Major aorto-pulmonary collateral arteries of patients with pulmonary atresia and ventricular septal defect are dilated bronchial arteries

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Abstract

Objective: To test the hypothesis that major aorto-pulmonary collaterals (MAPCAs) have the same anatomy as bronchial arteries. Methods: Two hundred and thirty-eight angiographies performed on 61 patients with pulmonary atresia, ventricular septal defect (VSD), and MAPCAs constituted the basis for this study. This represented all available angiographies performed on this patient group at our institution during the period 1972—2001. MAPCA anatomy was compared to bronchial artery anatomy as described in previous publications. Results: Each patient had one to five MAPCAs (mean 3.2 ± 0.94). A mean of 2.6 ± 0.66 MAPCAs came from the descending aorta. MAPCAs with anatomy similar to right intercosto-bronchial arteries were found in 87% of the patients. Fifty percent of the patients had MAPCAs originating from the subclavian artery regions. These numbers were all similar to those previously described for bronchial arteries. All MAPCAs had anatomy similar to bronchial arteries. The distribution in different branching patterns of MAPCAs arising from the aorta was similar to the distribution of bronchial arteries described in previous angiographic studies (p = 0.32 and p = 0.24). Conclusions: In patients with pulmonary atresia and VSD, MAPCAs are likely to be dilated bronchial arteries. Bronchial arteries may have limited growth potential and their known vasoreactivity might preclude any long-term beneficial effects of unifocalization procedures.

Keywords: MAPCA; Bronchial arteries; Pulmonary atresia; Congenital heart disease

1. Introduction

All patients born with pulmonary atresia, ventricular septal defect (VSD) and closed ductus arteriosus depend on lung perfusion from systemic collaterals for survival. Systemic collateral arteries from the aorta and subclavian artery regions, perfusing the lung parenchyma, have previously been named major aorto-pulmonary collateral arteries (MAPCAs) or systemic-pulmonary collateral arteries. It has been presumed that arteries, that did not have this initial destiny, developed to supply the native pulmonary circulation. MAPCAs have been the focus of multiple procedures that have been applied to these vessels, including ligation, embolization, and unifocalization to connect these vessels to native pulmonary arteries. However, very little is known about their embryological development and anatomy.

In this retrospective study, we have reviewed angiographies of patients with pulmonary atresia and VSD whose lung perfusion depended exclusively on systemic collateral arteries. The purpose of this study was to investigate whether these collateral arteries had the same anatomy as bronchial arteries, and could be regarded as dilated bronchial arteries.

The term MAPCAs has been used in the literature to describe all systemic to pulmonary collateral vessels, despite the fact that some of them are small, and some arise from branches of the aorta rather than directly from the aorta. To avoid confusion in nomenclature we have used the term ‘MAPCA’ to refer to all arteries branching from the systemic circulation and entering the lungs irrespective of their size, origin, or number. We have not distinguished between the nature and size of these vessels, but merely described their anatomy, and compared this to the previously described anatomy of the bronchial arteries [1—4].
1.1. Anatomy of the bronchial arteries

The anatomy of the bronchial arteries has been described in publications based on cadaver dissections [1,2], angiographies of patients with hemoptysis [4], and transplanted lungs [3]. The bronchial arteries have been found to originate from the following vessels: the descending thoracic aorta, the abdominal aorta, the brachiocephalic artery, the subclavian arteries, and their branches. The number as well as the branching patterns of the bronchial arteries show a high inter-individual variation.

Bronchial arteries leave the descending aorta above the fourth pair of segmental arteries. The number of bronchial arteries arising from the descending aorta varies from one to five per patient and the mean number of bronchial arteries per patient has been reported to vary between 2.3 and 2.9 [3,4]. Each bronchial artery may perfuse lobes in only one lung, or may leave the aorta as a trunk with branches for lobes in both lungs. In normal individuals, bronchial arteries are distributed to all lung lobes [1].

One type of bronchial artery has distinct anatomical features, easily recognized on angiography. The so-called right intercosto-bronchial artery leaves the descending aorta from the right branch of the first or second pair of segmental arteries [1]. As opposed to all other bronchial arteries it passes behind the esophagus. It then branches into the first right intercostal artery, and a right bronchial artery, which follows the branching of the right-sided airways.

Two studies have described the central branching patterns of the bronchial arteries from the descending aorta. Uflacker et al. [4], based on angiographic materials collected from 72 patients with life-threatening hemoptysis, described 10 different patterns. Nørgaard et al. [3] on the basis of 50 arteriographies of double lung transplanted patients with complete bronchial artery revascularization, divided branching patterns into six groups. Both these studies only described those bronchial arteries arising from the descending aorta. Only one large study performed on 40 cadaver dissections demonstrated that bronchial arteries also arise from the subclavian regions (the aortic isthmus, the brachiocephalic trunk, the subclavian arteries, or their side branches) [2]. The bronchial arteries arising from these vessels may perfuse the same-sided or the opposite lung, or both.

1.2. Microscopic anatomy and physiology of the bronchial arteries

In addition to perfusing extrapulmonary structures such as mediastinal lymph nodes and esophagus, bronchial arteries communicate with pulmonary arteries at precapillary level, through so-called bronchopulmonary shunts (Fig. 1). These shunts usually have a tortuous, coiled course and have been reported to measure 20—125 μm in external diameter [5—7]. Their walls contain spiral musculature and have contractile potential [5]. The variability of bronchial artery flow in response to vasodilating agents has been demonstrated in...
humans [8]. Multiple animal studies have described the physiology of bronchial artery flow regulation as response to physiological and pharmacological stimuli including changes in FiO₂ and FiCO₂ [9—17].

2. Materials and methods

The design of the study was submitted and approved by the hospital ethics committee.

All available angiographies from patients with pulmonary atresia, ventricular septal defect, and lung perfusion depending exclusively from MAPCAs, performed at the Royal Children’s Hospital, Melbourne during the period 1972—2001 were reviewed.

Angiographies were available for 66 patients. In five patients, the studies had been performed after MAPCAs unifocalization or ligation, or insufficient contrast injections made the assessment of MAPCA anatomy impossible. These patients were excluded from the study. The remaining 61 patients had a total of 238 angiographies. For eight patients, only one angiography was available, and the remaining 53 patients had a mean of 4.3 ± 1.7 angiographies (range 2—8).

Since the available angiographies were performed as part of assessment of patients prior to surgery, and not as a part of an anatomical study, not all angiographies allowed investigations of all parts of MAPCA anatomy. The angiography of a specific region (i.e., descending aorta or right/left subclavian artery regions) had to be obtained before any surgery was performed on the region. To estimate whether MAPCAs passed behind the esophagus (right intercosto-bronchial artery anatomy), two projection arteriographies of sufficient technical quality were necessary (n = 23). To study MAPCA branching patterns, the descending aorta had to be injected with sufficient contrast to visualize all side branches (n = 44).

To describe the MAPCAs from the subclavian artery regions and compare this to Kasai and Chiba’s [2] description of the bronchial arteries, the subclavian region had to be injected with sufficient contrast (bilateral n = 40, right only n = 4, left only n = 4).

Vascular anatomy was reviewed in two angiographic planes. The following parameters were recorded: side of the descending aorta, vessels from which the MAPCAs originated, existence of a right intercosto-bronchial artery, number and branching of the MAPCAs, and the presence of communication with hypoplastic native central pulmonary arteries.

All branches from descending aorta were delineated and their branching pattern was classified according to the different branching patterns of bronchial arteries described by Nørgaard et al. [3] (Figs. 2 and 3). The distribution of the MAPCAs of our patients in these different branching patterns was compared to the distribution of bronchial arteries under the same classification of branching patterns in the series of Uflacker et al. [4] and Nørgaard et al. [3].

We compared the incidence of MAPCAs arising from the left and right subclavian artery and their distribution in branches feeding the right, the left, or both lungs in our patient series to the only published series reporting this data [2]. In this work, Kasai et al. reported bronchial arteries branching from the subclavian vessels, and the aorta above the level of the left recurrent laryngeal nerve. We reported MAPCAs from this area of the aorta as belonging to the subclavian artery region, and have summarized Kasai et al.’s findings similarly.

2.1. Statistical analysis

Data were analyzed using Statistica 6.0® (StatSoft® Inc., Tulsa, OK, USA).

Data were reported as mean ± one standard deviation. Range was reported when appropriate. The comparison of the distribution of MAPCAs for the current study group with
the previous series of Uflacker and Nørgaard was performed by chi-square analysis. This was also repeated separately by unpaired t tests with similar results.

3. Results

Twenty-seven (44%) patients had a right aortic arch. A total of 180 MAPCAs were identified. One hundred and forty-four MAPCAs arose from the descending aorta, 34 from the subclavian artery regions, and two from the juxta-diaphragmatic aorta.

3.1. Complete arborization of MAPCAs to both lungs

In 37 patients, sufficient angiographic investigations of all vascular regions (bilaterial subclavian regions and descending aorta) allowed the delineation of all MAPCAs.

In these 37 patients, MAPCAs were distributed to all lung fields.

A total of 118 MAPCAs were identified. Each patient had between one and five MAPCAs (mean 3.2 ± 0.94 MAPCAs per patient). The right and the left lungs were supplied by a mean of 1.97 ± 0.64 and 1.97 ± 0.76 MAPCAs, respectively.

Twenty-six collaterals (22%) arose from the subclavian regions, 11 from the right side, and 15 from the left side. Ninety-two MAPCAs (78%) originated from the thoracic aorta below the isthmus and above the level of the fourth segmental arteries, 34 having an exclusive right distribution, 35 an exclusive left distribution, and 23 emerging as a truncus with a right and a left distribution. In two patients, MAPCAs were seen arising from the descending aorta just above the diaphragm and coursing in the inferior pulmonary ligament. Such arteries have previously been described as MAPCAs [18] as well as bronchial arteries [2,19]. Our angiographies rarely visualized this region, and the normal anatomy of bronchial arteries from this region has never been systematically described in any study. In 46% of the patients (17/37), contrast injection into one or another of the MAPCAs filled the central hypoplastic native pulmonary arteries via collaterals.

3.2. MAPCAs originating from the descending aorta

Angiography delineated all MAPCAs arising from the descending thoracic aorta in a total of 44 patients. A mean of 2.6 ± 0.66 MAPCAs per patient arose from the aorta (range 1–4). There was a total of 113 MAPCAs. They all arose from the aorta below the isthmus and above the level of the fourth pair of segmental arteries, and followed the airways. Forty-four went to the right, 42 to the left, and 27 originated as a truncus dividing into branches for both lungs.

The mean number of 2.6 MAPCAs arising from the descending aorta is similar to the number of 2.3 reported by Uflacker et al. [4] and 2.9 by Nørgaard et al. [3].

All these 44 patients showed branching patterns of the MAPCAs from the descending aorta identical to the previously described branching patterns of bronchial arteries [3,4]. In Table 1, the distribution in different branching patterns of our patient’s MAPCAs is compared to the distribution in branching patterns of bronchial arteries identified during autopsies studies in Uflacker’s work and of bronchial arteries visualized by angiography in Nørgaard study (Fig. 1). There was no difference in the distribution of MAPCAs in our patients and the distribution of bronchial arteries in the autopsy study (p = 0.32) and the distribution of bronchial arteries described by angiography (p = 0.24).

3.3. MAPCAs with anatomy similar to a right intercosto-bronchial artery

In 23 patients, angiographies enabled us to assess whether a MAPCA with anatomy similar to a right intercosto-bronchial artery was present. This was found in 20 (87%) of our patients.

A right intercosto-bronchial artery was present in 85% and 91% of previous autopsy reports [1,2], and 96% of patients undergoing an angiography for severe hemoptysis [4].

3.4. MAPCAs originating from the subclavian region

Forty-eight patients had injections of one or both subclavian arteries before surgery involving the MAPCAs was performed, permitting the study of 44 right and 44 left subclavian arteries. Forty patients had both subclavian arteries injected with contrast, and 20 of them (50%) had MAPCAs arising from the subclavian vessels: 8 patients had MAPCAs on both sides, 4 had only a right-sided MAPCA, and 8 had only a left-sided MAPCA. Four patients had only the right subclavian artery injected (two MAPCAs identified) and four had only the left subclavian artery injected (four MAPCAs found). We never found more than one MAPCA leaving any subclavian artery or its side branches.

The comparison between the incidence of MAPCAs arising from the subclavian arteries in the present study and of bronchial arteries arising from the subclavian arteries in Kasai’s work and their respective distribution is displayed in Table 2.

3.5. Incomplete visualization of some regions

In 17 patients, only a partial assessment of MAPCA anatomy was possible because these had either been unifocalized or ligated before angiography (n = 10), or because filling of the pulmonary arteries via other collaterals precluded an accurate assessment of the branching patterns (n = 4), or because only segments of the thoracic aorta had been injected.
In these 17 patients, 31 MAPCAs could still be identified. All the MAPCAs demonstrated anatomy and branching patterns similar to bronchial arteries.

4. Discussion

Current knowledge of the origin of MAPCAs in pulmonary atresia and VSD is vague and based on assumptions rather than facts [20,21]. The difficulty in identifying MAPCAs as bronchial arteries arose from the variability in the bronchial artery anatomy and the previous lack of accurate description of their various branching patterns. Bronchial arteries can originate from different vessels, from the subclavian region to the descending and juxta-diaphragmatic aorta. They can be configured as single or multiple vessels and their branching patterns are variable. We believe that MAPCAs are dilated bronchial arteries, because in the present series their anatomical positions, their numbers for each region as well as their branching patterns were similar to those of bronchial arteries. Furthermore, no other bronchial arteries could be identified in any patient.

Although the effects of hypoxia and hypercapnia on bronchial artery flow in humans remains to be demonstrated, it seems likely that flow changes may be observed following these stimuli, and explain their hypertrophy into MAPCAs in patients with pulmonary atresia (Fig. 1).

The understanding that MAPCAs are dilated bronchial arteries may influence our management of patients with pulmonary atresia and VSD, especially if we believe that these vessels may be subject to flow regulation through broncho-pulmonary shunts than to their flooding.

Lack of pulmonary blood flow in specific lung segments is more likely to be related to closure of broncho-pulmonary shunts than to their flooding.

There are potential limitations to the study. Despite the large number of subjects studied, this series may not take into consideration some rare forms of MAPCAs that have been described such as the one arising from coronary arteries [24]. Ideally, in order to ascertain our hypothesis, we would have liked to study histological sections of anastomosis between MAPCAs and native pulmonary arteries, but we did not have any specimens to analyze in the frame of this study.

In conclusion, in patients with pulmonary atresia and VSD, MAPCAs are likely to be dilated bronchial arteries because they share similar anatomic characteristics. Bronchial arteries may have limited growth potential and their known vasoreactivity might preclude any long-term beneficial effects of unifocalization procedures.

References


Appendix A. Conference discussion

Dr L.H. Edmunds (Philadelphia, PA, USA): So your recommendation is to try to develop the pulmonary artery vasculature with an early shunt?

Dr Edmunds: What we believe is that even when you don’t see central pulmonary arteries on the angiography, they’re still there. We have opened some patients where we haven’t been able to see the pulmonary arteries on the preoperative angiography, but they were there when we operated the patients and we were able to perform a shunt.

We are not recommending anything at the present stage. We have decided to change the policy at the Royal Children’s Hospital, but that doesn’t mean that everyone else should follow immediately. If I was at another center, I would wait for the results.

Dr Edmunds: Well, I’m going to ask you an unfair question, and I’m known for that.

Are you aware of any experimental work in which you would try to use an angiographic/angiogenic factor, like basic fibroblast growth factor, to stimulate the development of arteries in the pulmonary system?

Dr Nørgaard: Well, I don’t think it’s an unfair question. But no, I’m not aware of any such experimental studies.

Dr Edmunds: Well, that’s sort of an unfair answer.

Dr Nørgaard: Our cardiologist colleagues have tried to introduce growth factors into the coronary arteries, hoping that they’ll grow in adults with coronary artery disease, but I’m not aware of anyone who has done the same in pulmonary arteries.

Dr Edmunds: Well, you probably have a problem with the model, but I think that it would be at least something to look at at some point.

Dr D. Metras (Marseille, France): I must say that I agree totally with your last slide. And, our policy also is to try to promote growth of the pulmonary artery and try not to use the collaterals.

But my question is more directed to the topic of your presentation. What are the embryologic implications of your hypothesis that these collaterals are the same thing as bronchial? Because in my knowledge, the collaterals were persistence of the primary lung circulation. That’s quite different from the bronchial.

Dr Nørgaard: Well, this discussion was ongoing in the beginning of the 70s when no one really knew what these arteries were and no one had shown what the anatomy of these vessels looked like.

Some pathologists back then finished off the whole discussion, that had been going on for about a couple of years in the major journals, by saying that it was a complete misunderstanding that these arteries were bronchial arteries, and the reason that people could suggest this was that they had not understood the embryology of these vessels. However, this was never substantiated.

I don’t think anyone has histological proof that MAPCAs differ histologically from bronchial arteries. It would be very hard to make such a study. Nowadays these patients don’t die. In the last two years, they haven’t lost a patient like this in Melbourne. Frank Hanley is able to make more than 95% of these patients survive using unfocalization, which works well in his hands.

It would be very hard to make an anatomical study, but what you would need to do was to perform a dye-cast injection of these vessels followed by microdissection in order to sort out whether our theory is correct.

Dr Metras: Because if the MAPCAs were bronchial arteries, then bronchial arteries in normal people should also come from subclavian, carotid, and no aorta, which does not occur.

Dr Nørgaard: Indeed, bronchial arteries in normal individuals do arise from the subclavian artery regions. The materials that I have compared have been performed in normal individuals.

I know you’ve been involved in lung transplantation with bronchial artery revascularization as well. Even though, when we perform lung transplantsations with bronchial artery revascularization, we concentrate on the bronchial arteries coming from the descending aorta (and this appears to be enough to revascularize the pericarinal area) it’s well described that bronchial arteries arise from the subclavian regions as well.

Dr C. Brizard (Melbourne, Australia): Just one answer to your question, Dr Edmunds.

There has been a study done in Marie Lannelongue in Paris where vascular endothelial growth factor gene has been transfected to the pulmonary arteries using respiratory virus factor (Ann Thorac Surg 2004;77:458–63).