Electrophysiologic Study of the Left Ventricle*

Indications and Safety

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Eighty patients (69 with documented or suspected recurrent ventricular tachycardia or fibrillation, ten with left bundle-branch block, and one with the Wolff-Parkinson-White syndrome) underwent both right ventricular and left ventricular programmed electrical stimulation, including ventricular pacing and the introduction of one or two ventricular extrastimuli or electrode catheter mapping of the left ventricle (or both). Left ventricular catheters were introduced precociously via the femoral artery (of 61 patients, one required secondary repair) or via brachial arteriotomy (of 19 patients, two required secondary repair). All patients received an intravenously administered bolus of heparin (5,000 units) following the insertion of the left ventricular catheter and then 1,000 units/hr after the first hour of study. No patients had cerebrovascular, systemic thromboembolic, or cardiac sequelae. In four (12 percent) of 34 patients with inductive ventricular tachycardia, programmed electrical stimulation of the left ventricle was required for initiation. Extensive left ventricular endocardial mapping was performed in 45 patients. Our experience suggests that (1) electrophysiologic study of the left ventricle can be performed safely, (2) programmed electrical stimulation of the left ventricle is indicated when a suspected ventricular tachyarrhythmia cannot be induced from the right ventricle, and (3) endocardial mapping of the left ventricle is indicated when surgery is being considered to abolish recurrent sustained ventricular tachycardia.

Clinical electrophysiology has considerably advanced our understanding of surface electrocardiograms, including abnormalities of cardiac rhythm and conduction. Following the introduction of His bundle electrocardiography, techniques for programmed electrical stimulation were developed that enabled investigators to study more adequately the properties of the atrioventricular conduction system, evaluate the function of the sinus node, determine the mechanisms of ventricular and supraventricular tachyarrhythmias, and assess the effects of various pharmacologic agents.1,20 Many laborato-

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Materials and Methods

Eighty patients underwent electrophysiologic study of the left ventricle in the Electrophysiologic Laboratory at the Hospital of the University of Pennsylvania, Philadelphia, between January 1975 and July 1978 (50 of these between July 1977 and July 1978). All studies were approved by the Committee on Studies Involving Human Beings of the Hospital of the University of Pennsylvania and were performed under the direct supervision of one of us (M.E.J.). Patients included 62 men and 18 women ranging in age from 18 to 78 years. Sixty-nine patients were referred for evaluation of suspected or documented ventricular tachycardia or fibrillation (or both), ten patients were undergoing evaluation of left bundle-branch block, and one patient with the Wolff-Parkinson-White syndrome was studied. Because a pacemaker had been placed in the coronary sinus to terminate tachyarrhythmias, it was necessary to map the bypass tract via left ventricular recordings. Cardiac diagnoses included the following: ischemic heart disease (previous myocardial infarction, typical angina pectoris, or abnormal coronary angiograms), 50 patients; valvular heart disease, ten patients (none with calcific aortic stenosis); hypertensive cardiovascular disease, seven patients; and cardiomyopathy, five patients. Eight patients had no structural cardiac disease (by
Patients were studied in the postabsorptive state without sedation, after informed consent was obtained. Therapy with antiarrhythmic medications was usually discontinued at least 24 hours before study, except for six patients in whom infusions of lidocaine were discontinued between 8 and 12 hours prior to study. No patients had been placed on prophylactic therapy with anticoagulants in anticipation of manipulations within the left ventricle. At the time of placement of left ventricular catheters, patients received 5,000 units of heparin intravenously and thereafter 1,000 units/hr after the first hour of the study. At the end of the study, the effects of administration of heparin were reversed with intravenous administration of 0.5 mg of protamine sulfate per 100 units of heparin. All patients undergoing brachial arteriotomy underwent open catheterization of both the proximal and distal vessel with a balloon-tipped catheter (Fogarty catheter) prior to closure of the wound.

Studies using ventricular stimulation were performed via a programmable constant-current impulse generator (Bloom Associates, Ltd.). Impulses were 1.0 msec in duration and twice the diastolic threshold (≤ 3 mamp). Both right and left ventricular stimulations were performed in 44 patients in whom left ventricular catheters were inserted (24 with ventricular tachycardia, 19 with ventricular fibrillation, and one with the Wolff-Parkinson-White syndrome). In 36 patients, left ventricular catheters were used only for recording. The protocol for stimulation included ventricular pacing at control cycle lengths ranging from 500 to 1,000 msec, during which single or double ventricular extrastimuli (or both) were delivered after each eight paced complex. The ventricular extrastimuli were delivered at progressively premature coupling intervals until ventricular refractoriness was reached.

All 80 patients underwent at least limited left ventricular mapping. More detailed left ventricular endocardial mapping (i.e., more than three left ventricular sites) was performed in 45 patients (ten patients with left bundle-branch block, 28 patients during ventricular tachycardia, and seven patients during sinus rhythm, including one patient with the Wolff-Parkinson-White syndrome), as previously described.17 The positions of the catheters were verified fluoroscopically in multiple planes; left ventricular recordings included septal, anterior, inferoposterior, posterobasilar, and lateral free wall sites, as well as mapping of the endocardial surface of an aneurysm (when present). For mapping performed with catheters introduced percutaneously from the femoral artery, catheters were manipulated within their Teflon introducer sheaths. The remaining 35 patients had limited mapping of the left ventricle. The length of time required for study of the left ventricle ranged from 10 to 90 minutes.

Seventy-five of the 80 patients underwent routine electrophysiologic study before the left ventricular catheter was introduced. In each case, multiple electrode catheters were introduced percutaneously and were directed under fluoroscopic guidance from the femoral or antecubital veins (or both) to the right atrium, the right ventricle, the atroventricular junction (to record the His bundle electrogram), and the coronary sinus. Incremental pacing of the right atrium and right ventricle at multiple cycle lengths was then performed, as well as the introduction of programmed extrastimuli.

In addition, in each of these 75 patients, an electrode catheter was inserted into the femoral artery percutaneously (56 patients) or into the brachial artery by cutdown (19 patients) and was advanced to the left ventricle retrogradely for stimulation or mapping (or both). No. 6 French quadripolar electrode catheters (with a 1-cm interelectrode distance) were generally used for left ventricular study; in four patients a hexapolar catheter was used. In the remaining five patients (including five of the ten patients undergoing evaluation of left bundle-branch block), complete electrophysiologic studies were not performed, but recordings were made from a left ventricular electrode catheter at the time of angiographic study.

In 15 patients, electrophysiologic study was performed within two weeks of hemodynamic catheterization and angiographic studies. In five of these 15 patients, it was necessary for technical reasons to reenter the same artery. In addition, 13 of the 80 patients underwent a second or third (two patients) electrophysiologic study of the left ventricle (four patients in the course of evaluating potential therapeutic regimens for recurrent sustained ventricular tachyarrhythmias and nine following aneurysmectomy). In five of these 13 patients, this follow-up study was done at the time of hemodynamic and angiographic catheterization, in order to reduce the total number of left ventricular procedures.

RESULTS

Eighty patients have undergone electrophysiologic study of the left ventricle. The indications for left ventricular electrode catheterization are listed in Table 1. Forty-one patients were studied for evaluation of documented or suspected recurrent sustained ventricular tachycardia. In four of the 34 patients with inducible ventricular tachycardia, programmed electrical stimulation from the left ventricle was required for initiation.

In each of these patients, programmed electrical stimulation from the right ventricle had not been successful in inducing sustained ventricular tachycardia. This included the introduction of either single or double extrastimuli (at two or more different sites, e.g., apex and outflow tract) during right ventricular pacing (at two or more different cycle lengths) or with bursts of rapid ventricular pacing (e.g., cycle length of 250 msec). During programmed stimulation from the left ventricle, double extrastimuli were required for initiation of ventricular tachycardia in each case. The site of stimulation

| Table 1—Indications for Electrophysiologic Study of Left Ventricle in 80 Patients |
|----------------------------------|----------------|----------------|
| Indication                      | No. of Patients | Programmed Electrical Stimulation Mapping |
| Ventricular tachycardia or fibrillation | 69             | 43*            | 69             |
| Left bundle-branch block        | 10             | 0              | 10             |
| Wolff-Parkinson-White syndrome  | 1              | 1              | 1              |

*Includes five patients with ventricular tachycardia or fibrillation only inducible from left ventricle.
(left ventricle vs right) was apparently critical in these cases. Within the left ventricle, each of these patients was inducible from the first site attempted (apex). There were seven patients studied for evaluation of recurrent sustained ventricular tachycardia in whom this arrhythmia could not be induced using programmed stimulation from multiple sites in the right or left ventricle. Similarly, of 28 patients referred for evaluation of documented recurrent ventricular fibrillation, ventricular fibrillation occurred during right ventricular stimulation in nine patients, each of whom had a left ventricular catheter placed only for assessment of activation during sinus rhythm or at the onset of ventricular arrhythmias. The remaining 19 patients underwent programmed stimulation of the left ventricle, and ventricular fibrillation was induced in one patient.

The source of ventricular tachycardia was shown to be within a left ventricular aneurysm in 22 patients in whom extensive endocardial mapping (including one to four recordings from within the aneurysm) was performed. Twelve of these patients later underwent left ventricular aneurysmectomy, at which time the tachycardia was localized to the aneurysm, as determined by intraoperative epicardial or endocardial mapping (or both).17 None of these 12 patients had a fresh thrombus present in the left ventricle at operation.

Complications

There were no major complications in these 80 patients (that is, no death, myocardial infarction, cerebrovascular accident, major thromboembolic events, bleeding, perforation of a great vessel, or cardiac perforation) (Table 2). Of the 61 patients undergoing retrograde left ventricular electrode catheterization performed percutaneously from the femoral artery, two incurred minor complications; one patient had a diminished pulse and had a thrombus removed from the femoral artery via open catheterization with a balloon-tipped catheter (Fogarty catheter), a second patient had a decreased pulse in the left leg that was noted after defibrillation and was demonstrated at open exploration to be due to severe spasm at the site of the entry of the catheter into the femoral artery.

Nineteen patients underwent retrograde left ventricular electrode catheterization via brachial arteriotomy. In each of these patients, the femoral percutaneous approach was considered technically suboptimal (eg, marked obesity, a history of claudication, or poor pulses in the legs). Two patients required secondary repair (ie, repeat catheterization with a balloon-tipped catheter) (Fogarty catheter), which was related to a diminished pulse after study.

In each case, thrombectomy and repair were accomplished in the catheterization laboratory. None of the 80 patients had any other complications requiring specific therapy or prolongation of hospitalization.

In addition, left ventricular catheterization was not associated with the occurrence of sustained catheter-induced arrhythmias, other than those previously observed clinically to occur spontaneously. Occasional mechanically induced isolated ventricular premature depolarizations were observed. Similarly, there was no incidence of transient or complete heart block associated with left ventricular placement or manipulation of the electrode catheter, including seven patients with right bundle-branch block present prior to study.

Analysis of the small number of complications revealed no significant relationship between the occurrence of a complication and the duration of the study, the use of programmed electrical stimulation, extensive endocardial mapping, the indication for the study, or a second study using the same site for arterial entry. There was an increased (but not statistically significant) relative risk of minor vascular complications with brachial arteriotomy, compared to the percutaneous femoral arterial approach (P ≤ 0.10).

### Table 2—Complications of Electrophysiologic Study of Left Ventricle in 80 Patients

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<th>Arterial Technique</th>
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<td>Femoral (Percutaneous)</td>
<td>Brachial (Cutdown)</td>
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<td>No. of insertions of catheters</td>
<td>76**</td>
<td>19</td>
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<td>Major complications</td>
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<td>Death</td>
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<td>Thromboembolic</td>
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<td>Minor complications</td>
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<td>Reexploration</td>
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<td>Lost or diminished pulse</td>
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<td>Arterial dissection</td>
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<td>Bleeding (requiring transfusion)</td>
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<td>Allergic or pyrogenic reaction</td>
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*Ninety-five insertions of catheters.
**Thirteen patients had two or more electrophysiologic studies of left ventricle (nine before and after aneurysmectomy and four with ventricular tachycardia only inducible from left ventricle).
†One with thrombus and one with spasm but no arterial lesion.
ELECTROPHYSIOLOGIC routine not catheterization treatment. The lack of thromboembolic complications to date, particularly in patients with left ventricular aneurysms, may be attributable in part to judicious techniques of catheterization and full heparinization during the study.

Previous electrophysiologic studies of the left ventricle in man have been limited and performed only in conjunction with left ventricular angiographic catheterization. In our own laboratory prior to 1975, the only data obtained were from limited left ventricular mapping (eg, less than three sites in patients with right bundle-branch block). Others, including Narula et al,22 Lee and Lien,23 Rosen et al,24 and Cabeen and MacAlpin,25 have obtained recordings of the specialized conduction system (His bundle or left bundle branch) by the retrograde arterial approach. On occasion the left ventricle has also been studied using the percutaneous transvenous approach by crossing a patent foramen ovale, an atrial septal defect, or a ventricular septal defect. In addition, it has also been possible to record posterobasal left ventricular activation by catheterization of the coronary sinus, which can be performed routinely.

Limitations of the retrograde arterial approach have been related to the design of the catheter. Electrode catheters are relatively stiff and are not easily manipulated; therefore the aortic valve may be difficult to cross, and some endocardial sites are not readily accessible for mapping. Although the retrograde brachial approach allows better manipulation of the catheter, an increased relative risk of minor vascular complications appears to be associated with this approach.

Our present clinical indications for electrophysiologic study of the left ventricle include (1) programmed electrical stimulation of the left ventricle in patients with suspected or documented recurrent sustained ventricular tachycardia or ventricular fibrillation not inducible from the right ventricle, (2) mapping of the left ventricular endocardium in patients with recurrent sustained ventricular tachyarrhythmias refractory to medical treatment or therapy with a pacemaker, in whom aneurysctomy is being considered, and (3) rare patients with the Wolff-Parkinson-White syndrome in whom left-sided mapping via the coronary sinus or via a patent foramen ovale is not possible. Additional patients are being studied on specific research protocols (eg, evaluation of left bundle-branch block).

Thus, programmed electrical stimulation and endocardial mapping of the left ventricle in man (1) can be performed with relative safety and (2) can provide electrophysiologic data not available with electrophysiologic study from the right side of the heart.

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REFERENCES

logic testing for control of recurrent tachyarrhythmias. Am Heart J 93:658-668, 1977