Origin of Right Pulmonary Artery from Ascending Aorta

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A REVIEW of the literature reveals that origin of the right pulmonary artery from the ascending aorta is an extremely rare circumstance. The case reported by Ambrus is believed to be an example of this congenital malformation. Recently a similar case has been described in a clinicopathologic conference at the Mayo Clinic by DuShane and associates.

To the best of our knowledge, the following description represents the third example of the entity in the literature. Special attention was paid to two features: (1) the histologic structure of the right pulmonary artery, which is believed to be formed in part by a right ductus arteriosus, and (2) the structure of pulmonary arterial branches and arterioles, which we studied in both lungs because the vascularization differed significantly in the two. The specimen described in the aforementioned clinicopathologic conference was available for comparison of these features.

Report of Case

A white female infant was born to a 31-year-old primigravida. Pregnancy and hospital delivery had been uneventful, and the infant did well in the hospital. No cyanosis or distress was noted, and the infant was dismissed at the age of 5 days. During the following 2 weeks there was some difficulty with regurgitation and some irritability. On examination 10 days after dismissal no abnormalities of heart or lungs could be found. When 20 days old the patient suddenly died after feeding.

The relevant necropsy findings were confined to the heart, great vessels, and lungs. The heart was enlarged and showed right and left ventricular hypertrophy. All valves were normal, as was the atrial septum, except that there was a valvular-competent patent foramen ovale. The right ventricle gave rise to a large pulmonary trunk, which continued as a single wide pulmonary artery to the left lung (fig. 1a). No origin of the right pulmonary artery was found here. There was a short ductus arteriosus in the usual location, still patent but obviously in the process of closing. The aorta arose from the left ventricle. The arch was on the left side. The innominate artery, left common carotid artery, and left subclavian artery originated normally from the aortic arch. At the very base of the innominate artery a relatively long and thin right pulmonary artery originated from the ascending aorta (fig. 1b). Its lumen was narrow at the beginning and remained so for more than half of its length, but the distal portion was wide (fig. 2). The venous return to right and left atrium was normal. The right lung was large and markedly congested; the left lung was relatively small.

Histologically the ductus arteriosus on the left side presented the appearance usually found in the ductus shortly after birth: a thick media with a rather loose meshwork of elastic fibers, an internal elastic membrane, and a markedly thickened intimal layer. This layer, which in some areas had formed thick intimal cushions, was composed of a peculiar type of loose connective tissue with abundant collagenous fibers, relatively few elastic fibers, many smooth-muscle fibers, and much intercellular substance (fig. 3a, b, and c).

The structure of the long narrow portion of the right pulmonary artery was entirely similar to that described in the left ductus arteriosus, except that the media contained many thick elastic membranes (fig. 3d and e), just as did the distal part of the vessel. This latter portion had a normal appearance (fig. 3f), similar to that of the left pulmonary artery.

For studying the histologic structure of the pulmonary vascular tree, blocks were taken from 5 different segments of each lung. Sections of the paraffin-embedded blocks were stained with hematoxylin and eosin and with Lawson's elastic stain counterstained with van Gieson's.

A striking difference of thickness was found between the media of the muscular arteries in the right lung and that in the left. Quantitation was accomplished by the method described by Wagenvoort. The thickness of the media is expressed as a percentage of the diameter of the vessel. Increase of the thickness may result from vaso
constriction or from hypertrophy; decrease may

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Figure 1

be due to atrophy or dilatation. In our case the mean percentage in the right lung was 4.4 (fig. 4a); but in the left, where the pulmonary arterial branches were very thick-walled, the mean percentage was 15.4 (fig. 4b).

In a further stage, the area of the cross-sectional surface of media is related to the area of lung tissue in the slides. The ratio between vascular muscle tissue and pulmonary parenchyma is indicative of medial atrophy or hypertrophy. In the right lung the index was 121, and in the left it was 447.* The percentage and the index are quantitative expressions of the very marked difference in the appearances of the vessels in the two lungs.

Besides the abnormality of the media, the pulmonary arterial tree of the right lung showed concentric intimal proliferation in many vessels (fig. 4c). This intimal change was not combined with the elastic proliferation and splitting of the internal elastic layer, as seen in pulmonary hypertension; but in some small arteries it was so extensive that it caused almost complete obliteration of the lumen (fig. 4d). In the left lung no intimal lesions could be found.

Discussion
It has been suggested that origination of the right pulmonary artery from the ascending aorta might depend on abnormal development of the sixth aortic arch. A scheme of the aortic arches in a very early stage of development in the human embryo is given in fig. 5a. Of the original 6 pairs of arches, the third,
Figure 3

a. Intimal cushion in wall of left ductus arteriosus (hematoxylin and eosin stain). b. Wall of ductus arteriosus, showing loose connective tissue and smooth-muscle fibers (hematoxylin and eosin stain). c. Wall of ductus arteriosus, showing much compact elastic tissue in outer layer though most of ductus wall contained relatively few elastic fibers, separated by loose connective tissue (elastic-tissue stain). d. Wall of proximal part of right pulmonary artery: media contained many smooth-muscle fibers and much intercellular substance; intimal cushions consisted mainly of loose connective tissue (hematoxylin and eosin stain). e. Wall of proximal part of right pulmonary artery: intimal...
Figure 4

a. Pulmonary arterial branch in right lung, showing very thin media (elastic-tissue stain).
b. Pulmonary arterial branch in left lung, showing marked medial hypertrophy (elastic-tissue stain).
c. Pulmonary arterial branch in right lung, showing very thin media but marked degree of concentric intimal proliferation (elastic-tissue stain).
d. Pulmonary arterial branch of right lung, showing almost complete obliteration by intimal proliferation (hematoxylin and eosin).

cushions contained few elastic fibers; media contained many elastic membranes and resembled media of distal part of this artery (elastic-tissue stain). 
f. Wall of distal part of right pulmonary artery, showing parallel dense elastic membranes as seen in cases of pulmonary hypertension and in normal newborn (elastic-tissue stain).

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fourth, and sixth pairs remain, entirely or partly, as contributions to the definitive vascular system. The pulmonary arteries arise as branches from the corresponding sixth aortic arches. During normal further development the distal portion of the right sixth arch disappears, while the proximal part, in connection with the branch arising from the arch, forms the right pulmonary artery. On the left side normally the distal end of the sixth arch persists as the ductus arteriosus (fig. 5b).

When the distal end of the right sixth arch
Figure 5

Development of origin of right pulmonary artery from ascending aorta. R.D.A., L.D.A. = right and left dorsal aorta; R.VI, L.VI = right and left sixth aortic arch; R.P.A., L.P.A. = right and left pulmonary artery; R.S., L.S. = right and left subclavian artery; R.C., L.C. = right and left common carotid artery; I.A. = innominate artery; R.D., L.D. = right and left ductus arteriosus.

a. Modification of early stages of normal in which right dorsal aorta and fourth and sixth pairs of aortic arches are present. The modification involves placement of subclavian arteries as shown, at a more cephalad level than sixth aortic arches. Normally subclavian arteries lie in caudal position at this stage, and shift later, by differential growth, to position shown in this diagram. From sixth arches, right and left pulmonary arteries have arisen.

b. Normal situation at time of birth. Right dorsal aorta and distal part of right sixth aortic arch have disappeared. Distal part of left sixth arch forms (left) ductus arteriosus.

c. Persistence of part of right dorsal aorta and of whole right sixth arch. This situation represents double ductus arteriosus of type reported by Kelsey and associates. d. Developmental bases for the malformation reported here—origin of right pulmonary artery from ascending aorta. Persistence of part of right dorsal aorta and of distal part of right sixth arch. Proximal part of this arch, however, has disappeared. Since a ductus arteriosus represents distal part of a sixth aortic arch, this case fails to disappear, a symmetrical configuration of the great vessels eventuates with formation of an arcade (fig. 5e). This extremely rare situation, which indeed is a double ductus arteriosus, has been reported before.

In our case it is supposed that the proximal part of the sixth arch (which normally persists) was interrupted, and that the distal end (which normally disappears) was retained. As a result the right pulmonary artery originated entirely from the aorta (fig. 5d). If this supposition is correct, the proximal part of the right pulmonary artery was formed by the right dorsal aorta, and the distal part by the branch from the sixth arch, whereas a central part was formed by a right-sided ductus arteriosus. For this reason our case also is considered an example of double ductus arteriosus.

Ambrus believed that the right pulmonary artery in his case had developed as an anomalous branch from the fifth right aortic arch. Such an origin, however, seems not very likely, since the fifth pair of aortic arches in the human embryo are present during only a very short period and since normally only the sixth pair give rise to branches destined for the pulmonary circulation. No structures other than those which normally enter into the formation of the pulmonary arteries need be considered in explaining the developmental basis for the malformation here encountered.

The presence of typical ductal tissue in the proximal course of the narrowed right pulmonary artery gives strong support to the concept that in part this vessel is a ductus arteriosus. In the case reported by DuShane and associates, which also was studied by us, we found ductal tissue in the left ductus arteriosus, as could be expected. The right pulmonary artery, which in that case was very wide, contained in the portion close to the aortic origin a marked intimal thickening consisting of loose connective tissue. Whether this also was ductal tissue or just a patch of intimal sclerosis could not be established.
RIGHT PULMONARY ARTERY

An interesting aspect of the presently reported case was the structure of the pulmonary arterial branches, for the vascularization in the two lungs was entirely different. The cause of the intimal proliferation in several branches of the arterial tree of the right lung remains obscure. It did not resemble the intimal thickening with elastic proliferation seen in pulmonary hypertension, nor did it suggest organization of thrombi. No such proliferation was found in the left lung.

Also, the media of the muscular pulmonary arteries was markedly different in both lungs. The mean relative medial thickness in the right lung, 4.4 per cent, is very low for an infant of 3 weeks. In studying a group of lungs of normal infants we found\(^3\) that in the age period of 2 to 5 weeks the mean medial thickness of the pulmonary arteries ranged from 8.0 to 12.8 per cent of the diameters of the vessels. In the present case the index of the medial surface area per square centimeter of lung tissue was 121 in the right lung, while in the control group the range was from 180 to 257. Therefore we have concluded that the pulmonary arterial tree in the right lung shows medial atrophy. We believe this atrophy is related to the almost complete obliteration of the right main pulmonary artery. Probably both the narrowing of the right pulmonary artery and the medial atrophy in its branches began during fetal life.

It should be noted, however, that the configuration of the elastic tissue in the wall of the right pulmonary artery was similar to that in the left, showing the structure characteristic of a fetal pulmonary artery. This observation suggests that the stenosis occurred rather late in fetal life. Otherwise the pulmonary arterial wall might have shown a more irregular pattern of the elastic fibers.\(^4\) It seems likely that the narrowing in this case represents the normal closing of the right ductus arteriosus.

In the arteries of the left lung, however, the mean medial thickness was 15.4 per cent of the diameter of the vessels, and the index of the mean medial surface area per square centimeter was 447. In comparison with figures derived from normal lung vessels these quantities are very high and indicate medial hypertrophy. Since the left pulmonary artery was wide and was connected with the aorta by a patent left ductus arteriosus, we suppose that this medial hypertrophy is the expression of a persistent high pressure in the left pulmonary circulation.

As a parallel, the pulmonary vascular tree in the case of DuShane and associates\(^2\) was studied in the same way. That patient had been 4 months old at death. Her condition had been identical with that of our patient, except that the right pulmonary artery, which also originated from the aorta, was not stenotic but widely patent throughout. As in our case, the ductus arteriosus was patent.

The mean medial thicknesses in right and left lung were 13.6 and 13.4 per cent, and the mean medial surface areas per square centimeter of lung tissue in right and left lung were 388 and 309. Among cases of comparable age in our series of normal lungs\(^5\) the mean medial thickness was 7.7 per cent and the mean medial surface area 132. This shows that in DuShane and associates’ case there was marked medial hypertrophy, roughly equal in the two lungs. The finding is in agreement with the expectation of pulmonary arterial medial hypertrophy when the pulmonary circulation is in open communication with the aorta and the pulmonary arterial pressure is at systemic level.

Summary

A case is reported of a 20-day-old infant with origin of the right pulmonary artery from the ascending aorta. Besides its abnormal origin, the artery was stenotic in its proximal half. We believe the malformation results from persistence of the distal (instead of the proximal) part of the primitive sixth aortic arch and of a portion of the right dorsal aorta. The presence of ductal tissue in the wall of the right pulmonary artery supports this concept.

The pulmonary vasculature in the two lungs showed great differences in medial and intimal characteristics. A second case of origin of the right pulmonary artery from the aorta, de-
scribed elsewhere, provided material for comparative study of the structure of the right main pulmonary arteries and the intrapulmonary branches.

References

If therefore some may be apt to think that I have sometimes too far indulged conjecture, in the inferences I have drawn from the events of some experiments; they ought to consider that it is from these kind of conjectures that fresh discoveries first take their rise; for though some of them may prove false, yet they often lead to further and new discoveries. It is by the like conjectures that I have been led on step by step, through this long and laborious series of experiments; in any of which I did not certainly know what the event would be, till I had made the trial, which trial often led on to more conjectures, and farther experiments.—STEPHEN HALE, B.D., F.R.S. Haemastatics. Preface, Vol. II, London, 1733.
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