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ELECTROPHYSIOLOGIC STUDIES

Role of Signal Averaging of the Surface QRS Complex in Selecting Patients With Nonsustained Ventricular Tachycardia and High Grade Ventricular Arrhythmias for Programmed Ventricular Stimulation

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Signal averaging of the surface QRS complex was performed before programmed ventricular stimulation in 53 individuals with high grade ventricular arrhythmias or nonsustained ventricular tachycardia, or both. An abnormal signal-averaged electrocardiogram (ECG) was recorded in 22 patients and was associated with inducible ventricular tachycardia in 12 (55%) of the 22. In contrast, a normal signal-averaged ECG was associated with inducible tachycardia in only 1 (3%) of 31 individuals ($p < 0.005$). The group with inducible tachycardia had a longer duration of the signal-averaged QRS complex (124 ± 19 versus 96 ± 26 ms) and of low amplitude signals (44 ± 13 versus 29 ± 11 ms) ($p < 0.005$). In addition, the root mean square voltage of the terminal 40 ms was lower in this group (20 ± 14 versus 48 ± 34 μV, $p < 0.005$).

Twenty-seven of the 53 subjects had a prior myocardial infarction; 17 (63%) of the 27 had an abnormal signal-averaged ECG, and ventricular tachycardia was inducible in 10 (59%) of the 17. A normal signal-averaged ECG was recorded in 10 of the 27 patients and only 1 (10%) of these 10 had inducible tachycardia. An abnormal signal-averaged ECG had a 91% sensitivity and a 56% specificity with respect to subsequent induction of tachycardia.

During long-term follow-up, 2 (15%) of the 13 patients with inducible ventricular tachycardia who were treated with electrophysiologically guided antiarrhythmics therapy died suddenly; the remaining 11 patients (85%) are alive 15 ± 10 months after electrophysiologic testing. Both of these patients who died had an abnormal signal-averaged ECG. In contrast, only 2 (5%) of the 40 patients with no inducible tachycardia, both with a normal signal-averaged ECG, have had an arrhythmic event; the other 38 patients have remained free of sustained ventricular arrhythmia for a follow-up period of 17 ± 9 months.

In conclusion: 1) Signal averaging of the surface QRS complex is useful in identifying patients with nonsustained ventricular tachycardia or high grade ventricular arrhythmias, or both, who will have inducible ventricular tachycardia on programmed ventricular stimulation. 2) Inducibility of arrhythmia is unlikely in individuals who have a normal signal-averaged ECG despite the presence of complex ventricular arrhythmia. 3) The occurrence of spontaneous sustained ventricular tachyarrhythmias is low in patients with a prior myocardial infarction and without inducible ventricular tachycardia who have nonsustained ventricular tachycardia or complex ventricular arrhythmias and a normal signal-averaged ECG. 4) Signal-averaged electrocardiography may be useful in detecting low risk groups of patients with complex ventricular arrhythmias who do not require electrophysiologic testing or antiarrhythmic therapy.

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Several studies (1–4) suggest that patients with nonsustained ventricular tachycardia or high grade ventricular arrhythmias, or both, who do not have inducible ventricular tachyarrhythmias on programmed ventricular stimulation are at low risk for subsequent spontaneous tachyarrhythmic events. These patients probably do not need antiarrhythmic therapy if they are asymptomatic. In contrast, patients with nonsustained ventricular tachycardia or high grade ventricular arrhythmias who have inducible ventricular tachycardia on programmed ventricular stimulation may require antiarrhythmic therapy. Continuous ambulatory electrocardiographic (ECG) monitoring does not clearly indicate which patients with nonsustained ventricular tachycardia or high grade ventricular arrhythmias will have inducible tachycardia.

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Signal averaging of the surface QRS complex is a technique that can identify patients who have an underlying myocardial substrate capable of sustaining reentrant forms of ventricular tachycardia. This technique has been shown to aid in identifying those patients early after myocardial infarction who will subsequently develop malignant ventricular tachyarrhythmias (5–7) as well as those patients with syncope of unknown origin who will have inducible ventricular tachyarrhythmias on programmed ventricular stimulation (8–10). Thus, this prospective study was conducted to determine whether signal averaging of the surface QRS complex can detect patients with nonsustained ventricular tachycardia or high grade ventricular arrhythmia, or both, who will have ventricular tachycardia induced by programmed ventricular stimulation.

Methods

Study patients. Fifty-three patients were referred for evaluation of documented high grade ventricular arrhythmias, defined as ≥10 ventricular premature depolarizations/hour or ventricular couplets or nonsustained ventricular tachycardia on ambulatory ECG monitoring. Only three patients did not have nonsustained ventricular tachycardia recorded. Fourteen patients (26%) had experienced one or more syncopal or presyncopal episodes, 16 (30%) had awareness of ectopic beats and 23 (43%) were asymptomatic.

Patients were excluded from entry if 1) the spontaneous arrhythmia was detected <1 month after an acute myocardial infarction, 2) they were receiving antiarrhythmic agents at the time of the recorded arrhythmia, or 3) a bundle branch block configuration was present on the surface ECG.

Twenty-four hour ambulatory electrocardiographic monitoring. All patients studied had had nonsustained ventricular tachycardia or high grade ventricular arrhythmias detected on 24 hour ambulatory ECG monitoring. In each case, the recording was initially processed and evaluated with an on-line computer, subsequently reviewed by a nurse or technician trained in the interpretation of monitored arrhythmias and finally assessed by the two study physicians.

Signal-averaged electrocardiography. All patients underwent signal averaging of the surface QRS complex before electrophysiologic testing in the absence of antiarrhythmic agents. Seven silver-silver chloride electrodes were attached after the skin was cleaned with alcohol to comprise three orthogonal bipolar electrodes as follows: 1) The horizontal (X) electrodes were positioned at the right and left midaxillary lines at the fourth intercostal space; 2) the vertical (Y) electrodes at the left parastenal second intercostal space and the lead V_3 position; and 3) the sagittal (Z) electrodes at the lead V_5 position anteriorly and a corresponding posterior site. A ground electrode was positioned on the eighth rib in the right midaxillary line.

A high resolution ECG (Arrhythmia Research Technology, 101 System) with high gain amplification and bidirectional Butterworth filters (40 to 250 Hz) was used for signal averaging. Approximately 200 beats were amplified, filtered, digitally sampled and processed. A Hewlett-Packard 7470A X-4 plotter was utilized for data printouts. Signal averaging was performed in the absence of antiarrhythmic agents within ≤72 h of the electrophysiologic studies.

Programmed ventricular stimulation. After giving informed consent, all patients underwent electrophysiologic testing in the absence of antiarrhythmic agents and in the fasting state. Two quadripolar electrode catheters (USCI) were inserted percutaneously through the femoral vein and positioned under fluoroscopy in the high right atrium, across the tricuspid valve for recording of His bundle activity, and in the right ventricular apex and outflow tract. The distal poles were used for stimulation and the proximal poles for recording. Stimulation was performed with a programmable stimulator (Bloom Associates) that delivered impulses of 1.5 ms duration at a current that was twice threshold. Recordings were obtained in the following manner as previously described (8). The following stimulation protocol was utilized:

1. *Premature ventricular stimulation as follows:*
   a. *S_1S_2 method:* A single ventricular stimulus (S_2) was introduced after every eight ventricular paced beats (S_1S_1) at decreasing coupling intervals until ventricular refractoriness occurred.
   b. *$S_1S_2S_3$ method:* Two ventricular simuli (S_2S_3) were introduced during a basic paced ventricular cycle (S_1S_1) as before, beginning with an S_1S_2 interval 50 ms longer than the ventricular effective refractory period and an S_2S_3 interval equal to the S_1S_2 interval. The S_2S_3 interval was progressively decreased by 10 ms until S_3 was refractory. S_1S_2 was then decreased and S_3 reintroduced until S_3 captured the ventricle or S_2 became refractory.
2. *Incremental ventricular pacing* up to rates of 240 beats/min.

No patient studied for evaluation of nonsustained ventricular tachycardia or high grade ventricular arrhythmias had S_4 stimulation. All patients underwent ventricular premature stimulation at two cycle lengths (600 and 450 ms). If stimulation of the right ventricular apex did not initiate ventricular tachyarrhythmia, then right ventricular outflow tract stimulation was performed with the same protocol.

Definitions. The following definitions are used:

1. Nonsustained ventricular tachycardia on ambulatory ECG monitoring was defined as ≥3 repetitive wide complex ventricular premature beats at a rate of 120 beats/min lasting <30 s and terminating spontaneously.

2. High grade ventricular arrhythmias on ECG monitoring were defined as ≥10 ventricular premature depolarizations per hour or ventricular couplets, or both.

3. *Sustained ventricular tachycardia* was defined as a wide complex tachycardia of ventricular origin that was faster than 120 beats/min. This arrhythmia had to last >30 s or result in hemodynamic compromise requiring prompt termination.

4. *Signal-averaged variables* were measured at bidirectional Butterworth filter frequencies of 40 to 250 Hz, as previously reported (11–13).

   a. *The QRS duration* was taken as the time in milliseconds from the onset to the end point of the QRS vector complex. The end of the QRS complex was identified by the algorithm of Simson (11). A QRS duration >114 ms is considered abnormal for our laboratory.

   b. *The duration of low amplitude signals* was the time in milliseconds from the end of the signal-averaged QRS vector complex to the point at which signals measured 40 μV. Low amplitude signals lasting >38 ms are considered abnormal for our laboratory.

   c. *The root mean square voltage of the terminal 40 ms of the QRS vector complex was determined.* A value <20 μV is considered abnormal for our laboratory.

5. *Programmed ventricular stimulation:*

   a. *Nonsustained ventricular tachycardia* was defined as induction of ≥5 repetitive ventricular responses present for <30 s. The repetitive responses had to be reproducibly inducible and of a monomorphic nature.

   b. *Sustained ventricular tachycardia* was defined as a monomorphic tachyarrhythmia of ventricular origin lasting >30 s or accompanied by hemodynamic compromise, requiring cardioversion.

Statistics. All values presented are mean values ± SD. Unpaired Student's *t* test and chi-square analysis were used for comparisons. Sensitivity refers to the proportion of patients with a particular abnormal signal-averaged variable and inducible ventricular tachycardia in the total number of patients with inducible ventricular tachycardia. Specificity refers to the ratio of individuals with a particular normal signal-averaged variable and no inducible tachycardia to the entire noninducible group. Predictive accuracy is the percent of the total group individuals with a specific abnormal signal-averaged variable and inducible ventricular tachycardia at programmed ventricular stimulation.

Results

Patients with inducible versus noninducible ventricular tachycardia (Table 1). Of the 53 patients who had nonsustained ventricular tachycardia or high grade ventricular arrhythmias, or both, recorded on ambulatory ECG monitoring, 13 patients (25%) had inducible ventricular tachycardia at programmed ventricular stimulation (Group I). Of the 13 patients with inducible ventricular tachycardia, 8 (62%) had induction of a sustained monomorphic ventricular tachycardia and 5 (38%) had induction of reproducible, monomorphic nonsustained ventricular tachycardia. Forty patients (75%) had no inducible ventricular tachyarrhythmias (Group II). The mean ages of these two groups were similar. There was a similar frequency of nonsustained ventricular tachycardia and high grade ventricular arrhythmias in the two groups. Although not statistically significant, there was a trend toward a lower left ventricular ejection fraction in the group with than in the group without inducible tachycardia.

Table 1. Characteristics of 53 Patients With High Grade Ventricular Arrhythmias or Nonsustained Ventricular Tachycardia, or Both

	Inducible Group (n = 13)	Noninducible Group (n = 40)
Mean age (yr)	60 ± 10	62 ± 11
Ejection fraction (%)	26 ± 8	42 ± 15
Nonsustained VT	13 (100%)	35 (88%)
High grade arrhythmia	10 (77%)	30 (75%)
Prior myocardial infarction*	11 (85%)	16 (40%)
Cardiomyopathy	2 (15%)	8 (20%)
Mitral valve prolapse		4 (10%)
Hypertension		7 (17%)
Valvular heart disease		1 (3%)
No apparent heart disease		4 (10%)

*$p < 0.05$. VT = ventricular tachycardia.

The patients with inducible ventricular tachycardia were more likely to have had a prior myocardial infarction ($p < 0.05$). Eleven (85%) of the 13 patients with inducible tachycardia had had a prior myocardial infarction compared with only 16 (40%) of the 40 patients without inducible tachyarrhythmias. The presence of cardiac disease other than a remote myocardial infarction was greater in the group of patients with noninducible ventricular tachyarrhythmias.

Signal-averaged variables (Table 2). Twenty-two (42%) of the 53 patients with a complex ventricular arrhythmias had an abnormal signal-averaged ECG. Twelve (55%) of these individuals had inducible ventricular tachycardia, compared with only 1 (3%) of the 31 patients with a normal signal-averaged ECG ($p < 0.005$). The signal-averaged variables were more abnormal in patients with inducible ventricular tachycardia (Group I) than in the noninducible Group II. The QRS duration (124 ± 19 versus 96 ± 16 ms) and the duration of low amplitude signals (44 ± 13 versus 29 ± 11 ms) were longer in Group I patients than in Group II patients ($p < 0.005$), whereas the root mean square voltage of the terminal 40 ms was significantly lower in Group I patients (20 ± 14 ms) than in Group II patients (48 ± 34 ms, $p < 0.005$).

Table 2 highlights the number of abnormal signal-averaged variables in all patients with nonsustained ventricular tachycardia or high grade ventricular arrhythmias on ambulatory ECG monitoring. Whether considering one or more, two or more or three abnormal variables, there was a

Table 2. Signal Averaging in 53 Patients With High Grade Ventricular Arrhythmias or Nonsustained Ventricular Tachycardia, or Both

Number of Abnormal Variables*	Inducible Group (n = 13)	Noninducible Group (n = 40)	Sensitivity (%)	Specificity (%)	Predictive Accuracy (%)
>1	12 (92%)	10 (25%)	92	75	60
≥2	9 (69%)	3 (8%)	69	93	87
3	7 (54%)	1 (3%)	54	98	87

*$p < 0.005$.

Table 4. Signal Averaging Variables in 27 Patients With Prior Myocardial Infarction and High Grade Ventricular Arrhythmias or Nonsustained Ventricular Tachycardia, or Both

Number of Abnormal Variables	Inducible Group (n = 11)	Noninducible Group (n = 16)	Sensitivity (%)	Specificity (%)	Predictive Accuracy (%)
≥1*	10 (91%)	7 (44%)	91	56	70
≥2†	8 (73%)	3 (19%)	73	82	78
3	6 (55%)	4 (25%)	55	75	67

*$p < 0.05$; †$p < 0.01$.

higher incidence of abnormal signal-averaged variables in the patients with inducible ventricular tachycardia than in the noninducible group ($p < 0.005$). The presence of one or more abnormal signal-averaged variables resulted in the greatest sensitivity (92%); however, the specificity was greatest (98%) when an abnormal signal-averaged ECG was considered as one in which all three variables were abnormal. The predictive accuracy ranged from 60 to 87%.

Postmyocardial infarction patients (Tables 3 and 4). Because there was a higher incidence of prior myocardial infarction in the patients with inducible ventricular tachycardia, the 27 patients with prior myocardial infarction (mean age 61 ± 11 years) were analyzed separately. An abnormal signal-averaged ECG was present in 17 (63%) of these patients; 10 (59%) of these had inducible ventricular tachycardia on programmed ventricular stimulation. A normal signal-averaged ECG was present in 10 patients, only 1 (10%) of whom had inducible ventricular tachycardia ($p = 0.08$). There was a trend toward a lower left ventricular ejection fraction in the group of patients with inducible ventricular tachyarrhythmias; however, this difference did not reach statistical significance. The quantitative signal-averaged variables were significantly more abnormal in the patients with inducible tachycardia (Table 3). The duration of the signal-averaged QRS complex (124 ± 19 versus 105 ± 18 ms) and the duration of low amplitude signals (43 ± 13 versus 30 ± 12 ms) were longer in the patients with a prior myocardial infarction and inducible tachycardia ($p < 0.05$), whereas the root mean square voltage of the terminal 40 ms was lower in this group (21 ± 14 versus 40 ± 26 μV, $p < 0.05$).

Table 3. Signal Averaging in 27 Patients With Prior Myocardial Infarction and High Grade Ventricular Arrhythmias or Nonsustained Ventricular Tachycardia, or Both

	Inducible Group (n = 11)	Noninducible Group (n = 16)
LVEF (%)	30 ± 13	39 ± 19
QRS* (ms)	124 ± 19	105 ± 18
LAS* (ms)	43 ± 13	30 ± 12
RMS* (μV)	21 ± 14	40 ± 26

*$p < 0.05$. LAS = duration of low amplitude signals; LVEF = left ventricular ejection fraction; RMS = root mean square voltage of the terminal 40 ms of the QRS vector complex; QRS = duration of the signal-averaged vector complex.

The incidence of abnormal signal-averaged variables and the corresponding sensitivities, specificities and predictive accuracies in patients with a prior myocardial infarction are shown in Table 4. The patients with inducible ventricular tachycardia had an abnormal signal-averaged ECG more often than did those without inducible tachycardia. The sensitivity was greatest (91%) if one or more signal-averaged variables were required, whereas the specificity was highest (82 and 75%, respectively) if two or three variables were necessary to distinguish an abnormal signal-averaged ECG. The predictive accuracy was greatest (78%) when two or more abnormal signal-averaged variables were considered in determining an abnormal signal-averaged ECG.

Of the 27 patients with a prior myocardial infarction, 11 had an inferior infarct and 14 an anterior infarct (in 2 patients the infarct could not be localized); the inducibility of ventricular tachycardia was similar in both subgroups (45 versus 43%). Five (83%) of the six patients with inducible ventricular tachycardia and anterior infarction had abnormal signal-averaged variables as compared with all five (100%) of the patients with inferior infarction and inducible tachycardia. In contrast, three (60%) of the five patients with no inducible ventricular tachycardia and prior anterior infarction and four (44%) of the nine individuals with prior inferior infarction and no inducible tachycardia had an abnormal signal-averaged ECG. An abnormal signal-averaged ECG was highly sensitive in predicting inducibility of ventricular tachycardia in patients with either inferior or anterior infarction (100 and 83%, respectively); however, the specificity was only intermediate in patients with prior inferior (55%) or anterior (40%) infarction. The predictive accuracy of signal-averaged ECG was 71% for patients with a prior inferior infarction and 64% for those with a prior anterior infarction.

Examples of two patients with prior myocardial infarction and complex ventricular arrhythmias are shown in Figure 1. Panel A is the signal-averaged ECG of a 65 year old man with a prior anterior infarction. Left ventricular systolic function

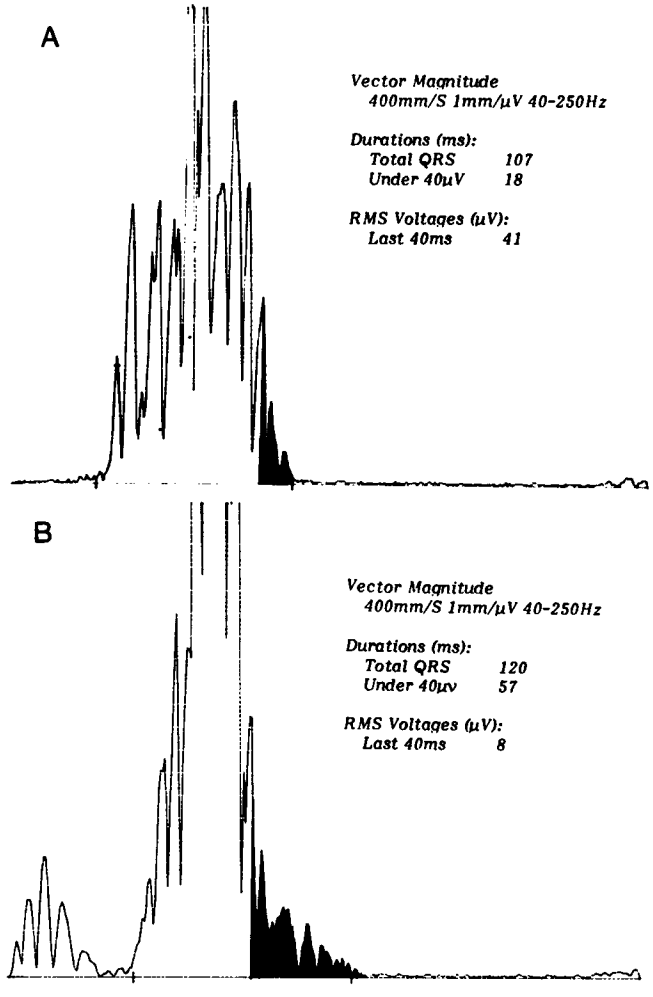

Figure 1. A, Signal-averaged electrocardiogram (ECG) from a 65 year old man with prior anterior myocardial infarction. The left ventricular ejection fraction was 27%. Holter ECG monitoring revealed 55 ventricular premature beats/h, 6 couplets and 14 episodes of nonsustained ventricular tachycardia. No ventricular tachycardia was induced on programmed ventricular stimulation. **B,** Signal-averaged ECG from a 55 year old man with prior inferior myocardial infarction. The left ventricular ejection fraction was 29%. Holter ECG monitoring revealed 118 ventricular premature beats/h, 112 couplets and 2 episodes of nonsustained ventricular tachycardia. Sustained monomorphic ventricular tachycardia was initiated on programmed ventricular stimulation. Note the difference in the three signal-averaged ECG variables in the two patients. RMS = root mean square voltage of the terminal 40 ms.

was impaired and frequent ventricular premature depolarizations, couplets and nonsustained ventricular tachycardia were present. All three signal-averaged variables were normal and no ventricular tachyarrhythmia was initiated by programmed ventricular stimulation. In contrast, panel B highlights the signal-averaged ECG in a 55 year old man with compromised left ventricular systolic function. In addition to complex ventricular arrhythmia, all three signal-averaged variables were abnormal. Sustained, monomorphic ventricular tachycardia was induced at programmed ventricular stimulation.

Patients with cardiomyopathy and high grade ventricular arrhythmias or nonsustained ventricular tachycardia. The significance of complex ventricular arrhythmia and the results of programmed ventricular stimulation in patients with cardiomyopathy have been questioned. In our group, ventricular tachycardia was inducible in 2 (20%) of the 10 individuals with a cardiomyopathy and associated high grade ventricular arrhythmia or nonsustained ventricular tachycardia, or both. Both patients had one or more abnormal signal-averaged variables. All eight patients with cardiomyopathy who had no inducible ventricular tachycardia, had a normal signal-averaged ECG.

Prospective follow-up of patients with high grade ventricular arrhythmias or nonsustained ventricular tachycardia. Of the 13 patients with complex ventricular arrhythmias and an abnormal signal-averaged ECG who had inducible ventricular tachycardia on programmed ventricular stimulation, 2 (15%) have died. One, a young woman who discontinued amiodarone because of a phototoxic skin reaction, died suddenly within 4 months of the study. The other died suddenly after 25 months of therapy with quinidine. The remaining 11 patients (82%) have been free of sustained ventricular arrhythmias for 15 ± 10 months. No patient with an abnormal signal-averaged ECG who had no inducible ventricular tachycardia has had sustained ventricular tachyarrhythmia or sudden death.

Of the 40 patients with complex ventricular arrhythmia and no inducible ventricular tachycardia, 6 (15%) were treated with a type I antiarrhythmic agent for supraventricular tachyarrhythmia or awareness of ventricular arrhythmia. One patient with a normal baseline signal-averaged ECG developed sustained ventricular tachycardia while receiving nonelectrophysiologic-guided antiarrhythmic therapy at the discretion of the treating physician. No other patient with a normal signal-averaged ECG experienced a significant arrhythmic event. One patient subsequently had spontaneous sustained ventricular tachycardia in the setting of a recurrent myocardial infarction. No other sustained ventricular arrhythmias have occurred during a follow-up period of approximately 17 ± 9 months. One patient died from a malignancy.

Discussion

Several studies (14–16) have shown that patients with spontaneous nonsustained ventricular tachycardia or high grade ventricular arrhythmia, or both, in the early post myocardial infarction period are at risk for clinically significant sustained ventricular tachyarrhythmia and sudden death. The risk appears to be increased if left ventricular systolic function is impaired (15,16). This holds true also in

some patients with a history of prior myocardial infarction and complex ventricular arrhythmias.

Prognostic significance of abnormal signal-averaged electrocardiogram. Late potentials recorded by signal-averaged ECG correlate with the direct recording of delayed and fractionated electrograms from the epicardium as well as the endocardium (17–19). These arise from areas marked by disturbed anisotropic communication among myocardial cells (20). Generally, such sites contain longitudinal arrays of myocardial fibers separated by scarred, fibrous septa (21). Subsequently slow conduction, unidirectional block and reentry can occur if the proper trigger (e.g., complex ventricular premature depolarizations) and autonomic milieu are present.

This study provides new insights into determining which patients with spontaneously occurring nonsustained ventricular tachycardia or high grade ventricular arrhythmias are not likely to have ventricular tachycardia induced at programmed ventricular stimulation. Inducibility in this study was defined as induction of sustained monomorphic ventricular tachycardia or reproducible nonsustained ventricular tachycardia (i.e., five or more repetitive ventricular responses). Patients with an abnormal signal-averaged ECG were approximately 18 times more likely to have inducible ventricular tachycardia than were those with a normal signal-averaged ECG. When only patients with prior myocardial infarction were considered, there was a sixfold greater likelihood of inducing ventricular tachycardia if the signal-averaged ECG was abnormal. Of importance, 91% of the patients with induced ventricular tachycardia had one or more abnormal signal-averaged variables. In addition, the degree of impaired left ventricular systolic function did not differ significantly between the groups with and without inducible ventricular tachycardia.

Buxton et al. (22) recently found that an abnormal signal-averaged QRS duration or a root mean square voltage of the terminal 40 ms of the vector complex <25 μV (i.e., late potentials) was more common in individuals with remote inferior myocardial infarction than in those with old anterior infarction who had complex ventricular arrhythmias or nonsustained ventricular tachycardia and induced ventricular tachyarrhythmias. They noted that the sensitivity of a prolonged QRS duration and the presence of late potentials was 94% and 75%, respectively, for patients with inferior infarction versus 71% and 61%, respectively, for patients with anterior infarction. However, they did not report whether the sensitivity of an abnormal signal-averaged ECG (defined as either a prolonged QRS duration or the presence of late potentials) differed between the two groups. In our study, the incidence of an abnormal signal-averaged ECG was similar in patients with inferior and anterior infarction.

Implications for patients with remote myocardial infarction. The potential ability to identify those patients with complex spontaneous ventricular arrhythmias who will have inducible ventricular tachycardia on programmed ventricular stimulation will enable better risk stratification and selection of vulnerable individuals for electrophysiologically guided therapy. The excellent survival of patients who have ischemic heart disease and complex ventricular arrhythmia but no inducible ventricular tachycardia has been demonstrated. Gomes et al. (3) showed that the short-term incidence rate of a lethal or potentially lethal ventricular arrhythmia is as high as 31.5% in patients with induced ventricular tachycardia compared with 2% in those without inducible tachycardia. Zheutlin et al. (2) detected no malignant or potentially malignant ventricular arrhythmias in 52 patients with organic heart disease and high grade ventricular arrhythmias but no inducible ventricular tachyarrhythmias who had followup for a mean of 22 months. Furthermore, Buxton et al. (1) recently found that 44% of patients who underwent programmed ventricular stimulation, with subsequent deviation from electrophysiologically guided therapy, died an arrhythmia-related death as compared with only 7% of patients who received electrophysiologically guided therapy. While reaffirming the excellent prognosis of patients with complex ventricular arrhythmia and remote myocardial infarction, but with no inducible ventricular tachycardia on electrophysiologic testing, our study confirms the useful role of signal-averaged ECG in aiding the selection of patients with complex ventricular arrhythmia for programmed ventricular stimulation.

In addition, these observations are supported by our finding of spontaneous sustained ventricular tachycardia in only two (5%) patients who had no inducible ventricular tachycardia over a 17 ± 9 month follow-up period. These two patients represented only 7% of the 30 patients studied in the noninducible group. One of these two patients had a cardiomyopathy and, despite lack of inducible tachycardia, was being treated with procainamide at the discretion of the treating physician. Procainamide and n-acetyl procainamide levels were therapeutic, and the QT interval was <25% longer than the baseline interval. One additional patient had sustained ventricular tachycardia during a subsequent acute myocardial infarction. No other patients with a prior myocardial infarction and without inducible ventricular tachycardia have developed spontaneous sustained ventricular tachycardia.

Implications for patients with cardiomyopathy. Whether the signal-averaged ECG and programmed ventricular stimulation are useful in patients with cardiomyopathy and nonsustained ventricular tachycardia or high grade ventricular arrhythmia remains controversial. Although the signal-averaged ECG may be abnormal in patients with cardiomyopathy and spontaneous sustained ventricular tachycardia (23), observations in small study groups have suggested that electrophysiologic testing may not be predictive of subsequent sustained ventricular tachyarrhythmia in such patients (24,25). Our finding of arrhythmia inducibility in the small group of two patients with a cardiomyopathy and baseline

high grade ventricular arrhythmias or nonsustained ventricular tachycardia with an abnormal signal-averaged ECG suggests that a large scale prospective study of such individuals should be performed.

Limitations. 1) Although our results and the findings of other investigators (1–4) support utilizing results of programmed stimulation to guide antiarrhythmic therapy in patients with complex ventricular antiarrhythmias, two studies (26,27) suggest that the results should be looked on cautiously. 2) Our study examined the relations among the signal-averaged ECG, site of myocardial infarction and inducibility of ventricular tachycardia in a relatively small group of patients. Prospective studies of larger numbers of patients with prior myocardial infarction are needed to explore these findings further.

Conclusions. Signal averaging of the surface electrocardiogram may be used as a screening tool to determine which patients with prior myocardial infarction and complex ventricular arrhythmias should be selected for programmed ventricular stimulation.

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References

1. Buxton AE, Marchlinski FE, Flores BT, Miller JM, Doherty JU, Josephson ME. Nonsustained ventricular tachycardia in patients with coronary artery disease: role of electrophysiologic study. Circulation 1987;75:1178–85.
2. Zheutlin TA, Roth H, Chua W, et al. Programmed electrical stimulation to determine the need for antiarrhythmic therapy in patients with complex ventricular ectopic activity. Am Heart J 1986;111:860–7.
3. Gomes JAC, Hariman RI, Kang PS, El-Sherif N, Chowdhry I, Lyons J. Programmed electrical stimulation in patients with high grade ventricular ectopy: electrophysiologic findings and prognosis for survival. Circulation 1984;70:43–50.
4. Buxton AE, Marfchlinski FE, Waxman HL, Flores BT, Cassidy DM, Josephson ME. Prognostic factors in nonsustained ventricular tachycardia. Am J Cardiol 1984;53:1275–9.
5. Gomes JA, Winters SL, Stewart D, Horowitz S, Milner M, Barreca P. A new noninvasive index to predict sustained ventricular tachycardia and sudden death in the first year after myocardial infarction. J Am Coll Cardiol 1987;10:343–57.
6. Kuchar DL, Thorburn CW, Sammel NL. Prediction of serious arrhythmic events after myocardial infarction: signal-averaged electrocardiogram, Holter monitoring and radionuclide ventriculography. J Am Coll Cardiol 1987;9:531–8.
7. Kanovsky MS, Falcone RA, Dresden CA, Josephson ME, Simson MB. Identification of patients with ventricular tachycardia after myocardial infarction: signal averaged electrocardiogram, Holter monitoring and cardiac catheterization. Circulation 1984;70:264–70.
8. Winters SL, Stewart D, Gomes JA. Signal averaging of the surface QRS complex predicts inducibility of ventricular tachycardia in patients with syncope of unknown etiology: a prospective study. J Am Coll Cardiol 1987;10:775–81.
9. Kuchar DL, Thorburn CW, Sammel NL. Signal-averaged electrocardiogram for evaluation of recurrent syncope. Am J Cardiol 1986;58:949–53.
10. Gang ES, Peter T, Rosenthal ME, Mandel WJ, Lass Y. Detection of late potentials on the surface electrocardiogram in unexplained syncope. Am J Cardiol 1986;58:1014–20.
11. Simson MB. Use of signals in the terminal QRS complex to identify patients with ventricular tachycardia after myocardial infarction. Circulation 1981;64:235–41.
12. Denes P, Santarelli O, Hooser RG, Uritz UT. Quantitative analysis of the high-frequency components of the terminal portion of the body surface QRS in normal subjects and in patients with ventricular tachycardia. Circulation 1983;67:1129–38.
13. Gomes JA, Mehra R, Barreca P, El-Sherif N, Hariman R, Holtzman R. Quantitative analysis of the high-frequency components of the signal-averaged QRS complex in patients with acute myocardial infarction: a prospective study. Circulation 1985;72:105–11.
14. Ruberman W, Weinblatt E, Goldberg JD. Ventricular premature beats and mortality after myocardial infarction. N Engl J Med 1979;197:750–6.
15. Mukharji J, Rude RE, Poole WK, et al. Risk factors for sudden death after acute myocardial infarction: two year follow-up. Am J Cardiol 1984;54:31–6.
16. Bigger JT, Fleiss JL, Kleiger R, Miller JP, Rolnitzky LM and the Multicenter Post-infarction Research Group. The relationships among ventricular arrhythmias, left ventricular dysfunction and the mortality in the two years after myocardial infarction. Circulation 1984;60:250–8.
17. Gomes JAC, Mehra R, Barreca P, Winters SL. A comparative analysis of signal averaging of the surface QRS complex and intracardiac electrode recordings in ventricular tachycardia (abstr). J Am Coll Cardiol 1986;7:242A.
18. Berbari EJ, Scherlag BJ, Hope RR, Lazzara R. Recording from the body surface of arrhythmogenic ventricular activity during the S-T segment. Am J Cardiol 1979;41:697–702.
19. Simson MB, Untereker WJ, Spielman SR, et al. Relation between late potentials on the body surface and directly recorded fragmented electrograms in patients with ventricular tachycardia. Am J Cardiol 1983;51:105–12.
20. Gardner P, Ursell PC, Fenoglio JJ, Wit AL. Electrophysiologic and anatomic basis for fractionated electrograms recorded from healed myocardial infarcts. Circulation 1985;72:596–611.
21. Fenoglio JJ, Pham TD, Harken AW, Horowitz LN, Josephson ME, Wit AL. Recurrent sustained ventricular tachycardia: structure and ultrastructure of subendocardial regions in which tachycardia originates. Circulation 1983;68:518–33.
22. Buxton AE, Simson MB, Falcone RA, Marchlinski FE, Doherty JU, Josephson ME. Results of signal-averaged electrocardiography and electrophysiologic study in patients with nonsustained ventricular tachycardia after healing of acute myocardial infarction. Am J Cardiol 1987;60:80–5.
23. Poll SA, Marchlinski FE, Falcone RA, Josephson ME, Simson MB. Abnormal signal averaged electrocardiograms in patients with nonischemic congestive cardiomyopathy—relationship to sustained ventricular tachyarrhythmias. Circulation 1985;72:1308–13.
24. Poll DS, Marchlinski FE, Buxton AE, Josephson ME. Usefulness of programmed stimulation in idiopathic dilated cardiomyopathy. Am J Cardiol 1986;58:992–7.
25. Rae AP, Spielman SR, Kutalek SP, Kay HR, Horowitz LN. Electrophysiologic assessment of antiarrhythmic drug efficacy for ventricular tachyarrhythmias associated with dilated cardiomyopathy. Am J Cardiol 1987;59:291–5.
26. Sulpizi AM, Friehling TD, Kowey PR. Value of electrophysiologic testing in patients with nonsustained ventricular tachycardia. Am J Cardiol 1987;59:841–5.
27. Veltri EP, Platia EV, Griffith LSC, Reid PR. Programmed electrical stimulation and long-term follow-up in asymptomatic nonsustained ventricular tachycardia. Am J Cardiol 1985;56:309–14.