Prospective Comparison of a Conventional and an Accelerated Protocol for Programmed Ventricular Stimulation in Patients With Coronary Artery Disease

Fred Morady, MD; Alan Kadish, MD; Michael de Buitleir, MD; William H. Kou, MD; Hugh Calkins, MD; Stephen Schmaltz, MPH; Shimon Rosenheck, MD; and Joao Sousa, MD

Background. This study compared the sensitivity, specificity, and efficiency of a “conventional” and “accelerated” programmed stimulation protocol in 293 patients with coronary artery disease who had a history of sustained or nonsustained monomorphic ventricular tachycardia (VT).

Methods and Results. In the conventional protocol, one and two extrastimuli were introduced during sinus rhythm and during basic drive trains at cycle lengths of 600 and 400 msec at the right ventricular apex and then at the outflow tract or septum. In the accelerated protocol, one, two, and then three extrastimuli were introduced at each of three basic drive train cycle lengths (350, 400, and 600 msec) at the right ventricular apex; the procedure was repeated at a second right ventricular site. Six hundred thirty-four electrophysiological tests were performed using one of these two protocols either in the baseline state (293 tests) or during drug testing (341 tests). The yield of sustained, monomorphic VT was 89% with the conventional protocol and 92% with the accelerated protocol during baseline tests in patients who had a history of sustained VT (p=0.5); 20% and 34%, respectively, during baseline tests in patients with a history of nonsustained VT (p=0.06); and 70% and 77%, respectively, during drug testing (p=0.2). To induce sustained, monomorphic VT, 10.1±5.0 (mean±SD) protocol steps and 14.4±8.7 minutes were required with the conventional protocol, compared with 4.0±3.7 steps and 5.6±6.1 minutes with the accelerated protocol (p<0.001 for each comparison). Among the tests in which sustained, monomorphic VT was induced, sustained polymorphic VT or ventricular fibrillation was induced more often with the conventional protocol (3.6%) than with the accelerated protocol (0.9%, p=0.05).

Conclusions. The efficiency of programmed stimulation can be improved by the early use of a basic drive train cycle length of 350 msec and three extrastimuli. Compared with a conventional stimulation protocol, the accelerated protocol used in this study reduces the number of protocol steps and duration of time required to induce monomorphic VT by an average of more than 50% and improves the specificity of programmed stimulation without impairing the yield of monomorphic VT. (Circulation 1991;83:764–773)

Many electrophysiology laboratories use programmed ventricular stimulation protocols that include the introduction of up to three ventricular extrastimuli at several basic drive train cycle lengths, first at the right ventricular apex and then, if necessary, at a second right ventricular site.1–10 However, a standardized and universally accepted stimulation protocol for inducing ventricular tachycardia (VT) does not exist. Conventionally, the use of single and double extrastimuli at two right ventricular sites has preceded the use of triple extrastimuli, and the extrastimuli have been introduced first during sinus rhythm and then during basic drive trains of progressively shorter cycle lengths, typically ranging from 600 to 400 msec.11–16 Prior studies have demonstrated that the induction of approximately 25% of sustained monomorphic VTs requires triple extrastimuli11,17,18 and that the
yield of monomorphic VTs increases as the cycle length of the basic drive train is shortened to 350 msec. The results of these studies suggest that conventional programmed stimulation protocols, in which the use of triple extrastimuli and the most rapid basic drive train are delayed, may be unnecessarily lengthy. On the other hand, the use of triple extrastimuli and a rapid basic drive train early in a stimulation protocol might impair specificity and increase the risk of inducing nonclinical polymorphic VT and ventricular fibrillation (VF). Therefore, the purpose of the present study was to compare the sensitivity, specificity, and efficiency of a “conventional” protocol and an “accelerated” protocol for programmed ventricular stimulation. The accelerated protocol involved the early use of triple extrastimuli and a basic drive train that had a cycle length of 350 msec. Because mechanisms of VT and the results of programmed ventricular stimulation may vary depending on the type of underlying heart disease, the study population was limited to patients with coronary artery disease.

Methods

Characteristics of Subjects

The subjects of this study were 293 patients with coronary artery disease who underwent an electrophysiological test because of a history of either documented sustained monomorphic VT (146 patients) or nonsustained monomorphic VT detected during continuous ambulatory or telemetric electrocardiographic monitoring (147 patients). Each patient had evidence of a prior transmural myocardial infarction or had undergone coronary angiography that demonstrated coronary artery disease. Patients who were suspected to have had monomorphic VT but in whom monomorphic VT had not been documented were excluded from this study, including patients with unexplained syncope, patients with undocumented cardiac arrest, and patients with aborted sudden death found to have VF at the time of resuscitation. These selection criteria were used to allow the accurate determination of the sensitivity and specificity of the stimulation protocols for the induction of monomorphic VT. Because none of the patients in this study had a history of polymorphic VT or VF, these arrhythmias were considered to be nonspecific when induced by programmed stimulation.

There were 258 men and 35 women, and their mean age (±SD) was 62±9 years. A quantitative measurement of the left ventricular ejection fraction by contrast or radionuclide angiography was available in 176 patients, and the mean ejection fraction in these patients was 0.36±0.08.

Protocol for Electrophysiological Testing

Electrophysiological tests were performed in the fasting, unseeded state after informed consent was obtained. Every subject had a baseline electrophysiological test at least five half-lives after discontinuation of treatment with antiarrhythmic drugs. If a follow-up electrophysiological test for the purpose of electropharmacological testing was indicated, this was performed after at least 2 days of therapy with class IA or IB drugs and after at least 4 days of therapy with class IC drugs. In the case of amiodarone, electropharmacological testing was performed after 1–2 weeks of treatment with a loading dose or after 2–3 months of treatment with a maintenance dose.

At least two quadriporal electrode catheters were inserted into a femoral vein and positioned in the right ventricular apex and against either the right ventricular septum or outflow tract. Leads V1, I, and III and the intracardiac electrogals were displayed on an oscilloscope and recorded at a paper speed of 25–100 mm/sec on a Mingograf 7 recorder (Siemens-Elema, Inc., Solna, Sweden). A 12-lead electrocardiogram was recorded whenever sustained VT that was hemodynamically stable was induced. Pacing was performed with a programmable stimulator (Bloom Associates, Ltd., Reading, Pa.). The pacing stimuli had a duration of 2 msec and a current strength equal to twice the late diastolic threshold, which was always less than 1 mA.

Sustained VT was defined as VT lasting more than 30 seconds or requiring termination because of hemodynamic collapse. Nonsustained VT was defined as VT that was six beats to 30 seconds in duration. Clinical episodes of VT were classified as monomorphic if the QRS configuration was constant in all available leads and if the cycle length was 220 msec or more. In the electrophysiology laboratory, monomorphic VT was defined as VT that maintained the same QRS configuration in leads V1, I, and III and had a cycle length 220 msec or more. Polymorphic VT was defined as VT in which the QRS configuration variable in at least one of the recorded leads. For the purpose of this study, no attempts were made to distinguish polymorphic VT, ventricular flutter, and VF; all induced ventricular arrhythmias that were sustained and that were polymorphic or had a cycle length less than 220 msec were classified as sustained polymorphic VT/VF.

Study Protocol

Starting in April 1988, patients who met the selection criteria of this study underwent programmed ventricular stimulation with one of two stimulation protocols, referred to as conventional and accelerated. The two stimulation protocols were alternated every 6 months, and each protocol was used for a total of 1 year. The same stimulation protocol was used in all patients undergoing programmed ventricular stimulation during a particular 6-month period of time.

The two stimulation protocols are described in Table 1. Both stimulation protocols had 18 steps. The conventional protocol consisted of the introduction of single and double extrastimuli during sinus rhythm.
TABLE 1. Description of the Stimulation Protocols

<table>
<thead>
<tr>
<th>Step</th>
<th>Site*</th>
<th>Conventional BDCL (msec)</th>
<th>ES</th>
<th>Accelerated BDCL (msec)</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>SR 1</td>
<td>350</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>600 1</td>
<td>350</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>400 1</td>
<td>350</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>SR 2</td>
<td>400</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>600 2</td>
<td>400</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>400 2</td>
<td>400</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>SR 1</td>
<td>600</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>600 1</td>
<td>600</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>400 1</td>
<td>600</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>SR 2</td>
<td>350</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>600 2</td>
<td>350</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>400 2</td>
<td>350</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>SR 3</td>
<td>400</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>600 3</td>
<td>400</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>400 3</td>
<td>400</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>SR 3</td>
<td>600</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>600 3</td>
<td>600</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>400 3</td>
<td>600</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

BDCL, basic drive cycle length; ES, extrastimuli; SR, sinus rhythm.

Site 1 was the right ventricular apex; site 2 was the right ventricular outflow tract or septum.

and then during basic drive trains that had cycle lengths of 600 and 400 msec, first at the right ventricular apex and then at the second right ventricular site. If sustained monomorphic VT was not induced, triple extrastimuli were then used. This stimulation protocol was considered to be conventional because it is representative of the stimulation protocol used in many electrophysiology laboratories.1-16 For example, a similar stimulation protocol is being used in a large-scale multicenter study of the clinical value of electropharmacological testing.14

The accelerated stimulation protocol differed from the conventional protocol in two regards. First, basic drive trains of 350, 400, and 600 msec were used in order of increasing cycle length. Second, triple extrastimuli were used at the first stimulation site directly after using single and double extrastimuli with the first basic drive cycle length. Therefore, triple extrastimuli were first used in the third step of the accelerated protocol but not until the thirteenth step of the conventional protocol (Table 1).

In both stimulation protocols, the duration of the basic drive trains was eight beats, and the intertrain pause was 3 or 4 seconds. When programmed stimulation was performed during sinus rhythm in the conventional protocol, the extrastimuli were inserted after every eight sinus beats.

The extrastimuli were always initially positioned 30-60 msec beyond the anticipated refractory periods. The coupling intervals of the extrastimuli were shortened individually in steps of 10 msec in consecutive fashion, starting with the last one, until the effective refractory periods of each of the extrastimuli or coupling intervals of 200 msec were reached. The coupling intervals of the extrastimuli were limited to 200 msec in both protocols because a prior study25 demonstrated that this decreases the probability of inducing nonclinical polymorphic VT/VF without significantly impairing the sensitivity of a stimulation protocol.

The end point of the conventional protocol was the induction of sustained monomorphic VT or two inductions of sustained polymorphic VT/VF requiring a countershock to terminate. Because the yield of programmed stimulation using extrastimuli introduced during sinus rhythm and after basic drive trains at cycle lengths of 600 and 400 msec has previously been studied,26 it was not felt necessary to repeat this comparison with the conventional protocol in the present study. In contrast, with the accelerated protocol, to compare the yield of programmed stimulation using basic drive train cycle lengths of 350, 400, and 600 msec, attempts were made to perform programmed stimulation with each basic drive train cycle length up to the point that sustained monomorphic VT was induced. However, programmed stimulation was discontinued whenever it was felt that additional inductions of VT would not be tolerated or would be deleterious to the patient.

For the purpose of comparing the duration of the two stimulation protocols, the amount of time required to induce the first episode of sustained monomorphic VT or to complete the stimulation protocol was measured in each patient. The starting time was taken to be at the onset of programmed ventricular stimulation, after the electrode catheters had been positioned. If a catheter became displaced during programmed ventricular stimulation, the amount of time required to reposi-tion the catheter was not included in the measured duration of programmed stimulation.

Analysis of Data

The electrophysiological tests performed with each of the two stimulation protocols were divided into three subgroups depending on the clinical indication for the test: 1) sustained VT, 2) nonsustained VT, and 3) electropharmacological testing in patients from the first two subgroups who had inducible sustained VT and who were treated with an antiarrhythmic drug. The antiarrhythmic drugs with which the patients were treated are listed in Table 2.

Among the electrophysiological tests that were performed for the purpose of electropharmacological testing, the tests were considered positive if monomorphic VT of 15 beats or more was induced. This criterion for assessing drug efficacy is based on the results of prior studies27-29 that demonstrated that the ability to induce 15 or more beats of VT is predictive of a clinical recurrence of VT.

Whenever two or more episodes of nonsustained polymorphic VT were induced during a particular step of a stimulation protocol, only the longest episode was used for analysis.
Continuous variables were compared by Student’s $t$ test or analysis of variance. The overall yields of the conventional and accelerated protocols were compared using contingency table analysis. The cumulative yield of induced VT for each step of the stimulation protocols was analyzed using survival analysis techniques. Nonparametric survival curves were fit to the data using the product limit estimator of Kaplan–Meier.30 The estimated standard errors of these curves were used to determine at which steps the cumulative yield of VT in the conventional and accelerated protocols was significantly different. The curves illustrating the cumulative yield of VT were compared using the Mantel–Haenszel log-rank test.31 A value of $p \leq 0.05$ was considered significant.

**Results**

**Induction of Monomorphic Ventricular Tachycardia**

The results of stimulation with the conventional and accelerated protocols are described in Table 3. The overall yield of sustained monomorphic VT was 89% with the conventional protocol and 92% with the accelerated protocol ($p=0.5$) among the baseline electrophysiological tests in patients who had a documented history of sustained VT. Among the patients who had a history of nonsustained VT, sustained monomorphic VT was induced by the conventional protocol in 20% of patients and by the accelerated protocol in 34% ($p=0.06$). Among the electrophysiological tests performed for the purpose of drug testing, the yield of monomorphic VT of 15 beats or more was 70% with the conventional protocol and 77% with the accelerated protocol ($p=0.2$). Therefore, the overall yields of monomorphic VT with the two stimulation protocols did not significantly differ from each other in any of the three subgroups of electrophysiological tests.

The mean cycle lengths of the monomorphic VT induced with the conventional and accelerated protocols were not significantly different (Table 3). Among the patients with a history of sustained VT

<table>
<thead>
<tr>
<th>Drug</th>
<th>Patients (n)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Accelerated</td>
<td></td>
</tr>
<tr>
<td>Quinidine</td>
<td>52</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>Procainamide</td>
<td>8</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Disopyramide</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mexiletine</td>
<td>6</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Quinidine and mexiletine</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Encaïnide or flecainide</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Amiodarone (1–2 wk)</td>
<td>55</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Amiodarone (2–3 mo)</td>
<td>24</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Amiodarone and class I</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>165</td>
<td>176</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3. Comparison of Conventional and Accelerated Stimulation Protocols: Induction of Sustained Monomorphic Ventricular Tachycardia

<table>
<thead>
<tr>
<th>Indication for EP test</th>
<th>Sustained VT</th>
<th>Nonsustained VT</th>
<th>Drug testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of EP tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>72</td>
<td>74</td>
<td>165</td>
</tr>
<tr>
<td>Accelerated</td>
<td>74</td>
<td>73</td>
<td>176</td>
</tr>
<tr>
<td>Yield (%)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>89</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>Accelerated</td>
<td>92</td>
<td>34</td>
<td>77</td>
</tr>
<tr>
<td>$p$</td>
<td>0.5</td>
<td>0.06</td>
<td>0.2</td>
</tr>
<tr>
<td>VT cycle length (msec)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>292±63</td>
<td>278±51</td>
<td>350±80</td>
</tr>
<tr>
<td>Accelerated</td>
<td>310±74</td>
<td>265±42</td>
<td>365±78</td>
</tr>
<tr>
<td>$p$</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>No. of steps†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>11.4±4.4</td>
<td>12.8±4.5</td>
<td>8.9±5.1</td>
</tr>
<tr>
<td>Accelerated</td>
<td>4.6±4.1</td>
<td>5.9±5.1</td>
<td>3.3±2.9</td>
</tr>
<tr>
<td>$p$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Duration (min)‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>16.4±7.8</td>
<td>19.3±8.2</td>
<td>12.6±8.8</td>
</tr>
<tr>
<td>Accelerated</td>
<td>6.3±6.3</td>
<td>8.8±8.3</td>
<td>4.6±5.1</td>
</tr>
<tr>
<td>$p$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Values are mean±SD.

VT, ventricular tachycardia, EP, electrophysiological.

*Percent of electrophysiological tests in which monomorphic VT was induced.

†Number of steps of the stimulation protocol required to induce monomorphic VT.

‡Elapsed time from onset of stimulation protocol until the first induction of monomorphic VT.
undergoing a baseline electrophysiological test, a 12-lead electrocardiogram of the spontaneously occurring VT was available in 22 patients tested with the conventional protocol and 19 patients tested with the accelerated protocol. The VT induced during electrophysiological testing had the same configuration as the spontaneous VT in 17 of 22 patients (77%) tested with the conventional protocol and in 13 of 19 patients (68%) tested with the accelerated protocol (p=0.05).

The number of steps of the stimulation protocol preceding the first induction of monomorphic VT was significantly less with the accelerated protocol than with the conventional protocol in each of the subgroups of electrophysiological tests (p<0.001, Table 3). Accordingly, the elapsed time from the onset of programmed stimulation to the first induction of the clinical end point of the stimulation protocol was significantly shorter with the accelerated protocol than with the conventional protocol (p<0.001, Table 3).

The cumulative yield of monomorphic VT at each step of the stimulation protocols is illustrated graphically in Figures 1–3. When tested at a significance level of 0.05, the cumulative yield of monomorphic VT was significantly greater with the accelerated protocol than with the conventional protocol for steps 2–13 or steps 1–14, depending on the subgroup of electrophysiological tests.

**Induction of Polymorphic Ventricular Tachycardia and Ventricular Fibrillation**

Among the electrophysiological tests in which monomorphic VT was induced, the induction of the clinical end point was preceded by the induction of sustained polymorphic VT/VF requiring countershock in 0.9% of the tests in which the accelerated protocol was used, compared with 3.6% of the tests in which the conventional protocol was used (p=0.05, Table 4). The induction of the clinical end point was more often preceded by the induction of nonsustained polymorphic VT when the conventional protocol was used (13%) than when the accelerated protocol was used (7%, p<0.05).

**Figure 1.** Graph showing cumulative yield of sustained, monomorphic ventricular tachycardia in patients with history of sustained, monomorphic ventricular tachycardia. Conventional protocol was used in 72 patients; accelerated protocol was used in 74 patients. Electrophysiological tests were performed in the absence of antiarrhythmic drug therapy.

**Figure 2.** Graph showing cumulative yield of sustained, monomorphic ventricular tachycardia in patients with history of nonsustained, monomorphic ventricular tachycardia. Conventional protocol was used in 74 patients; accelerated protocol was used in 73 patients. Electrophysiological tests were performed in the absence of antiarrhythmic drug therapy.

**Figure 3.** Graph showing cumulative yield of monomorphic ventricular tachycardia of 15 beats or more in patients undergoing electropharmacological testing. Conventional protocol was used in 165 tests; accelerated protocol was used in 176 tests.
Physiological tests; accelerated protocol was used in 227 tests. The overall yield of 13% with conventional protocol was significantly greater than the 7% yield with accelerated protocol (p<0.05); however, there were no significant differences in yields of the individual steps of the two stimulation protocols.

Among the electrophysiological tests in which monomorphic VT was not induced, the incidence of sustained polymorphic VT/VF with the conventional protocol was not significantly different from that with the accelerated protocol (12% versus 6%, p=0.14, Table 4). The incidence of nonsustained polymorphic VT was the same (24%) with both protocols.

The cumulative yields of nonsustained and sustained polymorphic VT/VF for each of the steps of the two protocols are illustrated in Figures 4–6. In comparing the conventional and accelerated protocols, there were no significant differences in the cumulative yield of polymorphic VT/VF at any of the individual steps of the protocols.

**Effects of the Basic Drive Cycle Length on the Induction of Monomorphic Ventricular Tachycardia**

Among the patients in whom the accelerated protocol was used, sustained monomorphic VT was induced in a total of 150 electrophysiological tests in which programmed stimulation was performed using each of the three basic drive cycle lengths (350, 400, and 600 msec). The yield of VT progressively decreased as the basic drive cycle length increased. Monomorphic VT was induced in 122 of the 150 tests (81%) when the basic drive cycle length was 350 msec, compared with 107 of 150 (71%) when the basic drive cycle length was 400 msec, and 85 of 150 (57%) when the basic drive cycle length was 600 msec (p<0.05 for each stepwise comparison). Monomorphic VT was induced only when the basic drive cycle length was 350 msec in 28 of 150 electrophysiological
tests (19%), compared with eight of 150 (5%), or 10 of 150 (7%) when the basic drive cycle length was 400 or 600 msec, respectively (p<0.05 for the 350 msec basic drive cycle length versus 400 and 600 msec).

Among the 150 electrophysiological tests in which sustained monomorphic VT was induced and in which each of the three basic drive cycle lengths was used for programmed stimulation with the accelerated protocol, VT was induced with all three basic drive cycle lengths in 63 tests (42%). The morphology of VT was the same with all three basic drive cycle lengths in 37 of these 63 tests (59%). Monomorphic VT of two different configurations was induced in 23 of the 63 tests (37%), and three different configurations of VT were induced using each basic drive cycle length in three of the 63 tests (5%). There were no significant differences in the mean cycle lengths of the VTs induced using the three different basic drive cycle lengths. The mean number of extrastimuli required to induce VT when the basic drive cycle length was 600 msec (2.2±0.8) was not significantly different from that when the basic drive cycle length was 350 msec (1.9±0.8) or 400 msec (1.8±0.8).

Discussion

Comparison of the Conventional and Accelerated Stimulation Protocols

The results of this study demonstrate that an accelerated programmed stimulation protocol, in which a basic drive cycle length of 350 msec and triple extrastimuli are used early in the protocol, is more efficient than a conventional protocol that uses longer basic drive train cycle lengths and in which triple extrastimuli are not used until late in the protocol. In patients with coronary artery disease, the accelerated and conventional stimulation protocols result in the same overall yield of monomorphic VT; however, the VT is induced with fewer steps of the protocol and in an average of less than half as many minutes with the accelerated protocol as compared with the conventional protocol. For example, in patients with documented, sustained monomorphic VT undergoing a baseline electrophysiological test, sustained monomorphic VT was induced in a mean of 4.6 minutes, compared with a mean of 11.4 minutes with the conventional protocol. Furthermore, in patients who have inducible monomorphic VT, the accelerated protocol less often results in the induction of nonclinical polymorphic VT/VF. Although the induction of sustained polymorphic VT/VF was infrequent with both protocols, the incidence of these nonspecific arrhythmias was more than three times greater with the conventional protocol than with the accelerated protocol.

Earlier Induction of Monomorphic Ventricular Tachycardia

Prior studies have demonstrated that the sensitivity of programmed stimulation for inducing monomorphic VT increases as the number of extrastimuli increases. In addition, the yield of monomorphic VT has been shown to increase as the basic drive train cycle length is shortened. However, conventional stimulation protocols traditionally have used basic drive trains in order of increasing cycle length and have postponed the use of triple extrastimuli until the completion of programmed stimulation with one and two extrastimuli at all stimulation sites and with all of the basic drive train cycle lengths. In contrast, the accelerated protocol used in the present study was designed to maximize the early induction of monomorphic VT by starting with a basic drive train cycle length of 350 msec and progressing immediately from the use of one to three extrastimuli. This design was highly effective in accelerating the induction of VT. For example, during the baseline electrophysiological test in patients with a documented history of VT, sustained monomorphic VT was induced by step 3 of the protocol in 66% of patients in whom the accelerated protocol was used but in only 6% of patients tested with the conventional protocol.

Effect of a Basic Drive Train Cycle Length of 350 msec

A comparison of the relative yields of monomorphic VT with basic drive train cycle lengths of 350, 400, and 600 msec was possible in this study in 150 electrophysiological tests in which programmed stimulation was performed using each of the three basic drive trains. This comparison demonstrated that a basic drive train cycle length of 350 msec is associated with a significantly higher yield of monomorphic VT compared with basic drive trains of 400 and 600 msec. Furthermore, a prior study demonstrated that the yield of VT is higher when programmed stimulation is performed using basic drive trains of 400 and 600 msec than when extrastimuli are introduced during sinus rhythm. Therefore, the earlier induction of monomorphic VT with the accelerated protocol is attributable not only to the early use of triple extrastimuli but also to the initial use of a basic drive train cycle length of 350 msec, as opposed to conventional protocols in which extrastimuli are first introduced during sinus rhythm or during a basic drive train cycle length of 600 msec.

Among the electrophysiological tests in which VT was induced with the accelerated protocol using each of the three basic drive train cycle lengths, the VT induced with the 350 msec basic drive train cycle length had the same configuration as the VT induced with either the 400- or 600-msec basic drive train cycle length in 95% of tests. Furthermore, the mean cycle length of all monomorphic VTs induced using a basic drive train cycle length of 350 msec was not significantly different from the mean cycle length of the VTs induced using basic drive train cycle lengths of 400 or 600 msec. Therefore, although the use of a shorter basic drive train cycle length facilitates the induction of monomorphic VT, there is no evidence that its use results in the induction of VTs that differ
in nature from the VTs induced using conventional basic drive train cycle lengths.

It is noteworthy that the VTs induced using a basic drive train cycle length of 400 or 600 msec at times differed in configuration from each other and from the configuration of the VT induced using a basic drive train cycle length of 350 msec. This finding emphasizes the importance of repeating programmed stimulation with multiple basic drive train cycle lengths if the aim of the electrophysiological test is to determine how many different types of monomorphic VT are inducible in a given patient.

Overall Yield of Monomorphic Ventricular Tachycardia

Although the accelerated protocol resulted in the earlier induction of monomorphic VT, the final yield of VT was similar with both protocols. However, because the yield of programmed stimulation was highest with the basic drive train cycle length of 350 msec and because this basic drive train cycle length was not used in the conventional protocol, the overall yield of monomorphic VT might have been expected to be higher with the accelerated protocol. The similar overall yield of VT with the conventional protocol may be attributable to the repetition of programmed stimulation during multiple steps of the conventional protocol. Prior studies have demonstrated that the sensitivity of programmed stimulation increases with repetitive stimulation.32,33 This may explain why programmed stimulation at a second right ventricular site was more often needed to induce VT with the conventional protocol than with the accelerated protocol.

Indication for Electrophysiological Testing

The electrophysiological tests in this study were divided into three subgroups depending on whether the patient’s clinical VT was sustained or nonsustained and whether an antiarrhythmic drug was being tested. The yield of sustained monomorphic VT of approximately 90% in patients with a history of sustained VT is similar to the overall yield of programmed ventricular stimulation reported in similar patients in earlier studies.5,11,17,18 As expected, the yield of sustained monomorphic VT was considerably lower (20–34%) in the patients in this study who underwent testing because of a history of nonsustained VT. This yield of sustained monomorphic VT in patients with coronary artery disease and a history of nonsustained VT is comparable with the yield found in prior studies.15,22,34–36 The electrophysiological tests in the third subgroup in this study were those performed for the purpose of drug testing in patients who had already been found to have inducible sustained monomorphic VT during a baseline test. The yield of monomorphic VT of 15 beats or more was 70–77% in this subgroup, indicating that the antiarrhythmic agents being tested were effective in suppressing the induction of VT in 23–30% of the tests. However, these figures underestimate the clinical efficacy of the antiarrhythmic drugs; slowing and hemodynamic stabilization of the VT may be a sufficient therapeutic end point,28,37,38 but the noninducibility of VT was the only end point compared with the two stimulation protocols in the present study.

Induction of Nonspecific Arrhythmias

Because only patients with documented monomorphic VT were included in this study, polymorphic VT/VF induced by programmed stimulation could be reliably classified as nonclinical arrhythmias. The incidence of these nonspecific arrhythmias was minimized in this study by limiting the coupling intervals of the extrastimuli to 200 msec. Nevertheless, in the patients in this study who had inducible monomorphic VT, the incidence of polymorphic VT/VF was lower with the accelerated protocol than with the conventional protocol. However, when monomorphic VT was not inducible and all 18 steps of the stimulation protocols were used, the incidence of polymorphic VT did not differ significantly with the two protocols. This suggests that the improved specificity of the accelerated protocol in patients with inducible monomorphic VT may be attributable to the earlier induction of monomorphic VT, which reduces the number of protocol steps to which a patient is exposed.

Limitations

A limitation of this study is that a 12-lead electrocardiographic recording of each patient’s spontaneous VT was available in only approximately one third of patients being tested because of a history of sustained VT. Although these patients all had been documented to have sustained VT, the precise morphology of the VT was not known in the majority. Therefore, it is unclear how often the induced VT had the same configuration as spontaneous VT. It should be noted that in patients in whom a 12-lead electrocardiogram of the spontaneous VT was available, the VT induced by programmed stimulation had the same configuration in 68–77% of patients, with no difference between the conventional and accelerated protocols.

To maintain a homogeneous patient population, only patients with coronary artery disease who had documented monomorphic VT were included in this study. Therefore, another limitation of the study is that the results may not necessarily apply to patients with other types of heart disease or to patients who have not had documented monomorphic VT.

Conclusions

This study has demonstrated that the efficiency of conventional programmed stimulation protocols can be improved by incorporating the early use of a basic drive train of 350 msec and triple extrastimuli. Although typically used conventional protocols may have a high sensitivity, accelerated stimulation protocols such as the one used in the present study can reduce the number of protocol steps and duration of time required to induce VT by an average of more
than 50% and can improve the specificity of programmed stimulation without impairing the yield of monomorphic VT.

Acknowledgment

The authors thank Marion Maguire for her excellent secretarial assistance.

References

1. Doherty JU, Kienzle MG, Waxman HL, Buxton AL, Marchlinski FE, Josephson ME: Programmed ventricular stimulation at a second right ventricular site: An analysis of 100 patients, with special reference to sensitivity, specificity and characteristics of patients with induced ventricular tachycardia. Am J Cardiol 1983;52:1184–1189


25. Morady F, DiCarlo LA, Baereman JM, de Buitelier M: Comparison of coupling intervals that induce clinical and nonclinical forms of ventricular tachycardia during programmed stimulation. Am J Cardiol 1986;57:1269–1273


**KEY WORDS** • ventricular tachycardia • programmed electrical stimulation
Prospective comparison of a conventional and an accelerated protocol for programmed ventricular stimulation in patients with coronary artery disease.
F Morady, A Kadish, M de Buitleir, W H Kou, H Calkins, S Schmaltz, S Rosenheck and J Sousa

_Circulation_. 1991;83:764-773
doi: 10.1161/01.CIR.83.3.764

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1991 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/83/3/764

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/