Using Electrocardiographic Activation Time and Diastolic Intervals to Separate Focal From Macro–Re-Entrant Atrial Tachycardias

Jason P. Brown, MD, David E. Krummen, MD, Gregory K. Feld, MD, FACC, Sanjiv M. Narayan, MB, MD, FACC
San Diego, California

Objectives
This study was designed to separate focal from atypical macro–re-entrant atrial tachycardia (AT) on the electrocardiogram (ECG).

Background
Focal AT often cannot be distinguished from macro–re-entrant AT until the time of electrophysiology study (EPS). We hypothesized that quantitative ECG metrics should separate focal AT, using its short activation relative to tachycardia cycle length (CL), from macro–re-entrant AT, whose activation should span the CL. We developed tools to accurately quantify CL and P- or F-wave duration even when overlying T waves, then prospectively applied them to patients during focal or macro–re-entrant AT ablation and compared them to the gold standard EPS diagnosis.

Methods
We studied 41 patients (27 men, 14 women) age 57 ± 17 years. In the training group (n = 20), tachycardia P or F waves overlying T waves were identified from transitions in slope (dV/dt) relative to “expected” T waves generated from scaling of the sinus-rate T-wave. Electrocardiographic P-wave duration agreed with the duration of intra-atrial activation. Autocorrelation was used to estimate ECG atrial CL (p < 0.001).

Results
Compared to macro–re-entry (n = 13), focal AT (n = 7) had shorter P waves (115 ± 31 ms vs. 227 ± 67 ms; p < 0.001) that were smaller ratios of CL (28 ± 7% vs. 85 ± 21%; p < 0.001). Receiver-operating characteristic curve areas for AT were 0.92 for P(F)-wave duration and 0.99 for P(F)/CL ratio. On blinded prospective analysis (n = 21), P(F)-wave duration <160 ms identified focal (n = 7) from macro–re-entrant AT (n = 14) with 90% sensitivity and 98% specificity, and a P(F)/CL ratio <45% gave 86% sensitivity and 98% specificity.

Conclusions
Quantitative ECG indexes of shorter atrial activation and longer diastolic interval separate focal from macro–re-entrant AT without diagnostic maneuvers. (J Am Coll Cardiol 2007;49:1965–73) © 2007 by the American College of Cardiology Foundation

It is often difficult to identify focal atrial tachycardia (AT) from atypical forms of atrial flutter (macro–re-entrant AT not using the cavotricuspid isthmus) using the electrocardiogram (ECG), and their separation is typically deferred until invasive electrophysiologic study (EPS) or ablation (1,2). Indeed, even expert ECG diagnoses of atypical atrial flutter may reflect focal AT when mapped at EPS (2), particularly after ablation. Nevertheless, this distinction is important because, in the absence of atrial fibrillation, focal AT may respond to different pharmacologic agents than macro–re-entrant AT (calcium channel blockers or beta-adrenoceptor antagonists rather than classes I or III antiarrhythmics), and the need for anticoagulation is less well-studied (1,3).

In principle, differences between focal and macro–re-entrant AT should be detectable at the bedside using the ECG. An established mechanistic feature of macro–re-entry is that activation spans the tachycardia cycle length (CL), whereas activation in focal AT is shorter (1,2). However, difficulties in visually measuring P or F waves across leads or when overlying T waves hinder accurate ECG estimation of the P(F)-wave duration or CL.

Therefore, we developed ECG tools to precisely measure atrial CL and P- or F-wave duration even if overlying T waves. We hypothesized that these quantitative ECG indexes in focal AT should reveal shorter P waves because of activation of a smaller ratio to CL that reflects longer diastolic intervals compared to F waves in...
Clinical protocol. We recruited 41 consecutive patients with focal AT (n = 14) and atypical macro-re-entrant AT (n = 27) referred to the University of California (UCSD) and Veterans’ Affairs Medical Centers (VAMC) San Diego for ablation. We excluded cases following ablation for atrial fibrillation (AF) because extensive prior ablation may alter atrial activation and P(F) wave duration. This study was approved by the joint UCSD/VAMC Institutional Review Board, and subjects gave informed consent. Patients had previously undergone standard clinical management that, for macro-re-entrant AT, included 3 weeks of prior anticoagulation or the lack of atrial thrombus on transesophageal echocardiography.

All patients underwent clinical EPS in the post-absorptive state after discontinuing anti-arrhythmic medications except amiodarone (Table 1). Routine diagnostic catheters were advanced transvenously, including a 6-F quadrapolar catheter to the His bundle position, an 8-F ablation catheter (EP Technologies, Sunnyvale, California) for mapping, and other catheters as clinically required.

Macro-re-entrant AT (atypical atrial flutter) was diagnosed by the absence of sequential activation around the tricuspid annulus, activation that spanned the tachycardia cycle, concealed entrainment at sites of earliest atrial activation or double potentials, and successful ablation at sites outside the cavotricuspid isthmus (1,4,5). Focal AT was diagnosed by a focal source with intra-atrial activation occupying a short proportion of the tachycardia cycle (1).

The diagnosis of focal AT was confirmed by termination during localized ablation at the site of earliest activation, with subsequent inability to induce the arrhythmia (2).

**Acquisition of data.** We recorded 12-lead surface ECGs (0.05 to 100 Hz bandpass-filtered) and corresponding bipolar intracardiac electrograms (30 to 250 Hz) that were digitized at 1 kHz and exported with 16-bit resolution from our recorder (Bard, Billerica, Massachusetts). Electrocardiographic analysis was performed on a personal computer using software developed by the authors in Labview (National Instruments, Austin, Texas) (6). Electrocardiographic analysis used leads V5, aVF, and V1 to represent orthogonal leads X, Y, and Z, respectively. Intracardiac electrograms were analyzed at 200 mm/s scale.

**ECG identification of tachycardia P or F waves.** We attempted to identify P or F waves in each orthogonal ECG lead (V5, aVF, or V1) regardless of the conducted atrial: ventricular ratio. When tachycardia P or F waves overlay T waves, they were revealed by comparison against “expected” T waves, computed for each patient using rate-adjusted linear scaling from the sinus-rate T-wave (Fig. 1).

First, from a sinus rhythm ECG, the QT interval (QTs) and RR interval were measured. We calculated the expected QT interval (QTe) at the tachycardia rate using the Bazett formula to obtain the corrected QT [QTc = QTs/√(sinus RR interval[s])] then scaled this to the tachycardia rate [QTc = QTc · √(tachycardia RR interval[s])] (7) (Fig. 1).

Second, we linearly scaled the sinus rhythm T-wave to yield an expected T-wave shape at the tachycardia rate (Fig. 1). Assuming that QRS duration (QRSd) does not alter significantly between sinus rhythm and tachycardia, the “expected” JT duration (JTe) = QTc − QRSd. Thus, the expected T-wave was generated by sampling the sinus T-wave (duration JTs = QTs − QRSd) every JTs/JTeth point. For example, if tachycardia JTe is half JTs, every second sinus T-wave point was sampled to yield the expected tachycardia T-wave (Fig. 1).

Finally, we compared observed with expected tachycardia T waves using subtraction to identify the obscured P- or F-wave. Figure 1 shows this for a case of focal AT. **Determining P- or F-wave onset and offset.** Slope transitions from the isoelectric baseline or T-wave (if superimposed) were used to reveal subtle changes in contour indicating P(F) onset and offset. Figure 1 shows dV/dt of tachycardia T waves in a case of focal AT, smoothed by applying a 3-point median filter. The upstroke, turning point, and downstroke in X-axis dV/dt (lead V5) correspond with visual P-wave onset, peak, and offset. We applied dV/dt separately for each lead, then expressed measurements in each axis and as the 3-axis mean. Leads in which P- or F-wave onset or offset remained obscure were not included. The 3-lead mean of P(F)-wave measurements was reported for each patient.

**Table 1.** Patient Demographics

<table>
<thead>
<tr>
<th></th>
<th>Focal AT (n = 14)</th>
<th>Macro-Re-Entrant AT (n = 27)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>56 ± 20</td>
<td>58 ± 15</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>14/0</td>
<td>20/7</td>
<td>—</td>
</tr>
<tr>
<td>Cycle length (ms)</td>
<td>375 ± 103</td>
<td>283 ± 43</td>
<td>0.006</td>
</tr>
<tr>
<td>Left atrial diameter (mm)</td>
<td>42 ± 5</td>
<td>42 ± 10</td>
<td>NS</td>
</tr>
<tr>
<td>Prior atrial fibrillation</td>
<td>0</td>
<td>10</td>
<td>0.009</td>
</tr>
<tr>
<td>Left ventricular ejection fraction (%)</td>
<td>55 ± 13</td>
<td>54 ± 13</td>
<td>NS</td>
</tr>
<tr>
<td>Prior cardiac surgery</td>
<td>3</td>
<td>9</td>
<td>NS</td>
</tr>
<tr>
<td>Documented coronary disease</td>
<td>2</td>
<td>7</td>
<td>NS</td>
</tr>
<tr>
<td>Amiodarone use</td>
<td>0</td>
<td>6</td>
<td>0.056</td>
</tr>
</tbody>
</table>

AT = atrial tachycardia.
ECG estimates of tachycardia cycle length. Because manual CL measurement may introduce errors, given difficulties in precisely identifying P- or F-wave onsets, we used novel autocorrelation and spectral methods to quantify CL.

First, atrial activity was emphasized using our described sliding correlation method (6,8). Briefly, a 120-ms ECG template was selected overlying a P- or F-wave (Figs. 2A.I and 2B.I). Sequential Pearson cross-correlations of this template across the ECG, indicated by the dashed templates in Figure 2A.I (left), yield a correlation-time series ranging from \(10^{-1}\) to \(10^1\) in which values near 1.0 indicate recurrent P or F waves. This correlation-time series reflects atrial activity across the ECG.

For autocorrelation CL estimates, this time series was correlated to itself repeatedly at progressive time shifts (Figs. 2A.II and 2B.II). Theoretically, autocorrelation reaches a maximum when the time-shifted series is again in phase with the original series (i.e., when the time-shift equals the CL). Atrial CL was assigned as the time-shift reflecting the autocorrelation peak in the range of 150 to 500 ms.

Spectral CL estimates were obtained from an 8,192-point fast Fourier transform (0.12 Hz resolution) (Figs. 2A.III and 2B.III). The dominant frequency was the largest magnitude between 2 and 6.8 Hz (reflecting 500 to 150 ms), and estimated CL was given by its reciprocal. Cycle length estimates were validated against measured atrial CL for 10 cycles at 200 mm/s scale.

Diagnostic criteria for focal AT and receiver-operating characteristics. In the training population (n = 20), we derived ECG P- or F-wave durations and P(F) duration-to-CL ratios to diagnose focal AT. Using Excel (Microsoft, Inc., Redmond, Washington), we created receiver operating characteristic curves for the diagnosis of focal AT to determine the optimal cutpoint for each index. This was applied in a blinded fashion in our pilot validation study (n = 21 patients).

Statistical analysis and sample size considerations for the validation study. Continuous variables were presented as mean ± SD. The 2-tailed \(t\) test was used to compare continuous variables between groups. The Fisher exact test was applied to contingency tables. Because of the small sample sizes, exact confidence limits for sensitivity and specificity were computed using binomial probabilities. Probabilities below 5% (\(p < 0.05\)) were considered significant.

Figure 1 Identifying Tachycardia P or F Waves From Underlying ECG T Waves
The top panel shows sinus rhythm, and the lower panel tachycardia in the same patient. The RR and QT intervals are identified in each. Linear scaling from the sinus beat (top) was used to generate an “expected” T-wave at the tachycardia RR. This was compared to the actual tachycardia T-wave with superimposed P waves. The first derivative (dV/dt), shown for the X-lead, helped identify P (or F) wave onset and offset (vertical arrows). Here, P-wave duration (3-axis mean) = 129 ± 17 ms. AT = atrial tachycardia; CL = cycle length; ECG = electrocardiogram.
For the diagnosis of focal AT in the training population, P-wave duration of 160 ms had an accuracy of 80%, and P-wave duration to tachycardia CL of 45% had an accuracy of 95%. To estimate sample sizes required for a prospective study of these tests, assuming an accuracy of 80%, a validation study would require 20 subjects to separate focal AT from macro-re-entrant AT with 80% power at the 5% level of significance.

**Results**

**Demographics.** Table 1 summarizes the clinical characteristics of all patients. The use of amiodarone (22% vs. 0%) and the proportion of male patients (74% vs. 100%) were greater in patients with macro-re-entrant AT (n = 27) than focal AT (n = 14). Groups were otherwise similar in left ventricular ejection fractions, left atrial diameters, and other parameters. The origins of macro-re-entrant AT were mostly in the right atrium (left atrium cases, n = 8), as were focal AT (left atrium cases, n = 4).

**Differences in sinus rhythm ECG.** P-wave durations (3-axis means) in sinus rhythm were shorter in focal AT (120 ± 33 ms) than macro-re-entrant AT (163 ± 39 ms; p < 0.001), despite no difference in sinus CL between groups (Table 2). For focal AT patients, P-wave durations did not differ between sinus rhythm and tachycardia, even though the P-axis typically changed (p = 0.86). Conversely, for macro-re-entrant AT patients, F-wave durations in tachycardia were significantly longer than P-wave durations in sinus rhythm (p < 0.001).

**ECG estimates of tachycardia CL.** Autocorrelation accurately estimated measured atrial CL for focal and macro-re-entrant AT (p < 0.001 using linear regression for ECG estimated vs. intracardiac CL for each group), whereas, surprisingly, spectral dominant frequency often gave poor CL estimates. An example of accurate autocorrelation and spectral estimates of CL is shown in Figure 2A.III, while Figure 2B.III shows an example of accurate autocorrelation but inaccurate spectral CL estimates. Therefore, we used autocorrelation CL estimates for the study.

**Training group: ECG estimated P(F)-wave duration and ratio to CL (Table 2).** In the training group (focal AT, n = 7; macro-re-entrant AT, n = 13), P-wave duration was substantially shorter in patients with focal AT.
compared to F-wave duration in macro–re-entrant AT (p < 0.001 in each orthogonal axis) (Table 2). There was no significant difference in ventricular rate between groups (134 ± 51 beats/min vs. 114 ± 56 beats/min; p = 0.48).

Figure 3A shows an activation map of focal AT in the lateral right atrium in a 28-year-old man. From the ECG, the measured P-wave duration (3-axis mean) was 127 ms, representing 43% of autocorrelation (estimated CL 284 ms). Detailed intracardiac mapping (NavX, Endocardial Solutions, Minneapolis, Minnesota) corroborated these values, showing that the extent of atrial activation was 125 ms, with measured CL 274 ms.

Figure 3B (same patient as Fig. 2B) shows an activation map of macro–re-entrant AT (right atrium lower loop re-entry) in a 27-year-old woman. The ECG showed a measured F-wave duration (3-axis mean) of 171 ms, representing 72% of CL 236 ms (autocorrelation-estimated in Fig. 2B.II). Detailed intracardiac mapping (Carto, Biosense Webster, Diamond Bar, California) confirmed duration of atrial activation of 181 ms, with measured CL 238 ms.

For the training group (Table 2), compared to macro–re-entrant AT, focal AT had a shorter P(F)-wave duration in all axes (p < 0.001), which represented a smaller ratio of CL (p < 0.001). For P-wave duration <160 ms (3-axis mean), sensitivity for AT was 90% (3-axis mean 95% confidence interval [CI] 0.70 to 0.99); specificity was 77% (95% CI 0.61 to 0.89). For P-wave duration to CL <45%, sensitivity for AT was 100% (95% CI 0.82 to 1.0); specificity for AT was 90% (95% CI 0.76 to 0.97).

Receiver-operating characteristics for focal AT. Receiver-operating characteristic curves for the diagnosis of focal AT were generated from the training population. The area under the curve for P(F)-wave duration was 0.92 (Fig. 4),
and P-wave duration <160 ms provided sensitivity 91%, specificity 89%, positive predictive value 83%, and negative predictive value 95% for focal AT (Table 3). The P(F) wave-to-CL ratio provided area under curve = 0.99 (Fig. 5), and ratio <45% provided sensitivity 86%, specificity 98%, positive predictive value 95%, and negative predictive value 91% for focal AT.

Validation study. In the blinded validation study of ECGs of focal (n = 7) and macro–re-entrant AT (n = 14), Table 3 summarizes that P-wave duration <160 ms provided 90% sensitivity (95% CI 0.70 to 0.99) and 90% specificity (95% CI 0.77 to 0.97) for focal AT. P-wave duration/tachycardia CL <45% provided 86% sensitivity (95% CI 0.64 to 0.97) and 98% specificity (95% CI 0.87 to 1.0) for focal AT. Figure 6 illustrates further examples of each rhythm. Ventricular rate in the test set was higher for patients with focal than macro–re-entrant AT (139 ± 55 beats/min vs. 84 ± 17 beats/min, p = 0.02).

Discussion
Quantitative ECG indexes effectively separate focal atrial tachycardia, in which atrial activation is short and the diastolic interval long, from atrial macro–re-entry without sawtooth F waves, in which activation spans most of the cycle with short diastolic intervals. P waves in focal AT were shorter than F waves in macro–re-entrant AT and occupied a shorter portion of the tachycardia cycle. Our methods allowed P- or F-wave measurements even when overlying T waves and were applicable to steady-state ECGs regardless of the atrial:ventricular conduction ratio, without maneuvers such as atrial or ventricular pacing. This ECG technique could be applied at the bedside to clarify the diagnosis and guide the approach to ablation.

Electrophysiologic separation of focal AT from macro–re-entrant AT. Shorter atrial activation and longer diastolic intervals are a robust identifier of focal AT from macro–re-entrant AT (1). At EPS, however, high-spatial-
resolution mapping may be required to define the duration of intra-atrial activation and determine whether it is focal or continuous (Fig. 3). Because the ECG represents bi-atrial activation, P or F waves ideally represent the duration of atrial activation. These ECG results confirm that focal AT can be separated from macro-re-entrant AT by short atrial

Table 3  Validation Study: Diagnostic Accuracy of P- or F-Wave Indexes for Focal AT

<table>
<thead>
<tr>
<th>Quantitative ECG Index</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-wave duration ≤160 ms in tachycardia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>85.7</td>
<td>92.9</td>
<td>85.7</td>
<td>92.9</td>
</tr>
<tr>
<td>Y</td>
<td>85.7</td>
<td>92.9</td>
<td>85.7</td>
<td>92.9</td>
</tr>
<tr>
<td>Z</td>
<td>100</td>
<td>81.5</td>
<td>77.8</td>
<td>100</td>
</tr>
<tr>
<td>3-axis mean</td>
<td>90.0</td>
<td>90.0</td>
<td>82.6</td>
<td>95.0</td>
</tr>
<tr>
<td>P-duration: tachycardia CL ≤45%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>85.7</td>
<td>100</td>
<td>100</td>
<td>93.3</td>
</tr>
<tr>
<td>Y</td>
<td>85.7</td>
<td>92.9</td>
<td>85.7</td>
<td>86.7</td>
</tr>
<tr>
<td>Z</td>
<td>85.7</td>
<td>100</td>
<td>100</td>
<td>93.3</td>
</tr>
<tr>
<td>3-axis mean</td>
<td>86.0</td>
<td>98.0</td>
<td>95.2</td>
<td>91.1</td>
</tr>
</tbody>
</table>

CL = cycle length; ECG = electrocardiographic.

Figure 5  Training Study: ROC of P(F) Wave Duration: CL Ratio for Focal AT

(A) X, (B) Y, (C) Z, and (D) 3-axis mean, showing optimal cutpoint <45%. Abbreviations as in Figures 1 and 4.
activation and a long diastolic interval. Accordingly, activation in focal AT was not prolonged compared to sinus rhythm, reflecting the long diastolic time of each, but was prolonged relative to sinus rhythm in macro–re-entrant AT. We applied our indexes to 3 orthogonal leads because P or F waves may not be represented equally in all leads (5,9,10), although inter-lead variations were minimal (Table 2).

These indexes could be influenced by many factors. First, left atrial sizes were similarly and mildly dilated in each group (Table 1), although structural remodeling may be more likely in patients with macro–re-entrant AT (11). Second, none of our focal AT patients, but one-third of our macro–re-entrant AT patients, had a history of AF (Table 1). Remodeling could explain the prolonged sinus P waves, and possibly tachycardia F-waves, seen in macro–re-entrant AT patients (12,13). Third, differences in ventricular rates could theoretically influence our results. However, our methods were effective whether ventricular rates differed (validation study) or did not differ (training study) between groups. Fourth, the relatively well-preserved left ventricular ejection fractions in both groups largely exclude heart failure-related atrial remodeling (14). Nevertheless, these methods should be applied to patients with a significant history of prior AF or heart failure.

Prior ECG estimates of P(F)-wave duration and tachycardia CL. Few methods have been described to separate focal from macro–re-entrant AT from the ECG, possibly because of difficulties in precisely measuring P- or F-wave onset, particularly if superimposed on T waves. Prior studies mostly compared P- or F-wave shape in AT (9,10) or macro–re-entrant AT (4,5), although the waves are known to overlap. One study of selective pulmonary vein pacing to simulate focal AT (10) reported P-wave durations of 110 to 130 ms, in close agreement with our results. However, that study examined only P waves unobscured by T waves. Those data, and comparisons of our P(F)-wave durations against intra-cardiac atrial activation times (Fig. 3), validate and strengthen the clinical utility of our approach.

Spectra have been used to estimate CL from the ECG (15,16), yet they were inaccurate in this study, hindered by harmonics and noise (Fig. 2B.III). For this reason, our novel use of autocorrelation more accurately estimated CL.

Existing methods to identify and separate focal from macro–re-entrant AT. Visible ECG criteria for separating focal from macro–re-entrant AT have largely been discarded in favor of mapping at EPS (1) because many P- or F-wave shapes, including even sawtooth patterns (1), may occur in focal AT. Although F waves may have low amplitude in macro–re-entrant AT, particularly if left atrial (5), this can also occur in focal AT (1,2,10). Electrocardiogram shape criteria may thus confuse focal with macro–re-entrant AT (1) and multifocal AT with AF (17), and even atrial rates are similar between arrhythmias, as supported by this study (1) (Table 1).

Clinical significance. Accurate noninvasive identification of focal AT may enable better prognostication because AF
often follows macro–re-entrant AT (18) and requires anti-coagulant as well as anti-arrhythmic drugs. Because ablation approaches for focal and macro–re-entrant AT ablation may differ, noninvasive diagnosis may also guide ablation from the bedside 12-lead ECG. Identifying focal AT from the ECG enables the use of P-wave polarity to predict the site of tachycardia origin (9). Notably, polarity may not effectively localize macro–re-entry because the exit direction of activation is not predictable for many circuit locations—witness the positive F-wave in lead V1 in both typical right atrial flutter and left atrial macro–entry.

**Study limitations.** This is a small study and, in particular, these results require validation in patients after ablation and with coexisting AF and heart failure, in whom conduction slowing may further prolong P waves at baseline (14). Second, macro–re-entrant AT patients had higher amiodarone usage than those with focal AT, which may have lengthened tachycardia F waves or sinus rhythm P waves. However, 75% of macro–re-entrant AT patients did not use amiodarone, and analysis of P(F)-wave durations excluding patients taking amiodarone still showed a highly significant difference between focal and macro–re-entrant AT (p < 0.001 for each lead, data not shown). Third, P(F)-wave durations overlying T waves were intended as estimates, although, in fact, they approximated atrial activation times from detailed mapping (Fig. 3). Generating an “expected” T-wave by linear scaling from sinus rhythm assumes that the T-wave does not change in shape as rates vary. Although these simplifications were empirically successful, T-wave dynamics are far more complex (19). Future work could thus use the T-wave at the closest rate from a series of native or paced atrial rates. Alternatively, atrial separation could be achieved via differences between sinus P-wave (20) and T-wave (19) spectra, although spectral differences between P waves in focal AT and F waves in macro–re-entrant AT (8) are less well described.

**Conclusions**

Quantitative ECG indexes of shorter atrial activation and longer diastolic intervals provide plausible and robust separation of focal from macro–re-entrant AT. This approach was effective in our blinded validation study in cases with and without 1:1 atrioventricular conduction, when P or F waves overlay T waves, and in steady-state ECGs without the need for diagnostic maneuvers. Such methods could be used at the bedside to guide pharmacologic management and the approach to ablation before EPS.

**Acknowledgments**

The authors are grateful to Paul Clopton, MS, for statistical advice and to Kathleen Mills, BA, for helping to coordinate these studies.

**References**