The computerized interpretation of the electrocardiogram (ECG) is widely used in clinical practice. In this study, the diagnostic accuracy of a computerized ECG analysis system in determining left atrial enlargement (LAE) was compared to readings made by two experienced cardiologists using LA measurements derived from echocardiography (echo) as a gold standard. LA size and the presence or absence of LAE on ECG was determined by computer analysis and by the cardiologists' readings in 181 patients undergoing routine echo. The computer classified patients according to the presence of LAE (n = 30), “consider” LAE (n = 59) and normal LAE (n = 92), whereas the echo identified 86 patients with normal LA size and 95 patients with varying degrees of LAE. ECG reading by both the computer and cardiologists showed a high specificity for different degrees of LAE, whereas sensitivity was generally poor for all sets of readings. Negative-predictive accuracy was high but positive-predictive accuracy was only fair to poor, for both the computer and the cardiologists. Both computerized and physician ECG readings identified patients with normal LA size but tended to overestimate the presence of LAE. New algorithms are required before LAE can be determined reliably from routine ECG in clinical practice.

Key Words: Left atrial Enlargement, Computerized Electrocardiography.
IDENTIFICATION OF LEFT ATRIAL ENLARGEMENT

Patients and Methods

This study was undertaken in the Division of Cardiology at Sunnybrook Health Science Center, a University of Toronto teaching hospital. The study population was derived from a consecutive series of inpatients undergoing a standard trans-thoracic echocardiogram during a three-month period. Eligible patients were required to have both an echocardiogram providing measurement of the left atrial size and an unedited, standard 12-lead ECG obtained within 7 days before or after the date of the echocardiogram. Exclusion criteria were similar to those used by the HP-ECG algorithm for determination of left atrial size and included rhythms other than sinus and ventricular rates in excess of 220 minus age or 150 beats per minute. Patients with technically difficult echocardiograms and uncertain left atrial measurements were excluded.

A total of 279 inpatients had a standard trans-thoracic echocardiogram performed. Thirty patients were excluded because of technically poor echocardiograms, 29 had atrial fibrillation, and 39 did not have an ECG within 7 days of the echocardiogram, leaving 181 patients for inclusion in the study.

The left atrial size was obtained for each patient by measuring the anteroposterior dimension from the M-mode tracing, in accordance with the American Society of Echocardiography criteria. LAE was considered to be present if the anteroposterior diameter exceeded 40 mm. Different degrees of LAE (> 40 mm, > 45 mm, > 50 mm) were also evaluated in comparison with the ECG readings. The HP-ECG described the left atrial size as "normal", "consider LAE", or "LAE". The computerized ECG interpretation was noted for each patient and compared to the corresponding echocardiogram-derived measurement of the left atrial size.

The accuracy of the HP-ECG was also compared to interpretations of the atrial size made by two cardiologists who applied published criteria for identifying LAE, similar to the algorithm employed by the HP-ECG (Hewlett-Packard personal communication). The cardiologists were unaware of the results of both the echo cardiogram and computerized ECG.

The criteria for identifying the presence of LAE included any of the following:

- I. P-wave terminal force in V1 > 40 mm s.
- 2. P-wave in V1 > 40 IDS.
- 3. Depth of P-wave in V1 > -1.0 mm.
- 4. Total P-wave duration > 110 ms.
- 5. Notched P-wave in any standard lead with an interpeak duration > 40 ms.

Data Analysis

Descriptive data were tabulated to compare different degrees of LAE, as defined by echocardiography, to the interpretations of the HP-ECG. Using the echocardiogram-derived left atrial size as the gold standard, estimates of sensitivity, specificity and positive- and negative-predictive accuracy were made from 2 x 2 contingency tables for patients with normal versus definite LAE, as reported by the HP-ECG and by the two cardiologists. The relationship between the echocardiogram and ECG-derived left atrial measurements was also examined by determining sensitivity, specificity, positive- and negative-predictive accuracy for: 1) normal left atrial size versus LAE + "consider LAE", and; 2) normal left atrial size + "consider LAE" versus LAE based upon the interpretations of the HP-ECG. The degree of agreement between the two cardiologists and the HP-ECG for individual readings was evaluated using Kappa co-efficients.

Results

Readings made by the HP-ECG were compared to the left atrial size as determined by the M-mode echo cardiogram (Table 1). The HP-ECG identified left atrial size as normal, consider (C) LAE, and LAE in 92, 59, and 30 patients, respectively, whereas the echo cardiogram identified 86 patients with normal left atrial size and the remaining 95 with varying degrees of LAE.

The accuracy of the HP-ECG in interpreting LAE was determined for patients with normal versus Table 1. The number of patients with normal versus possibly increased left atrial dimensions as determined by M-mode echocardiography and the HP-ECG

<table>
<thead>
<tr>
<th>Antero-posterior dimension of left atrium</th>
<th>HP-ECG</th>
<th>Normal CLAE</th>
<th>LAE</th>
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<tbody>
<tr>
<td>&lt;40</td>
<td>46</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>41 to 45</td>
<td>29</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>56 to 50</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>&gt;50</td>
<td>5</td>
<td>5</td>
<td>6</td>
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Total 92 59 30 181
LAE readings by HP-ECG with "consider LAE" readings being omitted from this part of the analysis. Using the standard 2 upper limit for normal left atrial size (≤ 40 mm), the HP-ECG was unable to classify accurately patients with and without LAE, as determined by echocardiography (Figure 1). Among the four parameters studied, only specificity (79%) showed fair ability of the HP-ECG to identify patients without LAE. Comparisons between normal versus LAE for the readings of the two cardiologists were similar to findings derived using HP-ECG data for left atrial size. Once again, only specificity for one of the cardiologists' (92%) was good enough to identify those patients without LAE. Overall, sensitivity and positive- and negative-predictive accuracy were only poor to fair for the HP-ECG and the cardiologists' readings.

The impact of including patients with HP-ECG readings of "consider LAE" was also evaluated (Figure 2). Regardless of whether these patients were included in the normal or LAE groups, measures of sensitivity, specificity, positive and negative-predictive accuracy were uniformly poor, with the exception of specificity for the normal + "consider LAE" versus LAE comparison (88%).

The accuracy of the HP-ECG in predicting normal versus LAE was also determined for different degrees of LAE (> 40 mm, > 45 mm and 50 mm). Sensitivity and positive-predictive accuracy were all less than 60% for each degree of LAE. Specificity was fair (79%, 81% and 78%) for increasing limits of LAE (> 40 mm, > 45 mm and 50 mm, respectively). Only negative-predictive accuracy progressively improved with limits of LAE.
being 50%, 81% and 95%, respectively. Since relatively few patients have severe LAE, the high negative-predictive accuracy value for LAE > 50 mm would be of little benefit in the clinical setting.

The degree of agreement between both cardiologists and the HP-ECG in interpreting the individual ECGs as normal, CLAE, and LAE ranged between 60% to 67%, with Kappa co-efficient of 0.32 to 0.38, which indicates only fair agreement.

Discussion

The diagnosis of left atrial enlargement by ECG had its beginning when Sir Thomas Lewis4 first reported the association between notched "P" waves on the ECG and the presence of mitral stenosis. Subsequent authors have presented more specific criteria for the identification of left atrial size by ECG.S,6 With the advent of echocardiography, numerous authors have compared estimates of left atrial size using different measurement criteria with a variety of ECG parameters.Y Ultimately, these findings led to the development of algorithms for ECG-derived diagnosis of left atrial enlargement.3 The HP-ECG uses a similar algorithm for interpreting standard 12-lead recordings.

In the present study, we evaluated the diagnostic accuracy of the HP-ECG in identifying LAE, using the echo cardiogram-derived left atrial size as the gold standard. Our results indicate that the HP-ECG is severely limited in its ability to identify patients with either normal left atrium or LAE. The specificity for the HP-ECG was only fair for all degrees of LAE, whereas the negative-predictive
accuracy was high only for patients with marked LAE.

Our study also compared the ability of the HP-ECG to utilize an algorithm for identifying LAE with readings performed by two cardiologists using a similar diagnostic algorithm. The finding that the readings of the computer and physicians achieved similarly poor to fair degrees of accuracy suggests that the HP-ECG correctly applies its algorithm in identifying LAE. Thus, the algorithm itself may need to be revised if the ECG is to be used as an accurate method for diagnosing patients with LAE.

The algorithm of Munuswamy et al. 3 is primarily based on five distinct criteria (see methods). When these authors used a combination of these five criteria in interpreting a series of ECGs recorded in 99 patients, they reported a sensitivity of 90% and specificity of 71% measurements. In contrast to their findings, the HP-ECG and two independent cardiologists were unable to duplicate these results.

Overall, readings made by the HP-ECG and the two cardiologist resulted in similar findings for sensitivity, specificity and predictive accuracy. However, the relatively low Kappa co-efficient indicate that agreement among the three sets of readings of left atrial size for individual patients was generally poor. These findings raise further concerns about the clinical usefulness of measurements of left atrial size from the standard 12-lead electrocardiogram.

In conclusion, the HP-ECG should not be used to identify individuals with either normal or increased left atrial size. New criteria needs to be developed before the ECG can identify accurately patients with
Figure 4. The positive pre accuracy of LA size as normal or LAE is shown for the HP-ECG and for the two cardiologists’ readings.

Table 2. Sensitivity, specificity and predictive accuracy for normal (≤40 mm) versus enlarged (>40 mm) left atria derived from echocardiography and the HP-ECG.

<table>
<thead>
<tr>
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<th>Sensitivity 28%</th>
<th>Specificity 79%</th>
<th>Positive-predictive accuracy 60%</th>
<th>Negative-predictive accuracy 50%</th>
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LAE, either using physician or computerized interpretations. Meanwhile, it would be prudent to avoid making a diagnosis of LAE solely upon the readings of the electrocardiogram.

References