JCI The Journal of Clinical Investigation

STUDIES OF CONGENITAL HEART DISEASE. III. VENOUS CATHETERIZATION AS A DIAGNOSTIC AID IN PATENT DUCTUS ARTERIOSUS, TETRALOGY OF FALLOT, VENTRICULAR SEPTAL DEFECT, AND AURICULAR SEPTAL DEFECT

L. Dexter, … , M. C. Sosman, J. M. Evans

J Clin Invest. 1947;26(3):561-576. https://doi.org/10.1172/JCI101841.

Research Article

Find the latest version:

https://jci.me/101841/pdf

STUDIES OF CONGENITAL HEART DISEASE. III. VENOUS CATHETERIZATION AS A DIAGNOSTIC AID IN PATENT DUCTUS ARTERIOSUS, TETRALOGY OF FALLOT, VENTRICULAR SEPTAL DEFECT, AND AURICULAR SEPTAL DEFECT [1]

By L. DEXTER, F. W. HAYNES, C. S. BURWELL, E. C. EPPINGER, M. C. SOSMAN, AND J. M. EVANS

(From the Medical Clinic and the Department of Radiology, Peter Bent Brigham Hospital, and the Departments of Medicine and Radiology, Harvard Medical School)

(Received for publication January 5, 1947)

Previous communications have outlined the technique of cardiac catheterization as applied to the study of congenital heart disease and defined the variations in pressures and oxygen content observed in a group of control patients (1, 2). This paper sets forth the results of study in 6 patients with 4 varieties of congenital heart disease as examples of the type of information which can be acquired by the catheter technique in such patients.

OBSERVATIONS

Patent ductus arteriosus

Patent ductus arteriosus is a persistence after birth of the vascular anastomosis between the pulmonary artery and the aorta. While in the fetus blood flows from the pulmonary artery to the aorta, the flow is from the aorta to the pulmonary artery after birth, as Eppinger, Burwell, and Gross (3) have demonstrated.

Case 1. I. G. was a 26-year-old woman. In early infancy she was found to have a heart murmur. She developed normally but was subject to palpitation, dyspnea, and fatigue on exertion. On physical examination, she was a well-developed woman without cyanosis or clubbing. Arterial blood pressure was 125/65 mm. Hg. The heart was enlarged to the left. There was a machinery murmur in the pulmonic region. The first sound at the apex and the second sound at the pulmonic area were accentuated. The lungs were clear, the liver was not enlarged, and no edema was apparent. X-ray of the heart (Figure 1) showed it to be about 20 per cent enlarged with prominence in the region of the pulmonary artery and with hilar engorgement. An electrocardiogram was normal.

Venous catheterization was performed, and Table I records the pressures and oxygen contents of blood samples obtained from the various points shown in Figure 1. It will be noted that the oxygen content of blood in the pulmonary artery was 2.2 volumes per cent higher than of that from the right ventricle. This is taken as indicating the entrance of arterial blood into the pulmonary artery. Arterial shunts, other than patent ductus arteriosus, are exceedingly rare in this region. The systolic pressures in the pulmonary artery and right ventricle were elevated. The shunt was calculated to be 7.6 l. per min.

A few days later, Dr. Robert E. Gross ligated and divided a patent ductus arteriosus. Two weeks later, venous catheterization was repeated, at which time the patient was weak and moderately anemic (hemoglobin 9.9 grams). Results

TABLE I

I. G. Age 26. Patent ductus arteriosus

Sample	Oxygen content	Pressure
	ml. per l.	*mm. Hg*
Left pulmonary artery (near bifurcation)	151	63/35
Right pulmonary artery (near bifurcation)	151	
Right ventricle (near pulmonary valve)	129	63/6
Right ventricle (mid-portion)	125	
Right auricle (near tricuspid valve)	130	6
Right auricle (upper portion)	119	
Systemic artery	167 (97 per cent)	125/65

A–P diameter of chest	17 cm.
Oxygen consumption	201 ml. per min.
Body surface area	1.53 sq. m.
Pulmonary arteriovenous oxygen difference	16 ml. per l.
Peripheral arteriovenous oxygen difference	40 ml. per l.
Pulmonary blood flow	12.6 l. per min.
Peripheral blood flow	5.0 l. per min.
Flow through shunt	7.6 l. per min.

[1] This investigation was aided in part by a grant from the John and Mary R. Markle Foundation, and from the Proctor Fund of the Harvard Medical School.

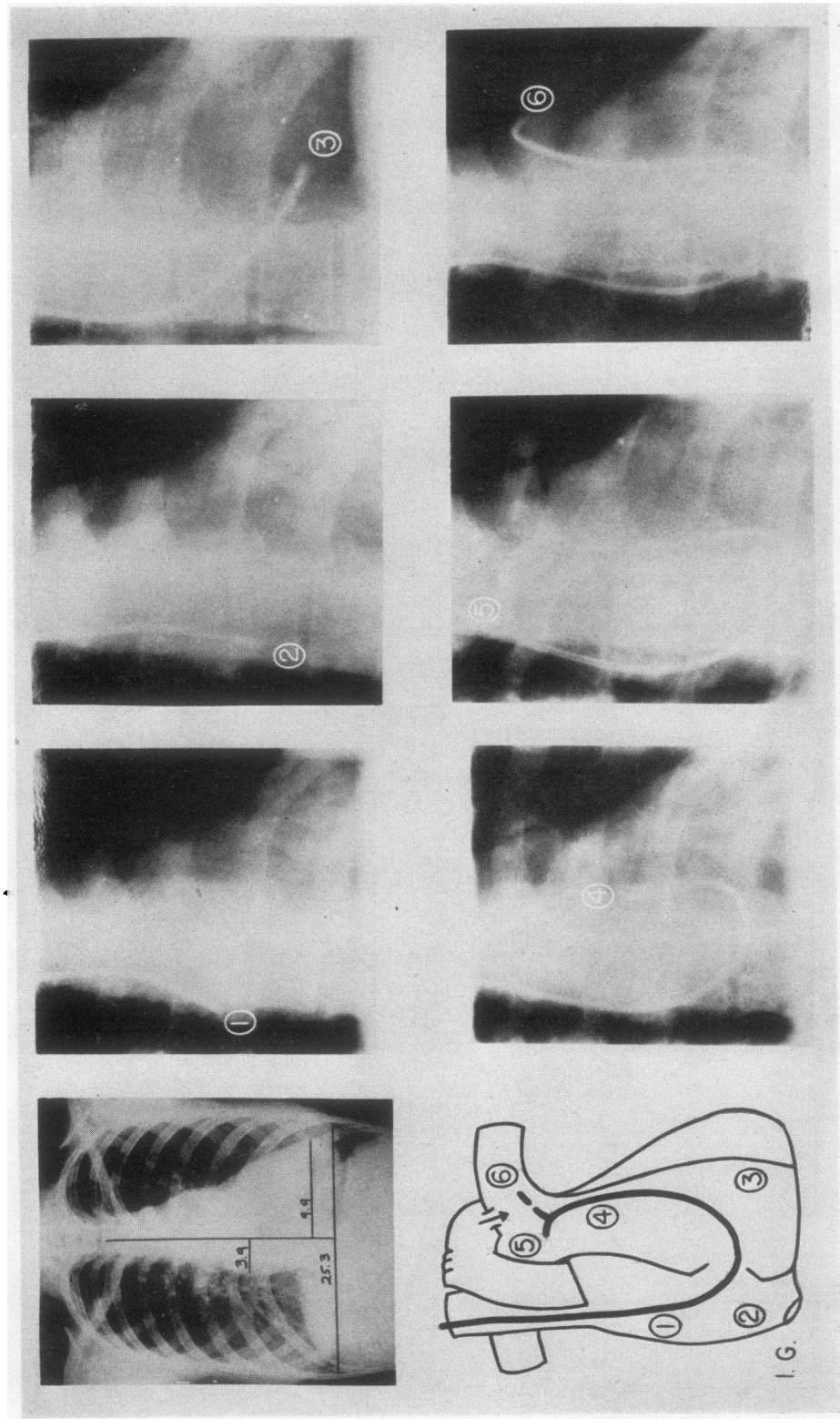

FIG. 1. PATENT DUCTUS ARTERIOSUS (CASE 1)
The positions of the catheter are identifiable by the corresponding numbers in the schema.

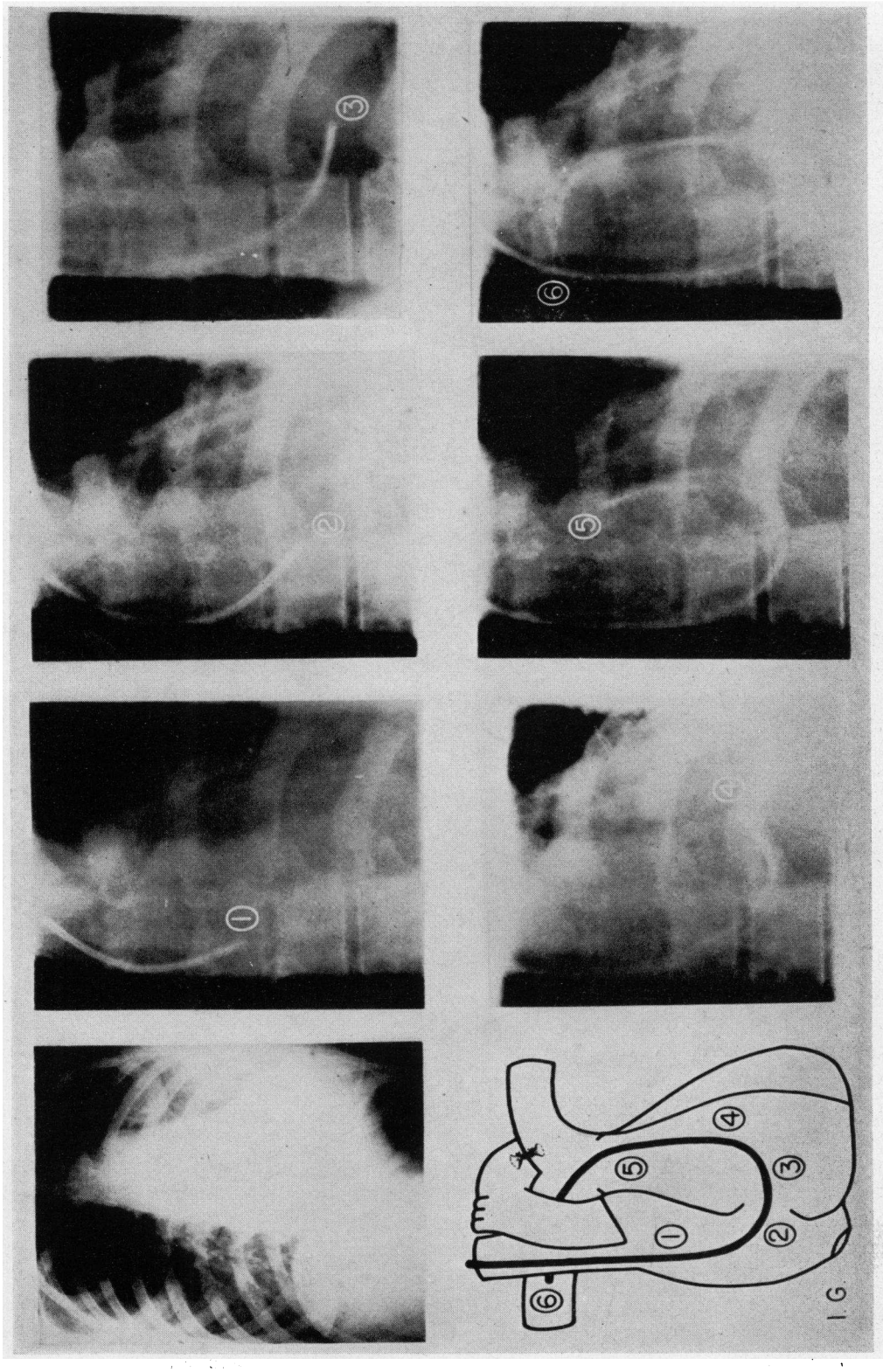

FIG. 2. TWO WEEKS AFTER DIVISION OF THE PATENT DUCTUS ARTERIOSUS (CASE 1)
The positions of the catheter are identifiable by the corresponding numbers in the schema.

of the catheterization are presented in Figure 2 and Table II. The oxygen values of bloods from the 3 chambers were in good agreement and showed no deviation from the normal. The pressures in the pulmonary artery and right ventricle were still elevated.

TABLE II

I. G. Age 26. 14 days after division of patent ductus arteriosus

Sample	Oxygen content	Pressure
	ml. per l.	*mm. Hg*
Right pulmonary artery (mid-portion)	91	80/45
Right pulmonary artery (near bifurcation)	92	
Right ventricle (near pulmonary valve)	92	80/−3
Right ventricle (mid-portion)	88	
Right ventricle (near tricuspid valve)	88	
Right auricle (near tricuspid valve)	75	−3
Right auricle (upper portion)	88	
Systemic artery	124 (90 per cent)	136/88

A–P diameter of chest	17 cm.
Oxygen consumption	244 ml. per min.
Body surface area	1.50 sq. m.
Arteriovenous oxygen difference	32 ml. per l.
Cardiac output	7.6 l. per min.
Cardiac index	5.1

Discussion: Calculation of the volume of flow through the ductus was made first by Eppinger, Burwell, and Gross (3) on the basis of blood samples obtained from the pulmonary artery at the time of operation. Blood samples withdrawn through the intracardiac catheter have the great advantage of being obtained with the patient in a relatively basal state. An oxygen content of blood in the pulmonary artery significantly higher than that in the right ventricle has been found regularly by venous catheterization in patients with patent ductus arteriosus.

In a previous study with the catheter in a control series of patients (2), it was observed that the greatest variation between the highest oxygen content of blood in the right ventricle and that in the pulmonary artery was 0.5 volume per cent. On this basis, it is believed that flows through the ductus of less than 0.5 l. per min., and possibly as high as 1.0 l. per min., are probably not detectable by the venous catheter method unless the tip of the catheter can be placed in the stream of arterial blood flowing into the pulmonary artery through the ductus, in which case smaller defects may be detectable.

Some patients with patent ductus have shown an elevation of pressure in the pulmonary artery and right ventricle, as in the example cited. In the majority of patients, however, the pressures have been normal.

The diagnosis of patent ductus arteriosus has been confirmed by venous catheterization in 7 patients to date and has been proved subsequently at the time of operation in each.

Tetralogy of Fallot

The tetralogy of Fallot consists of pulmonary stenosis, interventricular septal defect, dextroposition of the aorta, and right ventricular hypertrophy. There is a diminished blood flow to the lung. A shunting of blood from the right ventricle into the aorta produces cyanosis.

Case 2. P. B. was 22 years old and had been a "blue baby." All his life he had been subject to periodic attacks of intense cyanosis and syncope, and his activities had always been restricted. On physical examination, he was tall and well-developed with moderate cyanosis of lips and nails and pronounced clubbing of fingers and toes. The blood pressure was 103/84 mm. Hg. There was a harsh systolic murmur in the second left intercostal space transmitted widely over the precordium without thrill or diastolic component. There were no signs of congestive heart failure. X-ray of the heart (Figure 3) showed enlargement to the left. The apex appeared to be lifted above the diaphragm. An electrocardiogram showed right axis deviation. The red cell count was 8.2 million, the hemoglobin was 27.4 grams, and the hematocrit was 75.

The results of *venous catheterization* are shown in Figure 3 and Table III. It will be noted that 8 samples of blood from the right auricle, right ventricle, and pulmonary artery checked well as to oxygen content. The high systolic pressure in the right ventricle with a low pressure and narrow pulse pressure in the pulmonary artery indicated pulmonic stenosis (see Figure 4). Simultaneous pressures were not obtained from right ventricle and femoral artery, and hence the identity of these systolic pressures could not be tested. The systolic arterial blood showed a moderate degree of unsaturation. It was concluded that the patient had pulmonary stenosis and ventricular septal defect.

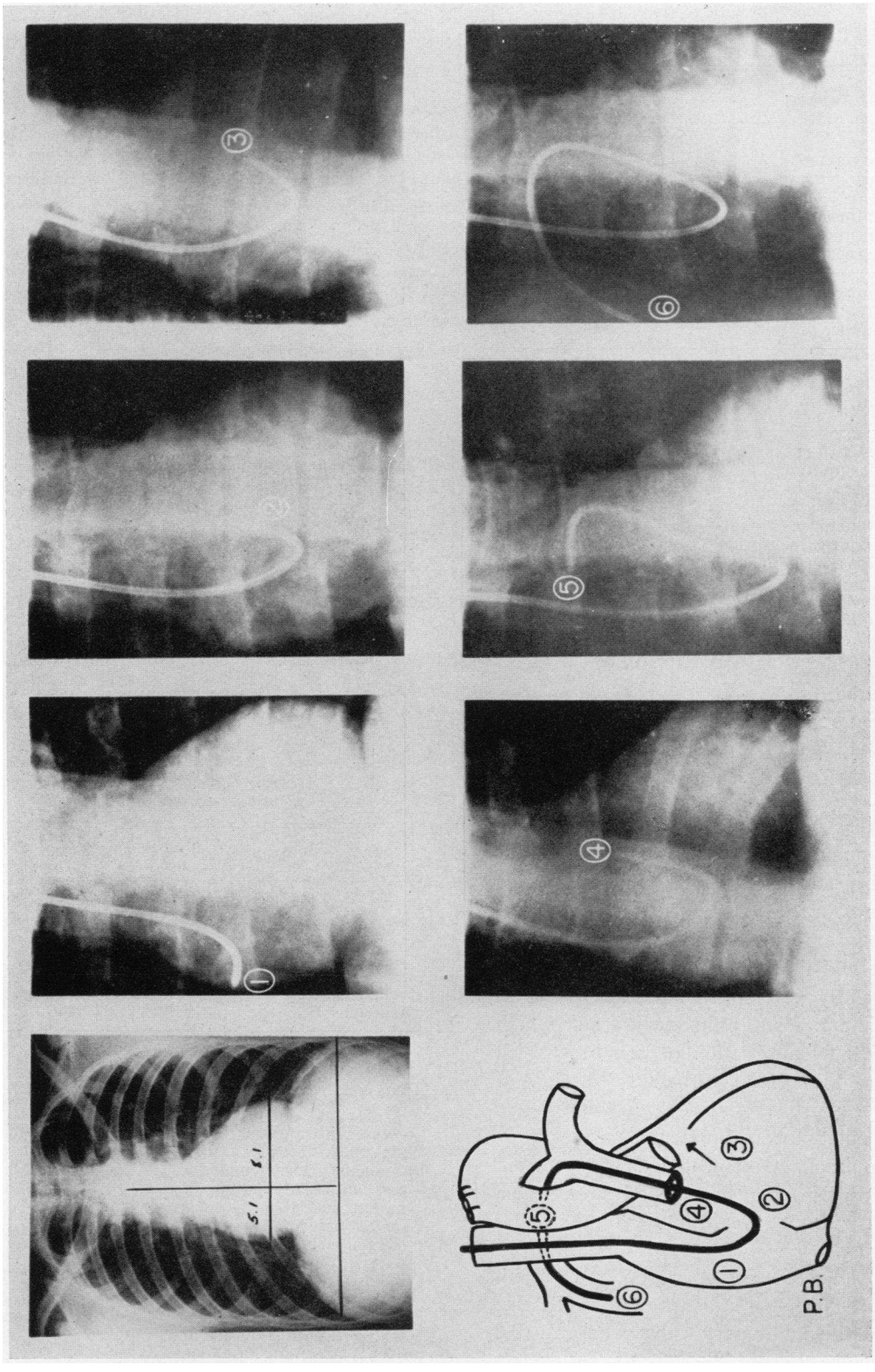

FIG. 3. TETRALOGY OF FALLOT (CASE 2)

The positions of the catheter are identifiable by the corresponding numbers in the schema. Note that the catheter entered the pulmonary artery through the stenotic pulmonary valve.

TABLE III

P. B. Age 22. Tetralogy of Fallot

Sample	Oxygen content	Pressure
	ml. per l.	*mm. Hg*
Right pulmonary artery	242	8/4
Right pulmonary artery	243	
Right ventricle (near pulmonary valve)	248	98/0
Right ventricle (mid-portion)	248	
Right ventricle (near tricuspid valve)	248	
Right auricle (lower portion)	255	0
Right auricle (mid-portion)	253	
Right auricle (upper portion)	250	
Systemic artery	295 (85 per cent)	103/80*

A–P diameter of chest	19.0 cm.
Oxygen consumption	220 ml. per min.
Body surface area	1.71 sq. m.
Pulmonary arteriovenous oxygen difference (assuming 95 per cent saturation for pulmonary venous blood)	89 ml. per l.
Peripheral arteriovenous oxygen difference	43 ml. per l.
Pulmonary artery blood flow	2.5 l. per min.
Peripheral blood flow	5.1 l. per min.
Flow through defect	
Right to left	2.6 l. per min.
Left to right	none

* Not recorded simultaneously with that of right ventricle.

Flow calculations indicated only a moderate reduction of pulmonary blood flow. Bing (4) has studied cases of tetralogy of Fallot in considerable detail by means of the venous catheter and by exercise and respiratory tests, and has evidence, both physiological and morphological, that these individuals frequently develop a collateral circulation from systemic arteries to pulmonary artery which is not revealed by application of the direct Fick principle with the venous catheter. In view of his findings, it is probably more accurate to define our flow calculations as pulmonary artery flow rather than pulmonary blood flow since we are in agreement with Bing that the method as described in this report will not reveal the collateral circulation to the lung.

Following a subsequent operation, the patient expired. *Post-mortem examination* revealed that the orifice of the pulmonary valve was only 0.5 cm. in diameter (Figure 5). A 1.5 cm. defect was present in the upper part of the interventricular septum. The right ventricular wall measured 15 mm. in thickness, and that of the left ventricle, 12 mm. There was dextroposition of the aorta.

Case 3. H. S. was a 10-year-old boy who at the age of 6 weeks was found to have a heart murmur. He had never been as active as his playmates and had had a constant cyanotic tinge to his nails and lips. He had always had dyspnea on climbing one flight of stairs, but this had not been progressive. On physical examination, he was well-developed and well-nourished. The lips and nail beds were slightly bluish. No clubbing was present. The heart was enlarged to percussion. The only murmur heard was a loud machinery murmur, maximal in the aortic region but audible over the entire precordium. There was no thrill. The blood pressure was 110/70 mm. Hg. There were no signs of cardiac failure. The hemoglobin was 17.3 grams, and the hematocrit was 49. Circulation time with magnesium sulfate was 8 seconds. An electrocardiogram showed right axis deviation. X-ray (Figure 6) and fluoroscopy of the heart showed it to be enlarged to the left with dilated engorged hilar vessels. The aortic knob projected to the right.

On *venous catheterization* the catheter passed into the right ventricle and thence into the aortic arch and the descending aorta (Figure 6). This demonstrated the existence of an over-riding aorta or a ventricular septal defect and also of a right-arched aorta. Oxygen and pressure data are

TABLE IV

H. S. Age 10. Tetralogy of Fallot and patent ductus arteriosus

Sample	Oxygen content	Pressure
	ml. per l.	*mm. Hg*
Aorta	187 (84 per cent)	110/70
Right ventricle (near pulmonary valve)	173	110/4
Right ventricle (near tricuspid valve)	140	
Right auricle (mid-portion)	130	4
Right auricle (upper portion)	120	

A–P diameter of chest	17.5 cm.
Oxygen consumption	166 ml. per min.
Body surface area	1.22 sq. m.
Pulmonary arteriovenous oxygen difference (assuming patent ductus arteriosus as only source and 95 per cent oxygen saturation of pulmonary venous blood)	25 ml. per l.
Peripheral arteriovenous oxygen difference	62 ml. per l.
Pulmonary blood flow (through patent ductus arteriosus assuming pulmonary atresia)	6.7 l. per min.
Peripheral blood flow	2.7 l. per min.

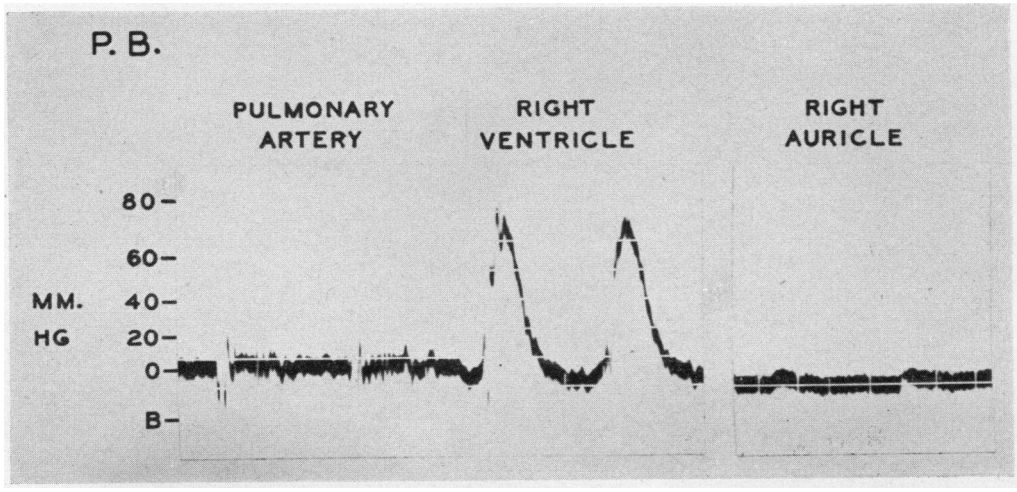

FIG. 4. BLOOD PRESSURES OBTAINED IN CASE 2

A continuous pressure was obtained as the catheter was withdrawn from the pulmonary artery to the right ventricle. Note the high systolic pressure in the right ventricle as compared with that in the pulmonary artery indicative of pulmonic stenosis.

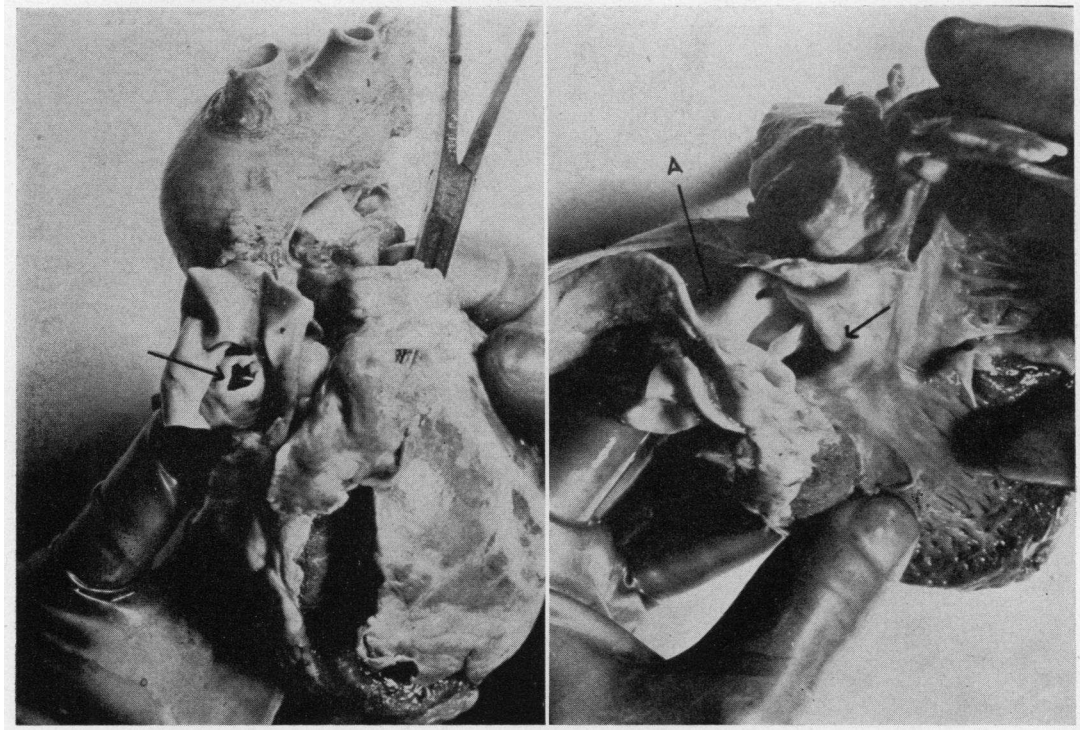

FIG. 5. HEART AT POST-MORTEM OF CASE 2

On the left, the arrow points to the stenotic pulmonary valve. On the right, the aorta is at A and the arrow points to the defect in the upper part of the interventricular septum.

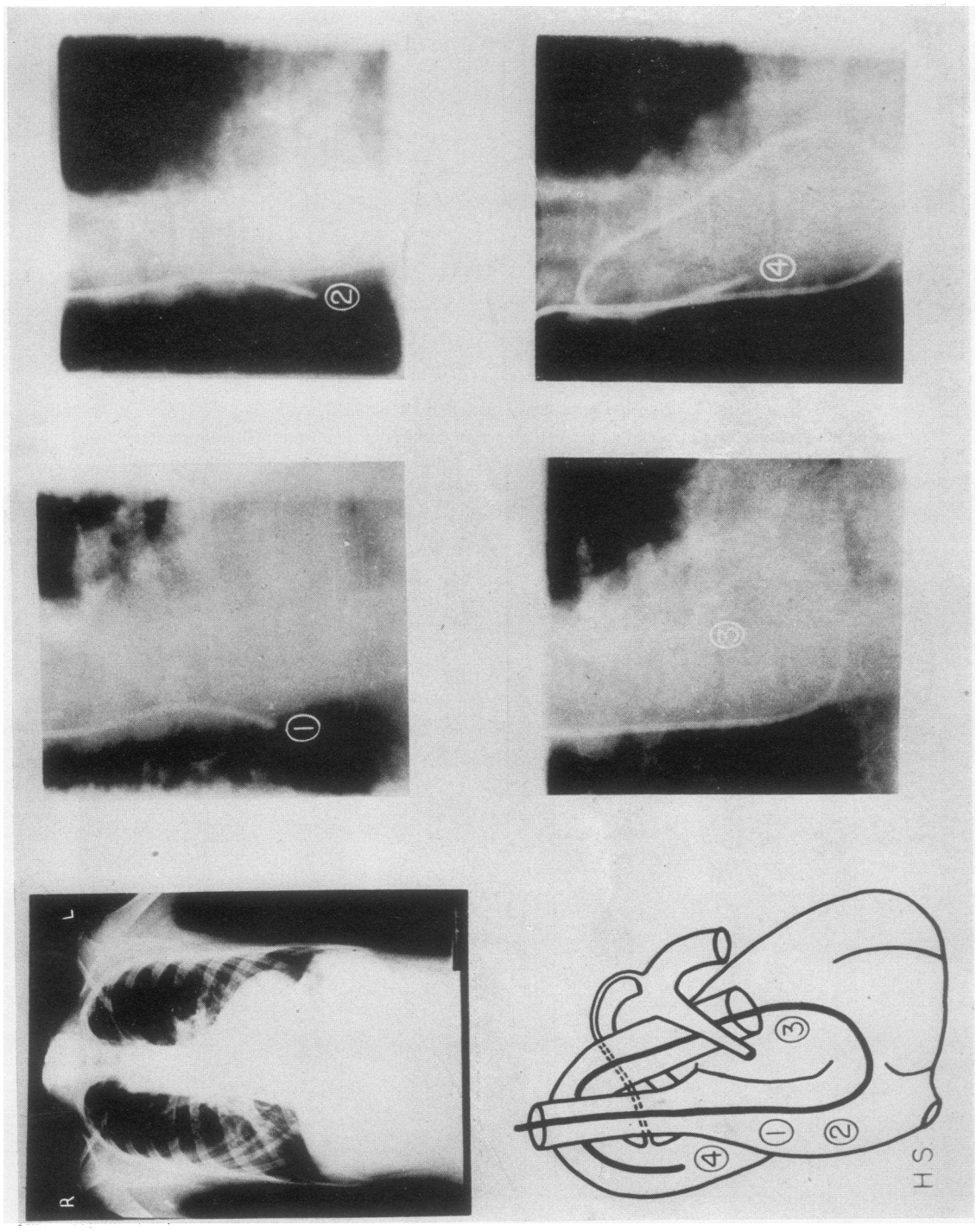

FIG. 6. TETRALOGY OF FALLOT (CASE 3)

The positions of the catheter are identifiable by the corresponding numbers in the schema. Note that the catheter passed from the right ventricle into the ascending aorta and followed the arch of the aorta to the right.

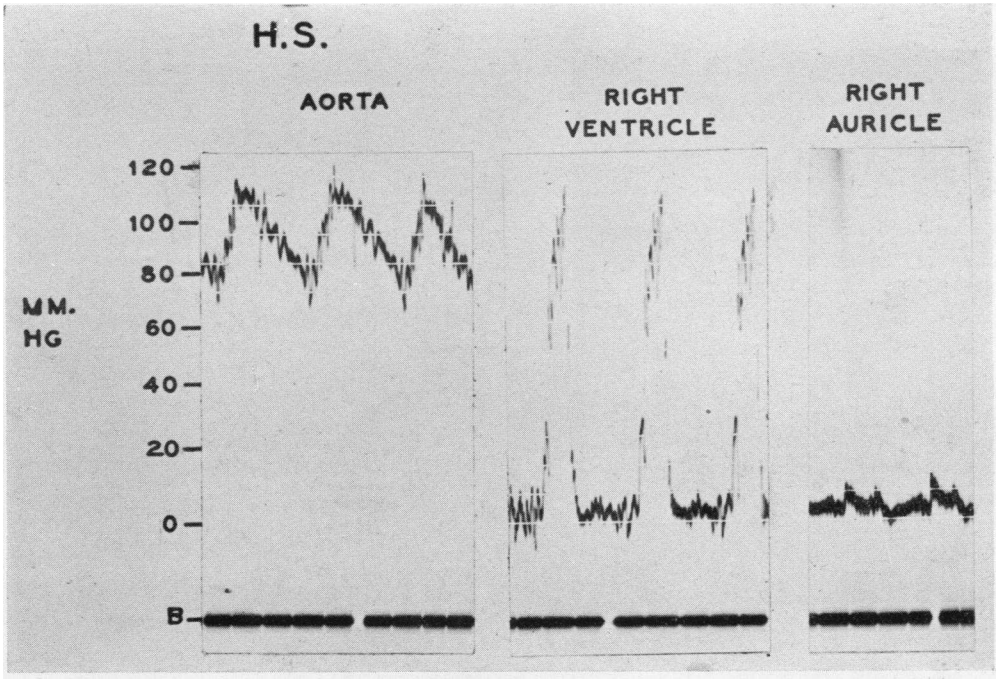

FIG. 7. BLOOD PRESSURES OBTAINED IN CASE 3
Note that the systolic pressure in the aorta and right ventricle appears to be identical.

shown in Table IV. The systolic pressures in right ventricle and aorta were identical (see Figure 7). The peripheral blood flow was small. It was assumed that most of the blood flow through the pulmonary artery entered by way of a patent ductus arteriosus, as indicated by the typical murmur. The presence of a right-arched aorta perhaps explained the localization of the machinery murmur at the aortic rather than at the pulmonic area. Assuming that *all* of the blood entering the lung entered by way of a patent ductus arteriosus, pulmonary blood flow was calculated to be 6.7 l. per min. It should be pointed out that this calculation represents a maximal estimate and that the methods utilized by Bing (4) for calculation of pulmonary blood flow in these cases are more reliable.

Discussion: It is not to be expected that the tetralogy of Fallot could be recognized in its entirety by study with the venous catheter. Right ventricular hypertrophy is perhaps best indicated by the electrocardiogram. Dextroposition of the aorta is largely a morphological diagnosis and is functionally indistinguishable from a ventricular septal defect in studies with the venous catheter. In the discussion to follow, the two will be included under the term, "ventricular septal defect."

The venous catheter may pass from the right ventricle through the stenotic pulmonary valve into the pulmonary artery (Patient 2). In this case, pulmonary stenosis may be recognized by the presence of a higher systolic pressure in the right ventricle than in the pulmonary artery (see Figure 4). A ventricular septal defect has been assumed to exist by the presence of diminished oxygen saturation of the systemic arterial blood in association with pulmonary stenosis.

In other cases, the catheter may pass from the right ventricle, through the septal defect, and into the aorta (Patient 3). In this case, ventricular septal defect is demonstrated by the course followed by the catheter. Pulmonary stenosis has been assumed to exist if the systolic pressures in the aorta and right ventricle are identical.

The tetralogy of Fallot has been confirmed at autopsy in 2 patients. In one, the catheter had been introduced into the pulmonary artery (Patient 2), and in the other, not described here because of clotting of blood samples, the catheter had entered the aorta.

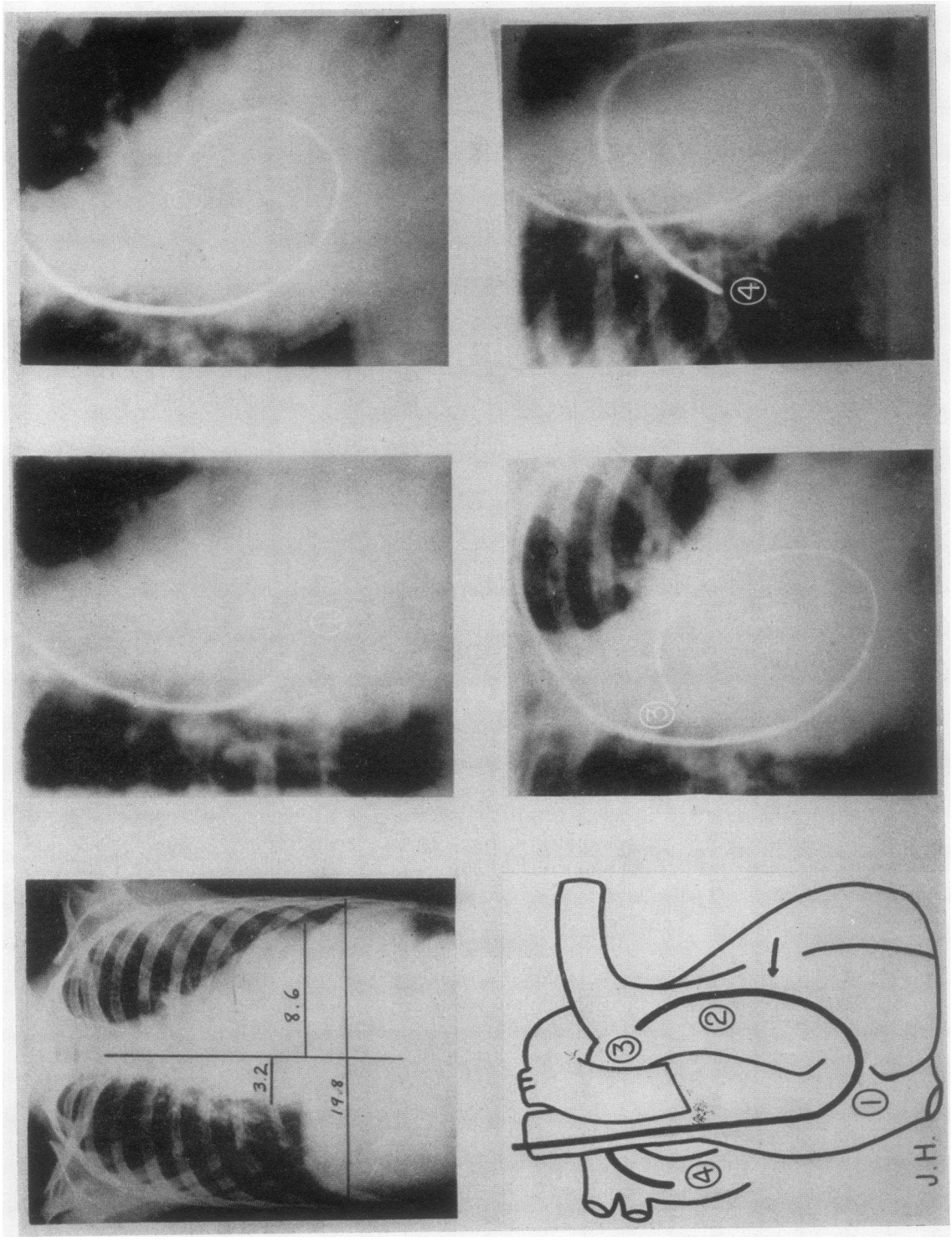

FIG. 8. INTERVENTRICULAR SEPTAL DEFECT (CASE 4)
The positions of the catheter are identifiable by the corresponding numbers in the schema.

In no case as yet has the catheter been introduced into both the aorta and the pulmonary artery in the same patient.

Interventricular septal defect (Roger's disease)

Defects in the ventricular septum vary in size and are most commonly located at the base of the heart just below the aortic valve. Since the pressure in the left ventricle is higher than that in the right ventricle, the shunt is from the left to the right side of the heart except under certain special conditions.

Case 4. J. H. was a 6-year-old boy who had had a known murmur since the age of 11 months but had never had any limitation of activity. Physical examination revealed a healthy-looking active boy of normal development. There was no cyanosis or clubbing. Cardiac findings included a blood pressure of 105/45 mm. Hg, a heart enlarged to left and right, and an extremely loud and harsh systolic murmur heard maximally at the third left intercostal space and transmitted over the entire precordium. This murmur was accompanied by a thrill. A soft early diastolic murmur was heard along the left border of the sternum. X-ray (Figure 8) and fluoroscopy of the heart showed marked enlargement, especially in the region of the left ventricle, a dilated left auricle posteriorly, and enlargement of the pulmonary artery. Hilar vessels were engorged but could not be demonstrated to pulsate. An electrocardiogram was normal.

Venous catheterization was performed as shown in Figure 8, and the results are tabulated in Table V. It is apparent that a considerable amount of arterial blood entered the right ventricle, suggesting the presence of a defect in the ventricular septum. The recorded pressures were normal. Catheterization did not explain the low diastolic pressure or the diastolic murmur. There was no evidence of a concomitant patent ductus arteriosus with pulmonary insufficiency. It was believed that this patient probably had an aortic insufficiency in addition to an interventricular septal defect.

Discussion: The recognition of interventricular septal defect by venous catheterization should depend upon finding a significant increase in the amount of oxygen in the right ventricle as compared with that from the right auricle. Two such cases have been described by Baldwin, Moore, and Noble (5). A significantly elevated oxygen content of blood in the right ventricle may reflect the presence of an interventricular septal defect or, theoretically, of a patent ductus arteriosus with an

TABLE V

J. H. Age 6. Ventricular septal defect, aortic insufficiency

Sample	Oxygen content	Pressure
	ml. per l.	*mm. Hg*
Right pulmonary artery (mid-portion)	160	29/12
Pulmonary artery (at bifurcation)	154	
Right ventricle (near pulmonary valve)	158	
Right ventricle (mid-portion)	155	29/4
Right ventricle (near tricuspid valve)	156	
Right auricle (near tricuspid valve)	126	4
Right auricle (upper portion)	121	
Superior vena cava	128	
Systemic artery	177 (100 per cent)	

A–P diameter of chest	14.5 cm.
Oxygen consumption	158 ml. per min.
Body surface area	0.82 sq. m.
Pulmonary arteriovenous oxygen difference	20 ml. per l.
Peripheral arteriovenous oxygen difference	52 ml. per l.
Pulmonary blood flow	7.9 l. per min.
Peripheral blood flow	3.4 l. per min.
Flow through shunt	4.5 l. per min.

associated pulmonic insufficiency. Three instances of the latter have been suspected, in one of whom division of the ductus eradicated all murmurs and subsequent venous catheterization failed to reveal any significant variations of oxygen in the right auricle, right ventricle, or pulmonary artery. It is believed, therefore, that a diagnosis of interventricular septal defect in the presence of a patent ductus arteriosus should be made with caution.

In our control studies (2), the greatest variation between maximal oxygen values in right auricle and right ventricle was 0.9 volume per cent. It is believed, therefore, that variations greater than 1.0 volume per cent are abnormal. This, in the average patient, corresponds to a shunt of 1.5 to 2.0 l. per min. Obviously, if the tip of the catheter can be placed in the arterial stream coming through the defect, smaller shunts can be demonstrated.

We have not been successful in introducing the catheter through a ventricular septal defect in the absence of an associated pulmonary stenosis. In the absence of pulmonary stenosis or cardiac fail-

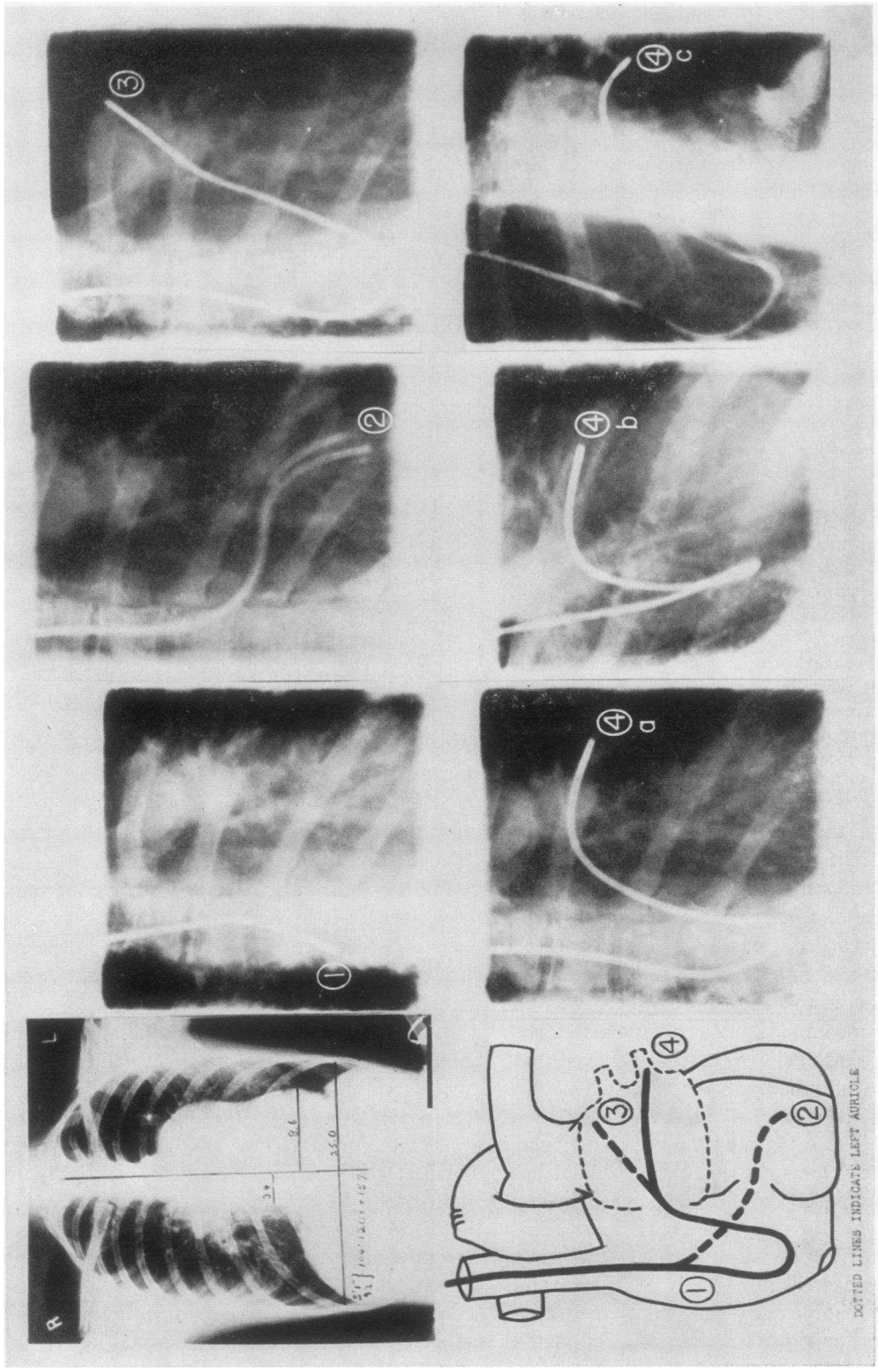

FIG. 9. AURICULAR SEPTAL DEFECT (CASE 5)

The positions of the catheter are identifiable by the corresponding numbers in the schema. Note that the catheter assumes an acutely oblique upward course in the right auricle and that the tip lies outside the cardiac shadow. The right anterior oblique view is shown in Figure 4-B, and the left anterior oblique view in Figure 4-C.

ure, the right ventricular pressure has been normal in all of our cases to date.

Interauricular septal defect

Defects in the interauricular septum vary considerably in size. The flow of blood is predominantly from the left auricle to the right auricle (6). If the defect is large or if pressure in the right auricle becomes elevated, a right-to-left shunt may likewise be present (7).

Two patients will be described to illustrate 2 different ways in which venous catheterization may aid in the recognition of auricular septal defects.

Introduction of catheter through the defect: Case 5. E. M. was a 25-year-old woman who had been found to have a heart murmur in grade school. She had always experienced fatigue rather than dyspnea on exertion. For 5 years she had had cyanosis on exposure to cold and on exertion. She was slender and there was no clubbing, but the fingers and lips were perceptibly cyanotic. The heart was overactive, and there was a harsh diastolic murmur without thrill at the fourth intercostal space. The blood pressure was 108/76 mm. Hg. X-ray (Figure 9) and fluoroscopy of the heart revealed it to be markedly enlarged with a huge pulmonary artery. An electrocardiogram showed right axis deviation.

Venous catheterization was incomplete in this patient. The catheter entered the right auricle (Figure 9), and followed a course acutely upwards and to the left so that the tip lay outside the cardiac shadow. Blood obtained from this point was 97 per cent saturated with oxygen (see Table VI). It was concluded that the catheter had passed through an auricular septal defect into the left auricle and into one of the pulmonary veins. Attempts to introduce the catheter into the pulmonary artery were unsuccessful.

Left-to-right shunt: Case 6. H. C. was a 56-year-old man who denied ever having had any symptoms referable to the heart. On admission to the hospital for carcinoma of the bladder, it was noted that his heart was enlarged to left and right, that the rate was rapid, and that there was a harsh systolic murmur without a thrill maximal at the third left intercostal space and widely transmitted over the precordium and back. No diastolic murmurs were heard. The pulmonic second sound was accentuated. Cyanosis and clubbing were absent. There were no signs of congestive failure. The hemoglobin and hematocrit were normal. X-ray (Figure 10) and fluoroscopy of the heart showed it to be considerably enlarged, especially to the left, with hilar engorgement. An electrocardiogram demonstrated no abnormalities.

TABLE VI

E. M. Age 25. Auricular septal defect

Sample	Oxygen content	Oxygen saturation	Pressure
	ml. per l.	*per cent*	*mm. Hg*
Superior vena cava	130	60	—
Inferior vena cava	156	72	—
Right auricle (along right wall)	142	66	6
Left auricle	196	91	10
Pulmonary vein	212	97	14
Systemic artery	187	89	108/76

Venous catheterization (Figure 10 and Table VII) revealed a large increase of oxygenated blood in the right auricle as compared with that in the superior vena cava, as well as a value in one of the samples from the right auricle practically identical with that found in the femoral artery. On the basis of these findings, the diagnosis of an auricular septal defect seemed justified. There was no evidence of other cardiac defects.

TABLE VII

H. C. Age 56. Auricular septal defect

Sample	Oxygen content	Pressure
	ml. per l.	*mm. Hg*
Right pulmonary artery	146	
Left pulmonary artery	145	35/10
Left pulmonary artery	140	
Right ventricle (near pulmonary valve)	142	35/2
Right ventricle (mid-portion)	142	
Right auricle (near tricuspid valve)	113	
Right auricle (mid-portion)	147	2
Right auricle (upper portion)	156	
Superior vena cava	107	
Superior vena cava	130	
Systemic artery	158 (92 per cent)	160/80

A–P diameter of chest	21 cm.
Oxygen consumption	280 ml. per min.
Body surface area	1.83 sq. m.
Pulmonary arteriovenous oxygen difference (assuming 95 per cent oxygen saturation in pulmonary vein)	14 ml. per l.
Peripheral arteriovenous oxygen difference	39 ml. per l.
Pulmonary blood flow	20.0 l. per min.
Peripheral blood flow	7.2 l. per min.
Flow through shunt	12.8 l. per min.

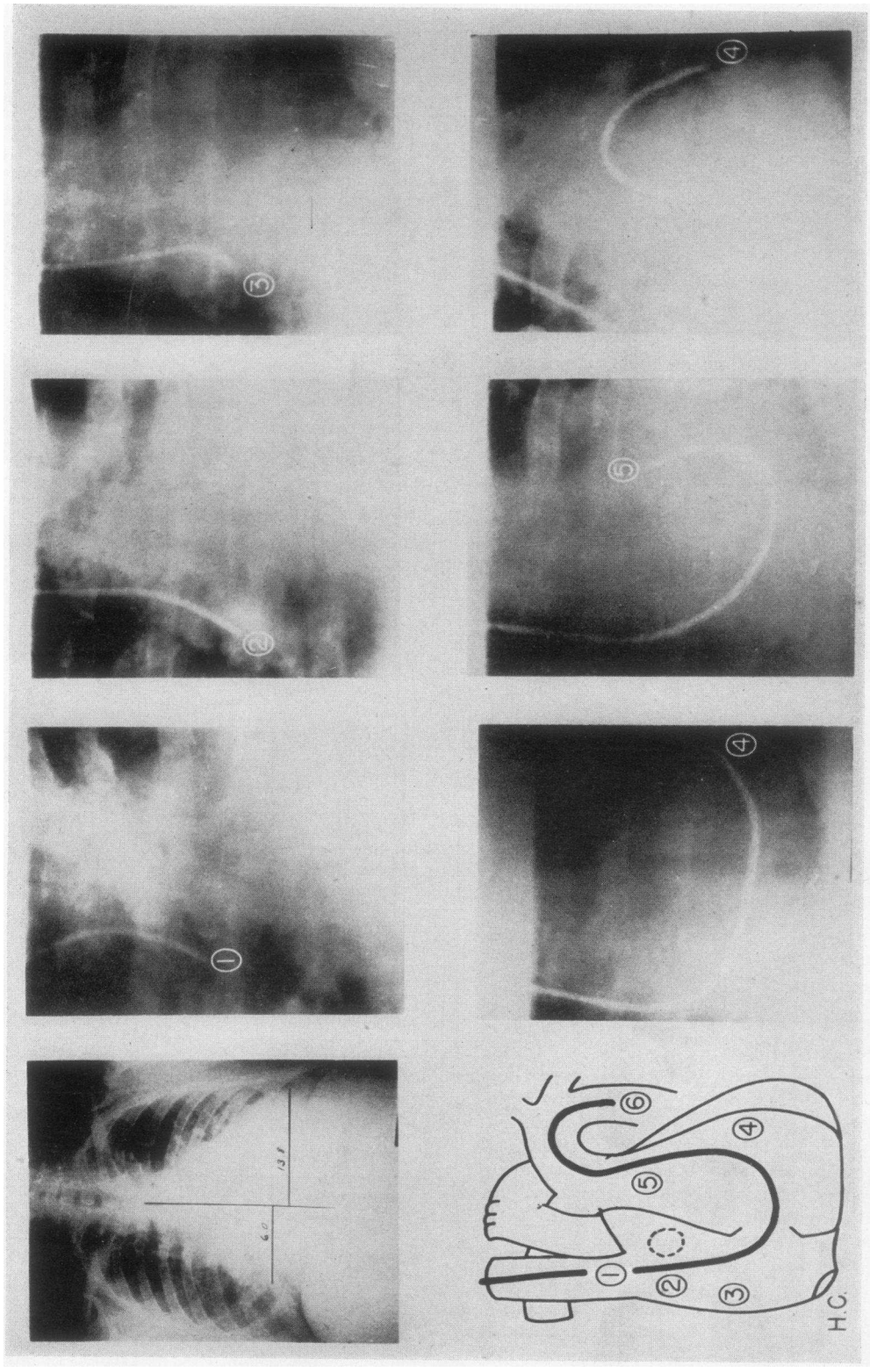

FIG. 10. AURICULAR SEPTAL DEFECT (CASE 6)
The positions of the catheter are identifiable by the corresponding numbers in the schema.

Discussion: Two methods, as described by Brannon, Weens, and Warren (9), can be utilized with the venous catheter to assist in the diagnosis of auricular septal defect: (*a*) Introducing the catheter through the defect (Patient 5), and (*b*) finding a significant increase in the oxygen content of blood in the right auricle (left-to-right shunt) (Patient 6).

Attempts to introduce the venous catheter through a defect in the auricular septum have been unsuccessful in the majority of cases. Anatomically, there appears to be no reason that, with experience, it could not be done with fair regularity.

A significant increase of oxygen content of blood in the right auricle may be present as the result of an interauricular septal defect with a left-to-right shunt, of an anomalous pulmonary vein emptying into the right auricle (7, 10), or of tricuspid insufficiency associated with interventricular septal defect. Baldwin, Moore, and Noble (5) have observed an instance of the latter and recognized tricuspid insufficiency by analysis of the auricular and ventricular pressure tracings as described by Cournand and associates (11). The recognition of a pulmonary vein emptying into the right auricle is practically impossible with our present knowledge. Statistically, auricular septal defect is much commoner than anomalous pulmonary veins emptying into the right auricle or tricuspid insufficiency associated with a ventricular septal defect. In control patients, the oxygen content of the right auricle has been observed to be as much as 1.9 volumes per cent higher than that of the superior vena cava (2). It is apparent that sizable auricular septal defects can be easily overlooked unless the catheter can be placed in the stream of arterial blood flowing from left auricle to right auricle.

DISCUSSION

Venous catheterization has opened new possibilities for the recognition of many congenital defects, for elucidating the hemodynamic changes, and for assisting in rendering a prognosis by defining the nature and physiological magnitude of the defects. As with other methods, it has its limitations and these we have tried to point out. The tetralogy of Fallot may be recognized with a high degree of accuracy if the assumptions on which the interpretations of pulmonary stenosis and ventricular septal defect were made are accepted. Patent ductus arteriosus can be detected in most instances where the defect is of sufficient size to produce symptoms or signs. Defects in the auricular and ventricular septa offer greater difficulties in diagnosis than the other 2 lesions. The diagnostic accuracy of the method in septal defects depends upon the success with which the tip of the catheter can be placed in the stream of arterial blood flowing into the right side of the heart from the left.

The necessity of obtaining multiple samples from each chamber is apparent, and a prerequisite of successful venous catheterization in patients with congenital cardiac defects is the gathering of as much information as possible by history, physical examination, x-ray, and fluoroscopy before catheterization is performed. Although we have not as yet used the method of Robb and Steinberg (12) of visualization of the cardiac chambers and great vessels with diodrast, information derived from this procedure should serve as a valuable adjunct to venous catheterization.

Finally, the increase of knowledge of hemodynamics acquired by techniques such as this will lead to increasing ease of diagnosis by simpler methods. Since certain varieties of congenital heart disease can be relieved or cured by surgery, precise diagnosis is of such importance that all doubtful cases should be studied with all available diagnostic techniques.

SUMMARY

1. Venous catheterization has been applied as a diagnostic measure and as a method of studying the hemodynamics of various types of congenital heart disease.

2. In patent ductus arteriosus, blood in the pulmonary artery is more highly oxygenated than that in the right ventricle.

3. In interventricular septal defect, blood in the right ventricle is more highly oxygenated than that in the right auricle.

4. In the tetralogy of Fallot, pulmonary stenosis is identified by finding a higher systolic pressure in the right ventricle than in the pulmonary artery. In some instances, the catheter may be introduced through the ventricular septal defect into the aorta. Other aspects of the diagnosis are discussed.

5. Auricular septal defect may be recognized by introducing the catheter through the defect into the left auricle, or by finding arterial blood in the right auricle in cases with a left-to-right shunt.

6. The limitations and potentialities of the method are discussed.

The authors are indebted to Dr. Samuel A. Levine for his help and encouragement in this study. Patients 1, 3, and 4 were referred by him for evaluation by venous catheterization, and Dr. Paul D. White sent us patient 5.

The authors wish to express their appreciation to Miss Barbara Jacobs for her technical assistance.

BIBLIOGRAPHY

1. Dexter, L., Haynes, F. W., Burwell, C. S., Eppinger, E. C., Seibel, R. E., and Evans, J. M., Studies of congenital heart disease. I. Technique of venous catheterization as a diagnostic procedure. J. Clin. Invest., 1947, **26**, 547.
2. Dexter, L., Haynes, F. W., Burwell, C. S., Eppinger, E. C., Sagerson, R. P., and Evans, J. M., Studies of congenital heart disease. II. The pressure and oxygen content of blood in the right auricle, right ventricle, and pulmonary artery in control patients, with observations on the oxygen saturation and source of pulmonary "capillary" blood. J. Clin. Invest., 1947, **26**, 554.
3. Eppinger, E. C., Burwell, C. S., and Gross, R. E., The effects of the patent ductus arteriosus on the circulation. J. Clin. Invest., 1941, **20**, 127.
4. Bing, R. J., Vandam, L. D., and Gray, F. D., Jr., Physiological studies in congenital heart disease. II. Results of preoperative studies in patients with tetralogy of Fallot. Bull. Johns Hopkins Hosp., 1947, **80**, 121.
5. Baldwin, E. deF., Moore, L. V., and Noble, R. P., The demonstration of ventricular septal defect by means of right heart catheterization. Am. Heart J., 1946, **32**, 152.
6. Bedford, D. E., Papp, C., and Parkinson, J., Atrial septal defect. Brit. Heart J., 1941, **3**, 37.
7. Abbott, M. E., Atlas of Congenital Heart Disease. New York, Am. Heart Assoc., 1936.
8. Adams, W. E., Thornton, T. F., Jr., and Eichelberger, L., Cavernous hemangioma of the lung (arteriovenous fistula). Report of a case with successful treatment by pneumonectomy. Arch. Surg., 1944, **49**, 51.
9. Brannon, E. S., Weens, H. S., and Warren, J. V., Atrial septal defect. Study of hemodynamics by the technique of right heart catheterization. Am. J. M. Sc., 1945, **210**, 480.
10. Brody, H., Drainage of pulmonary veins into right side of heart. Arch. Path., 1942, **33**, 221.
11. Cournand, A., Lauson, H. D., Bloomfield, R. A., Breed, E. S., and Baldwin, E. deF., Recording of right heart pressures in man. Proc. Soc. Exper. Biol. & Med., 1944, **55**, 34.
12. Robb, G. P., and Steinberg, I., A practical method of visualization of the chambers of the heart, the pulmonary circulation, and the great blood vessels in man. J. Clin. Invest., 1938, **17**, 507.