Magnetic resonance imaging of the pulmonary arteries and their systemic connections in pulmonary atresia: comparison with angiographic and surgical findings

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SUMMARY Patients with pulmonary atresia require several investigations and operations. The role of magnetic resonance imaging in assessing the anatomy of the central pulmonary arteries, the origin and course of systemic collateral arteries, and the patency of surgical shunts has been studied with the aim of reducing the need for invasive angiography. Transverse, coronal, and sagittal images were obtained in ten adult patients and assessed without knowledge of surgical and angiographic data. Central pulmonary artery anatomy varied from full development to complete absence. Transverse slices showed hypoplastic arteries particularly well and the findings accorded with surgical and angiographic data in all patients. The origin and proximal course of 15 large collaterals were identified on the magnetic resonance images and 18 were identified by surgical and angiographic data. Magnetic resonance imaging did not show their distal connections; if such information is required angiography will be needed. Five surgical shunts were shown to be patent and two occluded at surgery and angiography, and this was confirmed on the magnetic resonance images. The patency of a further four shunts was uncertain, but they were not seen by magnetic resonance and were presumed to be occluded.

Patients with pulmonary atresia depend upon branches of the systemic circulation to provide a pulmonary blood supply. Development of pulmonary arteries centrally and segmentally is variable, as is the size and number of the systemic collateral arteries, and there tends to be an inverse relation between the two.¹ Successful palliative or radical reparative surgery depends on complete demonstration of both, and currently this information cannot be obtained non-invasively, but requires angiography with multiple contrast injections and selective catheterisation of individual collateral arteries.²⁻⁴ It is also important to establish the state of surgical shunts.⁵

The role of magnetic resonance imaging in assessing the anatomy of the central pulmonary arteries, the origin and course of systemic collateral arteries, and the patency of surgical shunts has been studied and compared with angiographic and surgical findings with the ultimate aim of reducing the need for invasive investigation.

Patients and methods

We studied 10 adult patients (seven men and three women aged 19-40 (mean 24)). We chose to study adults because sedation was not used and it was essential for the patients to lie still during the acquisition of the images. Eight had a subaortic ventricular septal defect with normal atrioventricular connections. Two had abnormal atrioventricular connections. Up to the time of the study a total of 39 angiographic investigations and 13 operations had

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been performed in the 10 patients (table).

The magnetic resonance images were acquired with a Picker International Vista MR2055 machine with a superconducting magnet operating at 0.5 T. A spin echo sequence (echo time 40 ms) was used, and the radiofrequency signals were received with specially constructed thoracic surface coils. Images were acquired in transverse, coronal, and sagittal planes through the area of interest. Six or eight 1 cm thick tomographic slices were obtained simultaneously with electrocardiographic gating. Where indicated these were repeated with an offset of 0.5 cm to give an interleaved set of 1 cm thick slices 0.5 cm apart. The pixel size was 1.2 mm × 1.2 mm and each group of slices was obtained over 256 cardiac cycles, consisting of two acquisitions for each of 128 phase encoding steps. In order to maximise the contrast between moving blood and soft tissue, data acquisition was concentrated into the systolic period, and by use of the minimum repeat time it was possible to acquire eight slices within 560 ms of

Fig 1 Magnetic resonance image of coronal slice in patient 8 showing hypoplastic central pulmonary arteries (arrows). The aortic arch (AA) is to the right. LA, left atrium; RA, right atrium; T, trachea; VS, ventricular septum.

Table Data on patients

Patient No	Age (yr)	Sex	Diagnosis	Angiography	
				Date	Findings
1	28	M	Pulmonary atresia, tricuspid atresia	1964	
				1970	
				1976	
				1977	LPA seen
				1979	Small RPA, no LPA
				1982	Shunt blocked, multiple collaterals
2	23	M	Pulmonary atresia, VSD	1985	No PAs seen
				1965	
				1974	4 collaterals from descending aorta
				1978	Small central PAs
				1980	Patent shunt
3	22	M	Pulmonary atresia, VSD	1966	
				1969	3 collaterals: no PAs seen
				1976	2 collaterals: no PAs
				1978	LPA seen
				1985	No shunt seen
4	22	M	Pulmonary atresia, VSD	1965	No PAs seen
				1975	
				1981	Patent shunt
				1986	Patent shunt: small RPA: 1 collateral on right
				1969	
5	19	M	Pulmonary atresia, TAPVD, single atrium, single ventricle	1969	
				1978	
				1983	No PAs seen
				1984	
6	19	M	Pulmonary atresia, VSD	1969	
				1974	Multiple small collaterals: no PAs seen
				1977	Small central PAs
				1980	Confluent PAs
				1984	Both shunts patent: 1 collateral on right
7	19	M	Pulmonary atresia, VSD	1971	
				1976	No PAs
				1979	2 collaterals to left, 1 collateral to right
				1945	
8	40	F	Pulmonary atresia, VSD	1984	Collaterals to right and left: PAs not seen
				1984	1 collateral to left, 2 collaterals to right, small confluent PAs
				1984	Confluent PAs, no collaterals seen
9	28	F	Fallot: acquired pulmonary atresia	1963	
10	19	F	Pulmonary atresia, VSD	1966	
				1972	No PAs seen, 1 collateral
				1981	2 collaterals to right, 1 collateral to left

Ao, aorta; collateral, systemic-pulmonary collateral artery; L, left; PA, pulmonary artery; PT, pulmonary trunk; R, right; SA, subclavian artery; TAPVD, total anomalous pulmonary venous drainage; VSD, ventricular septal defect.

Fig 2 Magnetic resonance image of transverse slice in patient 6 showing hypoplastic central pulmonary arteries (arrows). AsA, ascending aorta; SVC, superior vena cava; LSVC, left superior vena cava; DA, descending aorta.

the R wave. The magnetic resonance images were interpreted without knowledge of the other findings and were subsequently compared with the most recent angiographic and surgical data.

Results

The table summarises the results. Confluent pulmonary arteries were seen on the magnetic resonance images in six patients (figs 1 and 2). They could be readily identified from their shape and position in the mediastinum. In five the picture accorded with the angiographic and surgical findings. In the sixth (patient 5) no central pulmonary arteries were seen at angiography or surgery, but they could have been missed owing to their small size.

A total of 15 collateral origins from the descending aorta could be identified on the magnetic resonance images compared with 18 on angiography (figs 3 and 4). Two were missed in patient 10, but the images were technically inadequate. It was possible to fol-

Surgery				
Site	Findings	Procedure	Magnetic resonance	Patient No
				1
972		Attempted Ao-RPA shunt	Small LPA, no RPA	
979	LPA 5 mm	Duramater Ao-LPA shunt	No collaterals	
982	LPA and shunt block	Exploration LPA	No shunt seen	
			Confluent PAs	2
			2 collaterals to left	
			1 collateral to right and left	
979	Small confluent PAs	Ao-PT direct shunt	Ao-PA shunt patent	
			Confluent PAs	3
			1 collateral to right	
			1 collateral to left	
969	2.5 mm left hilar vessel	Left Ao-collateral shunt	No shunt seen	
			Large LPA: small RPA	4
			No collaterals	
965	Small LPA	Left Blalock shunt	Patent shunt	
			Confluent PAs	5
			1 collateral to right	
984	No PAs: 2 collaterals to right	RSA-collateral shunt	No shunt seen	
				6
			Confluent PAs	
978	RPA present	Right Blalock shunt	1 collateral (?) side	
982	LPA 5 mm	Left Blalock shunt	Patent shunts	
			No PAs seen	7
			3 collaterals to left, 1 collateral to right	
978	3 mm right hilar vessel	Right Ao-collateral shunt	Patent shunt	
			Confluent PAs	8
			2 collaterals to left	
			1 collateral to right	
984	Confluent PAs, LPA 3 mm, RPA 2 mm	Ao-confluence shunt	No shunt seen	
			Confluent PAs. No collaterals	9
963	RPA present	Left Blalock shunt	No shunt seen	10
			Non-confluent PAs	
981	LPA 5 mm, 2 collaterals to left	Left Blalock shunt	1 collateral to left

Fig 3 Magnetic resonance image of transverse slice in patient 8 showing origin of systemic-pulmonary collateral (arrow) from descending aorta which is of a similar diameter. The vessel has a stenosis and passes to the left hilum. SVC, superior vena cava; AA, ascending aorta; DA, descending aorta.

low the course of most of the collaterals to the hilum, but not possible to establish their distal connections and interconnections. This is in contrast with selective angiography where such information can usually be obtained.

The magnetic resonance images and angiographic and surgical findings showed that five of the 11 surgical shunts were patent and two were blocked (figs 5 and 6). The state of the other four shunts on the angiograms was uncertain, but as they were not seen on the magnetic resonance images they were assumed to be occluded.

Discussion

Many patients with pulmonary atresia who survive into adult life have undergone multiple investigations and operations, like the ten patients in this study. At catheterisation there are practical problems in providing a complete angiographic assessment. Aortic flow is usually high so that aortography alone is inadequate. Selective catheterisation is necessary and failure to intubate all the branches is common, so that even in the first instance more than one investigation may be required to demonstrate the complete anatomy.⁶ The vital information is the size and connections of the central pulmonary arteries, which may be difficult to see on angiography as they are rarely connected directly to the aorta and fill only by retrograde flow.⁷ In some instances pulmonary venous wedge angiography may be necessary to demonstrate them.⁸ These vessels could be easily identified

on the magnetic resonance images from their resemblance to a seagull in flight and their position in the mediastinum.³

In contrast, the number of origins of collateral arteries arising from the descending aorta were underestimated on the magnetic resonance images; this may be because it is difficult to be certain about the number of origins from the aorta on selective angiography, as an early bifurcation may lead to an overestimation. Beyond the origin of these vessels, it

Fig 4 Magnetic resonance image of transverse slice in patient 3 showing origin of systemic-pulmonary collateral (arrows) from descending aorta (DA) passing to left hilum. AsA, ascending aorta.

Fig 5 Magnetic resonance images of contiguous transverse slices (a-d) in patient 5 showing widely patent left Blalock shunt (LBS). Slice a is cranial at the level of the aortic arch and slice d caudal through the hilar region. AA, aortic arch; AsA, ascending aorta; DA, descending aorta; LSVC, left superior vena cava; T, trachea; LPA, left pulmonary artery.

was possible in most instances to follow them to the hilum but not possible to establish their distal vascular connections. This information is of importance when planning operation, as the number of segments in the lungs to which the true pulmonary arteries, as opposed to collateral arteries only, are connected is an important determinant of prognosis.⁹⁻¹¹ Selective angiography remains the only method of demonstrating such connections and therefore will still be required for this purpose.

There was good agreement between the magnetic resonance and the angiographic and surgical findings on the state of surgical shunts. In those four patients in whom the state of the shunt was uncertain from the angiographic data, failure to visualise a

patent shunt by magnetic resonance was an indication that the shunt was likely to be occluded.

Magnetic resonance imaging in pulmonary atresia provides an alternative non-invasive method of obtaining much of the anatomical information required to plan surgical treatment and should reduce the need for invasive angiography in these patients.

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Fig 6 Magnetic resonance image of transverse slice in patient 6 through aortic arch (AA) showing patent right (RBS) and left (LBS) Blalock shunts. SVC, superior vena cava; T, trachea.

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