Pediatric Radiocardioangiography

Shunt Diagnosis

By F. P. Stocker, M.D., J. Kinser, M.D., J. W. Weber, M.D., and H. Rösler, M.D.

SUMMARY

On the basis of a comparison of the shunt diagnoses in 73 radiocardioangiographic examinations with those from cardiac catheterization supplemented by operation and/or autopsy findings, it is shown that an intravenous injection of technetium pertechnetate with subsequent evaluation using a scintillation camera and computerized regional time-activity curves is very accurate for the qualitative diagnosis of both left-to-right and right-to-left shunts down to the order of 1:2:1. The advantages of the method are: (1) it is quick (5–10 min for the patient, 20–30 min for the further processing and evaluation); (2) it is safe (extremely low radiation exposure enabling repeated examinations); (3) it is effortless for the patient (thus well suited for use in critically ill patients); and (4) it is applicable with the same accuracy in all age groups (including very young infants and neonates). Thus, the RCG is a promising method for ambulatory diagnosis of questionable heart disease, for the precatheterization workup, and for repeated follow-up studies, i.e., postoperative patients.

Additional Indexing Words: 99mTc Technetium Rapid scintillation camera Radioisotope indicator-dilution technic Right-to-left shunt detection Infants Children Left-to-right shunt detection Congenital heart disease

The development of the Anger scintillation camera1 combined with the introduction of technetium pertechnetate as a relatively safe radioisotope has opened a new field of investigation in pediatric cardiology. Since 1968 when Mason et al.2 first used the Anger camera for the registration of the selective intracardiac injection of 99mTc during heart catheterization, several authors have reported similar examinations although only a few have been done in children using an intravenous injection.3-10

The purpose of our investigation was to evaluate the accuracy of the radiocardioangiography (RCG) in the qualitative diagnosis of both left-to-right and right-to-left shunts in children in order to determine the value of this procedure as a precatheterization screening method and as a means of follow-up examination, i.e., as a method of postoperative evaluation. Thus, the results from the isotopic examinations were compared with those from cardiac catheterization supplemented by operation and/or autopsy data.

Material and Methods

Patients

Between November, 1970, and May, 1972, a total of 73 isotopic examinations in 66 children was performed. The ages ranged from 2 days to 14 9/12 years with an average of 4 4/12 years, 23 of whom were under the age of 1 year, seven under the age of 1 month. Thirty-two were girls and 41 were boys. The time interval between catheterization (or operation, or autopsy) and RCG varied from 1 day to 3½ months, averaging 8.8 days, with 60 of the examinations within less than 8 days of each other. The spectrum of cardiac diagnosis in these children is seen in table 1 and covers all the common congenital cardiac lesions.

Reference Diagnosis

The reference shunt diagnosis was based on cardiac catheterization in 72 patients (in one patient with an isolated patent ductus arteriosus, cardiac catheterization was not done, and the reference diagnosis is based on the operative findings). During catheterization the shunts were confirmed by oxygen saturation changes, dye-dilution curves, selective angiography, and/or catheter passage. The catheterization data were supplemented or corrected in 50 patients by the operative findings and in 10 patients by the autopsy findings. We attempted to divide the patients into different shunt categories which would allow a
Table 1

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>Ventricular septal defect (VSD)</td>
<td>15</td>
</tr>
<tr>
<td>Transposition of the great arteries (TGA)</td>
<td>14</td>
</tr>
<tr>
<td>Tetralogy of Fallot (T/F)</td>
<td>12</td>
</tr>
<tr>
<td>Atrial septal defect second (ASD II)</td>
<td>5</td>
</tr>
<tr>
<td>Patent ductus arteriosus (PDA)</td>
<td>4</td>
</tr>
<tr>
<td>Aortic stenosis (AS)</td>
<td>4</td>
</tr>
<tr>
<td>Endocardial cushion defect (ECD)</td>
<td>3</td>
</tr>
<tr>
<td>Myopathy</td>
<td>3</td>
</tr>
<tr>
<td>Total abnormal pulm venous drainage (TAPVD)</td>
<td>2</td>
</tr>
<tr>
<td>Coarctation of aorta (coarct)</td>
<td>2</td>
</tr>
<tr>
<td>Pulmonary stenosis (PS)</td>
<td>2</td>
</tr>
<tr>
<td>Ebstein's anomaly</td>
<td>1</td>
</tr>
<tr>
<td>Tricuspid atresia</td>
<td>1</td>
</tr>
<tr>
<td>Dextrocardia with pulm atresia</td>
<td>1</td>
</tr>
<tr>
<td>Double-outlet right ventricle</td>
<td>1</td>
</tr>
<tr>
<td>Constrictive pericarditis</td>
<td>1</td>
</tr>
<tr>
<td>Aneurysm of left atrium</td>
<td>1</td>
</tr>
<tr>
<td>No heart disease</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
</tr>
</tbody>
</table>

A comparison of the various examinations, even though all were done at different times.

**Isotopic Method**

For all examinations the patients lie supine with the camera* detector over the chest and upper abdomen (AP position). The radioisotope is injected in a scalp vein or in a peripheral arm vein. In most instances a scalp vein needle connected to a three-way stopcock is used to allow an immediate flushing of the isotope bolus with physiologic saline. Older children are occasionally injected using the Oldendorf bolus technic.

*99mTc-Technetium is always used, usually as Tc-pertechnetate, and occasionally as Tc-albumin, in a dose of 1 mCi/5 kg body weight up to 8 mCi, in a volume of 3–5 ml. The total body and gonadal radiation exposure is extraordinarily low, in the range of 10–20 mrad/mCi *99mTc.*

The activity distribution over thorax and abdomen is recorded over 40 sec on the videotape, then a survey picture is taken (100,000 counts). The videotape information is then processed in two steps: (1) Serial Polaroid photographs of the display on the camera oscilloscope are taken at 0.2–1-sec intervals from the videotape playback, usually with eight to 16 photos in the radioangiographic series. (2) The information is then transferred from the videotape into a computer (Nuclear Chicago CSD-4096), and four different "regions of interest" are chosen on the picture displayed on the computer oscilloscope: injected vein, right atrium, right lung periphery, and abdominal aorta. The time-activity curves over these four regions are then obtained, and Polaroid photographs of the chosen regions and the curves are taken. Each point in the curve represents the activity occurring in the particular region during 0.32 sec. The curves are not "smoothed." Figure 1 shows the complete scintiphoto series and time-activity curves in a normal patient.

The actual examination lasts 5–10 min for the patient, with another 20–30 min required for data evaluation after the patient is gone. The photographing and arranging of the serial series is done by a specially trained technician, while the selecting of the curve areas and the curves themselves are always done by a physician.

**Results**

**Evaluation of Left-to-Right Shunts**

The presence or absence of a left-to-right shunt was determined according to the following criteria.

**Analysis of the Scintiphoto Series.** Four main phases can be distinguished in the series of eight to 16 pictures: (1) filling of the superior vena cava and right atrium; (2) filling of the right ventricle and pulmonary artery; (3) filling of the lung; and (4) filling of the left side of the heart, ascending and descending aorta. When no shunt is present, the lung areas are practically free of radioactivity when the activity appears in the abdominal aorta in the fourth phase. This is seen schematically in figure 2 (middle row). The phases are well demonstrated in a 7-year-old patient in figure 3. When there is a left-to-right shunt, the lung in the fourth phase is again filled with radioactivity together with the abdominal aorta. This is presented schematically in the bottom row of figure 2 and seen in a patient study in figure 4.

**Analysis of the Time-Activity Curves.** Figure 5 (middle) shows schematically the four types of curves found over the four different areas when no shunt is present. Figure 3 illustrates the curves from a patient with no shunt. The diagnosis of a left-to-right shunt is mainly based on the configuration of the lung curve at the time of the activity appearance in the abdominal aorta. When no shunt is present the descending portion of the lung curve is smooth and shows in most of the cases a late recirculation. When a left-to-right shunt is present there is a double peak in the lung curve with the second hump signifying the pathologic early recirculation. This second peak varies in size depending on the size of the shunt, analogous to the early recirculation peak in the cardiogreen-dilution curve, and appears simultaneously with the beginning of the aortic curve. Thus, it is possible to distinguish between a left-to-right shunt and a prolonged lung circulation due to cardiac failure. This is seen schematically in figure 5 (right) and in

*Circulation, Volume XLVII, April 1973*
a patient in figure 4. The quality of the injection is critical: only with a good bolus injection, proven by a sharply peaked curve over the injected vein, is it possible to make a proper evaluation of a left-to-right shunt.

The 73 examinations were thus purely qualitatively diagnosed as to whether a left-to-right shunt was present or not. In five patients no evaluation was possible because of a protracted injection; in 28 cases no evaluation was possible because of a concomitant moderate or large right-to-left shunt which alters the lung and aortic curves in such a way that our criteria for the diagnosis of a left-to-right shunt cannot be used. The reference diagnoses were divided into the following groups: (1) left-to-right shunt in presence of no or only a small right-to-left shunt; (2) no left-to-right shunt; (3) left-to-right shunt in presence of a moderate-to-large right-to-left shunt.

In five instances the catheterization diagnosis was not decisive and no comparison was possible. Table 2 summarizes these results and shows that in the first group the RCG gave the “correct” information in all cases of left-to-right shunts in the presence of no or only a small right-to-left shunt. The smallest shunt in this group at the time of catheterization was 1.2:1. In the second group it became evident that the left-to-right shunt could not be absolutely excluded, the results correlating in only 78% of the nine patients. The final evaluation of the RCG results was based mainly on the analysis of the

Figure 1

(M.B., 7-year-old boy, 5-9-72.) Radiocardioangiography in a normal patient. (Left) The complete scinti-photo series. (Right) The time-activity curves from all four regions, including the demonstration of the choice of the areas.

Figure 2

Schematic demonstration of the four scintigraphic phases seen in normal patients and in those with left-to-right and right-to-left shunts.

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time-activity curves since the scintiphoto series allowed only the diagnosis of moderate-to-large left-to-right shunts. No attempt was made to quantitate the size of the shunts. We feel that our way of collecting reference data made an exact comparison impossible, since only examinations made exactly at the same time enable a valid quantitative comparison. In addition, we did not try to distinguish between different anatomic lesions.

Evaluation of Right-to-Left Shunts

All RCG results were also analyzed for the presence of a right-to-left shunt using the following criteria.

Analysis of the Scintiphoto Series. In the presence of a right-to-left shunt, the activity in the abdominal aorta is seen in the second phase, i.e. together with the filling phase of the pulmonary artery. In addition, the intensity of the radioactivity over the lung periphery is less than normal; this is particularly marked in patients with an appreciable hypoperfusion of the lung. A right-to-left shunt is seen schematically in figure 2 (upper row); figure 6 presents the study in a 2-day-old infant with transposition of great arteries.

Analysis of the Time-Activity Curves. As is seen in figure 5 (left) the main feature of a right-to-left shunt is...
shunt is the early appearance of activity in the abdominal aorta; the time difference between the appearance of the activity in the lung area and in the abdominal aorta region is always markedly decreased, separating clearly the group with shunts from that without shunts, as seen in figure 7. As a result of a moderate-to-large right-to-left shunt, the time-activity curve over the lung periphery will show only a small or even absent initial peak as an indication of the reduced perfusion. Figure 6 gives such an example. The evaluation of the appearance time of the activity is valid even with a somewhat protracted injection.

All 73 examinations were analyzed for the presence of a right-to-left shunt. In one case no evaluation was possible because of an injection into a leg vein. The remaining 72 cases could be evaluated independently of a concomitant left-to-right shunt. As reference the 73 patients were divided into three groups: (1) constant, obligatory right-to-left shunt; (2) inconstant, facultative right-to-left shunt (i.e. in cases of ASD, VSD with pulmonary hypertension, or PA band); and (3) no right-to-left shunt.

Table 3 shows the summary of the results. Here one can see that in the group with an obligatory right-to-left shunt the RCG gave the "correct" answer in 100% of the cases, the smallest shunt being in the order of 1.2:1 during catheterization. In the group with the facultative shunts there was a 50% correlation, which was to be expected statistically and expresses a very good correlation. "No shunt" was correctly diagnosed in 90% of 23 cases, showing again that the distinction between no shunt and a very small shunt cannot be made with 100% accuracy; however, the evaluation of patients with a very small right-to-left shunt is more accurate than that of patients with a very small left-to-right shunt.

Again the time-activity curves proved to be more reliable than the scintiphoto series and demonstrated even the very small shunts. As with the left-to-right shunts, no attempt was made to make a quantitative determination of the size of the shunt. In addition, no attempt was made to distinguish between anatomic lesions, the only exception being the combination of a hypervascularity of the lungs in the X-rays with a large right-to-left shunt and a clear-cut hypoperfusion of the lung in the RCG as very suggestive of a transposition of the great arteries.

Discussion

The RCG has its merits as a safe, quick, and easy method for the diagnosis of cardiac shunts in children with questionable heart defects, in extremely ill patients, or for repeated follow-up studies of cardiac patients, which avoids arterial puncture or venous catheterization. The use of the Anger scintillation camera and/or the computer analysis of regional radioactivity has been well documented in previous publications. The use of 99mtechnetium and especially its low radiation exposure has also been discussed thoroughly by other authors. The general value of a scintiphoto

### Table 2

<table>
<thead>
<tr>
<th>Correlation of Left-to-right Shunt</th>
<th>R C G</th>
<th>Correlation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catheterization (+ op. ± autopsy)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left-to-right shunt (+ no or small right-to-left shunt)</td>
<td>N = 26</td>
<td>26 0 100</td>
</tr>
<tr>
<td>No left-to-right shunt</td>
<td>N = 9</td>
<td>2 7 78</td>
</tr>
<tr>
<td>Left-to-right shunt (+ mod or large right-to-left shunt)</td>
<td>N = 28</td>
<td>No evaluation possible 0</td>
</tr>
<tr>
<td>Total</td>
<td>63 (5 cases with protracted injection; 5 cases with nondecisive catheterization)</td>
<td>100</td>
</tr>
</tbody>
</table>

Abbreviations: RCG = radiocardiographic angiography.
series has been shown.2, 3, 5, 8, 10, 16, 19 On the other hand, several authors have demonstrated the value of the time-activity curves over the lung in cases of left-to-right shunts,6, 10, 12–15, 17, 18, 20–22 while Hag-

Figure 6
(W.J.C., 2-day-old boy, 8-3-71.) Infant with right-to-left shunt (TGA.) (A) Scintiphoto series showing simultaneous appearance of the activity in the lungs and abdominal region. (B) Time-activity curves confirming the premature appearance of activity in the abdominal aorta.

gan et al.16 and Remedios et al.9 have described a similar choice of regions for shunt evaluation as we do. All these authors support the use of this isotopic method.

Figure 7
Difference in the appearance time of the activity in the lungs and abdominal aorta in the diagnosis of right-to-left shunt. There is a clear-cut separation between those patients with a right-to-left shunt and those without.
In giving criteria for the evaluation of shunts we have tried to be as simple and clear as possible, while attempting to avoid a subjective interpretation. The excellent correlation with catheterization data in both left-to-right and right-to-left shunts down to those as small as 1.2:1 proves the validity of the method. The scintiphoto series allows the diagnosis of moderate and large shunts, while the time-activity curves give accurate information in smaller shunts. In excluding a very small shunt (<1.2:1), especially in the case of left-to-right shunts, no completely accurate diagnosis is possible. This is in contrast to the accuracy reported by Hagan et al. using the C2/C1 ratio. However, even by using this ratio we were not able to improve our results: while a low C2/C1 ratio proved the absence of a shunt, we found high ratios when no shunt was present in patients with a hypoperfusion of the lung due to a right-to-left shunt and in patients with prolonged pulmonary circulation time due to cardiac failure. In these cases our criteria of looking for a second peak in the lung curve coming simultaneously with the appearance of activity in the aortic curve seemed to be more reliable. However, bronchial arterial blood flow and/or skin perfusion in the chosen lung region can imitate a small left-to-right shunt: in these instances the limitations of the method are exceeded. The errors in the evaluation of the absence of a right-to-left shunt are probably due to the low radioactivity in the region of the abdominal aorta secondary to dilution resulting in relatively large statistical error (an error which is accentuated by the smoothing process used by some authors).

One of the advantages of our method is that the examination can be made with the same accuracy even in very young infants, a fact demonstrated by the large percentage of infants in our series. It can be of help, for instance, in the differential diagnosis between cardiac and pulmonary disease in a cyanotic infant. The quantitative evaluation of the shunt size would be desirable as this would greatly increase the value of the method, particularly for serial follow-up studies.

Acknowledgment

We gratefully acknowledge the skilled technical assistance of Miss Esther Schnegg in performing the examinations.

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Table 3

<table>
<thead>
<tr>
<th>Correlation of Right-to-Left Shunt</th>
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</thead>
<tbody>
<tr>
<td>Catheterization (± op. ± autopsy)</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Constant (obligatory) right-to-left shunt (N = 31)</td>
</tr>
<tr>
<td>No right-to-left shunt (N = 23)</td>
</tr>
<tr>
<td>Inconstant (nonobligatory) right-to-left shunt (ASI, VSD IIIa, etc) (N = 18)</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

(1 series not usable because of injection in a leg vein)
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Pediatric Radiocardioangiography: Shunt Diagnosis
F. P. STOCKER, J. KINSE, J. W. WEBER and H. RÖSLER

Circulation. 1973;47:819-826
doi: 10.1161/01.CIR.47.4.819
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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