A New Technic for the Detection of Left-to-Right Cardiac Shunts by Use of an Esophageal Geiger-Müller Tube

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The left-to-right shunts found in small atrial or ventricular septal defects or in patent ductus arteriosus are easily demonstrated during cardiac catheterization by both right- and left-sided approaches. Efforts to evaluate shunting due to these defects without cardiac catheterization have depended on measurements of the cardiac output curves obtained by various external counting techniques. Because the external monitoring sites are relatively distant from the circulating radioisotope, the descending slope of the curve is influenced by factors other than the shunt itself. In an attempt to de-emphasize these extraneous factors a new approach has been developed utilizing the esophagus as an avenue for positioning a miniature Geiger-Müller tube as a detector immediately adjacent to the left atrium and much closer to the radioisotope circulating through the heart. Radioisotope curves then monitor recirculation shunts in more concentrated form from the left atrium than from externally placed precordial, pulmonary, or peripheral counters.

Method

The patient is studied after an overnight fast in the supine position and is premedicated 30 minutes prior to the study, usually with 50 mg. of meperidine and 0.6 mg. of atropine. Pyribenzamine in a 2 per cent solution is used for topical pharyngeal anesthesia. A no.-18 Courand needle is placed in the left antecubital vein and attached directly to 12 inches of polyethylene tubing, which has an approximate volume of 1 ml. This is connected to a three-way stopcock and to a 20 ml. syringe. Free flow in this system with a large vein is essential for a good curve. Radioisotope, in a volume of 0.3 to 0.6 ml., is placed into the lumen of the tubing by means of a tuberculin syringe and at the time of injection is rapidly flushed into the vein by 10 to 15 ml. of normal saline. The isotope, 131I-labeled hippuric acid,* is administered in conventional dosage of 50 to 75 μc. per injection. Usually only one injection is necessary but three injections, or 150 μc., have been given without fear of overexposure.9

Two scintillation detectors with 2-inch crystals† are used with two analytical rate meters.‡ Collimation for the scintillation detectors varies with the areas monitored. A 20-degree flat-field collimator is used for precordial curves and a 1-inch straight-bore collimator is used for the peripheral and lung curves. The esophageal detector (fig. 1) is a miniature gamma-sensitive halogen tube§ placed on the end of a shielded cable 5 mm. in width. The tube is protected by steel stays and plastic tape. The cathode or “hot” pole of the tube is completely surrounded by the grounded shield, so that in case of breakage there could be no voltage discharge to the patient; 500 volts is the standard operating voltage. The entire apparatus is coated with layers of polyvinyl to provide further insulation and strength as well as a smooth surface. A 3-cm. polyvinyl projection is added to the tube to aid in placing it in the esophagus. A copper wire is attached to the cable and then covered. One end is left exposed 1 cm. above the G-M tube, the other end is attached to the standard electrocardiographic precordial electrode to record an esophageal lead.

One scintillation detector is placed over the precordium between the point of maximal im-

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* Squibb Hipputope.
† Nuclear Chicago DS-201.
‡ Nuclear Chicago 1620BS.
§ Nuclear Chicago D 81.
pulse and the sternum with a slight cephalad tilt. The other is placed over the right lung field with care to avoid the liver, heart, kidney, and great veins. An alternate position for this detector is over the right eye, again with care to avoid "scatter" from the injection site and from the cardiac portion of the curve. The G-M tube is placed behind the left atrium (fig. 2). The position of the G-M tube is determined by the P-wave configuration of the esophageal lead in such a manner that when the P is diphasic the G-M tube is properly located behind the left atrium. The electrocardiogram displayed above the roentgen film was taken when the tube was in the position shown.

The characteristics of the G-M tube are noted in figure 3. This is a diagrammatic representation of the chest cut horizontally through the left atrium and esophagus. The diagram is drawn to scale, representing 85 per cent of the adult

**Figure 1**

The esophageal Geiger-Muller tube. The tube itself occupies an area between the 4 and 5 cm. marks on the ruler. It is protected by steel stays and tape and coated with polyvinyl. The esophageal electrode is exposed above the white tape.

**Figure 2**

A right anterior oblique chest x-ray film showing the esophageal tube behind the left atrium. The esophageal electrocardiogram taken while the tube was at this position is seen at the top. The curves from this study of a small patent ductus arteriosus are seen at the left. (A) Right heart circulation, (B) left heart circulation, (C) primary left atrial circulation, (D) left atrial recirculation, (1) precordial curve, (2) esophageal curve, (4) peripheral curve.
population. A radiation circle in centimeters is superimposed. The percentages of counts that are picked up from a source placed at certain distances from the G-M tube can be seen written in at 1-cm. intervals. The 50-per cent circle is between 2 and 3 cm. away from the esophagus and the left atrium contributes most of the radiation source. The proximity of the other heart chambers, especially the right side, can be visualized on the diagram.

The curves are recorded in four ways: (1) on a direct-writing rectilinear recorder for an immediate record; (2) on a multichannel oscillographic screen for visual monitoring; (3) on photographic paper by a multichannel oscillographic camera for simultaneous superimposed permanent records; and (4) on magnetic tape for future playback into any of the systems.

Reproducibility of the method was ascertained in two ways: (1) the initial studies were performed in duplicate with two separate doses of radioisotope, always showing agreement, and (2) one study (no. 3) was repeated on two separate occasions postoperatively, both times confirming the fact that the shunt remained open.

The patient's response to the procedure is variable. Most patients find swallowing the esophageal tube uncomfortable but relax promptly for the remainder of the procedure. In one patient, severe pharyngeal spasm prevented passage of the tube. Because of the size of the esophageal detector and the need of patient cooperation during passage and positioning of the tube and during isotope ingestion and recording, this procedure is not practical in general for the pediatric age group but is applicable to larger children and adults. The procedure is not dangerous, appears less traumatic than esophagoscopy or bronchoscopy, and yet provides information similar to that obtained from intracardiac catheterization.

Each of the precordial photographic oscillographic curves were analyzed and calculated by the method* of Cornell, Braunwald, and Morrow.11

Results

With use of the technic a small bolus of the isotope is injected rapidly into the vein. The resultant curve is usually clear-cut in spite of the peripheral injection site. With each injection the precordium, the lung, and the left atrium are monitored and recorded on a direct writer, an oscillographic recorder, and on magnetic tape. The record from the direct writer possesses the advantage of immediate availability. The photographic oscillographic record produces three simultaneously recorded curves superimposed on the same time scale. This permits comparative timing of the various peaks and slopes of the curves. The records when played back from tape may be varied in many ways to inscribe the curves. In practice, however, as doses and settings become standardized, tape playbacks are seldom used.

A representative normal curve is noted in figure 4. These are the original curves from a normal subject reproduced from the photographic oscillographic recorder. The time lines are at 1-second intervals. The electrocardio-

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* "The curves were analyzed (1) by replotting the descending limb of the curve on semi-logarithmic paper and calculating the rate of disappearance of the isotope during the early portion of the descending limb and expressing this as the percentage of decline of isotope concentration per second; (2) by determining the build-up time, i.e., the time interval between the appearance of radioactivity in the right side of the heart and the peak of that portion of the curve resulting from the isotope in the left ventricle; and (3) by calculating the product of disappearance rate and build-up time."

The values for the product of the disappearance rate and build-up time given by these authors are (1) patients without shunts, range 55 to 120; (2) patients exhibiting left-to-right shunts 9.1 to 64.8.
Direct writer pre- and postoperative esophageal curves superimposed showing disappearance of left atrial recirculation peak D in the postoperative record. (C) left atrial primary circulation, (D) left atrial recirculation.

Preoperative and postoperative curves in small patent ductus arteriosus. The detection of shunting by disappearance of the downslope of the precordial curve 1 (A, B) would have missed this shunt. The product of the build-up time and the disappearance rate in both preoperative and postoperative curves are normal. The esophageal curves 2 (C, D) detected the shunt by demonstrating the left atrial recirculation peak D preoperatively and noted its disappearance after surgery, 2 (C).

Figure 4
Normal curves. (1) precordial, (2) esophageal, (3) pulmonary. (A) right heart circulation, (B) left heart circulation, (C) left atrial circulation, (E) pulmonary circulation. The time lines are 1-second intervals, the injection time and electrocardiogram are at the top. Paper speed 5 mm./sec.

Figure 5

Figure 6
Preoperative and postoperative curves in small patent ductus arteriosus. The detection of shunting by disappearance of the downslope of the precordial curve 1 (A, B) would have missed this shunt. The product of the build-up time and the disappearance rate in both preoperative and postoperative curves are normal. The esophageal curves 2 (C, D) detected the shunt by demonstrating the left atrial recirculation peak D preoperatively and noted its disappearance after surgery, 2 (C).
peak located between the right and left precordial peaks. With these three points located, the esophageal curve can be accurately timed.

The initial upstroke of the esophageal curve is caused by the right heart circulation. The major peak caused by the left atrial primary circulation occurs at the time of left-sided filling. Following this peak there is a relatively rapid downslope marred tissueally by a small peak probably caused by transit of the radioisotope through the coronary arteries or down the descending portion of the thoracic aorta.

If there were a left-to-right shunt on this normal record in figure 4, one would expect another peak to appear at a time following the primary left atrial peak equal to the time required for the circulation through the lungs. In other words, the time measured between the right and left precordial peaks (A and B) is the pulmonary transit time, and this distance added to the left atrial primary circulation (C) should approximate the point at which a recirculation peak would appear if there were a left-to-right shunt.

Emphasis should be placed on the fact that the diagnosis of recirculation is made by the peak on the esophageal curve produced by the second circulation of blood through the left atrium and is not otherwise dependent on the character of the downslope of the curve. The peak is discrete and the diagnosis is made only by its presence or absence.

In figure 5 the preoperative and postoperative esophageal curves, reproduced from the direct-writer records of a patient whose ventricular septal defect was surgically corrected, are superimposed. The left atrial major circulation is labeled C in each record. The peak (D) on the preoperative curve represents recirculation of blood through the left

![Figure 7](image-url)

**Figure 7**

Photographic preoperative and postoperative recordings of a patient with a ventricular septal defect. (1) precordial curve, (2) esophageal curve, (3) pulmonary curve. (A) right heart, (B) left heart, (C) left atrial, (D) left atrial recirculation, (E) pulmonary circulation. The postoperative record on the right has a sharper downslope on the precordial curve and no left atrial recirculation hump.
atrium produced by the left-to-right shunt. In the postoperative curve this recirculation peak has disappeared because the shunt was abolished by surgical closure of the defect.

The original photographic record of a patient with a small patent ductus arteriosus is seen on the left in figure 2. This shows three curves, the precordial (1), esophageal (2), and peripheral, which was monitored in this case over the right eye (4). The precordial curve with its peak (A and B) was later played back from tape and made smaller to fit the paper. The recirculation peak (D) on the esophageal curve is diagnostic of a left-to-right shunt, but the downslope of the precordial curve (B) while notched, fails accurately to depict the shunt. Curve 4 reveals the rapid peripheral uptake of isotope beginning at the time of left-sided circulation.

In order to document further the potential of the esophageal tube to diagnose shunts not recognizable by precordial technics, two sets of curves are shown in figure 6 recorded from a patient exhibiting a small patent ductus arteriosus. The curves on the left were obtained prior to closure of the defect; the curves on the right were recorded after surgery. The product of the disappearance rate and build-up time both preoperatively and postoperatively, is within the normal range, 105 and 120, respectively. In contrast to the nondiagnostic precordial curves, the esophageal curves shown in both figures 6 and 2 are clearly diagnostic of early recirculation in the left atrium.

Figure 7 represents a larger shunt, which preoperatively shows the characteristic slowing of the precordial disappearance curve as well as the diagnostic recirculation peak D of the esophageal curve. Postoperatively, the esophageal curve and the precordial downslope are normal.

Of 23 patients studied, 11 were demonstrated to have left-to-right shunts. Eight of these 11 patients had corrective surgery; each patient was studied before and after operation, except for one who is still in the immediate postoperative period. The diagnosis of left-to-right shunting was made by the esophageal curves in each of the 11 patients (table 1). In five instances, however, comprising four patients preoperatively (cases 2, 6, 7, 9) and one patient postoperatively (case 3), the presence of shunting was missed by the precordial curves, but was clearly diagnosed by esophageal curves alone. Precordial curves were never positive for left-to-right shunts when the esophageal curves were negative.

The four preoperative cases included two

Table 1

Tabulation of Findings Exhibited by Eleven Patients with Left-to-Right Shunts *

<table>
<thead>
<tr>
<th>Patient</th>
<th>Diagnosis</th>
<th>Radioisotope curves</th>
<th>Preoperative</th>
<th>Postoperative</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Esophageal Precordial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>N.C.</td>
<td>ASD*</td>
<td>P+</td>
<td>P</td>
</tr>
<tr>
<td>2.</td>
<td>D.A.</td>
<td>PDA</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
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<td>J.R.</td>
<td>ASD</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>4.</td>
<td>B.M.</td>
<td>ASD</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>5.</td>
<td>L.C.</td>
<td>VSD</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>6.</td>
<td>W.C.</td>
<td>VSD</td>
<td>P</td>
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</tr>
<tr>
<td>7.</td>
<td>G.O.</td>
<td>PDA</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>8.</td>
<td>E.A.</td>
<td>ASD</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>9.</td>
<td>R.H.</td>
<td>ASD</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>10.</td>
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<td>ASD</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>11.</td>
<td>E.O.</td>
<td>VSD</td>
<td>P</td>
<td>P</td>
</tr>
</tbody>
</table>

* Patients 1 to 8 were operated upon; patients 9 to 11 were not. Five patients (2, 3, 6, 7, and 9) had positive esophageal curves, but not diagnostic precordial curves, two patients (2 and 7) are illustrated in figures 6 and 2, respectively.

†Key to abbreviations: ASD, atrial septal defect; PDA, patent ductus arteriosus; VSD, ventricular septal defect. P, shunt present; N, curve not diagnostic; T, technical trouble.
small patent ducts (cases 2, 7), one ventricular septal defect possessing a 2-liter per minute shunt (case 6), and one clinically classical but uncatheterized atrial septal defect (case 9).* The postoperative patient (case 3) presented a complicated low atrial septal defect with diagnostic esophageal and precordial curves preoperatively. Postoperatively, however, a persistent opening, subsequently confirmed, was detected on two separate occasions by esophageal curves alone when concomitant precordial curves were normal.

**Discussion**

While precordial detectors have been used to demonstrate left-to-right shunts, it is often difficult to differentiate a left-to-right shunt from other causes of secondary peaks. For instance, if one places the precordial detector in order to emphasize the contribution from the right side of the heart, then a minor contribution from the left side of the heart may be confused with a deflection caused by a left-to-right intracardiac shunt. On the other hand, if one places the detector in order to emphasize the left heart circulation or a combined right and left heart circulation, then the normal circulation in the coronary, bronchial, or the anterior chest wall arteries can be a source of confusion in some normal people. In certain precordial curves, a left-to-right shunt, although present, cannot be clearly recognized. The esophageal detector potentially obviates these sources of confusion and uncertainty. The superiority of the esophageal method over the precordial one in detecting left-to-right shunts is illustrated by the demonstration of positive esophageal curves in each of 11 patients, while precordial curves were negative in four patients preoperatively and in one patient postoperatively (table 1). Conversely, precordial curves were never positive for left-to-right shunt when esophageal curves were negative.

This procedure offers a simple and accurate technic for screening on an outpatient basis patients suspected of possessing left-to-right shunts. It can be accomplished with far less difficulty and morbidity than intracardiac catheterization, which generally requires hospitalization. It is particularly valuable in the postoperative period to assess the effectiveness of surgical closure of atrial and ventricular septal defects and of patent ductus arteriosus.

**Summary**

A new technic is described for the detection of left-to-right shunts. A miniature Geiger-Müller tube is placed in the esophagus behind the left atrium and positioned by the electrocardiogram. In this position the G-M tube measures radioactivity from the left atrium. Curves are then recorded simultaneously from the precordium, lung, and left atrium. Methods of injection, monitoring, and recording are presented that provide greater diagnostic accuracy over those external detector technics currently in use.

Of 23 patients studied, 11 presented left-to-right shunts. Eight of these 11 patients were submitted to surgery; all were studied preoperatively and seven were studied postoperatively. Seven of the 11 shunts were detected by both precordial and esophageal technics. Four of the 11 shunts were missed by conventional precordial technics but were correctly diagnosed preoperatively by the esophageal detector. In addition, one shunt, which remained open postoperatively, was demonstrated clearly by the esophageal technic but was not indicated by the precordial curves. In no instance was the precordial curve positive for left-to-right shunt when the esophageal curve was negative.

Although the accuracy of any radioisotope detection technic with external counting may not approach that of direct cardiac catheterization, this method, because of its relative simplicity and accuracy, is useful in the demonstration of left-to-right shunts both preoperatively and postoperatively.

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*Case 9 was a 69-year-old woman who died of carcinoma without postmortem examination. Case 10 was catheterized but because of age refused surgery. Case 11 was neither catheterized nor operated upon but presented a clinically typical Roger's defect.

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References


Primitive Medicine

In the early days of history, these three activities—magic, religion, and healing—were combined, and Egyptian, Babylonian, and Greek temples often took on many aspects of a hospital, along with those of a sanctuary dedicated to some god or goddess. Healing of illness of both body and mind was sought by prayer, votive offerings, and sacrifice to appease the gods, and by magic potions prepared from herbs and other strange mixtures.—Introduction, Edward D. Churchill, M.D. Listen to Leaders in Medicine. Edited by Albert Love and James Saxon Childers. Atlanta, Tupper and Love, Inc., 1963, p. 8.
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