Distribution of Pulmonary Blood Flow after Cavopulmonary Anastomosis (Glenn Operation)

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Anastomosis of the superior vena cava and right pulmonary artery (Glenn and Patiño, 1954; Edwards and Barger, 1968) is indicated in some patients with congenital heart disease associated with diminished pulmonary blood flow. The procedure represents a major interference with pulmonary haemodynamics. The blood supply to the right lung then comes from the superior vena cava and from the bronchial collaterals. The blood to the left lung comes from the inferior vena cava and from the systemic vascular bed via anastomoses. A part of the venous return from the inferior vena cava passes through interatrial or interventricular communications directly into the systemic circulation without having passed through the lungs. The total pulmonary blood flow after cavopulmonary anastomosis increases. The ratio between the left and right pulmonary blood flow varies according to the magnitude of the intracardiac shunt.

Another important feature of the haemodynamics after Glenn's operation is the difference between the character of the left and right pulmonary blood flow. This difference is due to the participation of myocardial contraction on the ejection of blood only to the left lung.

Evaluation of all these haemodynamic abnormalities created by Glenn's operation stimulated our present study. We expected to find the changes in the distribution of pulmonary blood flow. Great differences between the right and left lung appeared to be of special interest. It was possible to study the effect of pulsatile or steady blood flow on the distribution of blood in the lungs for the first time in conscious human beings. Finally, we tried to evaluate the contributions of lung scanning for assessing the patency of the anastomosis, as shown by Friedman (Friedman, Braunwald, and

Morrow, 1966). Furthermore, the method proved to be suitable for the demonstration of collateral pulmonary circulation.

SUBJECTS AND METHODS

Fifteen patients were investigated after cavopulmonary anastomosis. The ages ranged from 5 to 20 years. All operations were performed at the Department of Paediatric Surgery in Prague (Tables I and II). The operation had been indicated because of diminished pulmonary blood flow in patients with tricuspid atresia or Fallot's tetralogy in which unfavourable anatomical conditions substantially increased the risk of total correction at that time. Investigation was performed 3 to 5 years after operation in most patients (Tables I and II).

Pulmonary blood flow distribution was investigated by the isotope technique (Taplin *et al.*, 1964; Wagner, McAfee, and Mozley, 1960; Wagner *et al.*, 1964). Macro-aggregated human albumin was labelled with either technetium ^{99m}Tc , or iodine ^{131}I . The size of the particles was 10 to 100 μ . Total dose of 0.2 ml. up to 1.0 ml. was administered intravenously to the patients in sitting or supine position. The interval between the injection of macro-aggregated albumin and the start of the detection of its distribution was about 5 minutes. The doses ranged between 20 and 100 μCi , according to the age of the child. Radiation distribution was detected using Nucleograf (Siemens), Pho/Dot II Scanner, or gamma-camera (Nuclear Chicago). The face of the collimator was placed as close to the thoracic wall as possible. Special collimator (Nuclear Chicago) for ^{99m}Tc and 19-hole collimator for ^{131}I were used. Scanning speed of 60 or 90 cm./min. was chosen. During the scanning patients were in the supine position, or sitting if the gamma-camera was used.

RESULTS

Differences in the distribution were expected after the injection of macro-aggregated albumin into the region drained by the superior vena cava, in comparison with injection into the region drained by the inferior vena cava.

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TABLE I
PATIENTS AFTER CAVOPULMONARY ANASTOMOSIS

Case No.	Birth date	Sex	Diagnosis	Anastomosis	Date of operation	Time interval between operation and investigation
1	27.3.1956	F	Tricuspid atresia	End-end	27.2.1963	4 yr.
2	9.3.1962	F	Tricuspid atresia	End-end	26.5.1964	3 yr.
3	26.6.1961	F	Tricuspid atresia; transposition of great arteries	End-end	16.2.1967	1 mth.
4	12.2.1956	M	Tetralogy of Fallot	End-end	9.10.1962	5 yr.
5	11.4.1959	M	Tricuspid atresia	Side-end	19.2.1964	3 yr.
6	3.6.1956	F	Tetralogy of Fallot	End-end	13.3.1963	4 yr.

TABLE II
PATIENTS AFTER CAVOPULMONARY ANASTOMOSIS AS SECOND PROCEDURE

Case No.	Birth date	Sex	Diagnosis	Anastomosis	First operation	Late results	Anastomosis	Date of second operation	Interval between operation and investigation
7	10.7.1949	M	Tetralogy of Fallot	Blalock-Taussig	31.3.1953	0	End-end	14.3.1963	4 yr.
8	4.4.1953	M	" "	" "	4.7.1956	0	End-end	18.4.1963	4 yr.
9	17.8.1957	F	" "	" "	30.5.1961	+	Side-end	24.5.1967	3 wk.
10	4.9.1954	M	Tricuspid atresia	" "	8.6.1956	+	End-end	21.11.1962	5 yr.
11	16.7.1958	M	Tetralogy of Fallot	" "	20.4.1961	0	End-end	27.1.1965	2 yr.
12	18.8.1955	F	Tricuspid atresia	" "	24.4.1958	0	End-end	22.2.1962	5 yr.
13	4.5.1947	M	Tetralogy of Fallot	Potts	14.6.1952	0	Side-end	16.10.1963	4 yr.
14	7.4.1945	M	Tricuspid atresia	Blalock-Taussig	5.12.1952	0	End-end	6.6.1962	5 yr.
15	24.6.1950	M	Tetralogy of Fallot	" "	4.6.1954	+	Side-end	31.1.1965	2 yr.

0, anastomosis not patent. + to + + +, anastomosis patent.

Distribution of Blood from Superior Vena Cava. Macro-aggregated albumin was injected into the region drained by the superior vena cava in 12 patients in the sitting position, in 2 other patients, first sitting and then supine, and to another patient in the supine position only.

In 12 out of 14 children, in whom the pulmonary blood flow distribution was investigated in the upright position, a characteristic picture was found (Fig. 1). Blood from the superior vena cava enters the right lung only, and the distribution is altered conspicuously. The blood flow is not uniform, but is limited to a small region in the upper part of the lower right lung field. The distribution of radioactivity in this region has an oval shape. Blood flow through the remaining regions of the right lung is either very small or absent. The same typical picture was observed in all patients irrespective of whether Glenn's operation was a first or second procedure.

The blood flow distribution in the right lung was atypical in 2 patients. In the first of them, Case 2 (Table I), the picture of the distribution of blood flow, typical for patients after Glenn's operation, did not appear (Fig. 2). Radioactivity in the right lung was not limited to one area, but was distributed evenly. Very slight activity, with a gradient be-

tween the upper and the lower fields, appeared also on the left side. Activity of the same intensity as in the right lung was recorded also in other parts of the body. Cavography proved that the anastomosis was very narrow, only about one-fifth of the diameter of the superior vena cava. Blood from the upper part of the body bypassed the superior vena cava via collaterals, thus explaining the scattered activity outside the lungs.

In the second child, Case 3 (Table I), the typical concentration of activity in the right lung field failed to appear after the injection of macro-aggregated albumin into the right cubital vein. The radioactivity in the right lung exhibited equal intensity in the middle and lower lung fields, while the intensity in the right upper lung field was lower. No activity was recorded on the left side. Radioactivity in the upper part of the abdomen was higher than the so-called background activity. The whole picture was similar to that of the first child. Opaque medium injected into the right cubital vein revealed distinct narrowing at the site of the anastomosis. The right pulmonary vascular bed was poorly filled with the opaque medium. Cavography from the left cubital vein revealed a large hemi-azygos vein branching off from the persistent left superior vena cava above the ligature.

FIG. 1.—Case 14 (Table II). Scintigram after the injection of macro-aggregated albumin labelled with ^{99m}Tc into the right cubital vein in the sitting position.

FIG. 2.—Case 2 (Table I). Scintigram after the injection of macro-aggregated albumin labelled with ^{99m}Tc into the right cubital vein in the sitting position.

This vein, together with numerous additional collaterals, drained blood into the inferior vena cava.

In these two cases angiography disclosed the reasons for the atypical distribution of the blood from the superior vena cava, previously found by lung scanning. In all other patients, with a typical blood flow distribution, angiography proved a patent anastomosis with a normal anatomical structure of the pulmonary vascular tree on the right side (Fig. 3).

When macro-aggregated albumin is injected into the cubital vein in supine patients, the distribution within the right lung is distinctly more even, in comparison with an upright patient (Fig. 4).

Distribution of Blood from Inferior Vena Cava. Macro-aggregated albumin was injected into the veins of the lower extremities in 10 patients (7 sitting, 3 supine).

(A) *Scintigraphic picture of left lung.* Three (Cases 3, 5, and 6, Table I) out of 7 patients, in whom macro-aggregated albumin had been injected into the vein of the lower extremity in the upright position, did not have another anastomosis before Glenn's operation. In all of them the highest activity was recorded in the middle fields. In 4 other patients, who had undergone Blalock-Taussig

anastomosis before the cavopulmonary shunt, no uniform picture of the blood flow distribution was found. In 2 patients the distribution was normal,

FIG. 3.—Case 14 (Table II). Cavography. Contrast material (Verografin 76%, Spofa) injected into the right cubital vein.

FIG. 4.—Case 1 (Table I). Scintigram after the injection of macro-aggregated albumin labelled with ^{99m}Tc into the right cubital vein in the supine position.

with a very delicate activity gradient between the upper lung field and the others. Such a gradient was absent in one patient. In another, the activity was greater in the upper lung field.

In all patients in whom macro-aggregated albumin had been injected in the supine position, the highest activity was recorded in the upper left lung field.

(B) *Scintigraphic picture of right lung.* Lung scans were recorded in 9 upright and/or supine patients. In all of them the injection of macro-aggregated albumin into the region drained by the inferior vena cava was followed, in addition to the activity above the left lung, by a change in the scintigraphic picture of the right lung. The activity in the right lung was found also in regions where it had not been recorded after the injection of macro-aggregated albumin into the cubital vein in the same patients. This activity, however, was substantially lower (Fig. 5). The distribution of albumin within the right lung does not change with the position of the body. This activity expresses the collateral circulation in this lung.

DISCUSSION

The value of isotope methods in the estimation of the patency of cavopulmonary anastomoses has been proved by the work of Friedman and associates (1966). From our experience we can confirm that such an easy method as scintigraphy is useful in the control of the efficiency of cavopulmonary anastomosis. Information obtained by this method is of greater pathophysiological value than that obtained by radiography. This becomes evident in our material when the normal anatomical structure of the pulmonary vasculature is compared with the abnormal distribution of the blood flow in the right lung.

FIG. 5.—Case 11 (Table II). A: Scintigram after the injection of macro-aggregated albumin labelled with ^{99m}Tc into the right cubital vein in the sitting position. B: Scintigram after the injection of macro-aggregated albumin labelled with ^{99m}Tc 2 hours later into the vein on dorsum pedis in the sitting position.

The proof of serious disturbances of the pulmonary blood flow distribution is the most important information derived from this study. It has been shown that in the right lung the blood flow is restricted to the small region of the lower lung field. In the blood draining this area with higher blood flow, higher venous admixture might appear. On the contrary, in the remaining parts of the right lung the physiological dead space increases, and the patient needs more energy for the work of the respiratory muscles. These disturbances can influence unfavourably the general clinical condition. In this respect it is important that, in the supine position, the distribution of blood flow in the right lung is more even. The disturbance of the ventilation-perfusion ratio will therefore be lower than in the sitting or upright positions. Whether the generally recommended sitting position in the post-operative period is the best one in patients after cavopulmonary anastomosis is debatable. The unfavourable effect of pulmonary blood flow disturbance on gas exchange may be, to a certain degree, favourably modified by the effect of the autoregulatory mechanism of the ventilation-perfusion ratio (Šamánek, 1966; Šamánek and Aviado, 1967).

No explanation has yet been found for the abnormalities of blood flow through the left lung in some patients, and further research into this problem is in progress. There is no evidence that the abnormal left pulmonary blood flow distribution is due to morphological changes in the structure of pulmonary vessels in pulmonary stenosis (Wagenvoort *et al.*, 1967). It seems plausible that the higher velocity of the blood flow behind stenosis might influence the distribution (Dollery *et al.*, 1961).

The separate blood supply of the left and right lung from the inferior and superior vena cava, respectively, is favourable for the demonstration of collateral circulation. By injecting macro-aggregated albumin into any vein draining into the inferior vena cava, collateral circulation in the right lung can be depicted. To use the analogous manoeuvre for the evaluation of left lung collateral circulation is unsuccessful, because of anatomical differences in the underlying congenital malformation and in the operation itself.

Pulmonary haemodynamics after Glenn's operation is a suitable model for the study of the effect of myocardial contraction on the pulmonary blood flow distribution in conscious patients. The right and the left pulmonary blood flow are only slightly different as far as the volume, oxygen saturation, and pressure are concerned, but a conspicuous difference in blood flow distribution exists. In the left lung, supplied by blood coming from the right ventricle, the distribution is considerably more even

than in the right lung. The blood flow through the right lung, where the kinetic energy of the heart contraction plays no role, is limited to a small area of the lung. It can be concluded that the right ventricular contraction influences the pulmonary blood flow distribution in an important way.

Ventricular contraction seems to be also a factor restricting the effect of positional changes on the ventilation-perfusion ratio. The effect of gravitation on the distribution of pulmonary blood flow has been explained in several papers (Björkman, 1934; West and Dollery, 1960; Glaister, 1964). The modification of its influence due to myocardial activity seems to be obvious from our study. It has been proven that the changes of distribution due to gravitational forces are more evident in the right lung, with a steady blood flow coming directly from the superior vena cava.

SUMMARY

Pulmonary blood flow distribution was studied using scintigraphy in 15 patients with congenital heart disease after cavopulmonary anastomosis. Abnormal distribution was shown in both lungs, particularly in the right. The findings confirmed the usefulness of scintigraphy for the evaluation of the patency of the anastomosis. This method is also helpful in studying the pulmonary collateral circulation. It is suggested that cardiac contraction is an important factor governing pulmonary blood flow distribution. It might also be a limiting factor in the gravitational effect of body position on the pulmonary blood flow distribution.

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