Use of Alternating Current
During Diagnostic Electrophysiologic Studies

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SUMMARY When conventional programmed electrical stimulation did not yield ventricular arrhythmias suitable for testing implanted automatic defibrillator function and for mapping the location of arrhythmogenic foci, full-wave rectified alternating current (120 Hz) was used for inducing arrhythmias. Application of alternating current resulted in ventricular tachycardias 31 times; in 27 instances, these tachycardias were similar in rate (216 ± 37 beats/min) and morphology to those previously induced in the same patient by programmed electrical stimulation (191 ± 30 beats/min). During endocardial mapping, the origin of the tachycardias induced by both methods was found in the same region. Alternating current produced ventricular fibrillation only four times, twice when it was the patient’s spontaneous native arrhythmia and twice after apparently effective endocardial resection. No complications of the technique were observed. The use of alternating current was found to be simple, rapid and safe; it may be especially useful in the operating room during antiarrhythmic surgery because it markedly reduces the cardiopulmonary bypass time required for induction and may also be useful for testing the adequacy of endocardial resection.

PROGRAMMED electrical stimulation of the heart is recognized as a useful tool for evaluating patients with malignant ventricular arrhythmias. Induction of arrhythmias during an electrophysiologic study indicates a high probability of spontaneous clinical recurrence, while suppression of inducibility appears to be associated with a favorable clinical prognosis.1-4 Occasionally, however, noninducibility may interfere with optimal management; for example, during functional testing of implanted automatic defibrillators, preoperative ventricular endocardial mapping of tachyarrhythmias, and intraoperative mapping during antiarrhythmic surgery. In these highly selected cases, when conventional stimulation techniques were unsuccessful, we used alternating current to elicit suitable rhythms. Usually, these arrhythmias were ventricular tachycardias that morphologically closely resembled those previously produced in the same patients by programmed electrical stimulation. Under these circumstances, the approach is simple, rapid and free of discernible deleterious effects. In this report we describe our initial clinical experience in inducing ventricular tachyarrhythmias with alternating current during electrophysiologic studies and during antiarrhythmic surgery.

Materials and Methods

Twenty-two patients who were referred to The Johns Hopkins Hospital for evaluation and treatment of life-threatening ventricular arrhythmias form the basis of this study. Sixteen were men and six were women, ages 17-74 years (mean 51 years). All patients had survived multiple arrhythmic cardiac arrests. Diagnostic coronary arteriography and left ventriculography revealed coronary artery disease as the underlying pathophysiologic condition in 14 patients and nonischemic cardiomyopathy in eight. Each patient underwent implantation of the automatic defibrillator; in four patients with coronary artery disease, this procedure was combined with endocardial resection and aneurysmectomy.5-7

Electrophysiologic studies were routinely performed before and after implantation of the automatic defibrillator to determine the optimal drug regimen and to ensure that the device properly sensed and corrected the patient’s malignant arrhythmia. Our study protocol included the delivery of twice-threshold, single and double premature ventricular stimuli, with basic cycle lengths of 600, 500 and 450 msec, and ventricular burst pacing at progressively shorter cycle lengths until the effective refractory period was reached. At least the right ventricular apex and outflow tract were stimulated; in addition, one or two sites in the left ventricle were stimulated if right ventricular stimulation had failed.

All patients included in this study had noninducible arrhythmias, due to presumably effective drug therapy or after antiarrhythmic surgery, on one or more occasions using our protocol. When this occurred during testing of implanted automatic defibrillator function or during endocardial mapping in the operating room, alternating current was used to produce the needed ventricular tachyarrhythmias.

The alternating current source was a standard, line-operated battery charger. Its full-wave rectified output was 7 V as measured over a 50-Ω load. The current was delivered to the heart through the exposed leads of a bipolar ventricular pacing catheter that had a 2-cm interelectrode distance, or during open heart surgery through bipolar plunge electrodes placed in the ventricular myocardium. The initial exposure to the current lasted less than 1 second, but when sustained arrhythmias did not result, exposures of as long as 3...
seconds were used, and in two instances, 7 seconds of current application were needed to produce a sustained ventricular tachyarrhythmia.

The arrhythmias were considered to be ventricular tachycardias when their rates were 240 beats/min or less and the right ventricular bipolar electrograms were regular and of uniform configuration. In most cases, the frontal-plane axis could be easily discerned; when the axis could not be specified because it continually varied, the tachycardia was considered polymorphic. Ventricular fibrillation was considered to be present when the rates were faster and the right ventricular bipolar electrograms showed nonuniform configuration, irregular intervals and continuous fragmented activity throughout diastole.

Results

All patients exposed to the alternating current developed sustained ventricular tachycardia or fibrillation. In the electrophysiologic laboratory, the alternating current produced ventricular tachycardia 24 times and ventricular fibrillation twice.

In 20 instances, the frontal-plane axis was the same as that of ventricular tachycardia previously induced in the same patients by programmed stimulation (fig. 1) and in the other four the arrhythmias were polymorphic. During the previous conventional electrophysiologic studies in these patients, induced arrhythmias had a repeatable axis and bundle branch configuration more than 90% of the time.

Although a comparison of rates in the ventricular tachycardias induced by the two methods while the patients were on various drug regimens is inherently difficult, in five patients in whom the medications remained unchanged, the tachycardias induced with alternating current had rates similar to those elicited by programmed stimulation (table 1).

In two of the patients, even though programmed stimulation was effective only when applied to the left ventricle, application of the alternating current to the right ventricle elicited rhythms identical in rate and morphology.

In the operating room, during mapping procedures associated with endocardial resection, alternating current was used nine times in four patients. Ventricular tachycardias were elicited seven times; their earliest points of activation were in regions previously localized during preoperative laboratory studies using programmed electrical stimulation (fig. 2). Alternating current was first used in the operating room for a patient who had not responded to 30 minutes of programmed electrical stimulation during cardiopulmonary bypass; when alternating current was applied, the needed arrhythmia was induced instantly.

Alternating current produced ventricular fibrillation only four times, twice in the laboratory and twice in the operating room. When induced in the laboratory, ventricular fibrillation was also the patient's spontaneous native arrhythmia; conventional stimulation techniques had previously resulted in nonsustained ventricular tachycardias only. In the operating room, before extensive endocardial resection, alternating current produced only ventricular tachycardias. After resection, however, ventricular fibrillation was elicited and required 6 seconds of alternating current exposure in one case and 7 seconds in the other.

The hospital course after the inductions was uneventful, with no deaths and no unusual morbidity.

Discussion

Induction of ventricular arrhythmias with alternating current may be useful in the management of selected patients. The patients in this study had all survived multiple arrhythmic cardiac arrests refractory to therapy in whom the automatic defibrillator was implanted as a procedure of last resort. Because of the high risk of recurrence, it was essential to ascertain that these patients' life-threatening rhythm disturbances could be effectively corrected by the implanted device. Electrophysiologic studies were therefore routinely performed.

![Figure 1](http://circ.ahajournals.org/) Ventricular tachycardias induced in a patient using double premature stimuli (A) and alternating current (AC). (B) The first induction occurred in the electrophysiologic laboratory and the second in the operating room. Left-axis deviation is present in both cases.
TABLE 1. Heart Rates of Induced Ventricular Tachycardias

<table>
<thead>
<tr>
<th>Drug</th>
<th>Programmed electrical stimulation (beats/min)</th>
<th>Alternating current (beats/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aprindine</td>
<td>181</td>
<td>188</td>
</tr>
<tr>
<td>Amiodarone</td>
<td>207, 192, 188</td>
<td>215</td>
</tr>
<tr>
<td>Procainamide</td>
<td>200</td>
<td>188</td>
</tr>
<tr>
<td>Tocainide</td>
<td>200, 220</td>
<td>200</td>
</tr>
<tr>
<td>Encainide</td>
<td>214</td>
<td>210</td>
</tr>
</tbody>
</table>

Rates of ventricular tachycardias induced by programmed electrical stimulation and by alternating current in five patients who received similar drug regimens. The numbers represent the average heart rates in several episodes of ventricular tachycardia in patients receiving single medications.

after implantation to test the functional performance of the automatic defibrillator. These tests would have ended inconclusively if only our usual stimulation protocol had been used.

The method we describe provided the solution. The ability of alternating current to induce malignant rhythms in the experimental laboratory,

and as a result of accidental exposure,

has been well documented. Extensive efforts to eliminate contact with even minimal amounts of this current are routinely expended wherever patients have intracardiac lines as, for example, in intensive care units and in the catheterization laboratory. Nevertheless, in some institutions ventricular fibrillation is induced in the operating room with alternating sources. Although the deliberate induction of arrhythmias with alternating current during programmed electrical stimulation had not been previously reported, we believed that in the strictly controlled environment of the electrophysiologic laboratory, the benefits clearly outweighed the potential hazards of this very old method of arrhythmia induction.

Application of alternating current typically produced ventricular tachycardia rather than ventricular fibrillation. The tachycardias were usually similar in rate and morphology to those induced in the same patients with programmed stimulation. Moreover, during endocardial mapping before and during open heart surgery in the same patients, the site of origin of the arrhythmias produced with both techniques was identical. Alternating current resulted in ventricular fibrillation only when it was the patient's spontaneous native arrhythmia or after apparently successful endocardial resection.

This study leaves several unanswered questions. While the alternating current used was full-wave rectified, other wave forms might yield different results. The importance of precise quantification of the exposure time also must be determined. In addition, we did not try to compare this technique to programmed electrical stimulation during routine electrophysiologic testing or to define responses to alternating current in other patient groups.

In addition to its effectiveness and apparent lack of deleterious effects, alternating current may allow right ventricular induction of arrhythmias in patients in

![Diagram](http://circ.ahajournals.org/)

**Figure 2.** Mapping of ventricular tachycardia in a patient. (A) In the laboratory, the arrhythmia is induced with double premature stimuli and the earliest point of activation (arrow 1) in the high anterior septum is earlier than the surface ECG and precedes the reference electrogram recorded by a catheter located in the right ventricular apex by 142 msec (arrow 2). (B) In the operating room, the arrhythmia was induced with alternating current and the earliest point of activation (arrow 3) was again located in the high anterior septum. It is earlier than the surface ECG and precedes the reference electrogram recorded by plunge electrodes placed in the right ventricular apex by 132 msec (arrow 4). RV ref. = right ventricular reference electrogram; LV explor. = left ventricular exploring electrogram; perf.press. = perfusion pressure.
whom conventional techniques are only effective when the left ventricle is stimulated. In contrast to programmed ventricular stimulation, which may at times require very long periods of time for induction of suitable rhythms, alternating current produces sustained arrhythmias within seconds. By making possible a significant reduction in the cardiopulmonary bypass time required for induction, this advantage is especially useful during antiarrhythmic surgery. In addition, the approach may be useful for testing the adequacy of endocardial resection.

References
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