DETECTION OF LEFT-TO-RIGHT CARDIAC SHUNTS WITH THE SCINTILLATION CAMERA PULMONARY DILUTION CURVE

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Significant numbers of patients in the nursery and pediatric age groups present a diagnostic problem of a functional heart murmur versus congenital heart disease, or, in the nursery age group, primary pulmonary disease versus congenital heart disease. Often the correct diagnosis is made only at cardiac catheterization. In 1962 Folse and Braunwald (*1*) described a simple technique to evaluate patients suspected of having a left-to-right shunt. They obtained pulmonary vascular radionuclide dilution curves following an intravenous injection (femoral vein) of ^{131}I-labeled Diodrast. Their method consisted of placing a flat-field scintillation detector over a peripheral lung field and using a ratemeter to record the appearance and disappearance of the radionuclide beneath the probe. The resulting pulmonary dilution curves represented the time-concentration relationships of the radioisotope passing through the pulmonary vascular bed beneath the probe. The curves were found to be similar to standard dye dilution curves obtained during cardiac catheterization for the detection of intracardiac shunts. In their earlier work (*2*), the probe was placed directly over the heart, but this was found to be less satisfactory due to the complex curve produced.

Two points on the curve (Fig. 1) were defined and measured, C_1 and C_2. C_1 was the point of peak

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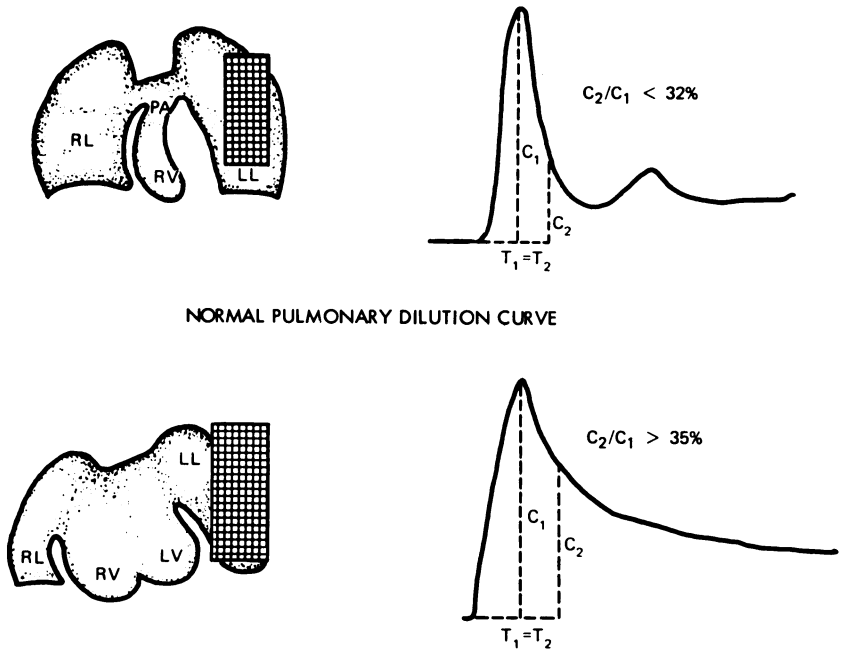

FIG. 1. Examples of pulmonary dilution curves obtained from areas of interest chosen in left lung are shown in normal (top) and left-to-right shunt (bottom).

activity, and C_2 was defined as the point on the curve which occurred at a time T_2 after the peak activity. T_2 was made to equal T_1 which, in turn, was equal to the time interval between the initial detection of the radionuclide beneath the probe and the point of peak activity. The ratio of C_2/C_1 was expressed as a percentage. In patients with left-to-right shunts, the ascending portion of the curve was noted to rise rapidly to a maximum, but the descending portion of the curve was prolonged, reaching the equilibrium background level much more slowly than in the normal, resulting in a higher C_2/C_1 percentage. Folse and Braunwald studied a total of 33 patients, all of whom underwent cardiac catheterization. In their series, all patients with a C_2/C_1 percentage above 46% were found to have a left-to-right shunt. All patients with 41% or lower did not have demonstrable shunts.

More recently (*3*) the same technique of curve analysis has been applied to pulmonary dilution curves derived from a gamma scintillation camera rather than individual detectors placed over the lung fields. The purpose of this report is to describe the technique in detail and to present the results of this procedure in 93 patients.

MATERIALS AND METHODS

All patients ranged in age from 2 days to 45 years (more than 90% were less than 18 years of age, and 25% were less than 5 years of age) and underwent standard radionuclide cardiac angiography. Each patient was examined in the anterior projection with respect to the scintillation camera (Nuclear-Chicago Pho/Gamma III). The injection of ^{99m}Tc as sterile sodium pertechnetate in a volume usually less than 0.5 ml was made into an antecubital vein in adults and children or into an external jugular vein in babies. Occasionally, a central venous catheter was used, or the injection was made into the femoral vein with a Cournand needle. In babies and young children, a scalp vein set was used. The catheter extension of the scalp vein needle was filled with sterile saline and the needle placed in the external jugular vein. The radionuclide (in a volume of less than 0.35 ml) was then introduced into the catheter extension of the scalp vein needle which had a volume capacity of approximately 0.35 ml. The radionuclide could then be flushed into the vein at the desired moment with 3–5 cc of saline. Particular attention was given to assure that the child was not crying or breathing irregularly at the time that the radionuclide was flushed into the vein since abrupt changes in intrathoracic pressures usually resulted in holdup of the bolus at the level of the superior vena cava or distally. A dose of 100 μCi/lb was used for children and a maximum of 6 mCi for adults.

Hand-pulled Polaroid scintiphotos were obtained immediately following the injection at a rate of approximately 1/sec. All studies were simultaneously recorded on digital magnetic tape at a rate of 2 frames/sec or faster.

Each study was reviewed and an area of interest was assigned to each peripheral lung field, carefully avoiding any portion of the heart. With the aid of a small dedicated computer system (Nuclear Data 50-50 MED) (*4*), counts appearing in that area of interest per unit time (0.5 sec) were plotted on the ordinate against time on the abscissa. The C_2/C_1 ratio was measured from the curve automatically produced by the computer and expressed as a percentage.

RESULTS

The C_2/C_1 ratios obtained on the 93 patients studied are shown in Fig. 2. Of the 50 patients in the left-to-right shunt group, 40 were proved to have left-to-right shunt by cardiac catheterization. The remaining ten patients in this category were classified as having left-to-right shunt on the basis of clinical, radiographic, vector analysis, and phonocardiographic data. Of the 43 patients in the no left-to-right shunt group, eight underwent cardiac catheterization because of suspected cardiac lesions including left-to-right shunt. None of these eight patients were found to have left-to-right shunt. The remaining 35 patients in the no left-to-right shunt group were classified as such on the basis of detailed clinical radiographic, vector analysis, and phonocardiographic data. Based on the clinical evaluation, it was not deemed justified to subject these patients to cardiac catheterization for further confirmation of the fact that they did not have left-to-right shunts.

In patients with no left-to-right shunts determined by clinical or catheterization data, a range of C_2/C_1 ratios of 15–32% was established with an average value of 23%. In patients with left-to-right shunts, the range of C_2/C_1 ratios was 35–94%, with an average value of 56%. Seven of these patients had trivial left-to-right shunts detected by hydrogen probe analysis only, indicating a pulmonary-to-systemic flow ratio of less than 1.2 to 1.0. Patients with right-to-left shunts and no evidence of left-to-right shunt had normal C_2/C_1 ratios.

Although a fairly close relationship between the C_2/C_1 values and the pulmonary to systemic flow ratios as determined by cardiac catheterization appeared to exist ($R = 0.81$), the degree of left-to-

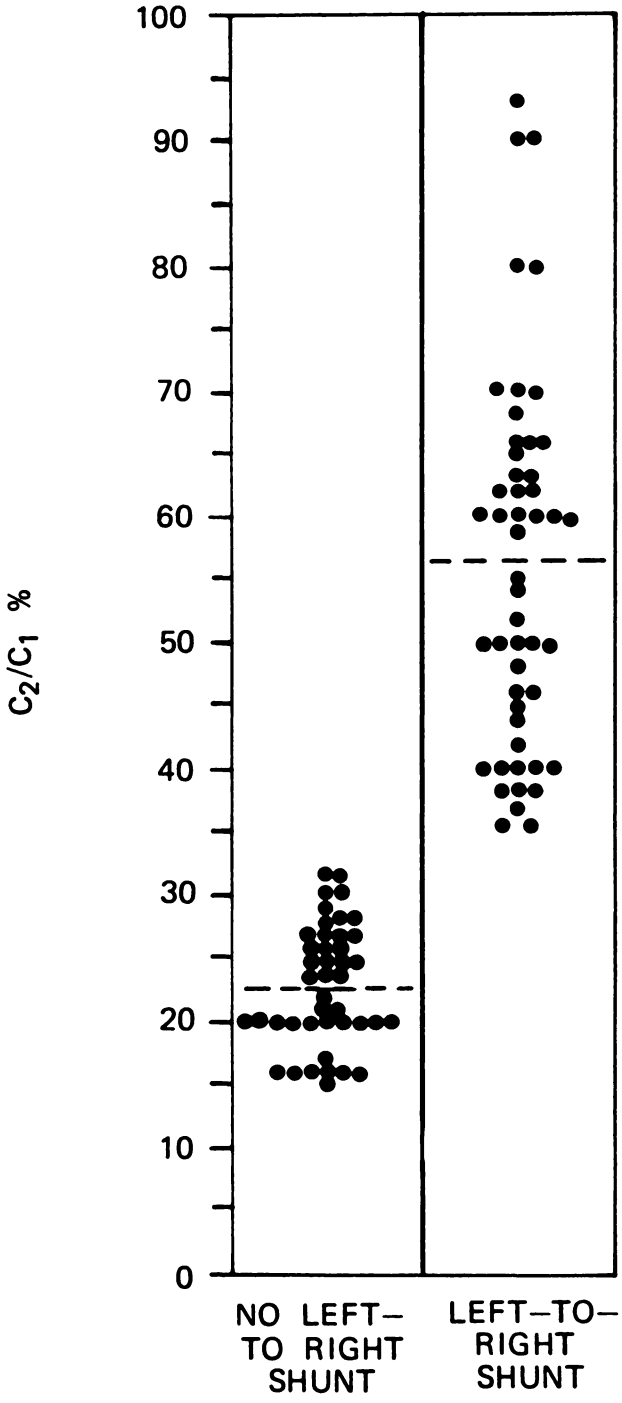

FIG. 2. Results of studies on 93 patients are shown. C_2/C_1 (see text) in patients without left-to-right shunt range from 15 to 32% with average value of 23%. C_2/C_1 in patients with left-to-right shunt range from 35 to 94% with average value of 65%.

right shunt could not be accurately predicted from C_2/C_1 value (Fig. 3).

DISCUSSION

The technique described in this report is currently being used as a screening procedure for children with murmur of undetermined etiology. Such a screening

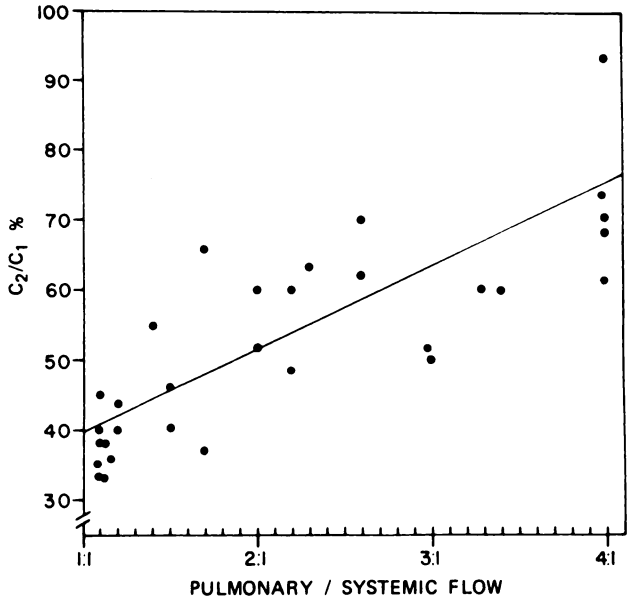

FIG. 3. Graphic plot of pulmonary-to-systemic flow ratios determined at cardiac catherization as function of C_2/C_1 ratio. Only patients with left-to-right shunt in whom pulmonary-to-systemic flow ratio could be accurately determined are included in graph. Correlation coefficient was 0.81.

procedure would appear to be very much needed by general practitioners, pediatricians, and even cardiologists, since making the diagnosis of an innocent murmur without cardiac catheterization is often difficult (*5*). Coleman and Doig (*6*) reviewed the records of 444 patients (age 1 week to 14 years) followed for a 2–7-year period and finally dismissed with a diagnosis of "innocent" murmurs. Forty two of these patients were subjected to cardiac catheterization because of the suspicion of a left-to-right shunt, and 22 of these patients indeed had no defects. The authors stressed the emotional and psychological complications encountered in patients and parents when no definitive diagnosis could be offered regarding an innocent murmur versus congenital heart disease.

We have also found the technique of great value in following pre- and postoperative left-to-right shunt patients. Figure 4 illustrates two pulmonary dilution curves from two studies of different dates on a 9-year-old girl who had a ventricular septal defect at the time of the first study. The C_2/C_1 ratio on the first examination was 50%, indicating a left-to-right shunt. In the second study, following surgical closure of the ventricular septal defect, the C_2/C_1 ratio was 26%, indicating no left-to-right shunt.

Figure 5 shows curves from both lungs taken from a study on a 7-year-old boy who had a Blalock-Taussig anastomosis on the left side (left subclavian

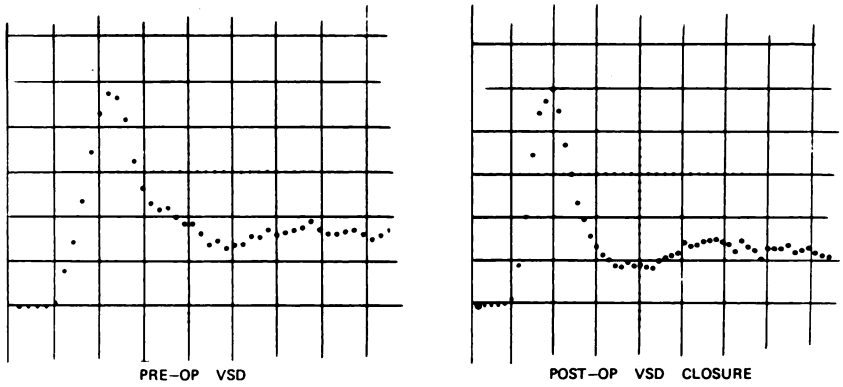

FIG. 4. Pulmonary dilution curves from studies on 9-year-oid girl. Left curve shows C_2/C_1 of 50% indicating left-to-right shunt. Right curve following closure of ventricular septal defect shows C_2/C_1 of 26% which is normal.

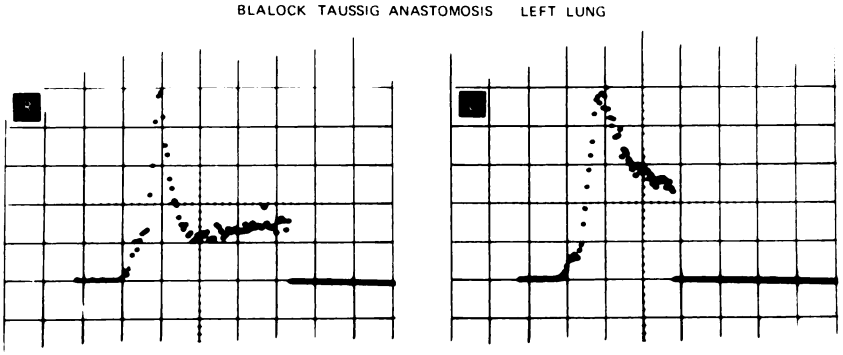

FIG. 5. Pulmonary dilution curves from right and left lungs show C_2/C_1 of 22% in right lung and 60% in left lung indicating patent Blalock-Taussig anastomosis on left.

artery to left pulmonary artery) for tetrology of Fallot. A question of patency of this left-to-right shunt was raised clinically. A C_2/C_1 ratio of 22% calculated from the pulmonary dilution curve of the right lung and C_2/C_1 ratio of 60% over the left lung indicated that there was left-to-right shunting of blood in the left lung, thus proving patency of the anastomosis.

More recently curves have been obtained from areas of interest placed over the superior vena cava, the right heart, and the left heart, in addition to the curves obtained over both lungs. The dilution curve obtained over the superior vena cava has been particularly important in indicating whether the peripherally injected radionuclide arrived in the heart sufficiently intact to permit interpretation of the pulmonary dilution curves.

Figure 6 illustrates curves obtained from the superior vena cava and right lung on two studies of different dates on a 19-year-old boy referred because of a heart murmur and the suspicion of a left-to-right shunt. On the first study in January 1971, at which time the ^{99m}Tc bolus was injected into an antecubital vein, the curve derived from the right lung produced a C_2/C_1 ratio of 40%, thus strongly suggesting a left-to-right shunt. However, on examining the superior vena cava curve, it was clear that the radionuclide did not reach the heart as an intact bolus. The descending limb of the curve was prolonged and might be expected to generate a pulmonary dilution curve which also had a prolonged descending limb and thus an abnormal C_2/C_1 ratio. Thus the validity of an abnormal pulmonary curve in the presence of an abnormal superior vena cava curve would have to be questioned. The curve obtained on a repeat study in April 1971 with a central venous catheter in place showed a prompt rise and fall of activity in the superior vena cava indicating a discrete bolus. The resulting lung curve showed a C_2/C_1 ratio of 22%, which is normal. The patient did not have a left-to-right shunt at cardiac catheterization.

Figure 7 shows a curve from a study on a 2-year-old child. The lung curves were abnormal with C_2/C_1 ratios of 50% in the right lung and 65% in the left lung, indicating the presence of left-to-right shunt. The superior vena cava curve showed a prompt rise and fall indicating an intact bolus. The right heart curve looked very much like the superior vena cava curve and did not suggest the presence of a left-to-right shunt. Thus a normal right heart curve in the presence of left-to-right shunt, as suggested by the abnormal pulmonary curve, indicated that the shunting was occurring distal to the right ventricle. At cardiac catheterization this patient had a patent ductus arteriosis.

Flaherty et al (7) have described a different method of detecting left-to-right shunts by injecting a radioactive bolus into the proximal right pulmonary artery at the time of cardiac catheterization.

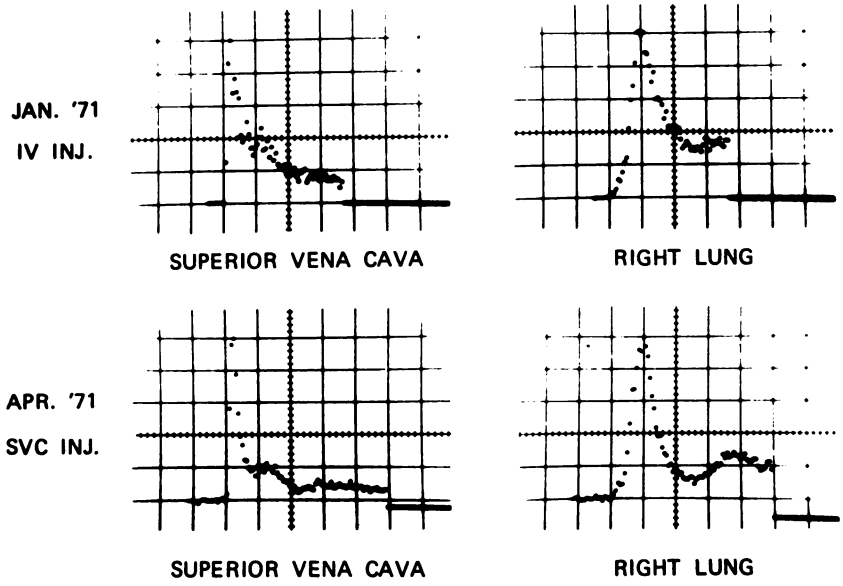

FIG. 6. Top: prolonged descending limb of superior vena cava (SVC) curve indicates bolus is not discrete, and abnormal right lung curve is generated. Bottom: repeat study shows normal SVC curve and normal right lung curve.

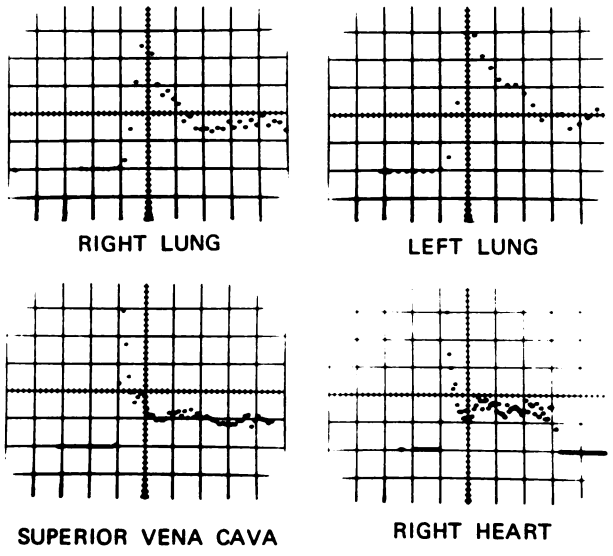

FIG. 7. Top: abnormal pulmonary dilution curves from study on 2-year-old child show C_2/C_1 of 50% in right lung and 65% in left lung. Bottom: SVC and right heart curves are normal indicating that left-to-right shunt is at location distal to heart. Child had patent ductus arteriosus at cardiac catheterization.

Although quantitation of the degree of left-to-right shunt was possible, the method required a more complex analysis of the externally monitored radionuclide pulmonary dilution curve. We have not attempted to obtain such quantitative data; rather our aim has been to identify the presence or absence of a shunt with a noninvasive, simple technique, generally avoiding the use of centrally placed catheters (except in selected cases as described previously) and never resorting to arterial catheters.

In addition, our current method of left-to-right shunt detection does not involve a complicated curve analysis, requiring only that certain points on the curve be defined and measured directly.

Although the radionuclide dilution curves shown in the report were generated by a small computer system, equally satisfactory curves can be produced by any device which permits recording scintillation camera data and assignment of areas of interest from which time-count plots can be generated (*8*).

Recently other investigators (*9,10*) have reported different values for C_2/C_1 ratios. The explanation for these variances is not entirely clear but may relate to differences in techniques, instrumentation, etc. This might suggest that each laboratory should establish its own standard technique and normal range of values.

For the purposes of this study, the curves obtained were the chief interest. The hand-pulled Polaroid scintiphotos were extremely valuable for viewing position of anatomic structures and for detecting a right-to-left shunt by early appearance of the radionuclide in the descending aorta. This is the subject of another study not yet published (*11*).

CONCLUSION

Based on our results in 93 patients, we feel that this noninvasive radionuclide technique will, in most cases, indicate the presence or absence of a physiologically significant left-to-right shunt and may save the patient with an innocent murmur the psychological and physical trauma, as well as expense, of a cardiac catheterization. In addition, the technique has application in following pre- and postoperative shunt patients and as a diagnostic tool in differentiating primary pulmonary disease from congenital heart disease in ill infants.

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