Detection of Heart Shunts by Means of $^{125}$I

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Radiocardiography has been in use since 1948. Radiocardiographical information derived from the external detection of the passage of a radioactive bolus through the heart chambers has been described and analyzed by many investigators.

Prinzmetal et al, used $^{24}$Na for this purpose (1), while others used albumin $^{131}$I (2). With more extensive experience, procedures improved over the years until, in 1958, Pritchard et al (3) reported an effective method for the external precordial detection and determination of cardiac output with albumin $^{131}$I. During this time, a good correlation with dye dilution technique by means of arterial puncture was also noted. Later, Vernejoul (4) used $^{125}$I for this same purpose.

In 1958 Lammerant et al (5) devised a further analysis of the precordial record by separating the radioactivity originating in the right ventricle from the one of the left ventricle. This method provided a means of determining the mean pulmonary transit time, which in turn permitted calculation of pulmonary blood volume. They designated this procedure as Selective Radiocardiography.

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However, certain technical limitations within the method yielded uncertain results. Donato et al (6) noted this inconsistency in their thorough analysis of the radiocardiography procedure by delineating its limitations and potential. From all indications, limitations are dependent upon the physical characteristics of the tracer. $^{131}$I particularly has a half value layer of 7 cm in tissue that makes collimation difficult. If one could overcome these difficulties, selective radiocardiography could prove to be an excellent diagnostic tool.

The object of this article, therefore, is to report on our experience with the use of $^{125}$I in order to obtain a pure right ventricle dilution curve. $^{125}$I photons have low energy (27-35 keV, with a half-value layer of 2 cm in tissue). This property simplifies collimation and permits the establishment of an independent record of the passage of the radioactive bolus through the right heart chamber and the left chamber. The following results in a group of normal individuals and patients with heart shunts exemplify our contention.

**METHOD**

Both normal and individuals with pathological defects were studied. Of the normal patients, 20 were males and 10 were females whose ages ranged between 20 and 35 years. An additional 10 normal children, ages 8-9 years were included. The pathological population was comprised of 20 patients with atrial septal defects and 9 patients with ventricular septal defects. Radiocardiography was also attempted, before and after surgery, in an additional five patients.

$^{125}$I, which has been used biologically since 1960, was our isotope of choice. The physical characteristics of $^{125}$I are emission of low energy photons (27-35 keV), and a half-life of 60.2 days.

Detectors used in the experiment were shielded by employing lead collimators 5 mm thick. The sodium iodide crystals used were cylindrical 1 inch thick and 2 inches in diameter, and the lead collimators had an aperture of 2.5 cm for adults and 1.5 cm for children.

Each detector lay in the collimator at a distance of 1 cm from the skin. It was connected to a high pulse analyzer with a 6-volt window (spectrometer N°510-Baird Atomic) set to register energies of 27 keV. The signal is sent from the high pulse analyzer independently for each detector to a two channel prototype EPUT system similar to Digital Ratemeter N°425-Baird Atomic.

The EPUT meter is an electronic recording device which is, in effect, a digital computer. It adds up all the counts during a predetermined time interval. It can be set to count for periods of tenths of a second to 100 seconds; 1 second was chosen for the counting period. After each time interval it resets automatically; prints the recorded information; and, after a display time of 5 microseconds, starts to count again. There is complete independence between the preceding events and the following counting periods.

Before initiating the experiment, the exact location of the $^{125}$I radiation peak is checked.
Prior to the procedure, the patient received 30 drops of Lugol's solution. The patient lies supine on an examining table. One detector is placed 4 cm above the base of the xiphoid appendix and 1 cm to the left of the midternal line. According to angiocardiographic information, this point is a projection of the right side of the tricuspid valve at the beginning of the inflow tract of the right ventricle. The empty collimator is located over this point by directly looking through it. The external limits of the detector are drawn on the thorax for the purpose of checking the position. Later, the detector is slipped into the empty collimator. The second detector is located over the apex of the heart.

A third dilution curve is obtained by means of arterial puncture with an 18-gauge needle. Novocaine is used as a local anesthetic. The arterial catheter is 10 cm long and 2 mm in internal diameter.

The technique of injection is important in order to insure a good bolus effect. The basilica antecubital vein is chosen and the arm elevated and abducted until collapse of the vein wall is observed. As a further test for venous collapse, a tourniquet is applied in order to observe the venous filling and rapid emptying of the vein upon its removal. The ligature is replaced and a syringe with 400-600 μc of 125NaI in a volume of 0.60 cc is prepared. The tracer is rapidly injected through a 20-gauge needle at the moment of tourniquet release. Simultaneously, counting is started on the electronic device and arterial blood sampling is begun. Forty samples of approximately 1 cc each are collected in 53 seconds. (Arterial puncture was not performed on subjects under 12 years of age).

Two independent and simultaneous records for right ventricle and left ventricle are recorded. The results are expressed in counts per second and plotted on linear graph paper. The blood samples which are in precalibrated vials are counted in a well-type counter and weighed on an analytical balance. Specific activity in terms of μc/gm is determined and plotted as counts/second/gm on the same graph with the heart curves. The right ventricle record is analyzed to determine the relationship of maximum-to-minimum height recorded. In addition, the half period of the washout slope is also determined. The minimum height is recorded 12 to 14 seconds after injection and appears immediately before systemic recirculation. Similar parameters are determined for the arterial curve.

The data from the descending limb of the right ventricle record are plotted on semi-log paper. The drop is exponential down to a level of 20-30 per cent of the peak. For this reason, extrapolation to the abcissa is accurate. The exact level at which the recorded tracing deviates from the exponential down slope is defined as the “deviation level”. The information is replotted on linear paper. Delimitation of an area of contamination, i.e., counts originating outside the right ventricle, is thus possible. The limits of this area are indicated on Fig. 1 as: (1) the recorded slope of the linear graph, d-e, (2) the extrapolated segment of the exponential down slope, d-f, and (3) a horizontal line drawn at the lowest level before systemic recirculation reappears, e-f. This surface is measured by planimetry and compared with the area of the right heart curve, (Fig. 1), designated by the boundaries a-b, b-c, c-a.
RESULTS

The shape of the right ventricle curve in 30 normal individuals was very similar to the shape of the arterial dilution curve. Through extrapolation of the descending limb, it was possible to establish the magnitude of the excess radioactivity recorded over the right ventricle from the left ventricle and other structures. This excess of counts corresponded to $11.5 \pm 5$ per cent of the area of the original curve. The minimum count rate of the right ventricle curve was $12 \pm 2$ per cent of the maximum; in the arterial curves this value was $10.4 \pm 2$ per cent. T% of the descending slope of the right ventricle was $1.6 \pm 0.4$ seconds, which was significantly lower than the arterial T% of $2.4 \pm 0.5$ seconds (Fig. 2). The ratio of the half-periods of right ventricle and arterial curves was $1.5 \pm .14$. Furthermore, in 30 normal individuals the descending slope was exponential to a level of $27 \pm 4$ per cent (deviation level).

In 10 normal children, the values were similar to those in adults (Figs. 3-5).

In 20 patients with an atrial septal defect, abnormal central recirculation produced a deviation level of $62.4 \pm 17$ per cent. Minimal counting level was

![Selectivity Radiocardiography](selectivity-radiocardiography.png)

**Fig. 1.** Normal right ventricle and femoral artery dilution tracings. Radioactivity expressed as counts per second in the right ventricle and counts/second/gm of blood for the femoral artery. D.L. = deviation level. M.C.L. = minimal counting level.
41.4 ± 11.4 per cent. Furthermore, the hemodynamic distortion produced by an atrial septal defect resulted in a markedly decreased artery down slope, thus increasing the ratio of T½ artery over T½ right ventricle index to 4.75 ± 1.39 in comparison with this ratio in normal individuals of 1.5 ± 0.14.

In nine patients with ventricular septal defect, distortion of the right ventricle tracing was less important than the previous group. The deviation level had a mean value of 45 per cent (Fig. 3), the mean of the minimal counting level was 30 per cent (Fig. 4), and the mean of the T½ artery over T½ right ventricle ratio was 2.74 (Fig. 5).

Five patients were studied before and after surgery. Table I shows the results before and after closure of the defect (Fig. 6).

DISCUSSION

The results we achieved confirm our view that 125I is a more precise and convenient tracer for the external detection of a dilution curve originating in the right ventricle. Furthermore, the descending slope of the right ventricle record is exponential to a level of 20-30 per cent of the peak, thus allowing precise extrapolation to the abcissa and a clear delimitation of extra right ventricle radioactivity.
DETECTION OF HEART SHUNTS BY MEANS OF $^{125}\text{I}$

The descending limb of the arterial segment is exponential but with a longer T½ that of the right ventricle curve. This is explained by further dilution of the bolus in the diluting pool of the pulmonary vessel (7). The contamination recorded by the right ventricle detector originates in the left ventricle and other stressed by Lammerant (5) and Donato (6), who worked with $^{131}\text{I}$. Their 9, 10).

The possible value of this determination which we have outlined has been stressed by Lammerant (5) and Donato (6), who worked with $^{131}\text{I}$. Their results had not proven satisfactory because of the inconveniences indicated for $^{131}\text{I}$. Specifically, $^{131}\text{I}$ generates a composite radioactive tracing simultaneously in the four heart chambers, thus rendering the right ventricle curve imprecise.

![Deviation Level Diagram](image)

Fig. 3. Deviation level in normals and patients with atrial and ventricular septal defect.
Fig. 4. Minimal counting level in normals and patients with atrial and ventricular septal defect.

### TABLE I

<table>
<thead>
<tr>
<th>Type of defect</th>
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<th>Minimal counting level</th>
<th>Deviation level</th>
<th>Minimal counting level</th>
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<td>44</td>
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<tr>
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<td>14</td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td>27 ± 4%</td>
<td>12 ± 2%</td>
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</table>
Fig. 5. Ratios of $T_{1/2}$ femoral artery / $T_{1/2}$ right ventricle in normals and patients with atrial and ventricular septal defect.
However, we found working with $^{125}$I to be much more precise and exacting. The physical features that made $^{125}$I- our tracer of choice for this type of measurement are:

1) High absorption coefficient of soft photons simplifies collimation problems (half value layer of 2 cm of tissue), and
2) Much of the energy of this radiation is absorbed in tissue photoelectrically (10).

$^{125}$I photons are unidirectional thus simplifying collimation problems. This contrasts with $^{131}$I gamma rays where the Compton effect produces scattered multidirectional radiation and makes collimation difficult (11, 12).

However, it must be noted that this technique requires precise positioning of the detector. In several cases repeated a week later, placing the detector further to the left produced a greater percentage of contamination. In the one individual where the largest percentage of contamination was found, the EKG showed a counter clockwise rotation around the longitudinal axis.

The technique of injection is important to insure that a compact radioactive bolus gets to the heart. This requires a vein with a rapid and easy drainage. For this reason we always chose the basilic vein and checked the speed of col-

**SELECTIVE RADIOCARDIOGRAPHY**

![Graph](image)

Fig. 6. Right ventricle tracing, before and after closure of atrial septal defect.
lapse upon removal of the arm tourniquet. The tourniquet was applied two minutes before injection and released at the moment of injection. The radioactive bolus is flushed in a compact volume through the rapid drainage of the venous blood pooled in the arm. This can be confirmed by the vertical upswing segment of the right heart curve.

However, if a larger volume of radioactive solution, e.g., 5 to 10 cc is injected with the same 20-gauge needle, one can record both a distortion of the different segments of the precordial record and the arterial curve. A similar effect is observed if the venous blood flow is slow.

An analysis of the results of the left ventricle precordial record obtained with $^{125}$I shows that such records are often unsuitable for accurate interpretation because of large oscillations of uncertain origin.

In order to study this aspect further, work is being done at present by injecting a mixture of $^{125}$I and $^{131}$I and separating these isotopes by pulse height analysis. The right heart curve is recorded with the radiation released by $^{125}$I and the left ventricle with $^{131}$I gamma radiation. Results of this study will be reported in a later paper.

$^{125}$I radiocardiography seems to be worthy of wider clinical use and trial. A precise diagnosis of left-to-right heart shunts with this method apparently is possible. Blood passing through the septal defect appears as early recirculation by interrupting the exponential descending part of the right heart record at an earlier time and raising the counting level before systemic recirculation. All but one of the patients with atrial septal defects demonstrated an abnormality of these segments. The single patient with normal deviation level and normal minimal counting level showed a minute atrial septal defect at surgery. The efficiency of these two elements in detecting the existence of a ventricular septal defect is less than the one reported for atrial septal defect. There were three patients with normal deviation level and two with normal counting level. In these patients, the shunt was located above and to the right of the point where the detector was located. Further attempts to focus toward that specific area has been unsuccessful because of its nearness to the aorta.

The presence of abnormal central recirculation may be clearly visualized in the distortion of the descending part of the arterial curve. All of the patients with atrial septal defects studied by means of arterial puncture showed an abnormal washout segment that increased the ratio T% artery / T% right ventricle. However, there were patients with ventricular septal defects in whom this ratio was normal in addition to a normal right ventricle tracing. In our opinion, our inability to determine these defects may have been due to the fact that their shunts were too small for detection. Other types of left-to-right shunts are now being studied to verify this hypothesis.

However, there are other pathological situations where the shape of the right heart radiocardiogram might be modified. Right heart congestive failure could mean a diluting pool for the radioactive bolus which could produce a spread of the ascending limb and a slowing down of the washout segment of this curve. Presumably, tricuspid insufficiency could have a greater influence on the
descending limb of the tracing. Similar effects on the right radiocardiogram could be produced by pulmonary sigmoid insufficiency. Further study is therefore indicated on this problem.

Improvement in left heart recording could permit a more accurate determination of the pulmonary blood volume by determining the mean pulmonary transit time in the manner described by Lammerant et al (5).

SUMMARY

External scintillation detection of a pure dilution curve originating in the right ventricle has been pursued by investigators for many years. The use of the soft photons of $^{125}$I offers an improved method of determination by allowing excellent collimation through two mechanisms: (1) A small half value layer of 2 cm in tissue, and (2) Unidirectionality, in part due to all-or-none photoelectric absorption of these photons as compared with the pluridirectionality due to Compton scatter in the case of $^{131}$I.

In 30 normal individuals, externally detected dilution curves from the right heart ventricle and arterial dilution curves obtained by arterial puncture are compared. Five hundred microcuries of $^{125}$I are injected into an antecubital vein. The amount of radiation absorbed from a 500 μc dose in an adult of 70 kilos is 1000 to 2000 mradS when injected in the form of $^{125}$I iodide. The use of $^{125}$I orthiodihippurate is advised due to its short biological half-period and the integrated whole body radiation exposure is decreased 100 fold in comparison with the $^{125}$I iodide. The shape of the right heart curve is very similar to the arterial dilution curve with a 13 ± 5 per cent excess of counts originating outside the right ventricle area. The descending segment of the right ventricle curve has a minimum count rate of only 12 ± 2 per cent of the peak of the curve as compared with the arterial curve of 10 ± 2.5 per cent. A mean T% of the descending down slope of the right ventricle is $1.52 \pm 0.45$ seconds for the right heart curve and $2.4 \pm 0.65$ seconds for the arterial curve.

The clinical usefulness of this procedure in 20 patients with atrial septal defects and 9 patients with ventricular septal defects is analyzed.

In summary, it seems possible to perform selective right-heart radiocardiography by means of external precordial detection of $^{125}$I. The method is simple and reproducible.

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REFERENCES

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