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CIRCULATORY BY-PASS OF THE RIGHT HEART. I. PRELIMINARY OBSERVATIONS ON THE DIRECT DELIVERY OF VENA CAVAL BLOOD INTO THE PULMONARY ARTERIAL CIRCULATION. AZYGOS VEIN—PULMONARY ARTERY SHUNT**

The surgical treatment of certain congenital anomalies of the right side of the heart characterized by mal- or non-function of the right auricle or right ventricle or both may depend on the possibility of the direct delivery of blood from the vena cava into the pulmonary arterial circulation.†

The immediate and ultimate success of this procedure would depend on the volume of blood flow through the pulmonary artery. As stated by Dexter, *et al.*,[1] "The volume of blood flowing through the pulmonary artery per unit of time is dependent upon the pressure in the pulmonary artery, the resistance to blood flow offered by the pulmonary vasculature, and the ability of the left side of the heart to handle the volume of blood which it receives." On the basis of studies by these investigators on the pulmonary artery pressure in normal adult humans, a mean pressure of about 13 to 17 millimeters of mercury would be sufficient to propel a normal blood flow through the pulmonary artery at rest. A venous pressure of this magnitude would, acting alone, usually be insufficient to produce peripheral edema.[2] Prolonged increased venous pressure may, however, lead to varicosities and the development of a collateral venous circulation.

METHODS

Mongrel dogs were anesthetized with nembutal and using sterile technique the azygos vein on the right side was divided and the peripheral end ligated. The central end was trimmed close to the superior vena cava, its connection with the cava being temporarily occluded by a curved Potts' bulldog type clamp. An anastomosis was then performed

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† In a paper delivered before the Forum on Fundamental Surgical Problems, Warden, *et al.*,[4] described experiments where they anastomosed the right auricle to the main pulmonary artery for the purpose of by-pass of the right ventricle. H. B. Shumacker in discussion of this paper indicated that experiments in his laboratory were being carried out where the venae cavae were anastomosed directly to the pulmonary artery.

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between the stump of the central end of the azygos vein and the distal end of the divided right main pulmonary artery. The cardiac end of the right pulmonary artery was ligated. Following the completion of the anastomosis, the superior vena cava was occluded as it entered the right heart by a double ligature of heavy silk. In one animal the anastomosis was made between the distal end of the divided right pulmonary artery and the inferior vena cava.

Studies in the majority of these experiments included: venous pressure recorded from the superior vena cava, (i) before ligation of the cava, (ii) after ligation of the cava and before opening of the anastomosis to the pulmonary artery, and (iii) after opening of the anastomosis to the pulmonary artery. Oxygen studies (content, capacity, saturation) were done on the blood obtained from the superior vena cava and the aorta, (i) before ligation of the cava and (ii) after ligation of the cava with the

TABLE 1. VENOUS PRESSURE STUDIES

	Pressure superior vena cava mm. saline		
		After ligation SVC azygos-PA shunt	
Experiment No.	*Initial*	*Closed*	*Open*
1	60	400	250
2	61	225	180
3	30	245	180
6	<30	165	134
7	30	600	214
8	<25	300	118
9	<30	477	145

anastomosis of the cava to the pulmonary artery open. A venogram of the superior cava was performed in four experiments two to three weeks following operation, and in one of these it was performed a second time 73 days following operation; 15 to 25 cc. of a 70% solution of Diodrast were injected into either a vein in the foreleg or the external jugular vein in approximately five seconds.

RESULTS

The results of this investigation are based on nine experiments where studies were made.

Venous pressure. (Table 1). The pressure in the superior vena cava was low (30-60 millimeters of saline) prior to ligation of the superior vena cava but rose rapidly on complete caval occlusion at the level of the right heart (165-600 millimeters of saline). Following opening of the anastomosis between the superior cava and the right pulmonary artery the pressure in the occluded superior cava invariably fell as blood passed into the pulmonary arterial circuit of the right lung. After opening of the anastomosis

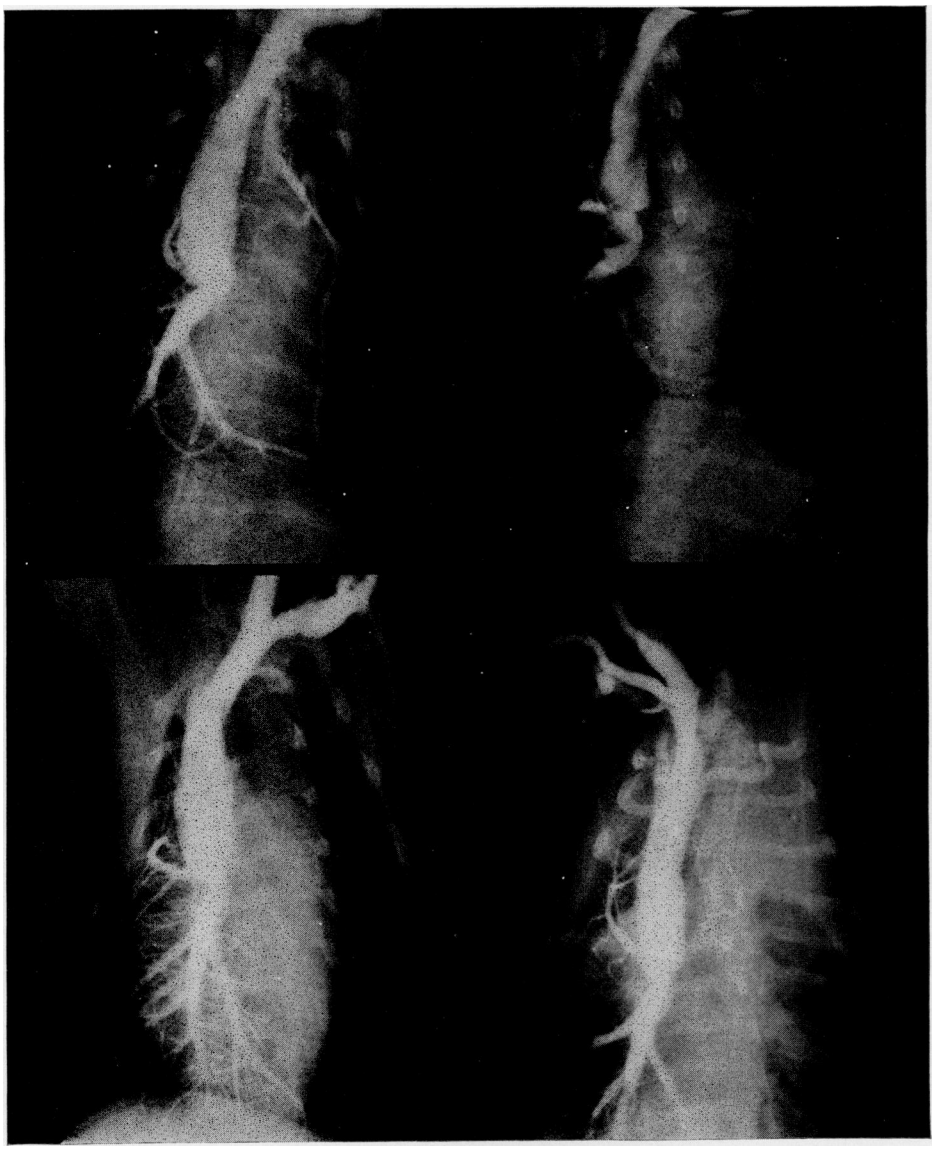

FIG. 1. Angiocardiogram made in four experiments. Experiment 1 (upper left) 73 days postoperatively. Experiment 2 (upper right) 43 days postoperatively. Experiment 7 (lower left) 21 days postoperatively. Experiment 8 (lower right) 16 days postoperatively.

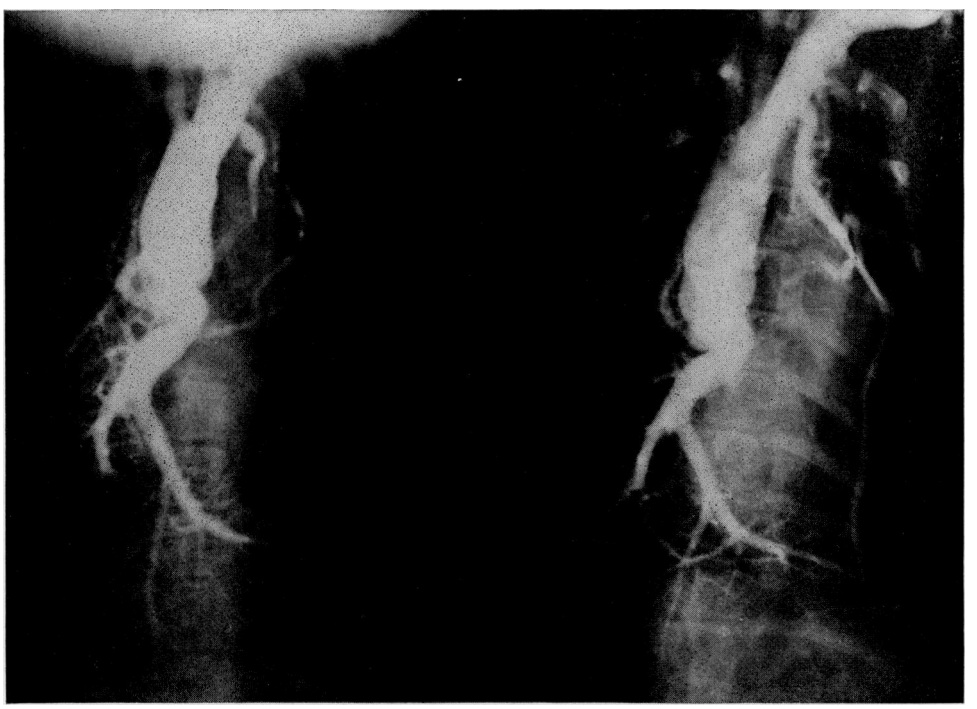

FIG. 2. Angiocardiogram made in Experiment 1, 18 days postoperatively (left) and 73 days postoperatively (right).

the pressure in the superior cava varied from a minimum of 118 millimeters of saline (Experiment 8) to a maximum of 250 millimeters of saline (Experiment 1). The percentage of fall varied from 18.8 (Experiment 6) to 69.6 (Experiment 9). In a few experiments vena caval pressures were repeated at a later time. In Experiment 1 the pressure in the external jugular vein was found to be 68 millimeters of saline and 65 millimeters of saline on the 73d and 88th days following operation as compared with a superior caval pressure of 250 millimeters of saline on the day of operation. The external jugular pressure in Experiment 2 was 140 millimeters of saline 43 days after operation as compared with 180 millimeters of saline in the superior cava on the day of operation. In Experiment 7 the pressure in

TABLE 2. OXYGEN STUDIES

	Blood oxygen per cent saturation			
	azygos-PA shunt			
*Experiment No.**	*Pre-*	*Post-*	*Pre-*	*Post-*
	Aorta		*Superior vena cava*	
6	96.5	99.4	48.5	19.2
7	98.7	99.8	92.1	89.9
8	97.4	100+	88.8	70.2
9	100+	100+	68.7	64.5

* All animals breathing 100% oxygen.

the superior vena cava 21 days after operation was almost the same as on the day of operation.

Oxygen studies. (Table 2). These studies usually revealed a fall in the oxygen saturation of the venous blood in the superior vena cava after the anastomosis of the cava to the pulmonary artery had been opened for 5 to 20 minutes. There was no significant change in the saturation of the arterial blood (aorta).

Angiocardiography. (Fig. 1 and 2). In four experiments angiocardiography was carried out in the postoperative period. In all experiments the pulmonary vascular tree on the right side was clearly visualized. In one animal a delay in emptying of the dye from the right upper lobe was noted.

COMMENT

The results of these early experiments suggest that an anastomosis between the superior vena cava and the distal end of the right pulmonary

artery can be expected to remain patent in the majority of animals. The evidence suggests that at least some blood from the superior vena cava passes through the right lung. The evidence also suggests that there may be a difference in pulmonary arterial resistance from animal to animal under the imposed experimental conditions. There is some suggestion (Experiment 1) that there may actually be a lowering of pulmonary arterial resistance after the relatively prolonged exclusion of the pulmonary artery from direct continuity with the right heart. Whether this is an expression of decreased pulmonary vascular resistance or decreased flow through the shunt due to an expanding collateral venous circulation between the superior and inferior venae cavae remains to be determined. The serial angiocardiograms taken on this animal at intervals of 55 days (Fig. 2) do not suggest, however, the formation of extensive collateral venous circulation.

By-pass of the right heart may be accomplished by the anastomosis of the inferior and superior venae cavae to the right and left pulmonary arteries. By-pass of the right ventricle alone can be accomplished by the anastomosis of the right auricle to the main pulmonary artery.[8] Our interest in attempts to by-pass the entire right heart developed following unsatisfactory results in several patients with tricuspid stenosis on whom a systemic artery-to-pulmonary-artery shunt had been performed. In these patients there usually exists an interauricular septal defect as well.

The cardiac anomalies which might benefit from this operation include stenosis or atresia of the tricuspid and pulmonary outflow tracts. By-pass of the right side of the heart may also be indicated where a poorly functioning right ventricle, although there is no obstruction to the outflow, accompanies an anomaly in the position of the tricuspid valve (Epstein's anomaly). Further, when there is a single ventricle or a bilocular heart, the direct passage of blood from the cavae to the pulmonary arteries may be beneficial. Possibly, by-pass of the right side of the heart may be indicated in conditions characterized by pulmonary hypertension, particularly Eisenmenger's syndrome, where the hypertension has not become irreversible. Also, in transposition of the great vessels, by-pass of the right heart may be beneficial, especially if there is an associated pulmonary stenosis. By-pass of the right heart may also be indicated where there is obstruction of the cavae where they join the heart, or where there is an abnormal insertion of either cavae into the left auricle.

Further experiments are in progress with two main purposes: (i) to determine if the entire venous circulation can be made to by-pass the heart directly into the lungs, and (ii) to investigate changes in pulmonary vascu-

lar resistance with part or all of the venous blood made to by-pass the right heart.

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