Comprehensive Clinical Electrophysiologic Studies in the Investigation of Documented or Suspected Tachycardias

Time, Staff, Problems and Costs

DAVID L. ROSS, M.B., B.S., JERONIMO FARRE, M.D., FRITS W.H.M. BAR, M.D., EDDY J. VANAGT, M.D., WILLEM R.M. DASSEN, PH.D., ISAAC WIENER, M.D., AND HEIN J.J. WELLENS, M.D.

SUMMARY To assess time, staff, problems and costs involved in clinical electrophysiologic studies for documented or suspected tachycardia, 33 consecutive cases were analyzed prospectively. At least seven staff members were used for each study. Insertion of catheters required 24-105 minutes (mean 63 ± 20 minutes). Programmed stimulation required 12-210 minutes (mean 87 ± 38 minutes). Total fluoroscopy times were 6-67 minutes (mean 22 ± 15 minutes). Each study used 360-2100 feet (mean 1260 ± 390 feet) of recording paper. Detailed analysis of tracings took 1-11 hours (mean 5 ± 2.5 hours). Delays occurred during electrophysiologic study in 25 cases (76%), with multiple causes of delay in 14 cases (42%). These were caused by 1) difficulty in obtaining venous access (five patients); 2) difficult initial catheter placement (15 cases); 3) repositioning of catheters during stimulation (17 cases); 4) sustained atrial fibrillation (four cases). Coronary sinus catheterization was achieved from the groin in 21 of 27 cases (78%) in whom a sustained attempt was made. The approximate cost of each study was greater than $800. Our data show that clinical electrophysiologic studies in the investigation and management of tachycardias are difficult, time-consuming and expensive.

DESPITE THEIR LIMITATIONS, clinical electrophysiologic studies have an established and ever-growing place in the investigation and management of cardiac tachyarrhythmias.1 These studies are invasive, time-consuming, require elaborate, expensive equipment, involve a large number of staff members and are difficult to perform at a satisfactory level. No data are available on these problems. Since many centers are considering establishing or expanding electrophysiologic services, we report the staff required, time, problems and costs involved in comprehensive electrophysiologic studies in a prospective series of 33 consecutive patients with documented or suspected tachycardias.

Methods

Patients

Thirty-three consecutive patients were prospectively analyzed in our electrophysiologic laboratory for documented or suspected tachycardias. All patients were being investigated for the first time. Repeat studies were excluded. Ages ranged from 12-92 years (mean ± sd 45 ± 17 years). Weights ranged from 40-87 kg (mean 66 ± 11 kg). Indications for electrophysiologic study were to determine the presence of or site of origin, mechanisms, and effects of therapeutic maneuvers in patients with documented tachycardias. Informed consent was obtained before the electrophysiologic investigation. Antiarrhythmic drugs were withdrawn at least five half-lives before study. Premedication with intramuscular fentanyl (0.05 mg) and droperidol (2.5 mg) was used in 13 patients and oral diazepam (10 mg) in 20 patients.

Catheterization

Catheters were inserted by a staff cardiologist with the assistance of a cardiology fellow. One or both femoral veins were punctured percutaneously under local anaesthesia and the catheters positioned under x-ray control. The following catheters were most often used: 1) a #6F quadripolar catheter (interelectrode distance 10 mm) placed in the high right atrium (HRA) for stimulating and recording; 2) a #4F bipolar catheter (interelectrode distance 5 mm) placed across the tricuspid valve ring to record the His bundle electrogram; 3) a #4F bipolar catheter (interelectrode distance 10 mm) placed at the right ventricular apex for ventricular stimulation; and 4) a #6F quadripolar catheter (interelectrode distance 10 mm) placed in the coronary sinus (CS). CS catheterization was always initially attempted from a femoral vein by forming a loop in the right atrium (RA) and advancing the catheter tip into the CS (fig. 1). If the femoral route

From the Department of Cardiology, University of Limburg, Annadal Hospital, Maastricht, The Netherlands.
Dr. Ross is an overseas clinical fellow of the National Heart Foundation of Australia.
Dr. Farre was supported by the Fundacion Conchita Rabago de Jimenez Diaz, Madrid, Spain. His present address: Servicio de Cardiologia, Fundacion Jimenez Diaz, Madrid, Spain.
Dr. Wiener's present address: Division of Cardiology, Department of Medicine, Mount Sinai School of Medicine, New York, New York.
Address for correspondence: Hein J.J. Wellens, M.D., Department of Cardiology, University of Limburg, Annadal Hospital, Maastricht, The Netherlands.
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**FIGURE 1.** Technique of coronary sinus (CS) catheterization from the femoral vein. The catheter is looped in the right atrium (RA) as shown. When the catheter tip reaches the floor of the RA and points laterally to the left and slightly upwards, the catheter tip is advanced to enter the CS orifice. Normally some counterclockwise rotation of the loop is required before the CS can be entered. IVC = inferior vena cava; TV = tricuspid valve; Cath = catheter.

was unsuccessful and CS catheterization was considered essential, a left antecubital vein approach was then attempted. An i.v. cannula with a valve was inserted into a right arm vein for administration of drugs and withdrawal of blood samples. Catheters were manipulated until satisfactory electrograms were obtained and cardiac stimulation could be achieved at acceptable thresholds (less than 2 mA for HRA and right ventricle [RV] and less than 4 mA for CS) without causing patient discomfort. Heparin (1 mg/kg body weight) was given after inserting catheters.

One member of the medical staff remained scrubbed in order to change sterile connectors for stimulation at different cardiac sites and to reposition catheters when necessary. Full-time attendance of a nurse was required during the study for provision of drugs and equipment, disposal of blood samples and ministration to the patient. Full resuscitation facilities were available.

**Recordings**

Intracardiac electrograms were preamplified using Janssen JSI 0387 preamplifiers located at the bedside and directly connected to the catheters. This ensured adequate patient isolation from leak currents and minimized extraneous noise in the recordings. Electrograms were further amplified and filtered by Hewlett-Packard 8811 A amplifiers and recorded directly on paper by a 16-channel ink-jet recorder (Mingograf, Siemens-Elema, Sweden). Five external conventional ECG leads (I, II, III, V1 and V6) and as many as six intracardiac electrograms were recorded simultaneously at a paper speed of 100 mm/sec. Stimulus artifact, 20-msec time marks, and case number, time, tape number, driving basic cycle length and coupling interval of premature beats were also recorded automatically onto paper with the remaining channels (fig. 2). All electrograms were also recorded simultaneously on a 14-channel tape recorder (Ampex PR 2200) to enable playback at various speeds, preparation of illustrations and data retrieval. Electrograms were monitored continuously on an eight-channel oscilloscope at the control panel, and also via a video-coupled oscilloscope. The paper recorder was operated by a cardiac technician, who ensured satisfactory amplification and filtration of electrograms and high-quality recordings. The paper was run continuously during stimulation sequences and tachycardias.

**Stimulation**

Stimulation was performed using a programmed stimulator (Janssen Pharmaceutica, Belgium) modified to deliver as many as four extrastimuli with interstimulus intervals individually variable to an accuracy of 1 msec. The stimulator was operated by the electronics engineer in charge of the laboratory (this also permitted rapid and effective attention to any technical problem arising during the study). Stimulation was achieved with 2-msec pulses at twice diastolic threshold. The protocol of investigation was directed by the senior investigator, who viewed the records as they were written. Although a basic protocol was used, unusual findings frequently required initiation of a special sequence of investigation relevant to that finding. The basic protocol of investigation included:

1) **Recording of basic conduction intervals:** PA is the interval between the earliest onset of the P wave in any of the extracardiac ECG leads and the beginning of atrial activation in the His bundle recording; AH is the interval between the beginning of atrial activation and the beginning of His bundle activation in the His bundle recording; and HV is the interval between the beginning of the His bundle ECG and the earliest beginning of ventricular activation in any of the extracardiac ECG leads.

2) **Pacing and extrastimulus testing at two or more basic cycle lengths:** Extrastimuli were given late in
diastole and then with increasing prematurity (10-msec steps at coupling intervals of 400 msec or less) until the effective refractory period at the site of stimulation was reached. Multiple sites of stimulation were used (HRA, CS, RV and other sites when specially indicated).

3) Atrial (HRA and CS) and ventricular pacing at increasing rates until atrioventricular (AV) or ventriculoatrial (VA) block occurred: Rates of 300 beats/min or higher for supraventricular pacing and up to 240 beats/min for ventricular pacing were used. Pacing was ceased if symptoms or signs of intolerance were observed.

4) Timed single or multiple premature beats delivered at various sites during tachycardia: In each case the location and mechanisms of tachycardia and the most effective site and mode of pacing for initiation and termination of tachycardia were determined.

Drugs

Cardioactive drugs were given when indicated during electrophysiologic study either to test the efficacy of antiarrhythmic drugs or to facilitate induction of tachycardia by alteration of autonomic tone. In eight cases, after specific consent had been given, the electrophysiologic effects of a drug under investigation were determined according to a specific research protocol.

Analysis

Tracings were measured and analyzed by cardiologists with previous experience in clinical electrophysiology and the findings were reviewed with the senior investigator. A comprehensive report was made that included conduction intervals, cardiac refractory periods at various cycle lengths and sites, tachycardia and echo zones, type, location and mechanism of observed tachycardias, influence on tachycardia of carotid sinus massage, presence and mechanisms of aberrant conduction, and the effects of antiarrhythmic drugs.
Definitions

Catheterization Time

Time from insertion of local anesthesia to achievement of stable pacing sites and recording of satisfactory electrograms. The end of catheterization time coincided with the beginning of stimulation time.

Stimulation Time

Time from onset of stimulation to completion of study, withdrawal of catheters, and achievement of hemostasis. Time required for a research drug study was included in this time.

Fluoroscopy Time

Total fluoroscopy time used during the study.

Delays

Placements that took longer than 5 minutes to manipulate a catheter to a satisfactory position. Other delays were of various kinds, such as DC countershock and technical problems.

Repositioning of Catheters

This was defined as the need to stop stimulation and significantly change the position of a catheter.

Study Diagnosis

Diagnosis made during electrophysiologic study but before full, detailed analysis of tracings.

Final Diagnosis

Diagnosis made after detailed analysis.

Analysis Time

Working hours from beginning of detailed analysis to completion of a comprehensive written report.

| Table 1. Number and Types of Tachycardia Induced at Electrophysiologic Study |
|--------------------------------|------------------------|------------------|
| Type                         | Sustained | Nonsustained |
| Intranodal reentrant tachycardia | 10       | 2      |
| AVJ CMT using an AP retrogradely | -        | -      |
| AVJ CMT using an AP antegrade | 1        | -      |
| Intra-atrial reentrant tachycardia | 4       | 2      |
| Atrial flutter                | 6        | 1      |
| Atrial fibrillation           | 4        | 2      |
| Ventricular tachycardia       | 1        | 1      |
| Ventricular fibrillation      | -        | 1      |

Abbreviations: AVJ = atrioventricular junctional; CMT = circus movement tachycardia; AP = atrioventricular accessory pathway.

Results

Tachycardias

Tachycardias were induced at electrophysiologic study in 27 patients (82%). Twelve patients (36%) had multiple types of tachycardia (table 1).

Times Required and Problems Encountered

The times required and length of paper are shown in table 2. Two cases in which the tracings were analyzed by a cardiologist without previous electrophysiologic experience were excluded from analysis time statistics. Delays occurred during electrophysiologic study in 25 patients (76%). Multiple causes of delay occurred in 14 patients (42%). Obtaining venous access to the heart caused delays in five patients (15%) for various reasons, including previous venous surgery, radiotherapy and an uncooperative patient. Initial place-

| Table 2. Times and Length of Paper Required for Electrophysiologic Study |
|--------------------------------|---------------------|-------------|
| Number of cases | Range       | Mean  | sd  |
| Catheterization time (minutes) | 33 | 24-105 | 63  | 20 |
| Fluoroscopy time (minutes)    | 33 | 6-67  | 22  | 15 |
| Stimulation time (minutes)    |            |        |
| All cases                     | 33 | 12-210 | 87  | 38 |
| Cases with tachycardia        | 27 | 12-210 | 93  | 38 |
| Cases in whom no tachycardia could be initiated | 6 | 22-96 | 60  | 27 |
| Cases with tachycardia and without research drug study | 19 | 12-210 | 86  | 41 |
| Research drug study time (minutes) | 8 | 22-73 | 47  | 20 |
| Analysis time (hours)         | 31 | 1-11  | 5   | 2.5|
| Length of paper recorded (feet) | 33 | 360-2100 | 1260 | 390 |
ment of catheters in a satisfactory position for pacing and recording was difficult in 15 patients (45%) because of problems in obtaining a satisfactory His bundle electrogram in six cases (18%), and in one case, the use of two catheters to record both His bundle and right bundle branch activity simultaneously. Initial coronary sinus catheterization caused delay in 10 of the 30 cases (33%) in which it was attempted. These data include two patients in whom manipulation of catheters for His bundle and CS recording proved difficult. Repositioning of catheters during the stimulation period was needed in 17 cases (52%) because of poor electrograms or unsatisfactory pacing. Multiple catheters needed repositioning in eight cases (24%). Repositioning or replacement of the His bundle catheter was required in 17 patients, and repositioning of HRA, RV and CS catheters in 7, 2 and 1 cases, respectively.

Induction of sustained atrial fibrillation occurred in four patients (12%). It occurred during introduction of catheters in two patients and during electrical stimulation in two. All patients with sustained atrial fibrillation were older than 33 years and suffered from documented reentrant tachycardias (Wolff-Parkinson-White in two and AV nodal in two). DC shock was used in three of these cases to cardiovert atrial fibrillation to sinus rhythm. The fourth patient was treated with drugs. Very frequent ventricular extrasystoles that were not catheter-induced caused delay in one patient by preventing establishment of a stable driving heart rate for delivery of premature beats. If no tachycardia could be initiated during the study, stimulation time was usually shorter (table 2).

Coronary Sinus Catheterization

In 30 patients recording and stimulation from the left atrium was initially attempted from the femoral vein. Delays were encountered in 10 cases (33%). In three cases the catheter passed through a probe-patent foramen ovale to the left atrium. Since a left atrial electrogram near the AV ring was not essential in these cases, further attempts to cannulate the CS were not made, and the catheter was left in situ. The CS was catheterized from the femoral vein in 21 cases (78%). In one of the six failures (a patient with ventricular tachycardia) CS catheterization was performed to obtain a left ventricular electrogram. When this failed the catheter was then positioned in the right ventricular outflow tract. In the other five failures it was performed to obtain a left atrial electrogram. In four of these patients an AV-ring left atrial electrogram (i.e., CS electrogram) was considered desirable, and further attempts were made to catheterize the CS from a left antecubital vein; this was successful in two cases. When the CS could not be catheterized from either leg or arm, the catheter was placed in the pulmonary artery (PA) to record an anterosuperior left atrial electrogram.2,3 Thus, a left atrial electrogram (LA, CS or PA) was recorded in all patients in whom it was desired, and CS electrograms were obtained in 23 of 30 patients (77%) in whom it was initially attempted from the groin.

Study Diagnosis vs Final Diagnosis

A qualitative comparison was made. Study diagnosis of the type, location, and mechanism of tachycardia was identical in all cases to the final diagnosis. Discrepancies occurred in the study diagnosis of infrequent transient tachycardias induced in addition to the main arrhythmia, minor electrophysiologic phenomena, and complex electrophysiologic mechanisms, primarily of academic importance.

Personnel and Time Spent

At least seven staff members were used for each study. The senior catheterizer was present during catheter insertion. The assistant catheterizer, cardiac technician and laboratory nurse were present throughout the study. All four spent an estimated extra half-hour in preparation or after completion of the study. The electronic engineer was present during the stimulation period. The senior investigator was present during the stimulation period and spent another hour in review of the detailed analysis of tracings. The clinical electrophysiologist was present during the stimulation period and spent additional time in subsequent detailed analysis of tracings. Table 3 gives the mean hours per study for the seven staff members.

Costs

Table 3 is a list of approximate personnel costs of each study. Rates per hour were estimated from yearly gross salaries. These salaries are those of a university hospital department and are believed to be conservative estimates. For example, detailed analysis of tracings was performed by cardiologists solely paid for by research or study grants rather than full-time university staff members who are paid more for their training and experience. Costs of specific electrophysiologic equipment and disposable materials used in each study were estimated from current prices (table 4). We used angiographic radiographic facilities for fluoroscopy (cost $750,000); therefore, the costs were not computed. Simpler and cheaper radiographic

<p>| TABLE 3. Cost of Personnel Involved in Electrophysiologic Studies for Tachycardias |
|-------------------------------------|---------|-----------|-----------|</p>
<table>
<thead>
<tr>
<th>Person</th>
<th>Mean hours per study</th>
<th>Cost per hour (dollars)</th>
<th>Total cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior investigator</td>
<td>2.5</td>
<td>31</td>
<td>77.5</td>
</tr>
<tr>
<td>Catheterizer</td>
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<td>18</td>
<td>27</td>
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<td>Assistant catheterizer</td>
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<td>13</td>
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<td>13</td>
<td>19.5</td>
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<tr>
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<tr>
<td>Nurse</td>
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<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Clinical electrophysiologist</td>
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<td>6</td>
<td>39</td>
</tr>
<tr>
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equipment (approximate cost $50,000) would be satisfactory for a purely electrophysiologic laboratory.

**Discussion**

In recent years the emphasis of electrophysiologic studies has shifted from investigation of conduction defects and sinus node function to that of tachycardias — a much more complex and time-consuming endeavor. The findings in this study of a representative sample of patients with tachycardias confirm that many hours are required both for performance and analysis of this type of investigation. On the average, it involved 2.5 hours on the catheterization table for the patient and 5 more hours of detailed analysis for the clinical electrophysiologist. Delays were the rule (76% of the patients) rather than the exception. Furthermore, a mean fluoroscopy time of 22 minutes was involved for both patient and catheterizers, a time similar to published fluoroscopy times for angiographic heart procedures and probably far longer than fluoroscopy times used in most institutions for general catheterization procedures. The prolonged fluoroscopy time is related to the large number of catheters involved and difficulties in achieving and maintaining satisfactory positions for several hours, simultaneous intracardiac recordings from several sites being essential. The main causes were initial placement of His and CS catheters and repositioning of the His catheter during the stimulation period. The latter problem is a result of the relatively unstable position required for recording a His bundle electrogram. Repositioning of catheters at a late stage in the study tended to displace other catheters. Manipulation of catheters at this stage was often difficult due to catheter floppiness. The studies we have described generally involved cases of tachyarrhythmias referred from other centers because of problems with medical management. Since ours is an academic clinical electrophysiologic laboratory with a research bias, we have attempted to perform complete studies to gain maximum information. In some situations less sophisticated electrophysiologic procedures requiring less time, equipment and staff may be of specific diagnostic and therapeutic value.

Catheterization of the CS from the femoral vein is not routinely used in most institutions because the left antecubital or subclavian vein is preferred. However, catheterization from the femoral vein has advantages. It preserves arm veins, patient comfort, and ease of access. We could achieve an acceptable success rate (78%) for CS catheterization by a femoral approach. The main limitations of this technique were that advancement of the catheter to a lateral position in the CS and catheter mapping along its length were more difficult than with an arm approach.

Although detailed analysis of tracings is essential to confirm diagnoses, quantitate data, and elucidate
complex problems, an accurate assessment of the type, mechanism, location and general characteristics of the arrhythmia can and should be made during the investigation. This ensures that appropriate stimulation techniques have been used to investigate fully the arrhythmia. Inadequately performed stimulation studies recognized in retrospect after detailed analysis can result in failure to obtain vital diagnostic information. There is no substitute for a competent analysis of tracings during the study. Ability to recognize unusual features as they occur and to investigate them appropriately is crucial. A direct-writing recorder is therefore essential; photographic recorders, delayed developing ultraviolet recorders, and analysis direct from the oscilloscope are, we believe, not satisfactory.

Research drug studies significantly prolong an already lengthy study by a mean of 47 minutes. Although such studies provide valuable information about in vivo drug effects in the patient population for whom the drug is intended, the effects of the extra time on the patient must be considered.

Our data show that electrophysiologic studies are expensive. This is due to the expensive equipment, large number of staff and time required. Estimates of cost per study reflect only a fraction of the real costs involved. Maintenance and depreciation of equipment, roentgenographic facilities, surgical instruments, sterilization, cleaning, cost of electricity, provision of space and cost of training staff cannot be quantitated adequately. Furthermore, hospitalization costs or treatment of any complications arising from electrophysiologic study were not included. Nonetheless, disposable items consumed during the study and staff salaries cost around $550 per study. Using a depreciation and replacement rate of 20% per year for an estimated 120 studies per year, the specific electrophysiologic equipment costs $210 per study. Using the cheapest available roentgenographic equipment at the above depreciation rate would cost $83. Total cost per study is therefore in excess of $800 per study. Staff costs were a major item and have been underestimated by calculation of an hourly rate derived from yearly gross salaries. Staff costs on a fee-for-service basis would clearly be higher, especially for the most time-consuming part of detailed analysis. We must emphasize that we have attempted to perform optimal studies in the investigation of complex, often medically refractory arrhythmias. In many centers electrophysiologic studies are satisfactorily performed with a smaller staff; for example, one physician manipulating catheters, one technician running the stimulator, one nurse and one electrophysiologist. Reduction of staff from seven to four personnel would reduce staff costs by approximately $90. Savings can also be made in the quality and quantity of electronic equipment to further reduce the cost of the studies. Direct-writing ink jet recorders use very cheap paper. This is a considerable saving compared with photographic recorders, for which paper costs at least 10 times more. Using the length of recording paper required for our studies, several hundred dollars would be saved in the cost of paper alone.

Although electrophysiologic studies are costly, many have a direct therapeutic benefit for the patient, resulting in reduction or abolition of symptoms. In addition hospitalization costs due to repeated admissions for tachycardias that have been ineffectively treated may greatly exceed the cost of electrophysiologic study in the long term. Thus, if effective drug, pacemaker or surgical treatment is found as a result of electrophysiologic study, the cost of the procedure is justified.

All phases of an electrophysiologic study in the investigation of tachycardias are difficult, time-consuming and costly. Skill and experience are demanded at all staff levels to minimize the time involved and to provide the maximum of diagnostic information. Electrophysiologic studies of this type should therefore be limited to selected centers.

Acknowledgment

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References

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