Visualization of the Pulmonary Arteries in Pseudotruncus by Pulmonary Vein Wedge Angiography

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SUMMARY Pulmonary venous wedge angiography revealed the anatomy of the mediastinal and parenchymal pulmonary arteries in 22 patients with obstruction of the right ventricular outflow tract, proximal pulmonary arteries or branch pulmonary arteries, when conventional angiographic methods had failed. Nine of these patients had pseudotruncus-type anatomy and had no previous surgery. One pulmonary artery was not visualized in 13 of the 22 patients because of postoperative occlusion in 10, congenital "absence" of the left pulmonary artery in two, and suspected sequestration of the left lower lobe in one.

Retrograde pulmonary wedge angiograms were obtained by wedging an end-hole catheter in a pulmonary vein and slowly injecting, by hand, 0.2 to 0.45 ml/kg of contrast material followed by a flush of dextrose solution (1-2 ml/kg). In seven of the nine patients without previous surgery, the confluence of the pulmonary arteries in the mediastinum could be seen clearly by this method. Nine patients had a previous systemic-to-pulmonary anastomosis, and only the ipsilateral pulmonary arteries were visualized by aortography. Venous wedge angiography filled the pulmonary arteries of the nonopacified lung up to the point of obstruction in the mediastinum in each patient. Eight patients were able to have a systemic-to-pulmonary shunt because of the visualization of the previously unseen pulmonary arteries.

We conclude that pulmonary venous wedge angiography is a valuable adjunct to the current angiographic methods of investigating patients with pulmonary atresia and related conditions. In some cases, it may be the only way to determine the presence of surgically accessible pulmonary arteries.

RECENTLY, OPERATIONS have been devised to repair main pulmonary artery atresia associated with ventricular septal defect (pseudotruncus arteriosus), as well as similar conditions in which the pulmonary artery branches are discontinuous with the right ventricle.1, 2 The diagnosis of pulmonary atresia covers a range of anomalies, including 1) atresia of the right ventricular outflow tract and pulmonary valve; 2) atresia of the proximal main pulmonary artery; 3) atresia of the pulmonary valve and entire pulmonary artery with well-formed right and left branches which are connected at the bifurcation; 4) the same as #3, except that the right and left pulmonary arteries are discontinuous; 5) the same as #4, except for atresia of the proximal portion of either the right or left pulmonary artery, and 6) the same as #4, except for atresia of the proximal portion of both the right and left pulmonary arteries.3, 4 In each of these situations, blood reaches the pulmonary artery branches and the capillary bed of the lung by way of a ductus arteriosus, bronchial arteries or systemic collateral arteries from the descending aorta.

Aortic origin of the true pulmonary arteries usually results in systemic pressure in these arteries. In the several forms of pulmonary atresia, however, there is a low pressure and usually a low blood flow in the pulmonary artery distal to the systemic connections.

Successful repair or palliation of patients with pulmonary atresia depends in part on the preoperative identification of the anatomy of the mediastinal pulmonary arteries and the site and extent of the atretic areas. Routine radiographic examination provides little helpful information. Aortic root angiography may reveal the presence of pulmonary arteries, but the large number of bronchial and systemic collateral vessels may obscure the precise and complete anatomy of the pulmonary arteries. Selective injection of systemic collateral vessels may define the pulmonary artery supplied by the systemic vessel entered, with retrograde filling of the rest of the mediastinal pulmonary arteries. This technique may not demonstrate the entire anatomy of the mediastinal pulmonary arteries when numerous bronchial or collateral vessels are present. When systemic collateral vessels enter the lung parenchyma, it may not be possible to determine if they anastomose to the true pulmonary arteries in that part of the lung, or whether they are supplying a sequestered lobe.

This paper describes a little-known angiographic technique5, 7 which allows better visualization of the true intrapulmonary and mediastinal pulmonary arteries in patients with pulmonary atresia and related conditions, so that surgical management may be planned more precisely.

Material and Methods

Pulmonary vein wedge angiography was performed in 22 patients during cardiac catheterization at Texas Children's Hospital between May, 1976 and November, 1977. Patients ranged in age from 9 days to 28 years; all except one were cyanotic (SaO2* 58 — 98%) with decreased pulmonary blood flow.

*SaO2 — Systemic arterial saturation.
TABLE 1. Clinical and Angiographic Data, Group A. Nine Patients with Pulmonary Atresia + Ventricular Septal Defect; No Previous Surgery. Ages: 9 Days - 26 Years; Weight: 2.8 - 63 kg

<table>
<thead>
<tr>
<th>Pulmonary Confluence</th>
<th>Systemic Collaterals</th>
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<tbody>
<tr>
<td>Not seen</td>
<td>2 patients</td>
</tr>
<tr>
<td>Faintly seen</td>
<td>5 patients</td>
</tr>
<tr>
<td>Well seen</td>
<td>2 patients</td>
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Abbreviation: PDA = patent ductus arteriosus.

The patients were divided into two groups. Group A consisted of nine patients with atresia of the right ventricular outflow tract or proximal main pulmonary artery, who had no previous surgery (table 1). Six of these patients had typical pseudotruncus anatomy while three had complex malformations: dextrocardia in two patients, transposition in two patients and single ventricle in one patient. Their ages ranged from 9 days to 28 years. Four were less than 2 years old. Biplane cineangiograms were performed from the right and left ventricles and either the ascending or descending aorta with at least 1.5 cc/kg of contrast material for each injection. Selective arteriography of large systemic collaterals was performed in three patients.

Group B included 13 patients in whom one pulmonary artery was not visualized after standard ventriculography and aortography. Patients ranged in age from 1-16 years, and in weight from 7.5-45 kg. Eight of these patients had occlusion of the contralateral pulmonary artery after a systemic-to-pulmonary shunt, and one had occlusion of the ipsilateral pulmonary artery. Two patients had a congenital absence of the left pulmonary artery, and one had ventricular septal defect. Another patient had severe tetralogy of Fallot, and we could not determine from selective angiography whether there was sequestration of the left lower lobe which was supplied by a large systemic collateral vessel.

Scanty, small collateral vessels entered the non-perfused lung after aortography in 12 of the 13 patients in Group B, without retrograde filling of the proximal pulmonary artery.

Pulmonary Vein Wedge Angiography

A Goodale-Lubin catheter was introduced percutaneously into the femoral vein and advanced into the pulmonary vein via an atrial septal defect or patent foramen ovale in 17 patients. In five patients, a transseptal puncture was required to enter the left atrium and pulmonary veins. The Ross transseptal end-and-side-hole catheter was used for angiography in three patients and a Goodale-Lubin catheter was exchanged for the Ross catheter over a guide wire in the other two patients who had transseptal puncture.

A satisfactory pulmonary arterial pressure wave form was recorded in nine patients when the end-hole catheter was wedged in the pulmonary vein, but only a damped mean pressure was obtained in six other patients. In the remaining seven patients, the pulmonary venous wedge pressure was not measured.

A slow hand injection of 0.3 to 0.45 ml/kg of contrast material (Hypaque 75) was made at the rate of 1 ml/sec with the catheter wedged into the pulmonary vein. The contrast was injected until retrograde filling of the intrapulmonary arteries was seen to the hilus of the lung (figs. 1A and 1B). A bolus of flush solution (1 to 2 ml/kg) was injected by hand more rapidly (2 ml/sec) to wash the contrast material out of the capillaries and increase the filling of the larger pulmonary arteries (figs. 1C and 1D). The flush solution was injected until all the contrast material had cleared from the capillary bed.

The venous injection was performed while running a biplane cine at 30-40 frames per second; the field covered included the area where the wedge injection was made as well as the mediastinum with the image intensifier in the non-magnify mode (10°). In those patient without previous surgery and pulmonary atresia, the whole mediastinum was included in the field so that both right and left pulmonary arteries could be visualized by retrograde filling (figs. 2A, 2B and 2C).

The internal diameter of the pulmonary artery was measured at the lung hilus or at the widest diameter in the mediastinum, using the catheter diameter as a reference measurement. When a surgical anastomosis was made, the surgeon made a visual estimate of the external diameter of the pulmonary artery at the anastomosis site.

Results

Up to four separate veins were injected with contrast material in each patient, and a total of 51 angiograms were performed in the 22 patients. The optimal amount of contrast material was 0.3 to 0.4 ml/kg. This was enough to visualize the pulmonary arterial anatomy in all the injected lung, together with the mediastinal vessels and proximal intrapulmonary vessels of the opposite lung of the patients in Group A.

Every patient coughed one to four times during the injection, but there was no undue distress. Extravasation of contrast material into the lung parenchyma occurred in only one patient, and a small amount of contrast material entered the bronchus. This extravasation was probably caused by a too-rapid injection of the flush solution, coupled with coughing; there were no sequelae from this episode. No complications or staining of lung parenchyma occurred in the other patients and no special problems were encountered in the eight children 2 years of age or younger, particularly the two infants aged 9 days and 3 months.

Parenchymal pulmonary arteries were clearly seen by retrograde filling in all patients. During the initial phase of the injection, a dense capillary blush appeared with some reflux of contrast around the catheter. Other pulmonary veins were seen to fill by draining contrast from the capillary blush, or via direct interlobar venous collateral channels. The flush phase is important, as it pushes the contrast material from the capillary bed retrograde into the arteries — all the way to the confluence and into the other lung in Group A patients, and up to the hilus in
Group B patients. In spite of the high viscosity of 75% Hypaque, the sequential injection of this material followed by flush solution gave better visualization of the whole pulmonary tree than a larger injection of 50% Hypaque.

Group A: Pulmonary Artery Atresia With Ventricular Septal Defect and No Previous Surgery

Conventional ventriculography and aortography did not demonstrate any mediastinal pulmonary arteries or confluence in two patients in this group; both of these patients (ages 4 and 26 years) had numerous small collateral vessels entering the lung hilus from the descending aorta, and these could not be catheterized. Vein wedge angiography outlined the complete pulmonary arterial tree all the way down to the atretic pulmonary valve in one patient (figs. 3A, 3B and 3C). The pulmonary confluence was obscured by the numerous collateral vessels in the second patient, but was clearly seen in isolation after the venous angiogram from the left lower lobe.
Late retrograde filling of the confluence and the right and left mediastinal pulmonary arteries was seen in five patients after aortography, but the definition was poor and complete anatomy was not demonstrated well because of faint, transient filling with contrast and overlying large collateral vessels (fig. 4A). Venous wedge angiography demonstrated both the intrapulmonary and mediastinal pulmonary arteries in complete isolation with a good concentration of dye, even to the proximal pulmonary arteries in the opposite lung in three of these patients (fig. 4B).

The mediastinal confluence was not visualized by wedge angiography in two patients from Group A; there was an inadequate amount of contrast injected (0.2 cc/kg) in a 28-year-old patient, and washout by large collateral vessels at the hilus in another.

Although up to two injections in each lung were made in some patients, a single injection into one lobe was sufficient to see all the mediastinal pulmonary arteries and confluence. However, when large systemic vessels entered the lung parenchyma, injections into both the upper and lower lobes revealed the anatomy and course of the true arteries within the lung. By overlaying drawings of the aortic or selective collateral injections on the vein wedge angiogram, we could determine where the systemic vessel anastomosed to the parenchymal pulmonary artery and show that the systemic artery was not the only arterial supply to that section of the lung. No evidence of lobar sequestration was found in any patient from this group with large systemic collateral vessels.

This angiographic method demonstrated the complete main pulmonary artery to the atretic valve in one patient (fig. 3), and a short segment of main pulmonary artery which was not seen by conventional angiography in six others (fig. 4). No patients studied had absence of the central pulmonary arteries as a result of congenital absence of its forerunner, the sixth aortic arch.

Group B: Non-visualization of One Pulmonary Artery

Among this group of 13 patients, seven were catheterized specifically to have pulmonary venous wedge angiography in order to visualize a pulmonary artery which had not been seen at a previous catheterization.

Ten of the 13 patients developed occlusion of one pulmonary artery after a surgical procedure; we could not determine the presence of a pulmonary confluence...
or a contralateral pulmonary artery at the time of surgery in six of nine patients who had a systemic-to-pulmonary artery shunt and subsequent occlusion of a pulmonary artery proximal to the anastomosis.

Pulmonary venous wedge angiography was performed in the nonopacified lung in 12 patients, while the vein from the nonopacified right lung could not be entered in one patient after transseptal puncture.

Intrapulmonary arteries up to the obstructed hilar vessel were seen by wedge angiogram in eight of the patients with post-shunt occlusion, and the proximity of this vessel to the ascending or descending aorta was demonstrated (figs. 5A and 5B). In two patients, injections were made into the lung on the same side as the shunt, and retrograde filling of the pulmonary arteries was seen up to the area of the shunt, at which point prograde flow washed out the contrast into other pulmonary arteries.

Two patients had congenital “absence” of the left pulmonary artery; although faint pulmonary vascular markings could be seen behind the heart on the plain chest film, no retrograde filling of a pulmonary artery was seen after aortography. Wedge angiography in the affected lung showed retrograde filling of a very small, normally branching pulmonary arterial tree up to the hilus in both patients (fig. 6).

A large systemic collateral vessel entered the left lower lobe of one patient with severe tetralogy and appeared to supply the lung parenchyma directly. An antegrade main pulmonary artery injection failed to show any pulmonary artery branching to the left lower lobe, possibly due to washout from the systemic collateral vessel anastomosing to the pulmonary artery inside the lung. The vein wedge angiogram demonstrated continuity between the lung capillary bed, the small distal pulmonary artery branches, and the proximal left and main pulmonary arteries, ruling out sequestration of the left lower lobe.

Clinical Application

A systemic-to-pulmonary shunt was performed in eight patients after the existence of an accessible mediastinal pulmonary artery was demonstrated. In three patients a 7 mm Dacron graft was used to anastomose the ascending aorta to the confluence of the pulmonary arteries (fig. 3C). Two of these patients had transposition of the great arteries and the pulmonary vessels were too far posterior for a direct anastomosis. The other five patients had direct aorticopulmonary anastomoses, and all improved after surgery.

Discussion

When the pulmonary arteries are not connected anatomically to the heart, blood flows into the lungs via a patent ductus arteriosus, systemic collateral vessels, increased bronchial circulation or pleural collaterals. Jefferson and others maintain that the systemic collateral vessels always anastomose to, or are continuous with, the true parenchymal pulmonary arteries, regardless of whether they are connected to central pulmonary arteries lying within the mediastinum. The parenchymal lung vessels develop in the lung bud from a vascular plexus with dorsal aortic connections, and are embryologically separate from the development of the mediastinal pulmonary arteries which form from the sixth aortic arch. The pulmonary arteries supply the alveolar capillaries which, in the absence of anomalous pulmonary venous connections, drain into the pulmonary veins and left atrium. Many experiments have been performed in animals in which reversed perfusion of the lungs has been used, since there are no valves in the pulmonary veins. The pressure-flow characteristics of the lung during reversed perfusion are virtually identical to those during antegrade perfusion. Thus, if the perfu-
FIGURE 5. Pseudotruncus with a left Potts anastomosis and occluded left pulmonary artery. A. Injection into the left pulmonary artery and bifurcation with a catheter placed through the Potts anastomosis. There is no main pulmonary artery and the left pulmonary artery does not fill. There is congenital stenosis of the right pulmonary artery at the hilus. B. Left lower lobe venous wedge angiography showing opacification of the left pulmonary artery up to the level of the Potts anastomosis.

FIGURE 6. A 4-year-old patient with Type I truncus arteriosus and congenital "absence" of the left pulmonary artery. A. Left ventricular injection showing aortic root origin of the main pulmonary artery continuous with a stenotic right pulmonary artery. No left pulmonary is seen. B. Left lower lobe vein wedge angiogram showing filling of a normal pulmonary vascular tree up to the hilus.

sion pressure and blood flow in the pulmonary arteries are reduced due to pulmonary stenosis or atresia, only a modest amount of pressure is necessary to force contrast material retrograde through the veins and capillaries to the pulmonary arteries without damaging the capillaries. Even in the presence of moderate forward flow via large systemic vessels or from a systemic-to-pulmonary shunt, contrast material may be flushed through the lungs outlining almost all parts of the pulmonary vascular anatomy up to the point of entry of blood flow. Forward flow often will sweep the contrast material into other lobar arteries, producing an even more extensive picture of the pulmonary tree in that lung.

This angiographic technique first was mentioned briefly by Nadas in a discussion of the investigation of patients with pulmonary atresia, but was not recommended for routine use. There has been only
arteries and confluence which is seen in clear, sharp detail. The use of 50% Hypaque in one patient resulted in less definition of the mediastinal pulmonary arteries because the heart and spine shadows reduced the contrast and density of the radiopaque material in the pulmonary arteries.

Large doses of contrast material, coupled with a long filming sequence during aortography, is usually adequate to identify the presence of mediastinal pulmonary arteries and a confluence, if it exists. However, the image often is faint, unsharp and usually transitory, and numerous large collateral vessels may obscure parts of the proximal pulmonary arteries. Pulmonary venous angiography outlines these vessels with better definition without overlapping shadows of the collateral vessels and aorta.

One cannot always be sure that the large, tortuous systemic collaterals coursing through the hilus into the lungs actually anastomose to the true intrapulmonary arteries. If one or more of these vessels were to supply a sequestered lobe or lobes, then division of this vessel at the time of total repair would result in infarction of that part of the lung. Venous angiography enables one to identify the intrapulmonary course of the true pulmonary arteries in continuity with the capillary bed and the pulmonary veins. This distribution may be quite different from the ramifications of the large systemic vessels which enter the lung.

Retrograde femoral artery catheterization and selective injection of the systemic collateral vessels usually opacifies the intrapulmonary and mediastinal pulmonary arteries, but this technique may be difficult and even risky in infants. Opacification of the large systemic collateral vessels may obscure the true pulmonary arteries.

In two patients, venous angiography gave a more complete, clear picture of the pulmonary arteries, revealing the presence of a main pulmonary artery and sinuses with atresia of the valve, whereas aortography revealed only the bifurcation.

We feel that pulmonary venous wedge angiography often is superior to and at least complements standard angiographic methods of opacifying the pulmonary arteries in patients with pulmonary atresia or occluded pulmonary arteries. We recommend it as a routine part of the evaluation of these patients.

References

Use of Time Interval Histographic Output from Echo-Doppler to Detect Left-to-Right Atrial Shunts

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SUMMARY The primary purpose of this study was to attempt to select, by examination of the time interval histogram (TIH) output of a range gated pulsed Doppler (RGPD), all children with left-to-right shunt at the atrial level from a pool of 57 children. Fifty-four of the children had various forms of acyanotic cardiac disease.

A secondary purpose was to identify any associated lesions in those children with atrial defects. Examiners were unfamiliar with the children and their diagnoses. Results were interpreted independently by two examiners. Detection of diastolic TIH dispersion was used when studying the right atrial outflow tract to separate children with atrial left-to-right shunts from control children. All controls were judged negative by this technique, and 13 of 14 children with atrial shunts were detected by both examiners; the 14th was detected by one examiner. Of a total of 308 TIH decisions on the atrial shunt group, 298 were made identically by both examiners for a 97.7% agreement, demonstrating the objectivity of the method. This study demonstrated the usefulness of the TIH evaluation, indicating that continued investigation and equipment improvements are warranted.

THE USE OF range gated pulsed Doppler (RGPD), combined with echocardiography, has not grown clinically since its introduction in 1973. Although this could, in part, be due to concentration of investigators and clinicians on M-mode and two-dimensional echocardiography, it is probably more related to the difficulty in learning to use information obtained by RGPD. Until now, virtually all attention has been focused on the audible output which represents the Doppler frequency shift. Recently, a time interval histogram (TIH) output has become available. The TIH provides information which is closely related to results of spectral analysis. The theory underlying the principles and use of the TIH are covered in detail elsewhere.

The red cell velocity, under conditions of laminar flow in the heart or great vessels, is approximately uniform at a given instant of time. The RGPD senses the back scatter from each red cell that intersects the ultrasonic beam and reflects a signal back to the receiver. The receiver and processor electronically convert the information to frequency shift, and that shift is a function of particle velocity. Variance of velocity throughout the cycle causes the frequency to shift in a similar manner. The TIH depicts the frequency shift of reflecting particles as a point on the y axis of the histogram at a sampling rate of 4,000/sec. Thus, the velocity pattern from each heartbeat is represented by a series of points inscribed in a histogram format. Laminar flow produces a narrow band width of points, since the velocity of the reflecting particles is nearly uniform. Disturbed flow, such as results from an obstruction, produces a wide spectrum of velocities and thus a dispersed series of points on the TIH.

The theory of the TIH is sound in principle, but it has not been tested under rigorous conditions. This study assesses the diagnostic accuracy of the TIH, used under carefully controlled circumstances, to separate children with proven atrial septal defects from those with other cardiac malformations.

Methods

Our study population consisted of a random sample of children with left-to-right atrial shunts selected from the population at Sophia Children’s Hospital of Rotterdam. Controls consisted of 43 children with other forms of acyanotic congenital or acquired cardiac malformations. Each child was assigned a number and all information regarding that child was
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