AORTIC ATRESIA

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Several congenital malformations of the aortic valve have been described since the last century under the title of aortic atresia (Canton, 1849; Dilg, 1883). There are today more than 100 published reports of cases. Some cases of aortic stenosis with pinhole openings have also been included as aortic atresia. In all instances associated with the aortic atresia there is hypoplasia of the ascending aorta, of the left ventricle, and of the mitral valve, constituting a fairly constant pattern. It is interesting to note the occurrence of these associated defects that seem to be related to aortic atresia and probably represent a functional consequence of this malformation.

The present study is a clinical and pathological report of eight cases of aortic atresia with a discussion of the embryology and hæmodynamics of this defect. Notwithstanding the interesting functional problems involved, most cardiologists rarely have the opportunity of studying these subjects, due to the early death of patients with this malformation.

MATERIAL

Aortic atresia occurred in 8 instances among 36 fatal cases of congenital heart disease representing 0.5 per cent of all necropsies at the Department of Pathology of the Carmela Dutra Maternity Hospital. It was the most common type of congenital heart disease found in this department.

Clinical Findings. The average life span of these subjects was 33 hours ranging from 1 to 60 hours. The prenatal history was normal in six and there was threatened abortion in two cases. There was no history of maternal rubella or other virus infection during pregnancy. The labour was uneventful for five of these children and difficult for three of them. With only one exception, all patients were male. Immediately after birth vitality was considered satisfactory in five patients, regular in two, and very poor in only one who died within the first hour of life. The birth weight was over 3000 g. in five and under 2000 g. in one. All were cyanotic from birth. Dyspnoea and cough were common symptoms that became more severe later in life. A systolic murmur was heard in only one and then over the entire præcordium. Liver enlargement was not a prominent feature in this study (Table I).

Anatomical Study of Heart and Great Vessels. It was remarkable how similar all these hearts appeared macroscopically. In general, we did not recognize any gross cardiomegaly; however, the right chambers were enlarged (Fig. 1). The pulmonary trunk had a calibre five times larger than that of the aorta, the relative positions between the two vessels being normal. The aorta was hypoplastic from its origin until the site of the ductus arteriosus. A normal descending aorta was found in all cases. The coronary vessels were always of normal calibre and in normal position. Externally, the left heart chambers appeared to be hypoplastic. The internal aspect of the cardiac chambers showed the following changes.

TABLE I
MATERNAL AND NEWBORN DATA IN EIGHT CASES OF AORTIC ATRESIA

Autopsy number	Maternal data		Newborn data					
	Prenatal history	Labour	Sex	Vitality	Weight (g.)	Duration of life (hr.)	Symptoms and signs	Cause of death
A 6	Threatened abortion	Normal	M	Satisfactory	3250	60	Cyanosis and dyspnœa on second day; systolic murmur over entire præcordium; pulmonary râles, liver enlargement	?
A 35	Normal	Difficult	M	Satisfactory	3185	27	Cyanosis and dyspnœa and increased bronchial secretion on first day	?
A 52	Threatened abortion	Normal	M	Regular	1875	27	Cyanosis	Prematurity
A 335	Normal	Difficult	M	Satisfactory	2225	28	Cyanosis on second day	Hyaline membrane
A 390	Normal	Difficult	F	Poor	3600	1	Cyanosis and dyspnœa	Intrauterine anoxia
A 498	Normal	Normal	M	Regular	2640	35	Cyanosis and tachycardia	?
A 889	Normal	Normal	M	Satisfactory	3050	56	Cyanosis and dyspnœa and increased bronchial secretion on the third day; liver enlargement	?
A 898	Normal	Normal	M	Satisfactory	3000	31	Cyanosis and dyspnœa on the third day	?

FIG. 1.—External aspect of the heart. The pulmonary artery (PA) is increased in size as compared to the ascending aorta (A). The right atrium (RA) is dilated and the right ventricle (RV) is dilated and hypertrophied.

FIG. 2.—Internal aspect of the right cardiac chambers. The probe passes through a paradoxically patent foramen ovale. The right atrium (RA), right atrial appendage (Ap), tricuspid valve (t), and right ventricle (RV) are seen.

FIG. 3.—Internal aspect of the left cardiac chambers. The left atrium (LA) and a decreased left ventricle (LV) are seen. The probe is pointing to the mitral apparatus (m).

FIG. 4.—Relative sizes of the right (RV) and left ventricle (LV).

FIG. 5.—Outflow tract of the left ventricle (LV). One probe is pointing to the site of the non-existent aortic valve and the other one is passing under a hypoplastic ascending aorta.

Right atrium. Two cases had a normal right atrial volume whereas the others showed an enlargement of this cavity. The foramen ovale was always patent. In two the valve of Vieussens was found protruding towards the right atrium, which is an unusual finding: in most cases the valve was shorter than the size of the foramen. One case had a fenestrated foramen ovale. The size of the right atrioventricular orifice varied between 36 and 51 mm.

Right ventricle. This cavity was grossly dilated in all cases but one (Fig. 2). The endocardium had a normal aspect. In one instance several white plaques were observed on the endocardium surface. However, the microscopic examination of these plaques failed to disclose any evidence of fibro-elastosis. The thickness of the ventricular wall, measured at the outflow tract, was 5 mm. The interventricular septum was normal. In one case, there was an initial suggestion of a single ventricle due to ventricular dilatation; however, a further study revealed a small left ventricle which appeared as a slit in the wall of the enlarged right ventricle.

Pulmonary artery. This was dilated in all cases. The pulmonary valves were normal and the valve ring size varied between 16 and 27 mm.

Pulmonary veins. These were normal in position and number. In one single instance dilatation of these vessels was observed.

Left atrium. This cavity was decreased in size in all cases but one, in which the wall thickness was only 2.5 mm. (Fig. 3).

Mitral valve. There was hypoplasia of the mitral apparatus in seven cases. One case showed an atretic mitral valve.

Left ventricle. The ventricular volume was decreased in seven cases (Fig. 4). In one instance we found a slit-like cavity in the myocardial mass, corresponding to the left ventricle. The thickness of the left ventricle ranged between 4 and 14 mm. with an average of 7.6 mm.

Aortic valve. We found the three aortic cusps completely fused in six cases; in two there was a pinhole orifice (Fig. 5).

Ascending aorta. There was a general hypoplasia of the segment of the aorta until the junction with the ductus arteriosus. Its diameter measured between 3 and 6 mm. (average 4.7 mm.). In one case a pre-ductal coarctation was identified just after the origin of the left subclavian artery.

Ductus arteriosus. This was always persistent and normally situated. Its average diameter was 8 mm. The youngest patient had the narrowest ductus (less than 5 mm.).

Gross Study of Lungs. The lungs had a normal gross appearance in one case. In others, areas of increased density, some of them with crepitation, were present. They had an increased volume and were well expanded in some cases. There was a variable amount of fluid varying from bloody to serous pink fluid.

TABLE II
MACROSCOPIC APPEARANCES OF ATRETIC LUNGS

Autopsy number	Gross aspect of lungs
A 6	Subpleural petechiæ, small areas of increased density with darker colour than remaining parenchyma
A 35	Areas of pink colour with crepitation present; areas of increased density
A 52	Dark areas with uniformly increased density
A 335	Normal aspect
A 390	Clear pink areas; a large number of subpleural bullæ
A 498	Lungs well expanded; some clear pink areas with emphysematous aspect and dark areas without crepitation
A 889	Increased volume and density; increased amount of blood in pulmonary parenchyma
A 898	Emphysema; crepitation present; small amounts of serous pink fluid

Microscopic Study. We were especially interested in the microscopic examination of the lungs for evidence of the cause of death. In four cases there was much veno-capillary congestion, foci of alveolar hæmorrhage, and serous fluid filling alveoli and bronchi. In one case there was heavy infiltration of red blood cells within the alveoli and bronchi. The microscopic study of these five cases showed evidence of venous hypertension of the lesser circulation. Two cases were characterized by infiltration of the polymorphonuclears around the bronchi and within the alveoli. In one case there was atelectasis. In six cases the heart presented a normal myocardium. We did not observe any instance of fibro-elastosis in our series. We wish to emphasize the complete absence of any sign of infection in the histological examination of the atretic aortic valve (Table III).

TABLE III
MICROSCOPIC STUDIES

Autopsy number	Lungs	Heart	Cause of death
A 6	Infiltration with polymorphonuclears around bronchi and bronchioles	Normal myocardium	Bronchopneumonia
A 35	Much veno-capillary congestion; serous fluid filling alveoli and bronchi; perivascular hæmorrhagic infiltration	Normal myocardium	Acute pulmonary œdema
A 52	Infiltration with polymorphonuclears within alveoli and bronchi	Normal myocardium	Pneumonia
A 335	Much veno-capillary congestion; serous fluid within alveoli and bronchi; mild pulmonary hypoplasia and atelectasis	Small foci of interstitial hæmorrhage in myocardium	Acute pulmonary œdema
A 390	Atelectasis; subpleural vesicles penetrating through interstitial septa	Marked vacuolization of the myocardial fibres	Pulmonary hypoplasia with pneumothorax
A 498	Much veno-capillary congestion; alveolar emphysema; occasional foci of alveolar hæmorrhage	Normal myocardium	Acute pulmonary œdema
A 889	Heavy infiltration of red blood cells within alveoli and bronchi	Normal myocardium	Intra-alveolar pulmonary hæmorrhage
A 898	Much veno-capillary congestion; small foci of alveolar hæmorrhage; serous fluid filling alveoli	Normal myocardium	Acute pulmonary œdema

DISCUSSION

Embryology. It is well known that the aortic valve is formed between the fifth and the eighth week of foetal life. Ridges of mesenchymatous tissue are formed in the aortic vestibule, and, at the sixth week, it is partially filled with this tissue. In the seventh week, when there is absorption of the mesenchymatous tissue, the outline of the aortic valve at the apex of the aortic vestibule is observed. In the eighth week, the aortic valve is normally and definitively formed (Duckworth, 1958). Kramer (1942) has a somewhat different theory concerning the origin of the aortic valve. He established an arbitrary line in the trunco-conal area at the origin of the sigmoid valve. It is at this point where two endocardial thickenings appear; they are called intercalated valve swellings. They are situated between the main truncus ridges. The expanded margins of these ridges will form the right and left cusps of the pulmonary artery and aorta. The intercalated valve swellings will initiate the dorsal cusp of the aorta and the ventral cusp of the pulmonary artery. These are the more generally accepted theories of the embryological events that lead to the formation of the valve (De la Cruz and Da Rocha, 1956).

Six cases had aortic atresia and two had pinhole aortic stenosis, both groups having the same functional effects. Since we were always able to observe a diaphragm closing the aortic vestibule,

FIG. 6.—The intracardiac circulation and the arterial pathways in isolated aortic atresia (left) and coexistent aortic and mitral atresia. AD, right atrium; VD, right ventricle; AP, pulmonary artery; AE, left atrium; VE, left ventricle; VP, pulmonary vein, modified from Edwards (1948).

and this diaphragm was divided by three raphæ, we did not make any diagnosis of valvular agenesis. Our cases gave us the impression that there was an adhesion of the commissures of the three cusps with or without closing of the tip. By the same token, a diagnosis of valvular hypoplasia was ruled out (Macruz *et al.*, 1960). Edwards (1953) believes that aortic atresia is probably an accentuation of the same valvular phenomenon that occurs in cases of severe aortic stenosis. The previously-explained fact of a diaphragm divided by three raphæ that radiate from the centre to the periphery as three cusps adhered by their edges is a partial confirmation of this hypothesis.

We cannot explain the obliteration of the left ventricular outflow tract by a cessation of heart development, because this does not occur during embryological life. It seems reasonable to resort to an excessive growth of the primitive cusps, so that they adhere by their borders and tips (true aortic atresia) or only by their borders (pinhole aortic stenosis), both leading to the same hæmodynamic events. The adhered commissures could be the result of an intrauterine endomyocarditis (Farber and Hubbard, 1933; Abbott, 1936). Like Rossman (1942) we could not find any evidence of inflammation in the microscopic examination of the myocardium of these cases.

The hypoplasia above and below the aortic atresia could be caused by the lack of function, in

such a way that the primary defect would be the aortic atresia and the secondary defects the hypoplastic ascending aorta and the hypoplastic left ventricle and mitral valve. This is just an assumption, because we know of cases in which there was selective hypoplasia of a certain chamber without any other defect (Cooley *et al.*, 1950; Uhl, 1952).

As the ascending aorta has a calibre five times smaller than the main pulmonary trunk, this fact could be hypothetically explained by an equal division of the truncus arteriosus communis by an anomalous dividing septum. However this does not seem reasonable, because an interventricular septal defect is not found, a defect that certainly would be expected if there were anomalous division of the primitive truncus. Moreover, according to Shaner (1949) one can experimentally demonstrate that the calibre of a vessel is dependent upon the blood flow through this vessel.

One of our cases had a mitral atresia and a slit-like left ventricle in the wall of a large right ventricle. The relation between aortic atresia and mitral atresia is unknown: however, it appears that one is not the consequence of the other, since this association occurred in only one case of our series (Walker and Klinck, 1942). Also, a matter of simple coincidence is the finding of a case with aortic coarctation and another with a left persistent superior vena cava. In our material there was no instance of fibro-elastosis as has been described elsewhere (Keith, Rowe, and Vlad, 1958).

Hæmodynamics. Since only the right side of the heart functions, there is an enlargement of the right atrium, right ventricle, pulmonary artery, and ductus arteriosus, all of which handle a much greater amount of blood than usual for the respective age-groups. The right ventricle obviously has a volume overloading, but we did not find evidence of right ventricular failure in spite of the right ventricular overloading. The aortic atretic heart would have only a single ventricular filling atrium and a single pumping ventricle and would function as a cor biloculare. The right atrium would receive blood from the venæ cavæ and also through a paradoxically patent foramen ovale from the left atrium. It was very common to find a Vieussens valve smaller than the foramen ovale. There is some evidence that the size of the left atrium depends upon the interatrial communication; however, we could not determine the exact relation between the size of the left atrium and the size of the communication. The right ventricle was very dilated and had a thick wall. In view of the hypertrophy of the right ventricle we believe that there was also a pressure overloading of this ventricle. The greater flow of blood through the pulmonary trunk determines a fivefold increase in relation to the hypoplastic ascending aorta. A dilated patent ductus arteriosus connects the pulmonary artery to the aorta. It is important to emphasize the patency of this vessel in relation to the survival of the patient since it is indispensable to the systemic flow. A good example of this fact is one case of this series in which a very short survival (one hour) was probably caused by a narrow ductus arteriosus. The left ventricle had a small and pyriform cavity with a thick wall. It is interesting to note that the case with mitral atresia had a thin left ventricular wall which is an obvious finding since it is well known that the pressure of blood inside the cavity is an essential condition for the hypertrophy of its wall (Edwards, 1948; Taussig, 1947). It is worth while to recall that the left ventricular wall in this case was so thin that the entire left ventricle was embedded within the wall of the right ventricle. This corroborates the general impression that a ventricle must contract against blood to induce hypertrophy. The ascending aorta was always patent in spite of the hypoplasia. This fact permitted the backward flow of blood across the ascending aorta, from the ductal segment to the coronary arteries, which is necessary for the patient's survival. There was no relation between the development of the ascending aorta and the size of the ductus arteriosus.

Thus, in aortic atresia, it appears that the blood flows from the right heart to the lungs and through the ductus arteriosus to the aorta. The oxygenated blood returns from the lungs to the left atrium and apparently forces its way through the foramen ovale, in a paradoxical fashion, from left to right. The unsaturated mixture of blood in the systemic circulation maintains life in a precarious way. The existence of this anomalous pathway is necessary to direct some oxygenated blood to the systemic circulation.

Cyanosis is caused by the unsaturated blood that flows through the ductus arteriosus. Another factor that contributes to the cyanosis is difficulty in emptying the left atrium, which constitutes an

obstacle to the free flow of the pulmonary circulation. This creates a stagnation of venous blood in the pulmonary veins, decreasing the blood oxygenation as needed, both in amount and velocity of flow. Evidence of this is given by the observation of venous hypertension and pulmonary oedema in the pathological examination of five cases. If this is true, it would be of great value to attempt a decrease of pressure in the left atrium by surgical enlargement of the interatrial communication. This type of operation could be performed in a closed heart through a purse in the right atrium (Bailey *et al.*, 1959). It would increase the amount of saturated blood reaching the systemic circulation and would decrease the left atrial pressure. It would constitute a temporary relief, with very unpredictable results. The same phenomenon that occurs with the left heart in aortic atresia is observed with the right heart in pulmonary atresia. It is a congenital defect causing hypoplasias and hyperplasias due to decrease and increase of blood flow respectively. It is logical to explain hypoplasia as a functional consequence of atresia, if we compare both conditions.

SUMMARY

Eight cases of aortic atresia are reported and the embryology and hæmodynamics of this congenital malformation are discussed. All were newborn infants who died during the first week of life. Clinically, they were characterized by dyspnoea, tachycardia, and progressive cyanosis. Anatomically, there was a dilated right atrium with dilatation and hypertrophy of the right ventricle. The pulmonary trunk had a fivefold increase in size, as compared with the ascending aorta. A paradoxically patent foramen ovale was generally noted. An open ductus arteriosus was the rule in all cases. The size of the left atrium was variable. The left ventricular wall was hypertrophied and the cavity was small and pyriform. The ascending aorta up to its ductal segment and the mitral valve were hypoplastic. In 62 per cent of the cases there was gross evidence of venous pulmonary hypertension and pulmonary oedema. The normal embryological events that lead to the formation of the aortic valve are reviewed.

The aortic atresia is explained by an excessive growth of the primitive semilunar cusps which adhere by their borders and extremities forming a true diaphragm. The main causative factors are discussed. The hypoplasia is explained as a functional consequence of the atresia. The blood apparently flows from the right heart to the lungs and across the ductus arteriosus to the aorta. The oxygenated blood returns to the left atrium and across a paradoxically patent foramen ovale to the right atrium. The heart practically functions like a cor biloculare with a single atrium filling a single ventricle.

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