Radioisotopic Angiocardiography

Wide Scope of Applicability in Diagnosis and Evaluation of Therapy in Diseases of the Heart and Great Vessels

By Joseph P. Kriss, M.D., Lee P. Enright, M.D., William G. Hayden, M.D., Lewis Wexler, M.D., and Norman E. Shumway, M.D.

SUMMARY
Radioisotopic angiocardiography has been performed in 120 patients after the intravenous injection of $^{99m}$Tc pertechnetate. A scintillation camera and a variable time-lapse videoscintiscope were used. The results indicate that the method permits identification and physiologic assessment of a wide variety of congenital and acquired cardiovascular lesions, including septal defects, valvular stenosis and incompetence, aneurysm, tumor, venous obstruction, ventricular hypertrophy, and effusion. Emphasis particularly is given, therefore, to the wide scope of applicability of the procedure.

The diagnostic criteria employed for a representative group of these lesions are presented together with illustrative examples to demonstrate the type and quality of the information which may be obtained with the method. The procedure is rapid and safe and does not require hospitalization, heart catheterization, or special preparation of the patient, advantages which favor its use as a diagnostic screening test. In addition to its diagnostic uses, radioisotopic angiography may offer a useful and convenient method of assessing the effects of therapy or of following the course of disease.

Additional Indexing Words:
- Aortic valve insufficiency or stenosis
- Cardiac diagnosis
- Idiopathic myocardopathy
- Rheumatic heart disease
- Ventricular and aortic aneurysm
- $^{99m}$Technetium variable time-lapse videoscintiscope
- Aortopulmonary window
- Cardiac surgery
- Mitral valve insufficiency or stenosis
- Scintillation camera
- Superior caval obstruction
- Variable time-lapse videoscintiscope

In a series of recent reports from our laboratory, the diagnostic capability of the variable time-lapse videoscintiscope (VTV)

1. From the Departments of Radiology, Medicine, and Surgery, Stanford University School of Medicine, Stanford, California.

2. Supported by a grant from the Easter Seal Research Foundation, National Easter Seal Society for Crippled Children and Adults, Inc., and Grant GM-1707, National Institute of General Medical Sciences, National Institutes of Health.

3. Address for reprints: Dr. Joseph P. Kriss, Division of Nuclear Medicine, Stanford University School of Medicine, Stanford, California.

4. Received December 21, 1970; revision accepted for publication February 22, 1971.

5. Experience with additional patients, including many with other diseases of the heart and great vessels, availability of surgical confirmation, and the opportunity to perform serial postoperative studies have reinforced the early favorable impressions of the diagnostic power, accuracy, and simplicity of the method.
Clinical experience plus technical improvements have combined to enable us to define diagnostic criteria in specific disease states and improve diagnostic acumen. The purpose of this report is threefold: (1) to show, largely through case examples, the current state of the art and the greatly widened range of diagnostic capabilities; (2) to define diagnostic criteria for specific entities, and (3) to indicate our current views of the indications, limitations, and potential for the radioisotopic method. Particular emphasis will be given to those conditions which have not been the subject of the detailed reports just cited.

Methods

This report is based on an analysis of results obtained in 120 patients studied at Stanford University Hospital during the period January 1, 1969, to November 15, 1970. Of these, 23 patients have been studied both before and after surgical treatment. The disease categories and frequency with which specific lesions were found are indicated in table 1. Selection of patients was arbitrary and was based on such factors as daily angiographic case load, lesion under special investigation at any given time, availability of the patient for preoperative and postoperative study, age, and availability of patent veins. Both ambulatory and hospitalized subjects were studied, and there was no selection by sex. Patients varied in age from 1 month to 81 years. The test was performed on 11 children under 10 years of age with known or suspected congenital heart disease.

The clinical diagnoses were in all instances established or confirmed by other diagnostic procedures, including phonocardiography, echocardiography, cardiac catheterization, roentgenography, and contrast cineangiography. In many cases, direct confirmation of the diagnosis was made by visual and manual inspection at the time of open heart surgery.

The scintillation camera with our accessory variable time-lapse recording, display, and scintiphotographic system (VTV) has been described previously. The system allows for the recording, display, replay, and photographing of dynamic events for selected time periods and also permits the enhancement, suppression, or deletion of any portion of the record. Adults were usually studied while seated. The positioning techniques for performing studies in the anterior and modified left anterior oblique views were those reported by Matin and Kriss. The intravenous bolus injection technique recently has been modified to advance by employing a specially prepared two-compartment syringe.* The pushing of the plunger of this syringe fully forward results in the injection first of the radioactive bolus and this followed immediately by a saline wash and ausher bolus of up to 2 ml. The radiopharmaceutical employed was 99mTc pertechnetate, given in a volume of 0.5 to 3.0 ml. The usual adult dose was 10 mCi; that for children was 0.1 mCi/kg. An earlier report considers the radiation hazard, which is regarded to be very low (0.06-0.16 rads/dose). The times selected for exposing scintiphotographs varied widely from case to case, and even in the same case. They were determined on an individual basis dependent on the rate of passage of the bolus and the particular lesion one wished best to demonstrate; indeed, this option

---

*Described to one of us (J.P.K.) by Dr. Donald VanDyke, Donner Laboratory, University of California, Berkeley.

### Table 1

<table>
<thead>
<tr>
<th>Category of Disease</th>
<th>Incidence of Lesions Present in Study Group of Patients</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total patients studied</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>With congenital heart disease</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>With acquired heart disease</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Disease excluded</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Total lesions</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>Congenital</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Ventricular septal defect</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Tetralogy of Fallot</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Pulmonic stenosis</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Corrected transposition</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Complete transposition</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Coarctation of aorta</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Aortopulmonary window</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sinus of Valsalva aneurysm</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Postvalvular aortic stenosis</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Left superior vena cava</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Acquired</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td>Mitral insufficiency</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Mitral stenosis</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Aortic insufficiency</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Tricuspid insufficiency</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ventricular aneurysm</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Idiopathic myocardopathy</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Left atrial myxoma</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Primary pulmonic hypertension</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Superior caval obstruction</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous conditions</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

Circulation, Volume XLIII, June 1971
for time interval selectivity is the essential, unique feature of the VTV. Double exposures superimposing different cardiac phases on the same scintiphotograph\textsuperscript{1, 3, 5-7} were made routinely. In most instances, a high contrast setting on the television monitor was employed; this, plus the employment of a defocused light dot mode, tend to result in a diminished photographic representation of pulmonary radioactivity and a relative enhancement of activity in the heart and great vessels.

Infants and very young children were usually studied in the supine rather than the seated position, and the injection was made with the arm abducted. Special problems exist with young children. Venipuncture is more difficult. Crying is inevitable in the unstedated child, and the resulting involuntary Valsalva maneuver may interfere with bolus transit. Circulation times tend to be very rapid, and the size of the heart and the resulting scintiphotographic image are very small. It is important, particularly in the assessment of septal defects (see below) that the bolus enters the heart over a 1-2 sec interval. The pretest injection of a sedative, use of small injection volume (with two-compartment syringe), and milking the brachial vein immediately after injection are useful maneuvers to ensure prompt entry of the bolus. The size of the scintiphotographic image in very young children or infants may be increased by substituting a pinhole collimator for the multichannel collimator usually employed and positioning it close over the precordial area.

Results

General Comment

The procedure was easy to perform, was accomplished with minimal discomfort and inconvenience, required the presence of the patient in the Nuclear Medicine unit for a short period of time (10-30 min.), and was not accompanied by any discernible immediate or delayed toxic reactions. The duplicability of the procedure was excellent (e.g., see fig. 3, below). Occasionally, partial extravasation of a bolus occurred. If so, the injection site was massaged gently and compressed, and a different vein was chosen for a second attempt. Under these circumstances, the radiation dosage at the injection site and to the whole body are increased, but because of the rapid absorption of pertechnetate from soft tissues, the radiation hazard to the subject was still judged to be acceptably low.

Atrial Septal Defect (ASD)

This lesion was observed in 10 patients, and the scintiphotographic pattern in each was similar. A characteristic set of abnormalities was identified which provides the basis for an accurate diagnosis.

The scintiphotographic criteria for left-to-right intracardiac shunt at the atrial level stem from the fact that the radioactive blood, once it enters the left atrium on its first pass through the heart, in part is diverted through the septal defect and reappears in the right atrium, thereby initiating a continuous, recycling process. Thus, in atrial septal defect all four heart chambers and the lungs are concomitantly visualized. To make certain that the right atrium is clearly identified the angiographic study should be performed in both anterior and oblique positions. A typical study is presented in figure 1. In ASD the following scintiphotographic findings may be noted:

1. Enlargement of the right atrium.
2. Loss of apparent intensity of bolus during initial cardiac filling phase as it passes from right atrium to right ventricle. (This sign is especially noted in the presence of large shunts and is probably due to dilution of the bolus by unlabeled blood entering the atrium across the septal defect.)
3. Enlargement of the pulmonary conus.
4. Persistent visualization of activity in all four cardiac chambers and lungs after first passage of bolus into lungs, tending to produce a long-lasting "smudge" pattern. This is the most characteristic and universal diagnostic angiographic feature of this lesion. It is important to document that the right atrium specifically contains radioactivity at all time phases of the study.
5. Relatively poor delineation of the aorta, due to activity simultaneously present in the lungs.
6. Infrequently, during the recycling phase, reflux from right atrium to the superior vena cava occurs.

\textit{Circulation, Volume XLIII. June 1971}
Figure 1

Atrial septal defect, anterior and oblique positions. Note prominence of RA, smudge pattern in later phases (frames 3) with activity present in RA (proved by double exposures, frames 4) and the other three heart chambers, failure to isolate a LV-aortic pattern, prolonged visualization of intracardiac activity. Pulmonary-to-systemic flow ratio was 1.6.

The abbreviations used in this and the other scintiphotographs are as follows: SVC = superior vena cava; RA = right atrium; RV = right ventricle; PA = pulmonary artery; LA = left atrium; LV = left ventricle; A = aorta; X, Y = other specified regions of interest; Ant = anterior position; L.A.O. = modified left anterior oblique position; pre-op = preoperative study; post-op = postoperative study. Exposure time intervals in seconds after injection of the bolus are shown for each frame. In referring to frames the numbers begin with 1 for each position.

Our results indicate a high sensitivity of the method with respect to shunt magnitude. No failures of angiographic diagnosis have been observed in proven cases. The smallest visualized left-to-right shunt in the series studied was not demonstrable by $O_2$-saturation changes but was detected by hydrogen electrode studies performed during cardiac catheterization. Shunts associated with a calculated pulmonary-to-systemic flow ratio of only 1.2 have been readily visualized. The largest shunt was associated with a pulmonary-to-systemic flow ratio of 3:1.

The outstanding diagnostic angiographic features after successful surgical treatment are the prompt disappearance of the "smudge" pattern, normal right atrial emptying, and the ready visualization of an isolated left ventricular-aortic phase with normal circulation time.

However, right atrial enlargement and prominence of the pulmonary conus region may persist, at least for several weeks.

**Ventricular Septal Defect (VSD)**

The recycling of blood from left ventricle back into right ventricle following initial filling of the former chamber results in a characteristic abnormal angiographic pattern resembling, but not identical, to that of atrial septal defect (fig. 2). The noteworthy diagnostic features of VSD are:

1. Persistent visualization of the right ventricle, lungs, left atrium, and left ventricle, but not the right atrium after first passage of the bolus through the right heart and lungs.
2. Relatively poor delineation of the aorta due to radioactive blood simultaneously present in the lungs.
Ventricular septal defect, oblique position. Note smudge patterns in later phases (frames 2 and 3), late visualization of RV and LV, but not RA (compare frames 2 and 4), and prolonged visualization of cardiopulmonary activity. Pulmonary-to-systemic flow ratio was 1.2.

Aortopulmonary window, anterior position, before and after brief walking exercise. Note asymmetry of PA to the right, with tract filling ascending aortic area (frames 1 and 2, top arrow), early aortic (A) activity (frames 3), and relatively increased prominence of ascending aortic region after exercise (compare X, frames 5, before and after exercise).

The demonstration that, during recycling, the right atrium is not refilling serves to distinguish VSD from ASD. The smallest ventricular shunt demonstrated by the radioisotopic test was associated with a pulmonary-to-systemic flow ratio of 1.2.

**Aortopulmonary Window**

A variable right-to-left shunt between the main pulmonary artery and the ascending aorta was demonstrated in one patient who developed striking cyanosis and poor exercise tolerance on slight exertion, but who was minimally cyanotic at rest. Radioisotopic angiocardiography was performed before and after exercise. Both studies were abnormal (fig. 3). The scintigraphic study was unique and revealed the following findings:

1. Asymmetrical main pulmonary trunk, with anomalous right-sided tract leading to the region of the ascending aorta.
2. Demonstration of radioactivity in ascending aorta and arch nearly synchronous with presence of maximal activity in the pulmonary artery, and before delineation of left ventricle.
3. Rapid loss of radioactivity from the heart immediately after delineating the right-sided cardiac phase.
The findings are similar to those expected in patent duc tus arteriosus with Eisenmenger physiology except that in the latter the descending rather than the ascending aorta would be visualized, and a duc tus involving right side of pulmonary trunk would be unusual.

**Primary Pulmonary Hypertension**

Two patients with this disorder were studied with similar findings; the scintiphotos of one of them are shown in figure 4. The diagnostic features of note were:

1. Prolonged residence time of the bolus in the superior vena cava and right heart chambers.
2. Reflux of radioactivity into innominate vein contralateral to site of injection.
3. Enlargement of right atrium and right ventricle.
4. Striking decrease in delineation of main right and left pulmonary arteries and lungs, presumably due to narrowing of these vessels.
5. Delayed visualization of left ventricle and aorta.

It seems possible that similar findings might be found in patients with severe pulmonary hypertension due to some specific lesion, e.g., multiple pulmonary emboli. Thus, other tests would be necessary to establish the etiology of the pulmonary hypertension.

**Mitral Stenosis**

This lesion has been present in 21 of our patients. While the characteristic angiographic findings in this disorder have been detailed elsewhere, we are presenting the findings in another typical case (fig. 5) so that the reader may contrast and compare the findings with those seen in left atrial myxoma (see below). The presence of pure mitral stenosis is characterized by the following:

1. Enlargement of the left atrium.
2. Prolonged visualization of the left atrium.
3. Normal size of left ventricle.
4. Persistent dual visualization of left atrium and left ventricle with preponderance of radioactivity in left atrium.
5. Variable enlargement of pulmonary conus, dilatation of right ventricle, and prolongation of circulation time, reflecting pulmonary venous or arterial hypertension.

*Figure 4*

Primary pulmonary hypertension, anterior view. Note reflux (R) into innominate vein contralateral to injection site, very slow movement through right heart, bulbous configuration of RV and prominent RA in frames 4 to 8, failure to delineate main pulmonary arteries, late visualization of aorta, prolonged circulation time. P = pulmonary conus.
In a number of instances repeat studies were performed soon after surgery involving either mitral commissurotomy or valve replacement (fig. 5). Even a few days following surgery one may detect evidence of improvement, such as shortened circulation time, decreased size of the left atrium, improved filling of the left ventricle and aorta, and overall decreased heart size. However, complete regression to a normal-sized left atrium has not been demonstrated in the early postoperative period despite marked clinical improvement.

**Left Atrial Myxoma**

Striking findings were seen preoperatively in a woman with left atrial myxoma who presented with clinical and auscultory signs similar to those seen in mitral stenosis. Echocardiography yielded evidence of a mass within the left atrium, and contrast cineangiocardiography demonstrated that the mass was a spherical, pedunculated tumor which produced intermittent obstruction of blood flow through an otherwise normal mitral valve. The radioisotopic angiocardiogram (fig. 6) revealed the following abnormalities, leading also to the conclusion that a space-occupying lesion was present inside the left atrium:

1. Enlargement of the left atrium.
2. Presence of filling defect in the left atrium.
3. Prolonged visualization of the left atrium and the filling defect within it.
4. Normal left ventricle.

Following surgical removal of the tumor, radioisotopic angiographic study was normal (fig. 6).

**Mitral Insufficiency**

The characteristic angiographic findings that we observed in patients with mitral insufficiency have been reported, and can be summarized as follows:

1. Left atrial enlargement, frequently marked.
2. Left ventricular dilatation.
3. Persistent visualization of both left atrium and left ventricle, with about equal intensities of radioactivity in both chambers during late phases of the study, due to bidirectional reflux across the incompetent mitral valve.

4. Variable prolongation of circulation time, enlargement of pulmonary prolongation of circulation time, enlargement of pulmonary conus, dilatation of right ventricle, and delay of bolus in the pulmonary circuit, reflecting pulmonary venous or arterial hypertension.

As in the case of mitral stenosis, operative replacement of the mitral valve may be accompanied by striking, and rapidly developing evidence of improvement, but enlargement of the left atrium remains angiographically demonstrable for at least several weeks after surgery (fig. 7).

**Left Ventricular Aneurysm**

The normal left ventricular cavity appears in the radioisotopic study as an elongated or oval shape, sometimes tapering at its distal portion, and with a width usually not exceeding that of the normal aortic root. The demonstration of localized dilatations involving portions of the left ventricular wall or the interventricular septum has proved to be easily accomplished by the radioisotopic method. Aneurysms appear on the study as focal bulges in various portions of the ventricle, occasionally taking bizarre shapes, and usually demonstrating prolonged residence of radioactivity in the involved region. The ventricle as a whole may be dilated, and the accuracy of diagnosis usually depends on the ability to show on at least one view a localized region where a bulge is especially noticeable. We have demonstrated such abnormalities in five patients who subsequently have had an aneurysm repaired or excised. Postoperative evaluation has clearly shown the extent of change resulting from the surgical excision as well as the change in the functional state of the circulation. Findings typical of the preoperative and postoperative state in one of our patients is shown in figure 8. In another patient suspected of having a ruptured

---

**Figure 6**

Left atrial myxoma, oblique position, before and 1 week after operation. Preoperatively note enlarged LA (frames 2 to 4), filling defect (T) in LA (frames 2 to 4), failure to delineate clearly the aortic outflow; frames >18 <30 sec continued to resemble frame 3. A spherical myxomatous tumor about 5 cm in diameter was removed. Postoperatively, the angiographic pattern was normal; a possible reader’s impression of filling defect in frames 2 to 4 is due to normal pattern of LV-aortic arch flow.
Figure 7

Mitral insufficiency, oblique position, before and 6 weeks after operation. Preoperatively note large LA and LV (frames 2 to 5), poor delineation of aorta, prolonged visualization of left heart chambers with relatively equal intensity of activity in LV and LA. Postoperatively note smaller heart generally, enlarged but smaller LA, greatly reduced size of LV cavity, and normal aorta.

Figure 8

Ventricular aneurysm, anterior view, before and 1 yr. after operation. Preoperatively note aneurysms of apex of LV(X), and of septum (Y), prolonged circulation time, probable displacement to the right of interventricular septum (compare frames 1). Postoperative study is normal; both aneurysms had been excised and muscular walls patched.
Aneurysm of interventricular septum, oblique view. Note small aneurysm (S) in interventricular region (frames 2 and 4), prolonged circulation time, absence of left-to-right shunt (frame 3).

Aortic Insufficiency

This lesion, illustrated by a typical example in figure 10, has been present in six of the patients studied and is characterized by the following angiographic features:

1. Dilatation of the left ventricle, variable ventricular hypertrophy (see description below).
2. Persistent visualization of left ventricle and aorta, with about equal intensity in the two regions, during late phases of the study.
3. Clear identification of the region of the aortic valve, because of an abrupt change in activity contour or intensity.
4. Vigorous ventricular systole and diastole, beat by beat, often seen on the television screen as the heart repeatedly empties and overfills by regurgitation.

The beneficial effects of surgical replacement of diseased valves on size of the heart chamber, ventricular emptying, and circulation time may often be seen dramatically in

\[\text{Figure 9}\]

\[\text{Figure 10}\]
KRISS ET AL.

Figure 11
Aortic insufficiency and mitral insufficiency, oblique position, before and 1 week after operation. Preoperatively note very large heart (frame 4), prolonged circulation time, very large LV, large LA, and wide aorta (frames 2 and 3). Postoperatively (mitral and aortic valve replacement) note striking decrease in heart size, especially the LV, persistent enlargement of LA which empties better (frames 2 and 3), improved circulation time. The width of the septal region (frame 4, arrow) suggests that LV hypertrophy is present, made manifest by the elimination of LV dilatation.

the early postoperative period (fig. 10 and 11).

Aortic Stenosis
In pure aortic stenosis, which has been present in six patients, the following angiographic signs, illustrated by the example in figure 12, have been noted:
1. Small cavity of the left ventricle; if left ventricular failure is present, this sign becomes less noticeable.
2. Marked hypertrophy of the left ventricular wall, shown by (a) widening of the interventricular septum as seen on composite views containing both ventricles simultaneously, (b) large space between lower left lung activity and left ventricular cavity, (c) appearance of a penis sign, a phallic-like projection of left ventricular cavity directed leftward and downward from the region of the interventricular septum, seen in the anterior view.
3. Poststenotic widening of the ascending aorta.
When this lesion, or that of aortic insufficiency coexist with other valvular lesions, especially those involving the mitral valve, angiographic manifestations of both lesions may be demonstrable.

Left Ventricular Hypertrophy
In long-standing diastolic hypertension, such as may occur in chronic renal disease, the characteristic angiographic abnormality is left ventricular hypertrophy as shown by criteria in 2 for aortic stenosis.

Idiopathic Myocardopathy
We studied two patients in whom a final diagnosis of idiopathic myocardopathy appears to be justified after extensive testing failed to reveal other specific causes for cardiac failure. The radioisotopic angiocardiographic findings were similar in both cases; the findings in one of these are shown in figure

Circulation, Volume XLIII, June 1971
13. The following abnormalities were noted:
   1. Dilatation of all four cardiac chambers.
   2. Marked prolongation of the circulation time.
   3. Absence of signs of shunt, valvular disease, or cardiac hypertrophy.

   Similar findings have been noted in individuals with gross congestive heart failure due to advanced coronary artery disease.

Aortic Aneurysm

Saccular aneurysms of the aorta have been easily demonstrated in five patients studied. In two instances aneurysms of the ascending aorta were associated with aortic insufficiency, and angiographic evidence of both conditions was present. One of these (fig. 14) had surgical repair of the aneurysm with aortic valve replacement. A week later prominent carotid pulsations in the neck were noted, and widening of the upper mediastinum was seen roentgenographically. Angiography now revealed that the ascending aorta above the region of the aneurysm was markedly widened; at the same time, due to elimination of aortic insufficiency, the left ventricle had markedly diminished in size (fig. 14). Presumably the changed contour of the aortic arch and the observed carotid pulsations reflected some weakness in the wall of the upper part of the aorta made manifest by the surgical repair of the aneurysm of the lower region.

Aneurysms of the descending aorta are also demonstrable. Patients with lesions in that location should be studied in the left anterior oblique position (fig. 15). The results of successful operative repair are readily seen on postoperative study (fig. 15). Multiple aneurysms have been demonstrated in a patient with combined syphilitic and arteriosclerotic aortic lesions. We have not had occasion as yet to study patients with known dissecting aneurysms of the aorta.

The successful demonstration of an aneurysm of the sinus of Valsalva, with postoperative assessment of its repair has been documented in a separate report.6
Idiopathic myocardopathy, anterior and oblique positions. Note profound prolongation of circulation time, massive cardiomegaly involving all four heart chambers (e.g., frame 3, L.A.O.), and absence of signs of left-to-right shunt (frame 3, anterior, and frame 2, L.A.O.).

Superior Caval Obstruction

Figure 16 illustrates the striking findings seen in this disorder, namely:
1. Demonstration of collateral thoracic veins carrying the radioactive bolus downward past the heart into the subdiaphragmatic region.
2. Absence of filling of the superior vena cava.
3. Late filling of the heart, apparently via inferior vena cava.
4. Prolongation of total circulation time, but normal right heart-to-aorta circulation time.

An unusual case associated with pericardial effusion has been studied in our laboratory and presented elsewhere.

Other Conditions

Limitation of space prevents detailed documentation here of successful demonstration of a variety of other conditions, many of them congenital in nature and occurring in children. However, a listing of them serves to give further indication of the scope of the diagnostic capabilities of the method: tetralogy of Fallot, transposition of the great arteries, corrected transposition, left superior vena cava, tricuspid insufficiency, and successful Mustard correction of transposition. In several patients with thyrotoxic heart disease we have demonstrated the coexistence of dilatation of the left ventricle and unusually rapid passage of the bolus through the heart. Separate accounts dealing with the diagnosis of pericardial effusion and intracardiac tumor in our laboratory have been reported.

Diagnoses Excluded

In 23 of the 120 patients studied, radioisotopic angiography served to exclude the presence of a suspected lesion. The excluded
Aortic aneurysm and aortic insufficiency, anterior position, before and 1 week after operation. Preoperatively note saccular enlargement at root of aorta (frames 2 and 3), prominent LV cavity, clearly delineated aortic valvular area, widening of aortic area between superior vena cava and pulmonary artery (frame 1); prolonged circulation time with late dual visualization of LV and aorta. Postoperatively (aortic valve replacement and aneurysm repair) note smaller LV, absence of aneurysm at aortic root, poorer delineation of aortic valvular area, shorter circulation time, and widening of ascending aorta near the arch.

Discussion

Our results of intravenous radioisotopic angiocardiography performed in a relatively large number of patients demonstrate that markedly abnormal and distinguishable scintiphotographic patterns are obtained in a variety of specific cardiovascular diseases. The conditions include congenital and acquired heart disease, involving both right-sided and left-sided lesions and diseases of the great vessels and pericardium. The scintiphotographic criteria which are being applied currently in our laboratory for diagnostic purposes in evaluating these conditions have been described. The accuracy and immediate clinical relevance of the data gained combined with simplicity, speed, and safety of the procedure make this an attractive, useful, clinical procedure.

It is difficult to make a precise comparison between radioisotopic and contrast radiographic angiography. The latter procedure has superior resolution, an advantage which exists even if the radionuclide, like the contrast material, is introduced by means of a catheter as Mason and associates have reported. The intravenous radioisotopic method, however, in addition to having advantages of simplicity...
Figure 15
Aneurysm of descending aorta, oblique position, before and 1 week after operation. Preoperatively note saccular aneurysm of descending aorta (X, frames 3 to 5) at or near takeoff of left subclavian artery (S, frame 2), RC and LC = right and left common carotid arteries, respectively. Postoperatively (excision and repair of traumatic aneurysm), the aneurysm can no longer be seen; there is an increase in width of the aorta proximal to the site of repair (frames 2 and 3).

Figure 16
Superior caval obstruction, anterior position. Injection was made into left antecubital vein. Note filling of left axillary vein (Ax, frame 1), intercostal collaterals (B, frame 2) axillary collateral vein (D, frame 2), and internal mammary vein (C, frame 2), but no superior vena caval or cardiac activity was seen up to 10 seconds (frames 1 to 4). RA filled from below (frame 5), and aorta and LV were visualised late (frame 7). The composite view (frame 8) shows well the relationship of the heart (faint shadow in the center) to the collateral venous system. The obstruction was caused by metastasis from a bronchogenic carcinoma.

Circulation, Volume XLIII, June 1971
and safety, permits a diagnostically useful integration of information for longer periods and offers the opportunity for quantitative analysis of data when suitable accessory equipment is employed. Thus, use of the method has permitted the quantitative assessment of a number of hemodynamic functions, such as cardiac output, chamber size, and transit times. It is likely that in the near future additional radioisotopic methods will be developed which will permit the rapid quantitation of intracardiac shunts, stroke volume, myocardial contractility, and coronary blood flow.

The intravenous radioisotopic technique herein described does not lend itself to the study of patients with coronary artery disease. However, such patients may be studied by radioisotopic methods, if after coronary artery catheterization, a radiopharmaceutical is injected directly into the catheter. For such a purpose studies have been performed after the intracoronary injection of macroaggregated albumin labeled with \(^{131}\)I or with \(^{99m}\)Tc. The static type scintiphotographs obtained reflected the distribution of the labeled microemboli in the heart muscle. Poe reported that the injection of even very small amounts of such protein (0.01-0.5 mg) almost invariably adversely affected flow and muscular contractility, while Ashburn and associates and Endo and co-workers noted no untoward effects. In preliminary experiments on dogs we have successfully used the VTV system and \(^{99m}\)Tc pertechnetate to visualize the coronary bed and measure ventricular wash-out clearance rates of this radiopharmaceutical. Similar data have been attained in dogs after the injection of \(^{88}\)Xe with a different imaging and recording system. There is no reason to doubt that one can make similar measurements in man and thus avoid the possible hazards of intracoronary injection of particulate matter. For safety and convenience, the radioisotopic equipment should be in very close proximity to the X-ray angiographic facility.

In general, we recommend that radioisotopic angiocardiography be performed as a screening procedure prior to cardiac catheterization or selective contrast angiography. Specifically, we suggest that the radioisotopic procedure be considered under any of the following circumstances:

1. As a screening test in ambulatory or hospitalized patients with suspected congenital or acquired heart disease, caval obstruction, pericardial effusion, and thoracic aortic aneurysm.
2. In patients sensitive to radiographic contrast agents.
3. In patients too ill to undergo heart catheterization or contrast angiography.
4. Serially, as a guide to the effectiveness of medical therapy.
5. Serially, as a guide to the progression of disease in patients who are being followed expectantly.
6. Preoperatively and postoperatively to document effects of specific operative interventions.

Acknowledgment

The authors are indebted to Mrs. Jillian Love for her excellent technical assistance.

References

7. KRIS JP, MATIN P: Diagnosis of congenital and acquired cardiovascular diseases by radioisotopic angiocardiography.
topic angiocardiography. Trans Ass Amer Physicians 82: 109, 1970


Radioisotopic Angi cardiography: Wide Scope of Applicability in Diagnosis and Evaluation of Therapy in Diseases of the Heart and Great Vessels

JOSEPH P. KRISS, LEE P. ENRIGHT, WILLIAM G. HAYDEN, LEWIS WEXLER and NORMAN E. SHUMWAY

Circulation. 1971;43:792-808
doi: 10.1161/01.CIR.43.6.792

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1971 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/43/6/792

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/