiograms were obtained using a Smith Kline Ekoline 20 ultrasonoscope, interfaced with an Electronics for Medicine DR8 multichannel recorder, or on polaroid film using a 2.25 MHz focused transducer 0.5 inch in diameter. The technique of recording echocardiograms has been discussed previously.\(^9\) Briefly, the transducer was placed in the fourth intercostal space along the left sternal border and directed posteriorly, cephalad, and medially to record the aorta and left atrium. Measurements at this point were carefully obtained from the aortic root at end diastole and left atrium at end systole, as shown in figure 1. Adjustments in gain were sometimes necessary to clarify left atrial wall motion or the farthest posterior echo was defined as left atrial wall. An average of five cardiac cycles was utilized and echocardiograms were read by at least two observers. Echocardiograms were initially interpreted by one observer who was aware of the clinical diagnosis in a substantial number of patients. Echocardiographic dimensions were reassessed by a second observer who was unaware of the patients’ diagnoses. This resulted in modification of the dimensions in about 10% of the cases, but these were never greater than 0.3 cm for either aortic root or left atrial chamber. The left atrium was considered enlarged if the transverse dimension was greater than 4.0 cm\(^2\) or if the ratio of the left atrium to aortic root dimension was greater than 1.17.\(^7\)

Electrocardiograms in these patients were examined for the presence of left atrial enlargement, using the following criteria, as shown in figure 2: Criterion L is defined as a P wave duration in lead II equal to or greater than 0.12 sec with or without notching. A ratio of the duration of the negative terminal P wave to the subsequent P-R segment in \( V_1 \), equal to or greater than 1.0 is defined as \( V_3 \). \( V_3 \) or Morris index, consists of a negative P terminal force in \( V_1 \), less than \(-0.03\) mm sec.\(^9\) Due to its nature, criterion \( V_3 \) always included \( V_5 \). However, the opposite did not hold. Therefore \( V_3 \) is used in this study to define only those patients who had a positive Morris index without fulfilling criterion \( V_5 \). If none of these criteria were found, the electrocardiogram was classified as negative for left atrial enlargement. The 32 patients in atrial fibrillation were examined for coarse (fibrillary waves greater than 1 mm in amplitude) or fine fibrillary waves in \( V_1 \). Electrocardiograms were read by two of the authors without knowledge of the echocardiographic findings. Eighty percent of the tracings were read by one author, 20% by another.

Using clinical information (history, physical examination, chest X-ray, and electrocardiogram) as well as the results from a complete echocardiographic examination and data from cardiac catheterization, when available, the patient...
population was divided into the following diagnostic categories:

1) Mitral valve disease (55 pts): mitral stenosis (6 pts), mitral regurgitation (24 pts), combined stenosis and regurgitation (5 pts), mitral valve prolapse (12 pts), postmitral valve replacement (5 pts).

2) Aortic valve disease (52 pts): aortic stenosis (9 pts), aortic insufficiency (34 pts), combined lesions (6 pts), postaortic valve replacement (4 pts).

3) Left ventricular disease (105 pts): echo evidence of reduced left ventricular systolic performance (ejection fraction <50%, velocity of circumferential fiber shortening rate <1.1 circ/sec), or diastolic compliance (mitral valve EF slope <60 mm/sec). This group consisted of patients with congestive cardiomyopathy (74 pts), hypertrophic cardiomyopathy (concentric or asymmetric) (8 pts), and coronary artery disease (23 pts).

4) Miscellaneous (40 pts): pericardial effusion (24 pts), atrial or ventricular septal defects (7 pts), pulmonic stenosis or insufficiency (4 pts), Ebstein’s anomaly (2 pts), tricuspid valve disease (3 pts).

5) Normal (55 pts).

Results

Three hundred and seven patients in normal sinus rhythm were divided into five groups according to the left atrial dimension by echocardiogram. The nine patients with left atria greater than 5.0 all had positive electrocardiograms showing multiple criteria. Eight patients had criterion L + V a, and one had L + V b. Seventeen of 24 patients with left atrial dimensions between 4.6 cm and 5.0 cm had positive electrocardiograms. Multiple criteria were observed in 12 patients (L + V a in 8, and L + V b in 4). Three patients had criterion L, one had V a, and one had V b. Twenty-two of 39 patients with left atrial dimensions between 4.1 cm to 4.5 cm had positive electrocardiograms. Thirteen exhibited multiple criteria, 11 with L + V a, and 2 with L + V b. Four patients displayed criterion V a, 4 had V b, and one exhibited criterion L. Eighteen of 39 patients with left atrial dimension less than 4.0 cm, but an abnormal left atrium to aorta ratio, had positive electrocardiograms. Nine patients displayed multiple criteria: eight had L + V a, and one had L + V b. In this group, seven patients had V b alone, two had V a alone, and no patient exhibited criterion L alone. Forty-five of these 111 patients with enlarged left atria had negative electro-
cardiograms (false negatives); and of 196 patients with normal left atrial size, 39 had electrocardiographic evidence of left atrial enlargement (false positives).

The sensitivity and specificity of the various electrocardiographic criteria are depicted in figure 3. Singularly or combining three criteria, the electrocardiogram was 100%, 79%, and 67% sensitive in 111 patients with left atrial dimensions greater than 5.0 (9 of 9), 4.5 (26 of 33), and 4.0 cm (48 of 72) respectively, and 59% (66 of 111) in the presence of an abnormal left atrium to aorta ratio. When criterion Vb was excluded from the criteria examined, sensitivity remained unchanged in patients with left atria greater than 5.0 cm (100%), but decreased to 76% and 60% in those with left atrial dimension of greater than 4.5 and 4.0 cm respectively, and to 49% in the presence of an abnormal left atrium to aorta ratio. The percentage of patients with criterion L, Vb, or Vb alone was low regardless of the left atrial dimension.

Overall specificity of electrocardiographic criteria, alone or in combination, was 80% (fig. 3). However, excluding criterion Vb increased specificity to 94%. Criterion L and Vb were found to be more specific than Vb (99%) vs 86% respectively) when used alone in the presence of left atrial enlargement.

Figure 4 shows the distribution of electrocardiographic sensitivity and specificity among the various clinical and echocardiographic diagnoses. The majority of patients (37 of 55) with mitral valve disease had enlarged left atria by echography; 24 (65%) of the 37 patients exhibited one or more of the criteria (true positives), while the other 13 showed no evidence of electrocardiographic evidence of left atrial enlargement (false negatives). Of the 18 patients with mitral valve disease and normal left atria, 4 (22%) had positive electrocardiographic criteria (false positives) and the other 12 patients in this group (9 with prolapsed mitral valves) had no electrocardiographic evidence of left atrial enlargement (true negatives). In contrast, the majority of patients with aortic valve disease (40 of 52) had normal left atria, 12 (31%) of whom had a false positive electrocardiogram; five of these patients did have aortic root dimensions greater than 3.8 cm, possibly masking true left atrial size. In the enlarged left atria group (12 pts), seven had positive electrocardiographic criteria (54%) while five patients had a negative electrocardiogram. A similar incidence of enlarged versus normal left atria was observed in the left ventricular disease group (47 versus 58 pts respectively). Twenty-seven (58%) of the 47 patients with enlarged left atria were correctly identified by the electrocardiogram, and of 58 patients with normal left atria, 38 had abnormal P wave morphology (false positives). The majority of the patients in the miscellaneous group (28 of 40) had normal left atria, 3 (11%) of whom had a false positive electro-
cardiogram. Eight (67%) of the other 12 patients with enlarged left atria were correctly identified by the electrocardiogram. It is of interest to note that the majority of the false positive electrocardiograms were distributed among patients with organic heart disease; only four of 55 patients with no detectable heart disease had a false positive electrocardiogram.

The distribution by diagnoses of the 39 patients with false positive electrocardiograms is shown in figure 5. Criterion \( V_a \) was found in 27 of these 39 patients (69%) and observed in all diagnostic groups listed. Criteria \( L \) and \( V_a \), though seen alone or in combination in patients with disease of the left heart, were not observed in the miscellaneous or normal group.

Overall predictive indices were calculated for electrocardiograms with positive criteria for left atrial enlargement, and for those that were negative. Predictive index (%) for a positive electrocardiogram =

\[
\frac{\text{True positive (66)}}{\text{True positive (66) + false positive (39)}}
\]

Predictive index (%) for a negative electrocardiogram =

\[
\frac{\text{True negative (157)}}{\text{True negative (157) + false negative (45)}}
\]

The predictive index of the positive electrocardiogram for left atrial enlargement was 63%; however, if criterion \( V_a \) was excluded, the probability rose to 80%. The predictive index of the negative electrocardiogram for left atrial enlargement was 78%.

Since some of the patients were receiving digitalis, the possibility of this drug influencing the electrocardiographic criteria was investigated in 160 patients. The incidence of patients receiving digitalis was similar in the false positive (15 of 38 or 39.5%) and false negative groups (17 of 44 or 39%). In addition, 50% of the true positives (29 of 58) were on digitalis. Therefore, digitalis did not appear to be a factor influencing the results.

Of 32 patients with atrial fibrillation, 26 had left atrial enlargement, and 25 of these 26 patients had mitral valve disease; the other was a patient with congestive cardiomyopathy. Of six patients with normal left atria by electrocardiogram, four had left ventricular dysfunction, one had a pericardial effusion, and one was found to have a systolic murmur with no associated cardiac pathology other than

atrial fibrillation. Coarse fibrillary waves in \( V_1 \) were observed in 16 of 26 patients (62%) with enlarged left atria, and in three of six patients (50%) with normal size left atria.

**Discussion**

This study represents an attempt to correlate left atrial size, as determined by echocardiographic examination, with the P wave on the surface electrocardiogram. Alterations in P wave morphology in the frontal plane such as left axis deviation increased duration with or without notching, and increased ratio of P wave duration to P-R segment have been previously observed in left atrial enlargement.\(^3\)\(^4\) In addition, posterior displacement of the P wave axis in the horizontal plane has been suggested as a sensitive indicator of left atrial overload.\(^1\) Thus, Morris and co-workers found that the algebraic product of the duration and amplitude of the terminal portion of the P wave in \( V_1 \) (P terminal force) allowed them to separate patients with left-sided valvular disease from normal subjects in 92% of their series.\(^6\) A subsequent study by the same authors in 192 patients found that P terminal force was 89% diagnostic for left ventricular hypertrophy confirmed at autopsy.\(^12\) Hence, they used the nonspecific term "left atrial involvement" as a definition of P wave changes associated with left-sided heart disease. Various investigators have also demonstrated reversible changes in P terminal force during acute left ventricular failure and in the course of acute myocardial infarction.\(^13\)\(^14\) These observations represent a controversy as to whether an abnormal P wave indicates dilatation of the left atrium or pressure overload.

Echocardiography allows one to directly visualize an anteroposterior diameter of the left atrium. Absolute increases in this diameter, as well as increases in the left atrium to aorta ratio, have been shown to correlate well with angiographically-determined left atrial volume.\(^*\)** Using the echocardiogram in 307 patients, we have observed a direct relationship between the degree of left atrial enlargement and the sensitivity of P wave abnormalities in both frontal and horizontal electrocardiographic planes. Thus, abnormal P waves were observed in all instances of left atrial dimension greater than 5.0 cm, but in only 59% of cases with an abnormal left atrium to aorta ratio. As shown in figure 3, abnormalities in the frontal and horizontal planes were seen more often in combination than independently, regardless of the degree of left atrial dilatation. Likewise, each criterion, when taken independently, did not appear to be a more sensitive indicator of left atrial enlargement than the others. In contrast, difference in specificity between criteria \( L \) and \( V_a \) and criterion \( V_a \) were observed; and 27 of 39 (69%) false positives had criterion \( V_a \) alone. In addition, when \( V_a \) was excluded as a criterion, the overall specificity of the electrocardiogram increased from 80 to 94%, while sensitivity fell minimally in patients with left atrial dimension greater than 4.0 cm.

Criteria \( V_a \) and \( V_b \) were both part of the Morris index. However, \( V_a \) was more stringent as it required an increase in the duration of the negative component of the P wave; specificity of \( V_a \) was 99% while \( V_b \) was 86%. The observation that \( V_a \) alone occurred most commonly in the false positive group, and the mildest degree of left atrial dilatation (abnormal left atrium to aorta ratio only), together with the fact

![Figure 5. Thirty-nine patients with false positive electrocardiograms and echocardiographic diagnosis.](http://circ.ahajournals.org/)
that 20 of 27 patients with V₆ in the false positive group had
disease of the left heart, support the previous concept that V₆
may be an indicator of left atrial pressure overload rather
than dilatation. Therefore, in spite of its low specificity,
criterion V₆ alone may have clinical application. In contrast,
criteria L and V₆, both of which probably reflect abnor-
malities in intra-atrial conduction, were more commonly
associated with dilated left atria. Only 12 of 39 (31%) false
positives (all 12 had disease of the left heart), exhibited
either one or both criteria. A similar high correlation
between intra-atrial block and organic heart disease have
been reported by Bradley and Marriott. Although isolated
intra-atrial conduction disturbances may be observed
clinically as well as produced experimentally, the frequen-
cy of its occurrence is probably low, and for practical pur-
poses a prolonged P wave duration should be indicative of
left atrial involvement (most commonly dilatation).

Digitalis has been found to have no consistent effect on the
P wave duration or on its terminal force. Its effect on
prolonging and depressing the P-R segment has been well
established. In the present series, a similar percent of
patients (39%) in the false positive and false negative groups
were receiving digitalis. In addition, 50% of the true
positives were on digitalis. Since criterion V₆ is the most apt
to be affected by prolongation of the P-R segment, digitalis
might have changed a V₆ into V₆. However, the incidence of
V₆ (alone or in combination with L) was similar in patients
receiving digitalis and those who were not. Thus, digitalis
did not appear to alter the sensitivity or specificity of the
electrocardiographic detection of left atrial enlargement.

In patients with atrial fibrillation, coarse versus fine
fibrillary waves were unreliable in predicting left atrial size.
However, coarse atrial fibrillation was noted in 16 of 25
patients (64%) with rheumatic mitral valve disease. A simi-
lar association of coarse atrial fibrillation with left atrial
enlargement secondary to rheumatic heart disease has been
previously noted.

In conclusion, using appropriate criteria, the elec-
trocardiogram appears to be a reasonably specific but less sen-
sitive indicator of left atrial dilatation. However, as left
atrial dilatation progresses, electrocardiographic criteria
become increasingly sensitive.

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