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In Vivo Validation of the Origin of the Esophageal Electrocardiogram

PHILIP F. BINKLEY, MD, CHARLES A. BUSH, MD, FACC, BRUCE L. FLEISHMAN, MD, CARL V. LEIER, MD, FACC

Columbus, Ohio

Esophageal electrocardiography is a clinical and investigational technique that is useful for determining atrial conduction intervals, analyzing atrial rhythms and mapping conduction pathways. Although the left atrial origin of the esophageal electrocardiogram has long been implied, recently that origin has been questioned. In the present study, the origin of the esophageal deflection is defined by direct right and left atrial mapping studies performed with simultaneous esophageal electrograms obtained from three positions (high, mid and low). Seven patients with normal left atrial dimensions (group I) and five patients with left atrial enlargement (group II) underwent transseptal catheterization during the course of electrophysiologic study.

In group I (normal left atrial dimensions), conduction time from the high right atrium to each of the three esophageal positions corresponded to conduction times to left atrial sites ranging from 1 to 3 cm lateral to the left interatrial septum. The mid- and low esophageal conduction times were all significantly longer than conduction time to the left side of the septum ($p < 0.05$). In group II (enlarged left atrium), conduction times to each of the esophageal sites corresponded to conduction times to left atrial sites lying between the mid-left atrium and a point 1 cm lateral to the left side of the septum. A significant trend toward longer conduction time to the mid-esophageal position than to the left septum was noted ($p < 0.1$). In both groups, conduction times measured with the esophageal catheter were significantly longer than conduction time to the right interatrial septum ($p < 0.05$).

The esophageal electrogram corresponds to atrial deflections recorded within the left atrium distinct from the interatrial septum and right atrium. Esophageal electrocardiography is a valid technique for investigation of left atrial rhythms and interatrial conduction.

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The esophageal recording electrode is frequently utilized as an indicator of left atrial activity in studies investigating atrial conduction and arrhythmias (1–4). The validity of this technique has been assumed on the basis of early fluoroscopic examination of the course of the esophageal catheter (5,6). However, modern techniques of left atrial mapping have not been utilized to verify or precisely define the origin of the esophageal electrogram. Coronary sinus mapping studies (7) have, in fact, suggested that the esophageal electrogram reflects atrial septal depolarizations. We report direct left atrial mapping data obtained by means of transseptal left atrial catheterization in patients with normal left atrial size or left atrial enlargement which confirm the left atrial origin of the esophageal electrogram.

Methods

Study patients. Twelve patients undergoing electrophysiologic studies requiring evaluation of left-sided chambers and in whom a transseptal approach was considered preferable constituted the study group. Group I consisted of seven patients (four women, three men; mean age 42 ± 14 years) with normal left atrial size by echocardiography (mean echocardiographic left atrial dimension = 3.0 ± 0.6 cm). Group II consisted of five patients (four men, one woman; mean age 59 ± 6 years) with fluoroscopic or echocardiographic criteria for left atrial enlargement (mean echocardiographic left atrial size 4.8 ± 0.5 cm).

Indications for electrophysiologic evaluation were the following: 1) syncope or near syncope (seven patients); 2) frequent symptomatic premature ventricular complexes (two patients); 3) symptomatic palpitation of undetermined cause (one patient); 4) atrial flutter (one patient); and 5) docu-

From the Division of Cardiology, The Ohio State University College of Medicine, Columbus, Ohio. This study was supported by the Central Ohio Chapter of the American Heart Association,Columbus, Ohio and the William Davis Research Fund,Columbus, Ohio.

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Address for reprints: Philip F. Binkley, MD, Assistant Professor of Medicine, Division of Cardiology, Ohio State University Hospitals, 621 Means Hall, 1654 Upham Drive, Columbus, Ohio 43210

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mented ventricular tachycardia (one patient). All provided written informed consent before the study. The protocol was approved by the Human Subjects Review Committee of the Ohio State University.

Procedures. All patients were studied in the postabsorptive, nonsedated state. Antiarrhythmic medications were discontinued 24 hours before the study. Two bipolar catheters, 4F and 5F, were inserted through the right subclavian vein and positioned in the high right atrium for pacing and recording. A 6F hexapolar catheter was inserted percutaneously through the left femoral vein and positioned across the tricuspid valve for recording low right atrial, His bundle and right ventricular potentials. In all patients, a bipolar Medtronic pacing catheter (series 5824A, 10F, vernier-measured interpole distance of 1.0 cm) was inserted through the nares and advanced into the esophagus and positioned fluoroscopically as noted later.

After evaluation of right heart chambers was completed, transseptal catheter placement was performed. In two patients, this was accomplished by repositioning of the hexapolar catheter across either a probe-patent foramen ovale or an atrial septal defect. In the remaining patients, a guide wire was inserted through the right femoral vein and a 9F Ross catheter was placed over the guide wire. The guide wire was removed and a Brockenbrough needle inserted through the Ross catheter. Interatrial septal puncture and catheter placement were then performed in standard fashion under fluoroscopic guidance and with continuous pressure monitoring (8). A 4F or 5F bipolar catheter (interelectrode distance of 1 cm) was advanced through the Ross catheter and positioned in the left atrium or ventricle as required for clinical evaluation. A side arm was attached to the Ross catheter to allow continuous infusion of a heparin and saline solution around the bipolar catheter. All patients received from 2,500 to 5,000 U of heparin as a bolus at the time of placement of the left-sided recording catheter.

Recordings. After completion of the clinical protocol, the recording catheter was positioned fluoroscopically at the most lateral margin of the left atrium in the posteroanterior projection. Catheter position was then viewed in the 45° left anterior oblique projection to assure posterior placement of the left atrial catheter in a position immediately above the left superior pulmonary vein. Simultaneous recordings were obtained from the left atrial catheter and the esophageal catheter in each of the following three positions determined fluoroscopically in the posteroanterior projection: 1) high esophageal position: mid-bipole of the esophageal lead intersecting the horizontal line passing through the junction of the superior vena cava and the right atrium; 2) low esophageal: mid-bipole immediately above the diaphragm; and 3) mid-esophageal: mid-bipole at a point half the distance between the high and low points. Simultaneous recordings were also obtained from scalar electrocardiographic leads I, aVF and V_1. All signals were amplified and recorded on an Electronics for Medicine VR-12 at cutoff frequencies of 30 to 250 Hz, calibration of 0.1 mV/cm and a paper speed of 100 mm/s.

After recordings were obtained with the left atrial catheter in the most lateral position, it was withdrawn by a distance of 1 cm and the previous simultaneous recordings were again acquired. Recordings were thus obtained at 1 cm intervals across the left atrium until the catheter crossed the interatrial septum. A final recording at the right paraseptal region simultaneous with each of the three esophageal recording sites was then obtained.

Measurements. For each set of simultaneous left atrial and esophageal recordings, conduction times from the high right atrium to the left atrial deflection and to the esophageal deflection were measured. Ten determinations were made and averaged for each measurement. Thus, for each patient, the conduction time to each left intraatrial position was obtained three times (once for each esophageal position), and conduction time to each esophageal position was determined with each simultaneously obtained left atrial recording. Onset of high right atrial activation was defined as the upstroke of the first high frequency deflection obtained from the high right atrial recording catheter or the earliest onset of the scalar P wave, whichever occurred first. Onset of activation for each atrial and esophageal site was taken as the upstroke of the first high frequency deflection recorded. For each patient, the conduction time to the mid-left atrium was derived from the median of the conduction times to the left atrial recording sites (left paraseptal region to lateral left atrium).

Statistical analysis. Data were analyzed using the Clinfo Data Management and Analysis System of the Ohio State University (GCRC RR-34). The Student t test for paired data was used to compare conduction times within patient groups. Student t testing for unpaired data was performed for intergroup comparison. In each case, the hypothesis that equal variances existed for the population was tested by determination of the F ratio and accepted at the probability (p) < 0.05 level of significance. For nonparametric analysis, the Wilcoxon signed rank test was used to test paired data and the Wilcoxon two-group rank sum test to test unpaired data. Differences within and between groups were considered significant at the level of $p < 0.05$. A trend toward statistical significance was noted for $0.05 < p < 0.1$ (9).

Results

The means and standard deviations for conduction times from the high right atrium to each esophageal and left atrial recording site are shown for individual patients and each group in Tables 1 and 2. The number of left atrial recording sites varied among patients, but in each patient a minimum of four recording sites was obtained within the left atrium,

Table 1. Esophageal and Interatrial Conduction Times in Patients With Normal Left Atrial Dimensions (group 1)

	Esophagus			Left Atrium					Paraseptal Region	
Patient	High	Mid	Low	Lat	3 cm Lat	2 cm Lat	Mid	1 cm Lat	LS	RS
1	53.6	60 7	40 1	71 8	50 4	34.8	42.6	27.7	20.0	14.8
2	44.4	45 1	58 6	61 8	—	56.9	54.8	52 7	37 9	50.5
3	39.8	57 3	51.7	49 5	41.1	41.1	41 1	34.8	25.8	24 2
4	15.7	72.9	38.5	86.2	—	80.0	71.7	63 4	36.3	30.4
5	62.7	66.0	62.7	72.8	65.5	47.3	56.4	44 9	39.1	15.9
6	60.5	71.6	76 3	54 5	53 0	50.8	50.8	27.8	25 7	27.0
7	40.8	38.2	45 9	59 2	39.6	30 2	30.2	27 6	26.9	8.8
Group I mean	45.4	58.8	53.4	65.1	49.9	48.7	49.7	39 8	30 2	24.5
± SD	± 16.0	± 13 1	± 13.5	± 12.6	± 10.4	± 16 6	± 13.3	± 14 2	± 7 4	± 13.7

Conduction times are presented in milliseconds from high right atrium to three esophageal positions and the intraatrial sites. Lat = most lateral left atrial site; LS = left interatrial septum; RS = right interatrial septum; cm Lat = cm lateral to interatrial septum.

including the left paraseptal region, lateral left atrium and points at 1 cm intervals between. Conduction times to the right paraseptal region are listed for each patient.

Group I: normal left atrial size. Conduction times from the high right atrium to the three esophageal positions and to each left atrial site are shown for group I in Figure 1. Mean conduction time from the high right atrium to the mid-esophageal position (Fig. 1B) was significantly longer than conduction to a point 1 cm lateral to the left interatrial septum ($p < 0.05$) and was intermediate between conduction times to the mid- and most lateral left atrium. Similarly, conduction time to the low esophageal position (Fig. 1C) was significantly longer than conduction to the left paraseptal region ($p < 0.05$) and was intermediate between conduction times to the mid- and most lateral left atrium. Conduction time to the high esophageal position (Fig. 1A) lay between conduction times to points 1 and 2 cm lateral to the left septum. A significant trend toward longer conduction time to the high esophageal position than to the left interatrial septum was noted ($p < 0.1$). Conduction times to all esophageal positions were significantly longer than conduction time to the right interatrial septum ($p < 0.05$).

Group II: left atrial enlargement. Esophageal and interatrial conduction times for group II are shown in Figure 2. A significant trend toward longer conduction time to the mid-esophageal position compared with conduction to the left interatrial septum was observed ($p < 0.1$) (Fig. 2B). Furthermore, conduction time to the mid-esophageal position was identical to that measured to the mid-left atrium. Conduction times to the high (Fig. 2A) and low (Fig. 2C) esophageal positions were intermediate between conduction time to a point 1 cm lateral to the left septum and the mid-left atrium. However, in neither of these positions did differences between esophageal and left interatrial conduction time achieve significance. In all esophageal positions, conduction time was significantly longer than conduction time to the right septum ($p < 0.05$).

Interatrial conduction times. Mean conduction time to the lateral left atrium was 92.1 ± 22.1 ms in group II and 65.1 ± 12.6 ms in group I. Thus, conduction from the high right atrium to the lateral left atrium was significantly longer in patients with left atrial enlargement ($p < 0.05$) (Fig. 3A).

In both groups, conduction time to the mid-esophageal position tended to be longer than conduction time to the other two positions; however, this demonstrated a significant trend only in group II where mid-esophageal conduction time was longer than that to the high esophageal position ($p < 0.1$). In patients with left atrial enlargement (group

Table 2. Esophageal and Interatrial Conduction Times in Patients With Left Atrial Enlargement (group II)

	Esophagus			Left Atrium					Paraseptal Region	
Patient	High	Mid	Low	Lat	3 cm Lat	2 cm Lat	Mid	1 cm Lat	LS	RS
1	73.0	78 7	61 5	74 1	60.7	45 2	60.9	37 8	35.8	26.7
2	74.2	75.3	81 8	89 7	74.0	70 2	70.2	37.3	39.3	44.3
3	37 7	61 1	59.5	67.4	61 8	52 6	52 6	28.2	30.0	18.4
4	72 7	77.0	75 3	114 5	—	110.2	102 3	94 5	88 8	56.3
5	82.8	92.8	75.1	114.8	—	111.0	97 8	84 5	74.4	43.8
Group II mean	68.1	77.0	70.6	92 1	65 5	77 8	76 8	56.5	53.7	27.9
± SD	± 17.5	± 11.3	± 9.7	± 22.1	± 7.4	± 31.3	± 22.2	± 30.6	± 26.3	± 15.2

Conduction times are presented in milliseconds from high right atrium to three esophageal positions and the intraatrial sites. Abbreviations as in Table 1.

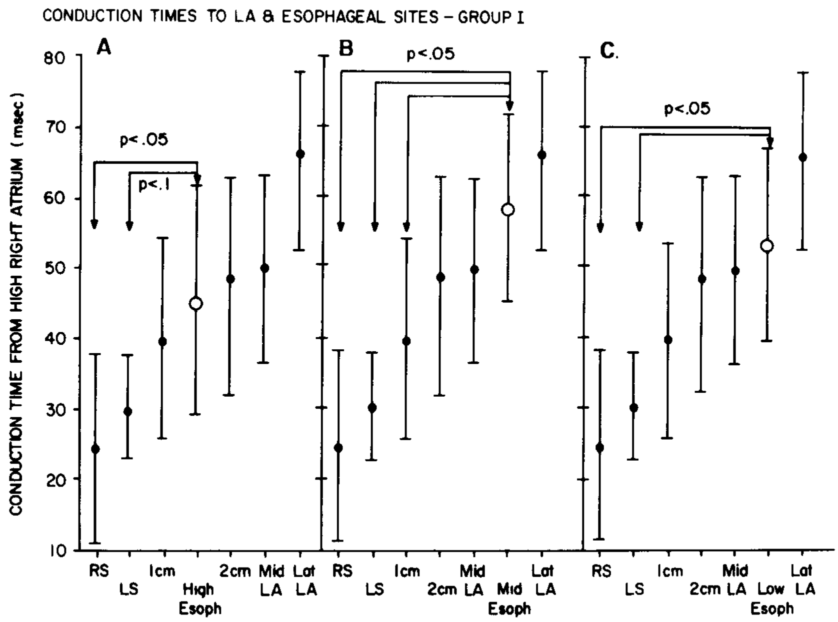


Figure 1. Mean and standard deviation of conduction times from the high right atrium to left atrial (LA) recording sites and to high (**A**), mid (**B**) and low (**C**) esophageal recording sites in patients with normal left atrial size. Conduction times measured from each esophageal recording site fall within the range of conduction times measured directly within the left atrium. **Open circles** = esophageal recordings; **solid circles** = intraatrial recordings. 1 cm and 2 cm = 1 and 2 cm lateral to the left interatrial septum, respectively; Lat LA = most lateral left atrial recording site; Low Esoph, Mid Esoph and High Esoph = low, mid and high esophageal recording sites, respectively; LS = left paraseptal; Mid LA = mid left atrium; RS = right paraseptal.

II), mean conduction time to each esophageal position was significantly longer than conduction time to the corresponding positions in patients with normal left atrial size ($p < 0.05$) (Fig. 3B).

Discussion

Significance and development of esophageal electrocardiography. Use of the esophageal lead of the electrocardiogram was described in 1889 (10) as a technique for investigating the cardiac conduction system in humans. That this lead is a valid reflection of left atrial activity was inferred from fluoroscopic examinations of the relation of the esophageal catheter to posterior cardiac structures (11). These studies concluded that the esophageal catheter lay in significantly closer proximity to the left atrium than to other cardiac structures and hence would be expected to record depolarizations arising from this site (6,12). It has subsequently become an integral tool in clinical and investigational electrophysiology as an indirect left atrial recording site (13). Electrical events not clearly discerned by surface scalar electrocardiography may be elucidated by esophageal recordings (1). Conclusions regarding mechanisms and pathways of tachycardias and normal conduction intervals, and descriptions of dissimilar atrial rhythms have evolved on the assumption that the esophageal electrocardiogram

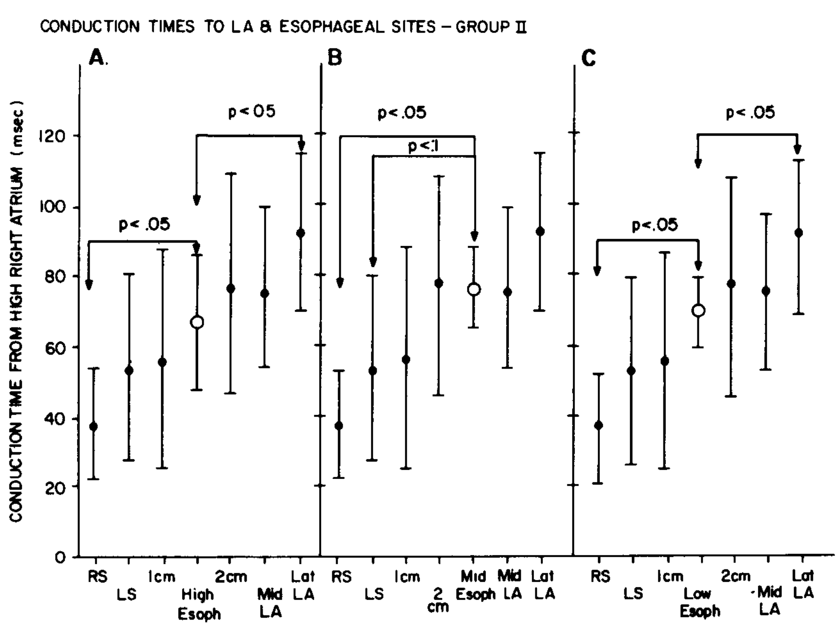


Figure 2. Mean and standard deviation of conduction times from the high right atrium to left atrial (LA) recording sites and high (**A**), mid (**B**) and low (**C**) esophageal recording sites in patients with left atrial enlargement. Conduction times measured with each esophageal recording site fall within the range of conduction times measured directly within the left atrium. **Open circles** = esophageal recordings, **solid circles** = intraatrial recordings. Abbreviations as in Figure 1.

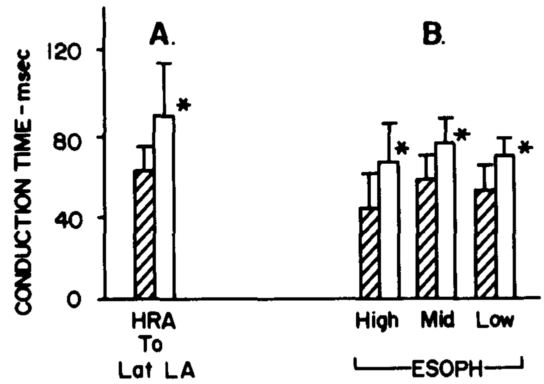


Figure 3. **A**, Mean conduction times from the high right atrium (HRA) to the lateral left atrium (Lat LA) for patients with normal left atrial dimension (group I) and left atrial enlargement (group II). Conduction time in group II is significantly longer than in group I ($p < 0.05$). **B**, Comparison of mean conduction times from the high right atrium to high, mid, and low esophageal (ESOPH) recording sites for groups I and II. Esophageal conduction times are significantly longer in group II ($p < 0.05$). **Hatched columns** = group I; **open columns** = group II. * $p < 0.05$.

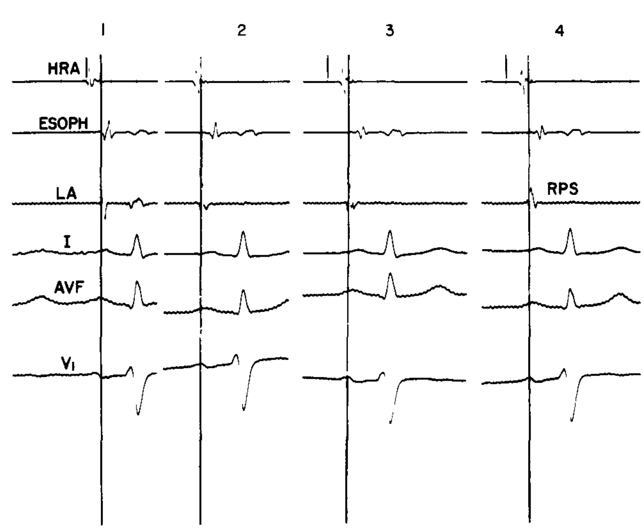
accurately represents left atrial electrical activity (1–4,11,14). Despite the frequent use of this method, its validity has not been confirmed by modern techniques. A recent report comparing ventriculoatrial conduction times obtained from coronary sinus, right atrial paraseptal and esophageal recording sites has suggested that the esophageal electrocardiogram reflects atrial septal activity (7). There have been no studies comparing esophageal electrograms with direct left atrial recordings.

Validation by direct left atrial mapping. The current study delineates the origin of the esophageal electrogram by comparison with simultaneous recordings obtained throughout the posterior left atrium from its most lateral margin to the left and right paraseptal regions. The technique of transseptal catheterization provides the opportunity to acquire direct left atrial recordings, which have been reported in only a limited number of patients (15–17). The data from this study indicate that the esophageal electrogram in the three positions examined clearly arises from left atrial sites distinct from the paraseptal region both in patients with normal and in patients with enlarged left atrial dimensions. A representative recording demonstrating this observation is shown in Figure 4. Specifically, in patients with normal left atrial size, the electrogram obtained from the mid- and low esophagus arises from a point lying between the mid- and lateral left atrium. The electrogram recorded from the high esophageal position originates at a point between 1 and 2 cm lateral to the left interatrial septum. In patients with left atrial enlargement, the mid-esophageal electrogram arises from the mid-left atrium. Deflections recorded from the remaining esophageal positions originate between the mid-left atrium and a point 1 cm lateral to the left septum. Conduction times to all esophageal positions in both groups were significantly longer than conduction times to the right paraseptal region.

Interatrial conduction times in left atrial enlargement versus normal left atrial size. True left interatrial conduction times from the onset of right atrial activation to the lateral left atrium were significantly longer in the patients with left atrial enlargement than in those with normal left atrial size (92.1 versus 65.1 ms). These conduction times approximate those reported by Josephson et al. (17) (112 versus 77 ms) in studies in which coronary sinus recordings were used to indicate left atrial activation in patients with left atrial enlargement and those with normal left atrial size as judged by electrocardiographic criteria. Furthermore, in the current study, conduction time to each of the esophageal recording positions was significantly longer in patients with left atrial enlargement. This observation adds to the validity of this technique as changes in esophageal conduction times paralleled those obtained from direct left atrial recording sites.

The increased interatrial conduction time in the patients with left atrial enlargement may be related both to geometric factors and to intrinsic properties of atrial conduction tissue. Increased atrial dimension would increase the length of interatrial conduction pathways. In addition, Legato et al. (18) have described significant increases in extracellular collagen in atrial tissue obtained from patients with marked P wave prolongation. Increased fibrosis of left atrial appendage tissue was noted by Scott et al. (19) in a group of patients with left atrial enlargement and P wave abnormalities. Thus,

Figure 4. Representative simultaneous recordings from the high right atrium (HRA), esophageal (ESOPH) lead in mid position, left atrial (LA) catheter and scalar electrocardiographic leads I, aVF and V_1. As the left atrial catheter is pulled back from the most lateral left atrial border (**position 1**) to the mid left atrium (**position 2**), the left atrial deflection precedes the esophageal deflection. This relation persists in the left and right paraseptal (RPS) regions (**positions 3 and 4**).



concomitant atrial fibrosis, which may impede normal atrial conduction (18), may have contributed to the prolonged atrial conduction times in our group with left atrial enlargement. The greater mean age of our patients with left atrial enlargement as compared with those having normal atrial dimensions (59 ± 6 versus 42 ± 14 years) may identify the former as a group predisposed to fibrodegenerative conduction disease, which may include the atria (2,20).

Conclusions. This study corroborates a previous cineangiographic study from our laboratory which demonstrated that the esophageal catheter lies significantly closer to the posterior left atrium than to the interatrial septum (21). It further indicates that the esophageal electrogram in the three positions examined originates from depolarizations arising within the left atrium distinct from the interatrial septum and right atrium in patients with normal left atrial size and in those with left atrial enlargement. It appears to accurately reflect changes in conduction times obtained from direct left atrial recordings. Thus, the esophageal electrocardiogram is a valid and reliable recording technique for the indirect assessment of left atrial electrical activity.

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