

Original Research

Anastomoses Between Bronchial and Coronary Circulation in a Porcine Model: Computed Tomographic and Angiographic Demonstration

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Introduction: Although the importance of the bronchial arteries is evident in modern day thoracic surgery, the significance of their communications with coronary arteries has yet to be appreciated, especially in cases of heart-lung transplantation and aortic aneurysm repair. We conducted a study to demonstrate the coronary-bronchial anastomotic routes in a porcine model using angiography and computed tomography.

Methods: Six young female white pigs were used. The heart and lungs were removed *en bloc*, including the lower trachea and oesophagus. Digital subtraction angiography of the bronchial circulation and spiral computed tomography scan were performed in a three-phase study before and after administration of contrast medium. This was achieved by infusion either into the cannulated bronchial artery or into the aortic root. Macroscopic evaluation was carried out using latex infusion into the bronchial or coronary circulation.

Results: We demonstrated communications between the bronchial and coronary systems in 5 of 6 subjects. This communication was located at the left atrial wall and the posterior and anterior wall of the left ventricle. In one case there were further anastomoses around the right atrial wall.

Conclusions: There were communications between the left coronary arteries and the bronchial arteries in the majority of cases. Digital subtraction angiography and spiral computer tomography scan can demonstrate these communications directly and indirectly by measurements of contrast enhancement within the heart wall. Our study emphasises the importance of the bronchial arteries in cases of heart-lung transplantation and repair of thoracic aortic aneurysms.

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The bronchial arteries, providing oxygenated blood under arterial pressure, are responsible for the nutrition of the lungs and the extracardiac mediastinal structures, including oesophagus, lymph nodes and autonomic nervous system. Nowadays, the identification and demonstration of their origin and course can be achieved using digital subtraction angiography (DSA) or spiral computed tomography (CT-scan).^{1,2}

Communications between the bronchial and coronary arteries have been reported anecdotally,³ while a few previous studies reported the existence of bronchial-coronary

anastomoses in man⁴⁻⁶ and in animals,⁷ but only as a result of an angiographic project.

Their importance is increasingly recognised, particularly in the setting of massive haemoptysis and infusion of chemotherapeutic agents in lung cancer cases.^{8,9} Although it seems that they reduce the postoperative complications in cases of lung transplantation, where they are reanastomosed,¹⁰ their role in heart-lung transplantation and in thoracic or thoraco-abdominal aortic aneurysm repair has not been investigated. Given that the porcine animal model is the most representative of human coronary and bronchial arterial systems,^{11,12} it was the aim

of our study to delineate the coronary-bronchial anastomotic routes in a pig model using either CT-scan or DSA and to correlate these with macroscopically demonstrable communications in order to validate the above observations.

Methods

Ethics

The animals received humane care in accordance with the directive of the European Community regarding the protection of animals used for experimental and other scientific purposes,¹³ and the study was approved by the Greek authorities for animal experimental studies.

Surgical methods

Six young female white pigs, mean weight 26 ± 3.1 kg, were used. Anaesthesia was induced with thiopentale (250-400 mg). The pigs were intubated through a tracheostomy and maintained with thiopentale (5 mg/kg/h), fentanyl (1 mg/kg/h) and pancouronium bromide (4 mg at regular intervals). The animals were operated on through a median sternotomy. After the pericardium was opened, the pigs were anticoagulated with heparin 300 IU/kg. The superior and inferior *vena cava* were ligated and with the heart still beating the heart and lungs were perfused with 2L of normal saline at room temperature to clear blood from the coronary and pulmonary circulation and cardiac chambers. Venous drainage was performed simultaneously to avoid oedema.

The heart, trachea and lungs, oesophagus, descending thoracic aorta and all mediastinal structures were removed *en bloc* by dissection from below the thyroid cartilage to the diaphragm. All visible vessels were ligated and the edges of pleura were sutured to each other to avoid the leakage of the contrast.

Radiological methods

DSA and CT-scan were performed in series. The contrast medium was injected at control pressure of 100 mmHg in two different ways: the bronchial circulation via the cannulated bronchial arteries (n=4) and the coronary circulation via the isolated aortic root (n=2).

DSA was performed in all blocks, using the angiographic unit DVIS Philips at 40 Kv, 1 image per second, with contrast medium injection (Iomeron 400, Bracco, Italy). One litre of normal saline was infused into each lung-heart block just after the DSA to remove the contrast medium. Following this, CT-scan was performed in

4 cases, acquired using a Somatom Plus 4 Power scanner (Siemens, Germany) in 2 mm slices for reconstruction. Scanning was performed in a three-phase study, before and after the administration of 50 ml contrast medium at 1 ml/s and in a delay phase at 2-3 minutes. Density measurements were obtained of the heart wall in all three phases of spiral CT-scan, in the form of region of interest (ROI). Technical issues prevented the administration of the contrast into the aortic root in 2 cases.

Macroscopy

Green latex (Vilene Hospital injecting and casting resin, MERCOX series, Japan) was administrated into the bronchial (n=4) and coronary circulation (n=2) and the outcome was evaluated macroscopically.

Results

Digital subtraction angiography

Selective angiography of the bronchial artery revealed clear communications between the bronchial and coronary circulations in three out of four blocks. The left coronary arteries were seen in all three cases, while the right coronary artery was detected in one. Subsequently the pulmonary outflow and coronary veins were detected in all three cases (Figure 1).

Isolated aortic root perfusion revealed the coronary arteries, coronary veins and bronchial arteries, but few collaterals with the oesophageal and mediastinal arteries around the left atrium were observed (Figure 2). Communications with the oesophageal arteries were present in all animals.

Spiral CT-Scan

Scanning after contrast administration in the bronchial circulation revealed small vessels around the left atrial surface, the left posterior and, to a lesser extent, the anterior ventricular wall in three out of four heart-lungs blocks. Additionally, the right coronary artery was filled in one out of four blocks.

Measurements from the cardiac wall (i.e. left ventricle) showed increasing density values for each phase, corresponding to contrast uptake. This is an indirect sign of cardiac perfusion through the bronchial arteries (Figure 3).

Macroscopy

The green-colored latex was easily detected macroscopically.

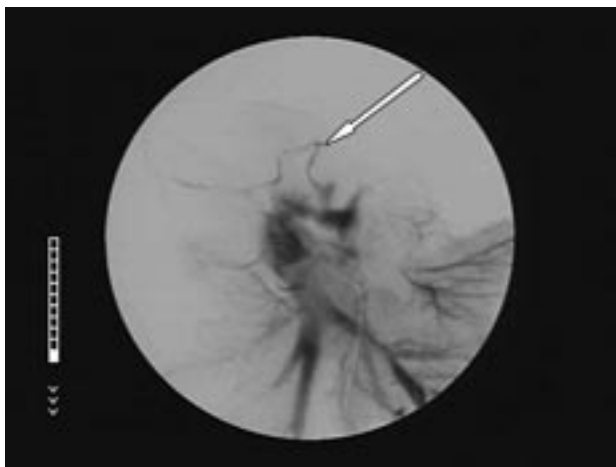


Figure 1. Fig 2. Digital subtraction angiography after the administration of contrast medium into the isolated thoracic aorta, including the bronchial artery. The arrow shows the communication with the coronary artery.

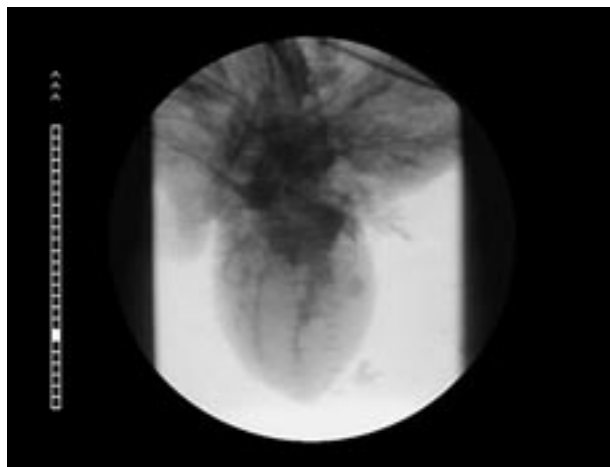


Figure 2. Fig 3. Digital subtraction angiography after the administration of contrast medium into the isolated aortic root. Demonstration of the bronchial circulation.



Figure 3. Spiral computed tomography (CT-Scan) in a three-phase study (Fig 4): a) Before administration of contrast medium phase. b) After administration of contrast medium phase. d) The delay phase.

pically in the bronchial arteries (2/2) after injection into the aortic root and in the heart after injection into the bronchial system (3/4). The oesophageal arteries and mediastinal collaterals were also observed. The latex was detected in the whole length of the oesophagus (Figure 4). The size of the main bronchial artery ranged from 1.8-2 mm, while the size of the coronary arteries ranged from 1.4-1.6 mm. As it would have required a corrosion cast study, we could not measure the size of the collaterals. However, their size was less than 0.10 mm compared to the angiographic catheter.

Discussion

The aim of our study was to assess not only the anastomoses between bronchial and coronary circulation in an experiment animal, using different radiological methods, but also their clinical importance.

The porcine broncho-oesophageal artery has a single aortic origin and is easily identified and controlled. In pigs, the bronchial branch of this arterial trunk arises as a single vessel, which divides into two branches and so is analogous to the human bronchial arteries.^{11,14,15} Each principal bronchus is followed by two bronchial artery branches.¹¹ The porcine model shows good homology, not only with human anatomy as regards origin, course, branching pattern and distribution of the bronchial artery circulation, but also with physiology, and so it is the most frequently studied animal model in this context.

White et al reported the existence of bronchial-coronary anastomoses in pigs, emphasising that the extracardiac sources of collateral flow, chiefly from the bronchial and internal mammary arteries, contribute up to 30% of the total non-vasodilated collateral flow potential in the bed at risk, hence indicating their impor-

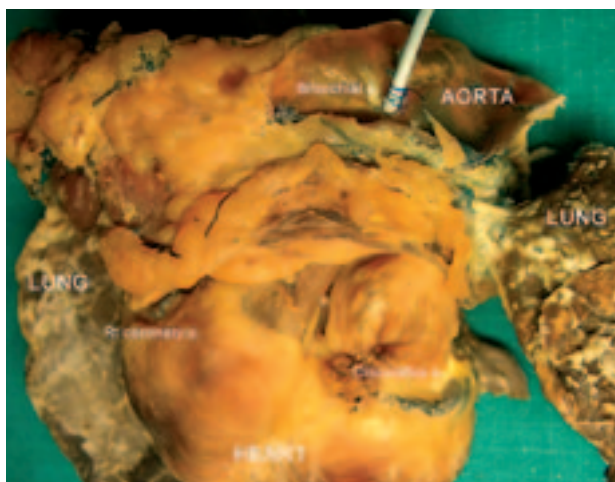


Figure 4. Fig 6. Detection of left and right coronary artery after the administration of green-coloured latex into the cannulated bronchial artery.

tance in the perfusion of ischaemic swine hearts.⁷ Although the bronchial-coronary anastomoses have been extensively investigated from a coronary point of view,^{7,16} Gade et al investigated the reverse situation of coronary-to-bronchial blood flow.¹⁷ In order to study this further, we used contrast medium injection not only in DSA, but also in CT-scan, as well as latex to demonstrate the bronchial arteries.

Previous studies have shown the usefulness of CT-scan to delineate the bronchial arteries *in vivo*, particularly on the right, but only in cases of enlarged and tortuous vessels and prior to bronchial arterial interventional procedures.^{1,2,18} In our study, we demonstrated the existence of bronchial-coronary anastomoses in a normal porcine heart-lung block model. The measurements taken in the cardiac wall for each of the three phases of the study showed a progressive increase in density values with respect to time, corresponding to contrast uptake by the heart. Communications between the bronchial and coronary arteries were clearly detected in the left atrial and the posterior and, to a lesser degree, the anterior ventricular wall in three out of four blocks, and in the right coronary artery in one case. This demonstrates the existence of a blood supply to the coronary arteries through the bronchial system. On the other hand, DSA depicted more information about the bronchial-coronary anastomotic route. The size of the bronchial and coronary arteries was up to 2 mm, while the calculated collaterals were less than 0.10 mm.

Variability in coronary anatomy is a frequent observation in humans and it is noteworthy that the bronchial arteries communicated with the left coronary arteries in the majority of cases, whereas only in one case

was there additional anastomosis with the right coronary artery. Although bronchial angiography revealed the oesophageal arteries in all cases, we did not detect any bronchial-oesophageal anastomoses; however, we could discern that these arteries were responsible for the blood supply of the distal oesophagus.

Our study of the reverse contribution, using angiography through the aortic root, revealed, apart from the coronary-bronchial anastomoses, only a few collaterals with the oesophageal and mediastinal arteries around the left atrium. Our findings agree partially with Gade et al, who described that the bronchial arteries communicate with coronary arteries, but with both of them in all cases.¹⁷ On the other hand, Riquet et al were not able to demonstrate anastomoses with both the right and left coronary arteries in the same subject in their study on cadavers, but highlighted the existence of the collateral bronchial-coronary circulation, especially in cases with severe coronary atheroma.¹⁹

Latex infusion permitted macroscopic examination of the bronchial-coronary anastomoses as adequate ligation of the visible vessels and suturing of the pleural edges prevented or minimised leakage into the mediastinum.

As our study showed, the bronchial arteries are not only the nutritive vessels for the lungs, but also contribute to the coronary circulation and *vice versa*. Therefore, we could argue that it might be useful to revascularise them during repair of thoracic or thoraco-abdominal aneurysms in patients suffering from ischaemic heart disease. That could be feasible, since the bronchial arteries originate from the descending aorta between the levels of the T5 and T6 vertebrae in 80% of cases.²⁰ Their revascularisation could be achieved using either the pedicled mammary artery or an aortic button, as occurs in lung transplantation cases.^{21,22} Moreover, in similar cases, but without ischaemic heart disease, it seems that the coronary arteries can contribute to the bronchial circulation because of the reverse distribution.

We also highlight the importance of bronchial circulation and bronchial-coronary anastomoses in cases of heart-lung transplantations. Cardiac allograft vasculopathy (CAV) is the major limiting factor for long-term survival after heart transplantation. The pathological features of CAV differ from those of coronary artery disease. It is typically characterised as a diffuse concentric proliferation of the intima. However, the pathophysiological features are not completely understood. The risk factors can be classified as immunological or non-immunological. The incidence of CAV is 42% in patients following heart transplantation after 5 years²³ and 11-

15% following heart-lung transplantation.²⁴ After heart-lung transplantation, persistent collateral vessels between the coronary circulation and the bronchial artery circulation may prevent severe ischaemia of the central airways and the tracheal anastomosis, explaining the low incidence of airway complications after heart-lung transplantations compared with *en bloc* dual lung transplantation without bronchial artery revascularisation.²¹ Moreover, the revascularised lungs are more resistant to infections, such as indicated by the study of lung abscesses in sheep.²⁵ We can postulate an active role for the bronchial circulation in such cases, either making the recipient more resistant to local infections by pathogens such as *Chlamydia pneumoniae* or viruses,²⁶ or maintaining the local physiological mediastinal status and contributing to the coronary circulation through these anastomoses, even in cases without tight coronary artery stenoses.

The limitations of our study represent those of *in vitro* studies. As we performed DSA and CT-scan in the lab, we were not able to study the normal cardiopulmonary circulation and to calculate collateral flow. Further experimental studies, laboratory-based and *in situ*, in pigs or cadavers, will be needed to investigate these inferences more exhaustively.

In conclusion, this study confirms the existence of communications between the bronchial and coronary systems in a porcine model and their mutual contribution. Both DSA and Spiral CT-scan can demonstrate these anastomoses. In most cases the communication is essentially between the bronchial arteries and left coronary arteries. Our study emphasises the importance of the bronchial arteries in cases of heart-lung transplantation and repair of thoracic aortic aneurysms.

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