Induction of Ventricular Fibrillation Versus Monomorphic Ventricular Tachycardia During Programmed Stimulation

Role of Premature Beat Conduction Delay

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Background. Premature stimuli can cause ventricular fibrillation (VF) during electrophysiological testing. The electrophysiological correlations associated with the onset of VF were evaluated in 40 patients who had this rhythm induced during programmed ventricular stimulation. These parameters were compared with those observed in 51 patients who had inducible sustained monomorphic ventricular tachycardia (VT) and 45 patients who had no inducible sustained ventricular tachyarrhythmias.

Methods and Results. Shortest premature coupling intervals for S2, S3, and S4 at induction of tachycardia or before achieving refractoriness, corresponding conduction latencies (defined as the time from the premature stimulus to the upstroke of the depolarization wave front recorded 35 mm away from the stimulation site), and ventricular activation times (defined as the time from the premature stimulus to the end of the depolarization wave) were compared. The mean coupling intervals were longest in the inducible VT patients: 300±30, 254±57, and 228±32 msec for S2, S3, and S4, respectively. In the inducible VF group, the coupling intervals were 260±47, 208±20, and 213±30 msec. In the group with no inducible VT or VF, these coupling intervals were 251±24 (p<0.01 versus inducible VT group), 209±27 (p<0.001 versus inducible VT group), and 194±21 msec (p<0.05 versus inducible VT and VF groups). The coupling interval of the last premature extrastimulus was above 200 msec in 70% of the patients in whom VF was induced. The largest increases in latency and activation times were recorded in patients in whom VF was induced. The cumulative increase in latency, defined as increased conduction time from baseline, summed for all the premature stimuli was also the greatest at initiation of VF. In contrast, the smallest increases in these parameters were noted in the patients with no inducible VT or VF. Measurements of total activation time yielded similar results as those recorded for latencies. The most important parameters distinguishing the VT patient population from the other two groups were the low ejection fractions and the longer coupling intervals at which VT was induced, whereas in the VF group, the most important discriminating factor was cumulative activation time. Sixty-three percent of the inducible VF patients presented with abnormal hearts (myocardial infarction or cardiomyopathy), whereas 88% of the inducible VT patients had abnormal hearts. In contrast, only 25% of the patients in whom no arrhythmia was induced presented with abnormal hearts. Mean ejection fraction was 32±15% for the inducible VT group, 45±13%* for the inducible VF group, and 51±17%* for patients with no inducible VT/VF (*p<0.001 versus VT).

Conclusions. The results suggest that 1) initiation of ventricular tachycardia during programmed ventricular stimulation occurs with minimal conduction latency; 2) because of the large overlap in coupling intervals where VF or VT were induced, a single coupling interval cannot be recommended to adequately separate these groups; and 3) induction of VF was preceded by increased latency and prolongation of the local activation time. These parameters should not be allowed to prolong if VF is to be avoided during programmed stimulation. In addition, 4) the initiation of VF during electrophysiological studies is often associated with the presence of structural heart disease; such structural disease may promote conduction latency and the development of VF. (Circulation 1992;85:1271–1278)

KEY WORDS • ventricular fibrillation • ventricular tachycardia
induction of VF. Despite these measures, VF can still be induced in some patients, whereas in others no arrhythmia may be inducible, even with the use of extrastimuli coupling intervals of less than 180 msec.

The purpose of this study was to compare the electrophysiological characteristics associated with induction of VF versus those seen with induction of sustained monomorphic ventricular tachycardia (VT) and to explore the factors differentiating those who have inducible ventricular tachyarrhythmias from those who do not.

**Methods**

Data for this report were gathered from 136 consecutive patients who underwent baseline electrophysiological studies. All electrophysiological studies were performed for clinically suspected or documented cardiac arrhythmias. No patient was being treated with antiarrhythmic medications at the time of study. The studies were performed using previously reported standard techniques,8 together with special modifications as described here. Pacing and recording of electrograms at the right ventricle were performed by a specially constructed electrode inserted into the right ventricular apex. Although the stimulation was applied to both apex and outflow tract, in this study only data from the apical stimulation were analyzed. The 6F catheter contained a pair of ring electrodes 1 mm apart located at the tip of the catheter, used for stimulation, and an additional proximal pair of recording electrodes, also 1 mm apart located 35 mm from the tip electrodes. Ventricular stimulation was performed with bipolar impulses of 2-msec duration, at two times diastolic threshold. Three different basic cycle lengths were used: 600 msec, 400 msec, and a short-to-long cycle length of 400–600 msec.8 This order of stimulation was maintained in each patient. As many as three premature beats were introduced during pacing at basic cycle lengths of 600 and 400 msec, whereas only two premature beats were used during the short-to-long basic drives. A single premature stimulus was applied first at each of the drive cycle lengths, followed by double and triple premature stimulation. The coupling interval of an extrastimulus was decremented by 10-msec intervals until ventricular effective refractory period was achieved. This extrastimulus was then fixed at 10 msec above refractoriness, and an additional premature beat was inserted, which was similarly decremented. Each given coupling interval was applied once.

**Data Acquisition**

Two types of intervals relating to impulse conduction of premature stimuli were measured in each patient as illustrated in Figure 1. Latency was defined as the time from stimulus to the beginning of the evoked electrogram's rapid upstroke. Total activation time was the time from stimulus to the end of the electrogram. All measured latency and total activation time intervals were normalized by subtracting the corresponding intervals during the basic drive, thus eliminating individual variations in baseline conduction. Data for the two above defined variables are presented for the last premature stimulus that initiated sustained VT or VF. In patients who had no inducible sustained tachyarrhythmias, the same variables were tabulated for the shortest stimuli just before achieving ventricular refractoriness at a basic cycle length of 400 msec. For ease of presentation, these will be referred to as the "last premature stimulus" variables, i.e., last premature stimulus coupling interval, last premature stimulus latency, and last premature stimulus activation time. The same variables were also measured for each sequential premature beat in the corresponding train of programmed stimuli and summed. The latter data will be referred to as cumulative latency and cumulative total activation time as depicted in Figure 1.

**Data Analysis**

The patient population was divided into three groups for data analysis. The first group consisted of patients with induced sustained monomorphic VT (induced VT group). Sustained VT was defined to be monomorphic if the VT was uniform on each of the 12-lead ECG and the VT cycle length was ≥200 msec. The second group comprised patients with induced VF (VF group), defined as polymorphic tachycardia (evaluated on a 12-lead ECG) of <200 msec cycle length; all had <200 msec polymorphic tachycardia with rapid hemodynamic decompensation requiring defibrillation for termination. The third group included the remaining patients who had no inducible sustained ventricular tachyarrhythmias (noninducible VT/VF group). In this group of patients, a maximum of two or three postpremature stimulation polymorphic beats were allowed; usually, no premature activity was recorded. In all cases, the paper speed was at least 100 mm/sec, which provided ±5-msec measurement accuracy. Recordings were made on a real-time strip-chart recorder as well as on an FM magnetic tape recorder and computerized laser disk.

**Figure 1.** The intervals that were evaluated at the recording electrodes for each of the premature stimuli (S2, S3, and S4) as well as the intervals for the last drive stimulus before the premature stimulation (S1) were latency of the basic drive (L1), latency of each of the premature stimuli (L2, L3, and L4), activation time of the drive stimuli (ACT1), and activation time for each of the premature stimuli (ACT2, ACT3, and ACT4). The cumulative latency for arrhythmia initiated with triple extrastimuli was (L3 + L2 + L1). The cumulative activation time for arrhythmia initiated with triple extrastimuli was (ACT2 + ACT3 + ACT4)
system. Measurements were done by at least two people independently. Representative tracings from each group of patients are shown in Figure 2.

Descriptive data are presented as mean±1 SD. One-way ANOVA was used to analyze differences among continuous variables. Correlation analysis was used to assess correlation between variables, and discriminant analysis was used to assess which of the variables independently distinguished among the three groups.

Results

Clinical Characteristics

Clinical characteristics of the three groups are shown in Table 1. The dominant sex distribution in each group was male, with a greater proportion of males noted in the inducible VT and VF groups. No significant difference was noted in the age distribution. There was a higher incidence of previous myocardial infarction in both the induced VF and induced VT groups. A majority (75%) of patients with no inducible VT/VF had no structural heart diseases. Three of 51 patients in the inducible VT group and eight of 40 in the inducible VF group presented with aborted sudden cardiac death, and two patients in the noninducible VT/VF group had this clinical presentation.

The most common reason for electrophysiological study in the noninducible VT/VF patients was syncope and presyncope (53%; Table 2). In contrast, ventricular arrhythmia was the predominant reason for study in the inducible groups (86% in inducible VT patients and 95% in inducible VF patients). Left ventricular function as measured by MUGA was clearly different between the groups. The inducible VT group had the lowest mean ejection fraction of the three groups (p<0.001). The noninducible VT/VF group generally had normal ejection fractions. Only five patients in this group had ejection fractions of <40% compared with 10 patients in the inducible VT group and 26 in the inducible VT group (Table 1).

Mode of Tachyarrhythmia Induction

The programmed stimulation protocol that initiated sustained tachyarrhythmia is shown in Table 3. Most VT and VF were induced with two (S2) or three (S3) premature stimuli. The only times when VF was induced with a single premature beat occurred with the short-to-long stimulation protocol. No VF was induced with a single premature beat at any coupling interval in this patient population using a fixed 400- or 600-msec basic drive cycle length. However, VT and VF were initiated with similar frequencies during delivery of double or triple extrastimuli (Table 3).

Coupling Intervals of Last Premature Stimuli

The average coupling intervals for the last premature stimuli at initiation of VT or VF and the shortest

![Figure 2. Representative tracings from each group of patients showing (from top to bottom of each panel) ECG leads I, II, and V1 and the ventricular electrograms. Top panel: Tracing of the last two stimuli from the drive (S1) and the triple extrastimuli that resulted in the initiation of sustained monomorphic ventricular tachycardia. Middle panel: Initiation of ventricular fibrillation (VF). Lower panel: No ventricular tachycardia (VT)/VF or no inducible arrhythmia. The recording paper speed was 100 msec/cm.](http://circ.ahajournals.org/)

### Table 1. Population Data

<table>
<thead>
<tr>
<th></th>
<th>Induced ventricular tachycardia</th>
<th>Induced ventricular fibrillation</th>
<th>No ventricular tachycardia/ventricular fibrillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female</td>
<td>46/5</td>
<td>32/8</td>
<td>32/13</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64±10</td>
<td>59±12</td>
<td>60±13</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>32±15</td>
<td>45±13*</td>
<td>51±17*</td>
</tr>
<tr>
<td>Previous myocardial infarction</td>
<td>32 (63%)</td>
<td>15 (38%)</td>
<td>8 (18%)</td>
</tr>
<tr>
<td>Cardiomyopathy</td>
<td>13 (25%)</td>
<td>10 (25%)</td>
<td>3 (7%)</td>
</tr>
<tr>
<td>Normal heart</td>
<td>6 (12%)</td>
<td>15 (38%)</td>
<td>34 (76%)</td>
</tr>
</tbody>
</table>

Values are mean±SD.

*p<0.001 versus ventricular tachycardia.
coupling intervals achieving ventricular capture in the noninducible VT/VF group are shown in Table 4. During single and double premature beats, the last stimulus was longer in the inducible VT group than in the inducible VF and noninducible VT/VF groups.

The last coupling intervals at induction of VF were shorter than at induction of VT, reaching statistical significance only when VT and VF were induced with double extrastimulation, whereas with triple extrastimulation the difference is not statistically significant. Thus, the last coupling interval would not adequately separate these groups. For example, the mean last coupling interval at induction of VT with single, double, and triple extrastimulation was 245±48 msec; this coupling interval was >200 msec in 46 of 51 patients. However, the last coupling intervals in the inducible VF group (mean, 216±32 msec) were also >200 msec in 28 of the 40 patients (Table 6). The achievement of short coupling intervals does not by itself explain induction of VF. In the noninducible VT/VF group, similar or shorter last coupling intervals were achieved without induction of VF (Table 4). In fact, the last coupling intervals before achieving ventricular refractoriness were <200 msec in 27 of the 45 noninducible VT/VF patients (60%), eight of whom had intervals of 160 or 170 msec. Despite these short coupling intervals, no arrhythmia was induced in these patients.

**Latency of the Last Stimulated Beat**

As shown in Table 5, sustained monomorphic VT was initiated with lower latency than the induction of VF. Furthermore, conduction delay in the noninducible VT/VF group was the lowest of the three groups, despite achievement of similar or shorter coupling intervals. The above findings suggest that conduction latency does not play a significant role in induction of VT but rather appears to be associated with induction of VF.

**Total Activation Time of the Last Stimulated Beat**

As shown in Table 5, total activation times were similar in the inducible VT and noninducible VT/VF groups; they were both significantly shorter than in the inducible VF group with single, double, and triple premature stimuli. These data indicate that prolongation of total activation time is associated with VF. Reduction of such prolongation despite achievement of short coupling intervals is not associated with induction of VF. It should also be noted that changes in total activation times among the three groups are similar to the corresponding changes in latency. However, the magnitude of the changes in total activation time is greater, as they also include widening of the recorded electrogram seen with premature beats.

To assess whether the electrophysiological parameters of the last premature stimuli are significantly different than those of the preceding premature stimuli, the last premature stimuli, and the preceding premature stimuli coupling intervals, latency and total activation time were compared in the inducible VT, VF, and noninducible VT/VF groups (Table 6). When comparing the last premature stimuli with the preceding stimuli, neither the coupling intervals nor the latency and activation times were significantly different within any group. The coupling intervals, latency, and activation times were remarkably similar. However, comparisons between the groups show significantly longer coupling intervals for induction of VT versus noninducible VT/VF and significantly longer activation times for the premature stimuli before the initiation of VF versus VT and VF versus noninducible VT/VF.

**Correlation Between Coupling Intervals and Conduction Delay**

The correlations between the last stimulus coupling interval and the increase in latency and activation time for all three groups of patients were evaluated using correlation analysis. No significant relation existed between the coupling interval and the increased latency or activation time for any of the patient groups. Although one would expect a relation between coupling intervals and latency in an individual patient, our analysis indicates that across many patients, this relation does not hold, possibly due to variation in refractoriness and preceding beat conduction slowing.

**Cumulative Latency and Activation Time**

The cumulative changes in latency and activation time from successive premature beats at the induction of VT or VF (inducible VT or inducible VF groups) or

### Table 2. Clinical Presentation

<table>
<thead>
<tr>
<th></th>
<th>Induced ventricular tachycardia</th>
<th>Induced ventricular fibrillation</th>
<th>No ventricular tachycardia/ventricular fibrillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premature ventricular complexes</td>
<td>3 (6%)</td>
<td>6 (15%)</td>
<td>6 (13%)</td>
</tr>
<tr>
<td>Nonsustained ventricular tachycardia</td>
<td>21 (41%)</td>
<td>18 (45%)</td>
<td>10 (22%)</td>
</tr>
<tr>
<td>Sustained ventricular tachycardia</td>
<td>17 (33%)</td>
<td>3 (8%)</td>
<td>4 (9%)</td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
<td>3 (6%)</td>
<td>8 (20%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Syncope</td>
<td>6 (12%)</td>
<td>5 (13%)</td>
<td>20 (44%)</td>
</tr>
</tbody>
</table>

### Table 3. Induction of Arrhythmias During Programmed Stimulation

<table>
<thead>
<tr>
<th></th>
<th>Ventricular tachycardia (n=51)</th>
<th>Ventricular fibrillation (n=40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>4 (8%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>S2</td>
<td>11 (21%)</td>
<td>6 (15%)</td>
</tr>
<tr>
<td>S3</td>
<td>27 (53%)</td>
<td>22 (55%)</td>
</tr>
<tr>
<td>400–600 msec, S1</td>
<td>1 (2%)</td>
<td>4 (10%)</td>
</tr>
<tr>
<td>400–600 msec, S2, S3</td>
<td>8 (16%)</td>
<td>8 (20%)</td>
</tr>
</tbody>
</table>
at shortest achievable coupling intervals (no inducible VT/VF group) were examined to detect any differences among the three groups. Only patients who received double or triple premature beats during programmed stimulation were included (the data for each premature stimuli latency and activation time is shown in Table 5). The cumulative latencies and activation times (shown in Figure 3) were the highest in the inducible VF group.

Discriminant analysis was used to assess which of the variables independently distinguished among the three groups. The most important parameters distinguishing the VT patient population from the other two groups were the low ejection fractions (for ejection fraction ≤40%, the sensitivity is 79% and the specificity is 81%) and the longer coupling intervals at which VT was induced (for coupling interval ≥215, the sensitivity is 70% and the 61% is specificity). Although in the VF group the most important discriminating factor was cumulative activation time (for cumulative activation time ≥24 msec, the sensitivity is 73% and specificity is 71%). Furthermore, eight patients in the VF group presented with aborted sudden death. These patients’ premature stimulation coupling intervals, latencies, and activation times just before the initiation of VF were compared with the same data from the patients in whom VF was induced with no prior clinical arrhythmia. The latency or activation time prolongation was not significantly different between the two groups.

**Discussion**

**Premature Stimuli Coupling Intervals and the Induction of Arrhythmia**

As the number of extrastimuli and current intensity increases along with shortening of the extrastimuli coupling interval, the frequency of VF induction increases. Under these circumstances, VF has been generally considered a finding without specific utility in guiding medical therapy.1–5 In a previous study, the coupling intervals that resulted in induction of VF have been shown to be shorter than those that induce VT.7,9 It was therefore recommended that S2, S3, and S4 extrastimuli coupling intervals be decremented to no less than 180 msec.7

The data presented in this study show that induction of VT required significantly longer coupling intervals for single and double premature stimulation than the coupling intervals that resulted in VF and that no significant difference was found between these two groups of patients with triple extrastimulation. VF was induced in 30% of the patients with a stimulation protocol that included a 400-msec paced drive followed by a 600-msec pause and single or double premature beats. Such a protocol was not used by other investigators7,9 and could play a role in the difference between the results. Furthermore, in the patients with induced VF, differences in ventricular function could account for the differences in stimulation coupling intervals that led to the initiation of VF (no ejection fraction data are provided in either of the above-mentioned studies).

The last coupling interval before initiation of VF in this report was >200 msec in 28 of 40 patients with inducible VF (70%). In contrast, this value was <200 msec in only five of 51 patients in whom VT was induced. Thus, limiting extrastimuli coupling intervals to 180 msec or greater will continue to result in frequent induction of VF. Although there is a relation between

**Table 4. Last Coupling Interval Before Initiation of Ventricular Tachycardia and Ventricular Fibrillation and Before Achieving Refractory Period in the Noninducible Ventricular Tachycardia/Ventricular Fibrillation Patients With Single, Double, and Triple Premature Stimulation (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Ventricular tachycardia</th>
<th>Ventricular fibrillation</th>
<th>No ventricular tachycardia/ventricular fibrillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single 30±30 (n=5)</td>
<td>300±50 (n=5)</td>
<td>260±37 (n=4)</td>
<td>251±124 (n=44)</td>
</tr>
<tr>
<td>Double 254±57 (n=19)</td>
<td>254±57 (n=19)</td>
<td>208±20† (n=14)</td>
<td>171±27† (n=14)</td>
</tr>
<tr>
<td>Triple 228±32 (n=27)</td>
<td>228±32 (n=27)</td>
<td>213±30 (n=22)</td>
<td>194±21† (n=44)</td>
</tr>
</tbody>
</table>

*p<0.01 versus ventricular tachycardia.

†p<0.001 versus ventricular fibrillation.

‡p<0.05 versus ventricular tachycardia and ventricular fibrillation.

**Table 5. Normalized Latency and Activation Time for S2, S3, S4, and S3S4S4 (msec) Used to Derive Cumulative Latency and Activation Times**

<table>
<thead>
<tr>
<th></th>
<th>Latency</th>
<th>Activation time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ventricular tachycardia</td>
<td>Ventricular fibrillation</td>
</tr>
<tr>
<td>S2 4±4*</td>
<td>17±13</td>
<td>1±6*</td>
</tr>
<tr>
<td>S2 5±5</td>
<td>10±14</td>
<td>1±6*</td>
</tr>
<tr>
<td>S3 4±5*</td>
<td>14±23</td>
<td>5±12*</td>
</tr>
<tr>
<td>S2 4±8</td>
<td>8±10</td>
<td>1±6*</td>
</tr>
<tr>
<td>S3 12±14</td>
<td>20±20</td>
<td>5±12*</td>
</tr>
<tr>
<td>S4 7±18</td>
<td>14±27</td>
<td>7±13</td>
</tr>
</tbody>
</table>

*p<0.01 versus ventricular fibrillation.

†p<0.001 versus ventricular fibrillation.

‡p<0.05 versus ventricular fibrillation.
short extrastimuli coupling intervals and induction of VF, this certainly is not an exclusive or causal relation, since the noninducible VT/VF group had the shortest achieved coupling intervals. Although the short coupling intervals reached in the noninducible VT/VF group may be related to the pacing cycle length of 400 msec, both the latency and the activation time prolongation were small.

Association of Latency and Activation Time Prolongation With the Induction of VF

In previous canine studies, Avitall and Bump10 demonstrated that the induction of VF was associated with markedly prolonged latencies between the final extra-stimulus and its captured response. The incidence of inducible VF was more closely associated with conduction latency and prolongation of myocardial relative refractory period (RRP) rather than with the coupling interval. In that study, there was no significant correlation between changes in latency or changes in RRP versus the coupling interval. However, when changes in latency were plotted against changes in RRP, the correlation coefficient was very high (r=0.93). These analyses suggest that the prolongation of latency and changes in RRP were closely related and are predictors of increased susceptibility to VF. Similarly, in the present study, absence of correlation between coupling interval and conduction slowing, even within each group, suggests that the coupling interval by itself is not a good predictor of the extent of conduction delay that a premature stimulus may elicit. Our data suggest that conduction delay, as indicated by increased latency and total activation time, plays an important role in the genesis of VF. Differences in the extent of myocardial disease between patients may cause variations in conduction delay at comparable coupling intervals. Because of these variations it is difficult to choose a single coupling interval as a minimum number to avoid conduction delay.

As shown in Table 6, the last premature beat latencies and activation times were comparable to those produced by the preceding premature beats at initiation of VF. For example, latency for S4 was frequently the same or less than the latency observed for S3 or S2 during the same drive. This observation suggests that the presence of conduction slowing after the last premature stimulated beat by itself is not the only determinant of VF. The presence of this conduction slowing, compounded with conduction slowing of preceding premature beats, may be the strongest facilitator of VF. This interpretation is also supported by the discriminant analysis that identified the cumulative activation time as the most important discriminating factor for the inducible VF group. These data are consistent with observations made in animal models of VF induced with premature beats.10-12

Local Electrophysiological Abnormalities and the Induction of VF

Data reported by others in animal models indicate that the presence of a critical degree of dispersion in myocardial refractoriness or recovery of excitability is crucial for a premature beat to induce VF. Kuo et al13 used a temperature-gradient model in the canine heart and showed that cooling a specific area of the heart to

| Table 6. Coupling Intervals, Latency, and Total Activation Time (msec) of Last Premature Stimuli and Preceding Stimuli |
|-----------------|-----------------|-----------------|-----------------|
|                 | Coupling interval | Latency | Activation time |
|                 | Preceding stimuli | Stimuli | Preceding stimuli | Stimuli | Preceding stimuli | Stimuli |
| Ventricular tachycardia | 237±52* | 245±48* | 9±11 | 5±13§ | 12±16β | 8±19β |
| Ventricular fibrillation | 217±27 | 216±32† | 16±19 | 14±25 | 32±25 | 33±34 |
| No ventricular tachycardia/ventricular fibrillation | 209±27 | 194±21 | 5±12‡ | 7±13 | 10±15§ | 15±17‡ |

* p<0.01 versus no ventricular tachycardia/ventricular fibrillation. † p<0.05 versus no ventricular tachycardia/ventricular fibrillation. ‡ p<0.05 versus ventricular fibrillation. § p<0.01 versus ventricular fibrillation.
achieve a critical prolongation of refractoriness allowed induction of VF with a single premature beat only when the premature stimulus was delivered to the warm area where refractory periods were shorter. In a similar manner, dispersion of myocardial recovery can be created by a premature beat.\textsuperscript{11,12} When such a beat is initiated within the relative refractory period of the muscle, two factors can contribute to the generation of such dispersion. Conduction slowing by itself causes dispersion of activation time between sites near the stimulating electrode and distant sites. Second, conduction slowing of the premature beat causes distant sites to experience a longer coupling interval of the premature beat than at the pacing site. This results in refractory periods following the premature beat being longer at distant sites than at the pacing site due to the effect of coupling interval on action potential duration and refractory periods.\textsuperscript{11} Both of these factors—delayed distant activation secondary to conduction slowing and longer refractory periods at myocardium distant from the pacing site—contribute to the establishment of a dispersion in myocardial recovery, with early recovery at the site of pacing and late recovery in the muscle distant from the pacing site. It is this dispersion that sets the stage for the next premature beat to induce VF. Also congruent with the above-mentioned animal data,\textsuperscript{13} the second premature beat would be delivered at the site with short refractoriness and conducted toward areas of myocardium that have delayed recovery. This interpretation could readily explain the clinical observation that induction of VF is difficult with a single premature beat, whereas it becomes easier with delivery of multiple premature stimuli.

\textbf{Clinical Relevance}

Based on the above interpretation of our data, some recommendations can be made regarding choices of coupling intervals used during programmed stimulation when the goal of testing is to assess inducibility of monomorphic VT while avoiding unnecessary induction of fibrillation. During programmed ventricular stimulation, it would be unlikely that the pacing catheter is located at the reentry site of a monomorphic VT. Most likely, the tachycardia focus would be at some distance from the pacing site. Previous studies\textsuperscript{8,10,14} have shown that utilization of stimuli coupling intervals shorter than those necessary to achieve the functional refractory period of the muscle do not result in shorter coupling intervals of ventricular response at sites away from the pacing site and are not necessary for the induction of monomorphic VT. Our data support this notion by demonstrating that no more than small increases in conduction latency and total activation time are needed for the induction of monomorphic VT. Therefore, monitoring of latency and activation times at a site distant from the pacing site can allow the selection of coupling intervals that would minimize the chance of inducing VF, yet permit induction of VT. Coupling intervals should be chosen to minimize any conduction slowing, especially in the premature beats preceding the last premature stimulus. Thus, when using triple premature stimuli (S2, S3, and S4), one should select the S2 and S3 coupling intervals long enough to avoid development of long cumulative activation times and latencies within those two beats.

The generation of VF during programmed stimulation was found to be associated with prolonged activation time. It is quite conceivable that structural disease or inherent dispersion of refractoriness within the myocardium of patients in the inducible VF group facilitated generation of conduction slowing more readily than in the noninducible VT/VF group. Such a difference could explain how lesser distal cumulative activation times occurred in the noninducible VT/VF group. Thus, the ease of inducing VF may reflect underlying myocardial disease or “electrical instability.” This interpretation would explain recent reports\textsuperscript{15,16} that found poorer prognoses in patients who had induced VF during programmed ventricular stimulation compared with those who had no inducible sustained ventricular tachyarrhythmias. In the present report, a significantly greater number of patients in whom VF was induced presented with structural heart disease, which may predispose these patients to induction of VF. Eight patients in the VF group presented with aborted sudden death. These patients’ premature stimulation coupling intervals, latencies, and activation times just prior to the initiation of VF were compared with the same data for the patients in whom VF was induced with no prior clinical arrhythmia. These parameters were not significantly different between the two groups. The small number of patients with aborted sudden death and induced VF preclude a firm conclusion regarding the prognostic significance of such a finding.

\textbf{Conclusions}

We conclude that the initiation of VT usually requires minimal or no latency and activation time prolongation. Because of the large overlap in the coupling intervals where VF or VT was induced, a single coupling interval cannot be recommended to adequately separate these groups. Since the induction of VF was preceded by prolonged latency and prolongation of the activation time, such prolongation should be avoided if one wishes to minimize the induction of VF. The data presented suggest that prolonged cumulative activation time is an important parameter causing VF during programmed stimulation. Therefore, during delivery of multiple premature beats, special attention should be directed at avoiding marked conduction slowing in the premature beats preceding the last stimulus. However, limiting prolongation of latency and activation time may decrease the sensitivity of the test. One potential means of circumventing this decrease in sensitivity is by adding more premature beats. It may be that avoidance of conduction latency would permit the use of more premature beats without decreasing the specificity of an electrophysiological test, that is, without generating VF. These issues would require further study.

\textbf{Acknowledgments}

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