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The Echo-Transponder Electrode Catheter: A New Method for Mapping the Left Ventricle

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The ability to locate catheter position in the left ventricle with respect to endocardial landmarks might enhance the accuracy of ventricular tachycardia mapping. An echo-transponder system (Telectronics, Inc.) was compared with biplane fluoroscopy for left ventricular endocardial mapping. A 6F electrode catheter was modified with the addition of a piezoelectric crystal 5 mm from the tip. This crystal was connected to a transponder that received and transmitted ultrasound, resulting in a discrete artifact on the two-dimensional echocardiographic image corresponding to the position of the catheter tip.

Catheters were introduced percutaneously into the left ventricle of nine anesthetized dogs. Two-dimensional echo-transponder and biplane fluoroscopic images were recorded on videotape with the catheter at multiple endocardial sites. Catheter location was marked by delivering radiofrequency current to the distal electrode, creating a small endocardial lesion. Catheter location by echo-transponder and by fluoroscopy were compared with lesion location without knowledge of other data. Location by echo-transponder was 8.7 ± 5.1 mm from the center of the radiofrequency lesion versus 14 + 7.8 mm by fluoroscopy ($n = 15$, $p = 0.023$). Echo-transponder localization is more precise than is biplane fluoroscopy and may enhance the accuracy of left ventricular electrophysiologic mapping.

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Arrhythmia surgery and catheter ablative techniques have become important alternatives to the pharmacologic treatment of patients with ventricular tachycardia (1–4). These methods require localization of the arrhythmia focus within the ventricle (2,5). Endocardial catheter mapping is used to identify the site of origin of ventricular tachycardia. The catheter is manipulated so as to record the site of earliest electrical activity during the latter half of electrical diastole. This recording is presumed to represent activation of an area at or near the reentrant circuit (6). Catheter tip location is determined with biplane fluoroscopy. Radiographic landmarks consist solely of epicardial shadows, making endocardial localization difficult (7). Such localization may be especially problematic in patients with chamber enlargement or distorted left ventricular anatomy, such as those with an aneurysm. In addition, the adequacy of electrode-tissue contact is difficult to assess with a fluoroscopic image.

Although two-dimensional echocardiography offers excellent visualization of the endocardium, recognition of a catheter tip may be difficult because each point where the catheter passes through the scanning plane can be misconstrued as the tip. A new transponder device developed by Cikes et al. (8) obviates this problem by creating a flashing marker on the two-dimensional echocardiographic image at the exact location of the catheter tip. We compared the accuracy of this echo-transponder system with biplane fluoroscopy for localization of an electrode catheter within the left ventricle.

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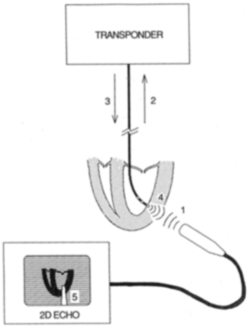

Figure 1. Diagrammatic representation of the echo-transponder system. Ultrasonic energy from the echocardiograph [1] impinges on the piezoelectric crystal in the transponder catheter. Ultrasound is detected by the transponder [2]. The device immediately responds with a series of electronic pulses [3], resulting in ultrasound emission from the transponder crystal [4]. This occurrence results in a flashing marker on the two-dimensional echocardiographic (2D ECHO) image at the location of the catheter tip [5].

Methods

Echo-transponder apparatus. The transponder system (Telectronics, Inc.) is shown in Figure 1. A standard 6F tripolar electrode catheter with 5 mm interelectrode spacing (USCI, Inc.) was modified by substituting a piezoelectric crystal for the middle electrode. This crystal was connected to the transponder and functioned as both a receiver and source of ultrasound. When the ultrasound beam from the echocardiograph impinges on the transponder crystal, it is detected by the transponder, which immediately produces a "reply" in the form of a series of ultrasonic pulses, resulting in a flashing marker on the two-dimensional echocardiographic image at the exact location of the transponder crystal.

Experimental protocol. Nine mature mongrel dogs of both genders were anesthetized with fentanyl (0.04 mg) and droperidol (2 mg) intramuscularly followed by sodium pentobarbital (10 to 30 mg/kg body weight) intravenously. The dogs were intubated, ventilated mechanically and blood pressure and electrocardiogram (ECG) were monitored continuously. With the dog oriented in the right anterior oblique position, standard electrode catheters were introduced into the coronary sinus by way of the right internal jugular vein and into the right ventricular apex by way of the right femoral vein to serve as points of reference during fluoroscopic mapping. The transponder catheter was introduced through a hemostatic sheath in the right femoral artery and advanced into the left ventricle. When a stable endocardial position was obtained, a biplane (right and left anterior oblique) fluoroscopic image of the heart was recorded on videotape. Then, two-dimensional images of the left ventricle were recorded with a standard echocardiograph (Ausonics M1000) with a 5 mHz transducer. Identification of the catheter tip was achieved by scanning in several planes until the transponder marker was seen most clearly. Both apical and parasternal windows allowed good visualization of the left ventricle in all dogs. Catheter location within the left ventricle was then marked by creating a burn at the point of contact between the distal electrode and the endocardium by applying radiofrequency energy between the distal electrode and a chest wall patch. Continuous, unmodulated current (550 kHz, 25 to 50 V and 5 to 10 s duration) was applied with a commercially available electrocoagulator (Microvaisive Bicap). This technique has been shown to produce small, well circumscribed endocardial lesions (9). The dogs were killed and the hearts fixed in 10% formalin.

Comparison of echocardiographic and fluoroscopic accuracy. The location of the center of each radiofrequency burn lesion on the endocardium was used as a reference point to compare the accuracy of echo-transponder and fluoroscopic techniques. The left ventricle of each heart was opened and the position of the radiofrequency lesion or lesions were marked on the mapping form used in our clinical laboratory. Then, the corresponding echocardiographic and fluoroscopic images were reviewed by experienced operators who were unaware of other data (echocardiographic images—N.B.S., R.B.H.; fluoroscopic images—J.M.H., J.O.F.), and the estimated catheter positions were recorded on an identical mapping form. All marks were then superimposed onto a single map and the distances between echocardiographic and fluoroscopic estimates and the center of the corresponding radiofrequency lesion were measured (Fig. 2). Because heart size was variable and slightly smaller than the size of the mapping form, each set of distance measurements was multiplied by a correction factor. The correction factor, derived by dividing mitral annular diameter on the two-dimensional echographic image by that on the mapping form ranged between 0.69 and 0.90.

Statistical analysis was performed using the t test for paired variables.

Results

Endocardial lesion locations. Fifteen different catheter positions were imaged in nine dogs and a radiofrequency lesion was produced at each location. Mean endocardial lesion diameter was 2.9 + 0.5 mm (range 1.5 to 3.5). When two lesions were made in the same dog ($n = 6$), widely spaced locations were used. We attempted to position the catheter in as many left ventricular sites as possible; four

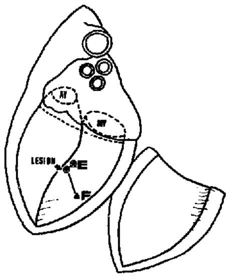

Figure 2. Comparison of distance from echo-transponder estimate of catheter location (E) and fluoroscopic estimate (F) to the location of the center of the corresponding radiofrequency lesion (see text for details). AV = aortic valve; MV = mitral valve.

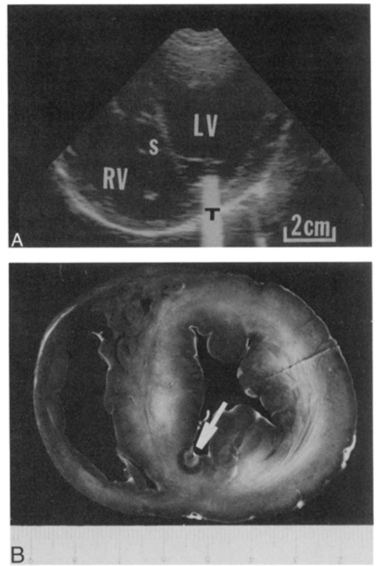

Figure 3. A, Short-axis echo-transponder image showing the transponder marker (T) at the junction of the inferior and septal (S) walls. **B,** Pathologic section showing the corresponding radiofrequency lesion (arrow). LV = left ventricle; RV = right ventricle.

lesions were apical, four were on the free wall, four were inferior and three were septal.

Echocardiographic images of transponder location. The transponder marker was visualized readily on the echocardiogram in all dogs. Images were obtained in both the parasternal and the apical views in all dogs. Figures 3 and 4 demonstrate the correlation between transponder location and the corresponding radiofrequency lesion. The echographic image in Figure 4 clearly shows the proximity of the catheter to the posterior leaflet of the mitral valve, which is not as apparent on the fluoroscopic view (Fig. 5).

Transponder versus fluoroscopic technique. The mapping data for both transponder and fluoroscopic techniques are summarized in Table 1. There was >5 mm difference in mapping accuracy between the two observers in 5 of 15 fluoroscopic measurements and in 6 of 15 echo-transponder measurements. However, there was no significant difference between the overall accuracy of the two observers in either the echocardiographic or fluoroscopic groups. In addition, the location of the catheter within the left ventricle did not affect the accuracy of either technique. The echo-transponder technique was significantly more accurate than was biplane fluoroscopy at localizing catheter position in the left ventricle (8.7 ± 5.1 versus 14 ± 7.8 mm, $p = 0.023$).

Discussion

Echocardiography has been used to determine the position of an electrode catheter within the right ventricle (10), to diagnose pacing lead perforation (11) and to guide catheter placement in pregnant women (12). It has also been employed during transseptal catheterization (13) and endomyocardial biopsy (14). However, the utility of echocardiography during catheterization is limited by reverberation and side lobe artifacts and, most importantly, by ambiguous identification of the catheter tip (8).

Accuracy of the echo-transponder system. This system, developed by Cikes et al. (8,15), allows precise identification of the catheter tip by producing a flashing marker at its location on a real time two-dimensional echocardiographic image. Thus, the position of a left ventricular mapping catheter can be determined relative to endocardial landmarks and more accurately than with biplane fluoroscopy.

Endocardial catheter mapping of ventricular tachycardia. This technique was described in 1978 (5). Its accuracy has been compared with that of intraoperative mapping under direct visualization, and of the catheter map localized the ventricular tachycardia focus determined at operation to within 4 to 8 cm^2 (16). A cineradiographic method has been

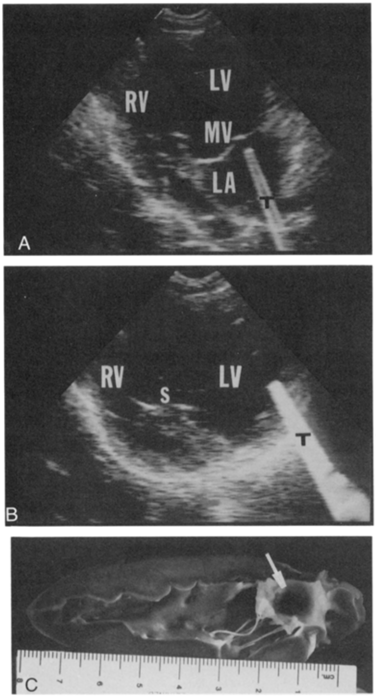

Figure 4. **A,** Long-axis and **B,** short-axis echo-transponder images. Note the proximity of the transponder marker (T) to the posterior leaflet of the mitral valve (MV). **C,** Pathologic section showing the corresponding radiofrequency lesion (**arrow**) involving the posterior mitral valve leaflet. Abbreviations as in Figure 3.

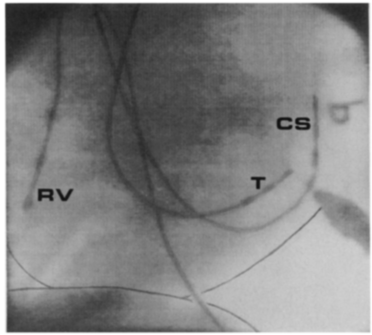

Figure 5. Left anterior oblique fluoroscopic image of the transponder (T) catheter in the left ventricle in the same position as in Figure 4. Although the posterolateral orientation of the catheter is evident, the proximity of the mitral apparatus is not as apparent as it is on the corresponding echocardiographic view. The cardiac silhouette and diaphragm have been outlined for clarity. CS = coronary sinus catheter; RV = catheter in the right ventricular apex.

described to improve the anatomic localization of a mapping catheter (7). The position of the distal electrode is computed relative to three reference points visualized during ventriculography. This technique was compared with intraoperative endocardial mapping with a multielectrode array and was able to localize the earliest site to within 1 cm for 11 of 12 tachycardias (17). This level of accuracy is comparable with that of the echo-transponder system described earlier. However, it is considerably more complex, requiring fluoroscopic calibration, ventriculography and off-line computer analysis of biplane images.

Limitations of the study. Experiments were performed in normal canine ventricles during sinus rhythm. The effects of tachycardia on transponder resolution are unknown. However, the frame rates of currently used echocardiographs (30 to 60 Hz) make it unlikely that rapid movements of the transponder during ventricular tachycardia would affect image quality.

The prototype catheters we used had the piezoelectric crystal placed 0.5 cm back from the distal electrode. Although this is a potential source of inaccuracy, catheter orientation could be appreciated on the echocardiographic image, allowing for extrapolation of tip location. A modification of this prototype has been designed with the piezoelectric element immediately adjacent to the distal electrode.

The correction factor used to adjust for differences between heart size and the size of the mapping form was derived from only one measurement (mitral annular diameter). However, any inaccuracy of this correction factor should not affect the comparison of the two techniques because each group of paired variables was divided by the same constant.

The differences in orientation of the heart in dogs and humans may have impaired the accuracy of fluoroscopic localization. Catheters were placed in the coronary sinus and right ventricular apex to serve as points of reference in an attempt to minimize this problem.

Table 1. Distances (in mm) Between 15 Fluoroscopic and Echo-Transponder Estimates of Catheter Position and the Center of the Corresponding Endocardial Lesion

Left Ventricular Site	Fluoroscopic Accuracy		Echo-transponder Accuracy	
	Observer 1	Observer 2	Observer 3	Observer 4
Apical	3.5	4.0	3.5	3.5
	21.0	17.5	23.0	16.0
	6.0	7.0	14.5	2.0
	27.5	26.5	2.0	3.5
Septal	13.5	11.0	6.5	8.0
	5.0	22.0	6.5	9.0
	20.5	13.0	24.5	11.0
	20.5	19.0	2.5	17.0
Inferior	11.0	5.5	6.5	8.0
	31.0	25.0	4.0	8.0
	22.5	22.5	8.5	21.5
	11.0	4.0	6.0	13.0
Free wall				
	8.0	8.5	8.0	3.0
	6.0	11.0	8.5	5.0
	5.5	7.5	3.5	5.0
Mean ± SD	14 ± 7.8 mm		8.7 ± 5.1 mm	
	p = 0.023			

The transponder technique may be of limited value in the 10 to 15% of patients who cannot be adequately imaged echocardiographically (18). The transponder could be used in these patients in conjunction with a transesophageal probe. Transesophageal echocardiography produces high resolution images of the ventricles (19) and may be particularly useful for mapping posterior structures including the atria and tricuspid anulus.

Clinical implications. Echo-transponder mapping may increase the accuracy of preoperative localization of ventricular tachycardia foci. Although large areas of endocardial scar are often resected during arrhythmia surgery in an effort to eliminate all potential arrhythmic sites (2,20), precise mapping is of importance. Arrhythmogenic foci are frequently found at the border of normal and diseased tissues or near the base of a papillary muscle (6). Thus, an accurate map may increase the likelihood of curative resection and minimize the amount of viable tissue excised and vital structures damaged. Improved preoperative mapping may also be beneficial by allowing the ventriculotomy to be made in a more favorable location. Echo-transponder use might also decrease the duration of fluoroscopy use, thereby decreasing radiation exposure to the patient and personnel.

Because of disadvantages associated with the use of direct current shock for catheter ablation, alternative energy sources such as laser (21) and radiofrequency (9) are being explored. These new methods tend to produce much more localized myocardial injury, necessitating more accurate mapping of arrhythmia foci. Such techniques may also require multiple applications of energy over a small area. The transponder system will enhance the reproducibility of catheter positioning, facilitating return to a previously mapped site. Transponder use may also help to prevent the inadvertent application of ablative energy to a mural thrombus or the mitral apparatus. As the ability to modify the arrhythmia substrate evolves, localization of electrode catheter position becomes increasingly important. The echo-transponder catheter may prove to be a useful tool for the interventional electrophysiologist.

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