Value of the P-Wave Signal-Averaged ECG for Predicting Atrial Fibrillation After Cardiac Surgery

Jonathan S. Steinberg, MD; Steven Zelenkofske, DO; Shing-Chiu Wong, MD; Mark Gelernt, MD; Robert Sciaccia, Eng ScD; Edith Menchavez, RN

Background. Atrial fibrillation (AF) is a commonly encountered arrhythmia in clinical practice, and it occurs frequently after cardiac surgery. The P-wave signal-averaged (SA) ECG noninvasively detects atrial conduction delay. Prior studies have described greater P-wave prolongation in patients with a history of AF, but prospective studies have not been performed.

Methods and Results. Consecutive patients undergoing cardiac surgery were enrolled. The P-wave SAECG was recorded before surgery from three orthogonal leads using a sinus P-wave template and a cross-correlation function. The averaged P wave was filtered with a least-squares-fit filter and combined into a vector magnitude, and total P-wave duration was measured. Patients were observed after cardiac surgery for the development of AF. One hundred thirty patients were enrolled, and 33 (25%) developed AF 2.6±2.0 days after surgery. Patients with AF more often had left ventricular hypertrophy on ECG (P<.05) and had a lower ejection fraction (P<.05). The P-wave duration on the SAECG was significantly longer in the AF patients than in those without AF: 152±18 versus 139±17 milliseconds (P<.001). An SAECG P-wave duration >140 milliseconds predicted AF with sensitivity of 77%, specificity of 55%, positive predictive accuracy of 37%, and negative predictive accuracy of 87%. The likelihood of experiencing AF was increased 3.9-fold if the SAECG P-wave duration was prolonged. P-wave SAECG results were independent of other clinical variables by multivariate analysis.

Conclusions. The P-wave duration recorded with the SAECG is a potent, accurate, and independent predictor of AF after cardiac surgery. (Circulation. 1993;88:2618-2622.)

Key Words • arrhythmia • surgery • electrocardiography

Atrial fibrillation (AF) is one of the most common arrhythmias managed in cardiology practice and is generally believed to result from reentry. The reentrant circuits are multiple and circulating (the multiple-wavelet hypothesis); many electrophysiological factors play a role in the development of AF, and like all reentrant rhythms, slow conduction is probably a critical prerequisite in many patients.

Recently, we3 and others4,5 have used the signal-averaged (SA) ECG to characterize atrial conduction delay during sinus rhythm as a marker of risk of AF. With this methodology, a prolonged P-wave duration, recorded and filtered by SAECG techniques modified for P-wave analysis, was strongly associated with prior AF compared with age- and disease-matched control subjects.3

AF occurs in a variety of settings and is generally associated with an increased risk of morbid consequences and even mortality. The ability to define the risk groups for AF would have important clinical relevance. One group in whom the risk is well defined and substantial, yet only short-term, is patients undergoing cardiac surgery. In this group, the incidence of AF is as high as 40%,8 and AF may be associated with hemodynamic instability, thromboembolus, and prolonged hospitalization.

The purpose of this investigation was to evaluate prospectively whether the P-wave SAECG can predict the development of AF in a large group of patients after cardiac surgery.

See p 2980

Patient Eligibility

All patients scheduled for nonemergent cardiac surgery at the St Luke’s/Roosevelt Hospital Center were screened for possible participation in this study. Patients were eligible if the preoperative underlying rhythm was sinus, if there was no requirement for class I or III antiarrhythmic medication, and if there was no previous history of AF. The study was approved by the Institutional Review Board of St Luke’s/Roosevelt Hospital Center, and all patients gave informed written consent.

P-Wave SAECG

The methodology of P-wave SAECG recording and analysis has been described previously.3 Briefly, an
Clinical Characteristics of Study Patients

<table>
<thead>
<tr>
<th></th>
<th>AF (n=33)</th>
<th>No AF (n=97)</th>
<th>Total (n=130)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>68±9</td>
<td>66±10</td>
<td>62±11</td>
</tr>
<tr>
<td>Male sex</td>
<td>27 (62%)</td>
<td>72 (74%)</td>
<td>99 (76%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>15 (45%)</td>
<td>51 (53%)</td>
<td>66 (51%)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>7 (21%)</td>
<td>37 (28%)</td>
<td>44 (34%)</td>
</tr>
<tr>
<td>Prior myocardial infarction</td>
<td>5 (15%)</td>
<td>16 (16%)</td>
<td>21 (16%)</td>
</tr>
<tr>
<td>LVH on ECG</td>
<td>4 (12%)*</td>
<td>2 (2%)</td>
<td>6 (5%)</td>
</tr>
<tr>
<td>P-wave duration on standard ECG, ms</td>
<td>96±22</td>
<td>88±30</td>
<td>90±28</td>
</tr>
<tr>
<td>EF</td>
<td>0.43±0.14*</td>
<td>0.50±0.15</td>
<td>0.48±0.15</td>
</tr>
<tr>
<td>EF &lt;0.40</td>
<td>15 (46%)†</td>
<td>18 (18%)</td>
<td>33 (25%)</td>
</tr>
<tr>
<td>CABG</td>
<td>24 (79%)</td>
<td>83 (66%)</td>
<td>107 (84%)</td>
</tr>
<tr>
<td>Valve surgery</td>
<td>7 (21%)</td>
<td>14 (14%)</td>
<td>21 (16%)</td>
</tr>
<tr>
<td>Aortic cross-clamp time, min</td>
<td>51.1±26.0</td>
<td>42.9±27.0</td>
<td>44.9±26.9</td>
</tr>
</tbody>
</table>

AF indicates atrial fibrillation; LVH, left ventricular hypertrophy; EF, ejection fraction; and CABG, coronary artery bypass graft surgery.

*P<.05, †P<.01, AF vs no AF.

Orthogonal lead arrangement similar to QRS acquisition was used. The QRS was used as the trigger for the signal-averaging process; however, the averaging window was altered. The fiducial point was shifted to the extreme right side of the 300-millisecond window, and the P wave and PR segment were exposed. A sinus P-wave template was selected by the operator, and P-wave complexes (e.g., ectopic beats, noisy beats, beats shifted because of autonomic tone) that did not match the template with a 99% correlation coefficient were automatically rejected. The P waves were acquired until a noise end point <0.3 μV was achieved (100 to 700 beats). Studies were usually completed in 20 to 30 minutes. A least-squares-fit filter with a window width of 100 milliseconds (equivalent to a high-pass cutoff of 29 Hz) was applied to the averaged output. The P-wave complexes of the three bipolar leads were combined into a vector magnitude by the formula \((X^2+Y^2+Z^2)^{1/2}\). Total P-wave duration was measured visually by consensus of two investigators who were unaware of patient end points.

**Standard ECG**

A standard 12-lead ECG recorded within 24 hours of the SAECG was reviewed for each patient. Total P-wave duration in limb lead II was manually measured. A P-wave duration on the standard ECG exceeding 110 milliseconds was considered abnormal. The ECG was also analyzed for left ventricular hypertropy (LVH) by use of Romholt-Estes criteria.

**In-Hospital Follow-up**

Patients were seen by one of the investigators on days 1, 2, 3, 7, 10, and 14 (not all patients remained hospitalized after 7 days) after cardiac surgery. During the early postoperative period, all patients were monitored with continuous ECG telemetry as well as daily 12-lead ECGs. Patients were transferred to a telemetry unit or a regular surgery floor with no telemetry at the discretion of the primary cardiologist and/or surgeon. During this phase, daily 12-lead ECG and telemetry results, when available, were reviewed. ECGs were recorded in all instances when clinical evaluation suggested AF. Any episode of AF lasting longer than 30 minutes was considered a study end point. The duration of AF was recorded. The postoperative day when AF started was also recorded. If more than one AF event occurred, the earliest day of AF was used.

**Statistical Analysis**

Patients were grouped on the basis of the development of AF (one or more episodes versus no episodes). Data are summarized as mean±SD for continuous variables, and the significance of group differences was determined by Student’s t test. Discrete variables are reported as percent prevalence and analyzed by Fisher’s exact test. Multivariate analysis was performed with stepwise logistic regression in which the potential significance of the addition of each variable to the prognostic model was tested sequentially by χ².

**Results**

**Occurrence of AF**

A total of 130 patients were enrolled in this study. The clinical characteristics of these patients are shown in the Table. Of the 21 patients who had valve surgery, 4 underwent mitral valve replacement and 17 underwent aortic valve replacement. During the period of observation, 33 patients (25%) developed AF. AF occurred 2.6±2.0 days (range, 1 to 8 days) after surgery. The vast majority (25 of 33) had AF on day 2 or 3. AF duration ranged from as short as 1 hour to as long as 12 days. The mean duration of AF was 2.3±2.4 days before self-termination or chemical or electrical cardioversion.

**Clinical Characteristics of Patients With AF**

There were only two demographic characteristics that distinguished patients who developed AF from those who had no AF (Table). Patients with AF more often had LVH on the preoperative ECG and had a lower ejection fraction (EF). However, LVH was present in small numbers of patients with AF.
There was no difference in the use of β-blockers in the AF group (42%) compared with those who did not experience AF (34%). However, therapy was not standardized; use, dosage, and timing after surgery were at the discretion of the primary physician. Similarly, digoxin therapy was as prevalent in those who had AF (83%) as in those who did not (75%). Postoperative use of class I antiarrhythmic drugs was uncommon in both groups: 9% in the AF group and 10% in the group without AF. Only 12% of patients developed AF while receiving intravenous inotropic or pressor support: two patients were receiving dobutamine and two patients were receiving renal dose dopamine. The use of these medications was comparable in patients who did not develop AF on days 2 (11%), 3 (9%), and 4 (8%).

**Standard ECG Results**

The AF patients had a longer P-wave duration on the standard ECG, but this difference did not achieve statistical significance (Table). The proportion of patients in whom P-wave duration exceeded 110 milliseconds was 27% in the AF group and 20% in the group without AF (P=NS).

**P-Wave SAECG Results**

The signal-averaged P-wave duration was significantly (P<.001) more prolonged in the patients who experienced AF than in those who did not experience AF (152±18 versus 139±17 milliseconds); the P wave was 9.5% longer in the AF patients than in the patients who did not develop AF.

The receiver-operator characteristic curve as a function of the SAECG P-wave duration is plotted in Fig. 1. Sensitivity and specificity were strongly related to P-wave duration. The occurrence of AF was best predicted by an SAECG P-wave duration >140 milliseconds with sensitivity of 77%, specificity of 55%, positive predictive accuracy of 37%, and negative predictive accuracy of 87%. Maximal specificity (70%) with adequate sensitivity (50%) was present at a P-wave duration of 150 milliseconds. However, positive predictive accuracy was not increased (37%).

If the analysis was restricted to coronary artery bypass graft surgery patients only, the results remained the same. The 24 patients who developed AF had a more prolonged SAECG P-wave duration (156±19 milliseconds) than the 83 patients who did not develop AF (139±17 milliseconds, P<.001).

Logistic regression analysis identified only one variable as predictive of AF: P-wave duration >140 milliseconds on the SAECG. The likelihood of developing AF was increased 3.9-fold (P<.0001) when the signal-averaged P-wave duration was prolonged >140 milliseconds compared with patients in whom the P-wave duration was not prolonged >140 milliseconds. The addition of EF or LVH to models containing SAECG failed to improve prediction. Neither EF nor LVH was predictive of the SAECG P-wave duration.

Representative SAECG tracings are shown in Fig 2.

**Discussion**

**Development of P-Wave SAECG**

The SAECG has been successfully used to accurately measure the entire ventricular activation period, including delayed conduction through small diseased regions. In several studies,6-11 the total QRS duration on the SAECG has predicted the development of sustained ventricular arrhythmias caused by reentry.

On the basis of these general considerations, similar techniques have recently been applied to analysis of the P wave3-5 and its association with AF. Mechanistically, AF is complex. However, experimental data from Allessie et al1 strongly support the concept originally proposed by Moe that AF is based on the simultaneous random activation of multiple wavelets distributed throughout the atria (the multiple-wavelet hypothesis). Many factors can facilitate the initiation and maintenance of AF according to this model.12 One such factor, common to all reentrant rhythms, is depressed conduction, which would result in prolonged atrial activation, ie, lengthening of the P wave recorded by the ECG.

The SAECG can enhance detection of conduction delay, especially if it occurs late in relatively small portions of the atria. Using SAECG techniques adapted for P-wave recording and analysis, we have previously demonstrated that the presence of a prolonged P-wave duration is strongly associated with a previous history of AF.3 P-wave prolongation predicted AF with an 80% sensitivity and 93% specificity in a sample of AF patients and age- and disease-matched control subjects.

The principal adaptations for P-wave SAECG (compared with QRS SAECG) were P-wave template matching with extremely accurate alignment and change in filtering to avoid ringing artifact and contamination of the P wave by QRS energy. Other investigators4-10 using somewhat different methodology and techniques have recently reported similar success. To date, the evaluation of P-wave SAECG has been tested by use of case-control methods.3-5 This is the first study to prospectively apply the P-wave SAECG for predicting AF.

**AF After Cardiac Surgery**

AF is common after cardiac surgery, occurring in 5% to 40% of patients.13,14 In the present study, we observed an incidence of 25%, similar to previous observations. AF generally occurs within the first week after surgery; it had a peak incidence on days 2 and 3 in our study. Approximately 76% of the total group of
33 patients developed AF during days 2 and 3; most AF was present for at least several hours and often persisted for several days.

Although often benign, AF can be associated with a number of complications in the postoperative patient, including hemodynamic compromise and stroke. The occurrence of AF can also significantly lengthen the duration of hospitalization.13

Previous clinical studies have not demonstrated consistent findings regarding the risk factors for AF.6.15 Among the many preoperative, intraoperative, and postoperative patient characteristics studied, those patients who were older or not taking β-blockers seemed to be at greatest risk. Among non-SAECG variables measured, only low EF and LVH on preoperative ECG identified an increased risk of postoperative AF in our study population. Both factors indicate underlying heart disease and thus risk of AF.

**P-Wave SAECG for Predicting AF After Cardiac Surgery**

The P-wave duration measured on the SAECG emerged as the most potent predictor of postoperative AF. It was far more predictive than the significant clinical variables, reduced EF and LVH on ECG, and was independently predictive by multivariate analysis. The optimal SAECG P-wave duration for predicting AF was 140 milliseconds; those patients with an abnormal SAECG faced a nearly fourfold increase in risk.

The finding of a prolonged P-wave duration implies lengthened atrial activation time and depressed atrial conduction. This preoperative observation suggests that patients who develop postoperative AF have an intrinsic atrial electrical abnormality that predisposes to AF. However, AF had not previously occurred in these patients; presumably, the presence of one or more of the many stresses present in the postoperative state triggered the AF.

The pathophysiology of this underlying electrical abnormality cannot be defined from the current investigation. Experimental data suggest that atrial enlargement and hypertrophy create the requisite milieu for AF.16 Because the SAECG was abnormal before surgery, anatomic or dynamic conditions developing as a result of surgery could not be responsible for the SAECG abnormality. Because of clustering of AF early after cardiac surgery, it is clear that factors other than conduction delay alone account for the high incidence of postoperative AF.
The ability to predict AF after cardiac surgery could have important clinical implications. Patients with heightened risk of AF may require greater observation by ECG telemetry or may be candidates for medical intervention known to protect against AF, such as β-blocker therapy.17,19

The use of P-wave SAECG in this population will need to be confirmed in other populations before these results can be extrapolated. Other high-risk populations, such as patients with valvular heart disease, hypertension, or coronary heart disease, may be suitable candidates.

Conclusions

The SAECG can be used to record P-wave duration. The P-wave duration recorded with the SAECG is a potent, accurate, and independent predictor of AF after cardiac surgery.

Acknowledgments

The authors would like to thank Gene Joyner for preparation of the manuscript, Dr Frederick Ehlerdt for careful and critical review of the manuscript, and the cardiologists and cardiovascular surgeons of St Luke’s/Roosevelt Hospital Center.

References
Value of the P-wave signal-averaged ECG for predicting atrial fibrillation after cardiac surgery.

J S Steinberg, S Zelenkofske, S C Wong, M Gelernt, R Sciacca and E Menchavez

*Circulation*. 1993;88:2618-2622
doi: 10.1161/01.CIR.88.6.2618

*Circulation* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1993 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/88/6/2618

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in *Circulation* can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to *Circulation* is online at:
http://circ.ahajournals.org/subscriptions/