Catheterization and Cardiovascular Diagnosis 10:507–513 (1984)

Thresholds for Transesophageal Atrial Pacing

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To determine the thresholds for transesophageal atrial capture, as well as factors that may influence the thresholds, we measured the minimal current and pulse width required to pace the atria through transesophageal bipolar lead systems in 12 patients, ranging in age from 1 day to 19 years, during 19 episodes of reentrant supraventricular tachycardia. Depending on the patients' age and size several electrode catheters were used. The protocol called for 1-msec step-wise increments in pulse width. At each pulse width the current was increased by 1 mamp until capture was achieved. The mean minimal pulse width and mean minimal current required for capture were 5.8 msec and 13.6 mamp, respectively. Atrial capture was achieved in 75% of attempts at a pulse width and current equal to or less than 6.5 msec and 17.5 mamp, respectively. No correlation between current and pulse width on the one hand and age, height, weight, or body surface area on the other was detected. Likewise neither electrode type nor existence of structural heart disease influenced the threshold required for capture. We conclude that atrial capture can be readily achieved through transesophageal electrodes and is not influenced by the subject's age or size.

Key words: arrhythmia, pacing, transesophageal

INTRODUCTION

We and others have reported the use of transesophageal pacing for conversion of reentrant supraventricular tachycardia as well as the route for delivery of programmed extrastimulation for measurement of electrophysiologic and hemodynamic responses [1–7]. This technique is dependent on the proximity of the esophagus to the heart. Limited information on the relationship between impulse strength and duration for transesophageal cardiac pacing in man exists [4,8]; however, little data is available that examines the possible relationships between threshold for atrial capture through

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Received April 13, 1984; revision accepted June 16, 1984

the esophagus and the subject's age, size, underlying heart disease, or type of electrode lead. It has been estimated that current density delivered to the atrium by the esophageal lead is about 4% of that from an intracavitary lead [8]; because atrial capture can usually be achieved through an intracavitary lead with equal to or less than 1 mamp current (at a pulse width of 2 msec), a current of approximately 25 mamps appears to be necessary to produce cardiac current density sufficient to pace the heart through an esophageal electrode. This estimation applies to both unipolar and bipolar esophageal systems. As can be seen in equation 1, when using a bipolar lead,

$$J = \frac{2Id}{4\ \pi R^3} \tag{1}$$

the current density, J, at the target site is dependent on the current delivered, I, half the interelectrode distance, d, and the distance of the electrode from the excitable tissue, R. Because the current density at the site of capture, when using a bipolar lead, is inversely related to the distance between the current source and the target tissue cubed [8], it is clear that a small change in this distance would alter the threshold of capture. To examine for the effect of patients' age, and size, as indices of the distance between the esophagus and the atrial tissue, we measured the minimal current (mamps) and pulse width (msec) in 12 patients during 19 episodes of reentrant supraventricular tachycardia. In this report we describe the technique of transesophageal atrial pacing, examine the distance to current-source relationship, and outline the threshold requirements for successful capture in man.

PATIENTS AND METHODS

The clinical and threshold data in the 12 patients studied are summarized in Table I. These 12 patients experienced 19 episodes of reentrant supraventricular tachycardia requiring pacing conversion. Nine of the episodes were paroxysmal supraventricular tachycardia and 10 were atrial flutter. There were six males and six females. The ages ranged from 1 week to 19 years, the weight from 4 to 91 kg, and the height from 38 to 190 cm. Informed written consent was obtained from each patient and/or parents when appropriate.

Depending on the age and size of the patient various electrode catheters were used. For the fully cooperative, older, nonsedated outpatient a pill electrode (Arzco Medical Electronics, Inc., Chicago, IL), with an interelectrode distance of 6.5 mm, was swallowed. The electrode was then allowed to pass by peristaltic motion, initiated by the swallowing of small sips of water, into the stomach. For infants, after estimating the nares-to-stomach distance on the body surface, a 4 French soft bipolar electrode catheter was gently passed through the nasopharynx and esophagus and advanced into the stomach. Alternatively, a 5 French quadripolar catheter (the electrode configuration is two electrodes 1 mm apart at the tip, then two more electrodes 1 mm apart 10 cm proximal to the most distal pair) was passed through a 8–10 French suction catheter into the stomach. In older children the nasopharynx was anesthetized with xylocaine viscous and posterior oral pharynx by an aersol anesthetic spray and the suction catheter was coated with lubricant. Prior to passage of the catheters the distance from the nares to the stomach was carefully estimated; likewise the distance

TABLE I. Clinical and Threshold Data

Episode/ Patient	Age (yr)	Arrhythmia	Threshold		Catheter type/ interelectrode distance	Wt (kg)	Ht (cm)	BSA (m^2)[a]
			Current (mamp)	Pulse width (msec)				
1/1	2	PSVT	9	3	5 Fr/10 mm[b]	14.5	90	0.5
2/2	13	Atrial flutter	20	10	5 Fr/10 mm	55.7	159	1.56
3/2	13	Atrial flutter	10	5	5 Fr/10 mm	55.7	159	1.56
4/3	9	Atrial flutter	12.5	6	5 Fr/10 mm	27.4	131	0.99
5/3	9	Atrial flutter	12	4	5 Fr/10 mm	26.6	131	0.99
6/3	9.5	Atrial flutter	14	5	Med/29 mm[c]	26.6	131	0.99
7/3	9.5	Atrial flutter	16	6.5	Med/29 mm	33	135	1.11
8/4	5	Atrial flutter	17.5	4	Med/29 mm	19.4	112	0.78
9/5	0.016	PSVT[d]	18	5	4 Fr/10 mm	4.2	55	0.24
10/5	0.019	PSVT	16	5	4 Fr/10 mm	4.2	55	0.24
11/6	14	PSVT	18	10	Med/29 mm	25.7	152	1.09
12/7	0.15	PSVT	14	7	5 Fr/10 mm	4.62	57.5	0.26
13/8	0.12	PSVT	18	10	4 Fr/10 mm	4.03	38	0.18
14/9	16	Atrial flutter	12	5	"Pill"/6mm	58	135	1.41
15/10	0.12	PSVT	8	4	4 Fr/10 mm	3.68	51	0.22
16/10	0.12	PSVT	12	5	4 Fr/10 mm	3.68	51	0.22
17/10	0.12	PSVT	8	3	4 Fr/10 mm	3.68	51	0.22
18/11	19	Atrial flutter	10	6	Med/29 mm	91.7	190	2.2
19/12	2	Atrial flutter	17	10	5 Fr/10 mm	11.58	81	0.49

[a]BSA, Body surface area.
[b]Fr, French.
[c]Med, Medtronic 6910R-58.
[d]PSVT, Paroxysmal supraventricular tachycardia.

required for extrusion of the electrodes beyond the suction catheter was carefully estimated and noted on the electrode catheter. Not infrequently the suction catheter required enlargement at the tip by creating a slit along the longitudinal axis of the tip of the catheter. The electrode catheter was then easily passed after lubrication through this suction catheter and positioned as previously described. This technique allowed the passage of a stiff, multielectrode catheter, minimizing discomfort and avoiding possible perforation. For five larger patients who declined the pill electrode, a soft transvenous pacemaker bipolar lead (Medtronic 6901R-58) with an interelectrode distance of 2.9 cm could be easily passed into the stomach. Once the recording and pacing catheter was in the stomach, the electrodes were then connected to standard an isolated amplifier (Electronics For Medicine V1205A) for display on an oscilloscope as well as for recording on photographic paper moving at 50–100 mm/sec. Two to three standard electrocardiographic leads were simultaneously monitored and recorded. The lead was then slowly withdrawn until the optimal pacing location was

found. This position was indicated by noting the maximal recorded atrial electrogram, which was usually equal to or greater than 2–3 times the size of the ventricular electrogram. Because of the distance-current relationship previously described, a specially designed battery-powered constant-current stimulator (Arzco Medical Electronics, Inc., Chicago, IL Model #5 esophageal stimulator) was used; this device provided a constant current pulse of 1–25 mamps and a constant pulse width of 1–10 msec over a wide range of pacing cycle lengths.

The protocol for determination of the threshold requirements was as follows: We began pacing a 4-msec pulse width and a 5-mamp current at 90% of the tachycardia cycle legth. The pulse width was then increased by 1-msec increments. At each pulse width setting the current was increased by a 1-mamp increment until capture was achieved. Thus the earliest point of capture indicated the minimal pulse width and minimal mamps required for pacing.

Analysis of the data included calculation of the mean and standard deviation of the current and pulse width required for capture. In addition linear regression analysis between the pulse width and/or current on the one hand and age, weight, height, body surface area, and type of lead (ie, interelectrode distance) used on the other was performed. Finally, analysis of variance comparing the threshold requirements between those subjects with normal hearts and those with structurally abnormal hearts was performed.

RESULTS

The results are summarized in Table II. Among the 19 episodes of reentrant supraventricular tachycardia in these 12 patients the mean minimal pulse width required for capture was 5.8 msec, whereas the minimal current required for capture was 13.6 mamps. Distribution of the pulse width and current values demonstrated that capture was achieved in 75% of attempts when a pulse width of 6.5 msec and a current of 17.5 mamps was achieved.

Linear regression analysis demonstrated that there was no correlation between the pulse width and the current at threshold on the one hand and the age, height, weight, body surface area, or type of lead used. Analysis of covariance demonstrated that no significant relationship was detected even when either pulse width or current was alternately held constant. Scattergrams between the threshold requirements on the one hand and the size and age variables on the other likewise failed to suggest a relationship. Analysis of variance demonstrated no significant difference in threshold between those patients with normal hearts and those with structurally abnormal hearts.

TABLE II. Threshold in Pulse Width (PW) and Current

Pulse width	5.8 ± 2.2[a] msec
current	13.6 ± 3.8 mamp

% Episodes successfully captured	PW (≤ msec)	Current (≤ mamp)
25%	4.0	10
50%	5.0	12.5
75%	6.5	17.5

[a] $\bar{x}$ ± SD.

To examine for reproducibility within the same patient, coefficients of variation were calculated for the four subjects who had multiple determinations. The coefficient of variation for these four subjects was 52% for pulse width and 29% for current. If one excluded patient No. 2, who was minimally sedated and quite anxious at the first trial, thus making precise determination of the threshold difficult, the coefficient of variation was 15% for current and 18% for pulse width.

DISCUSSION

These data are in accord with thresholds used by other investigators in transesophageal cardiac stimulation in man [2–7] In addition, they are compatible with the theoretical considerations regarding the estimate of 25 mamps required for transesophageal stimulation. Finally, they demonstrate that, with only a moderate increase in pulse width above the widely used intracavitary pulse width of 2 msec, atrial capture through esophageal leads can often be achieved with almost a 50% decrease from the estimated 25 mamps.

It is interesting to note that, despite the mathematical model describing the relationship between current density at the target site and distance between target site and current source, no relationship between the threshold requirements and the subject's size was detected. We had initially speculated that, because of the inverse relationship between distance and current source, increasing age and size would result in an increasing distance between the target atrial wall and the electrode. Thus current density would be reduced and threshold requirements would increase with increasing age and size. Failure to conform to this mathematical model may be explained by a relative constancy of the distance between the esophagus and the atrial posterior wall despite the obvious changes in somatic size and configuration as well as a constant esophageal wall thickness that does not change appreciably with increasing age or size.

Pulse width and current values required in this study were considerably below those thresholds required to produce hyperemia or epithelial erosion in canine experiments [8,9]. These experiments demonstrated that epithelial erosion, which self-repaired after 24 hr, appeared following pacing at 60 mamps at a pulse width of 2 msec for 4 hr. When pacing was limited to less than 30 min no epithelial injury was noted [8,9]. It is important to consider that the cumulative time required for conversion of reentrant supraventricular tachycardia in these patients was less than 2 min. No single sustained pacing interval exceeded 30 sec.

The threshold requirements over time in individual subjects appears reasonably constant given the variable placement of the catheter during each subsequent pacing conversion. It is possible that catheter movement could occur during pacing as a result of peristalsis and thus change the thresholds for pacing. These intrapatient data, along with the lack of correlation between patient age and size, suggest that the major determinant of successful transesophageal atrial capture is the identification of the optimal pacing site by recording the maximal atrial electrogram through the transesophageal leads. Because of possible lateral displacement of the electrode within the esophagus, several passes may be required to obtain the maximal atrial electrogram (usually equal to or greater than the ventricular electrogram) correctly identifying the optimal pacing site.

This experience indicates that the technique is safe and well tolerated by the subject. The only frequent sensation mentioned by the patient is that of esophageal discomfort or "heartburn" during pacing; this is transient, ceasing at the termination of pacing. This discomfort can be reduced by careful explanation of the procedure as well as the judicious use of sedation. Most babies tend to sleep during the procedure after positioning of the catheter. One patient had inadvertant passage of the catheter into the right main stem bronchus; severe coughing developed and the catheter was immediately withdrawn. Successful pacing was achieved when the catheter was correctly placed in the esophagus. Careful electrode catheter selection along with mucosal anesthesia reduces the discomfort during passage and reduces the risk of perforation of the esophagus. The risk of inadvertant ventricular stimulation is reduced by using catheters with an interelectrode distance of 6–10 mm and by careful selection of the optimal pacing site. In patients undergoing pacing studies while in sinus rhythm a rapid ventricular response during atrial pacing supported by either a "fast" atrioventricular node or an accessory connection with a short antegrade effective refractory period is a theoretical drawback of this technique. Such a response, for the most part, can be prevented by examining the surface ECG in conjunction with the transesophageal electrocardiogram. In addition inadvertant induction of atrial fibrillation may occur; this possibility could be desirable as it may represent an unstable transient rhythm that spontaneously converts to sinus rhythm [10,11]. In any event, as indicated by our data, the most likely outcome of introducing impulses during tachycardia is penetration of the reentrant circuit and the desired termination of the tachycardia. However, because these several possibilities exist, transesophageal atrial pacing should be performed only in facilities with immediate access to DC cardioversion.

This study demonstrates that the threshold for transesophageal atrial pacing is independent of patient age, size, and cardiac structural abnormality. The technique is safe, requiring current and pulse width well below those that produce epithelial injury in experimental animals. It avoids direct current cardioversion, which creates diffuse myocardial injury, and thus is especially useful in those individuals requiring repeated conversions. We therefore recommend this procedure for patients who require cardioversion for reentrant supraventricular tachycardias regardless of age, size, or underlying cardiac abnormality.

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