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The porcine bronchial artery: surgical and angiographic anatomy

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ABSTRACT

The pig is often used in experimental studies on the significance of bronchial artery circulation, but the anatomy of this artery is only poorly described. The purpose of this study was to improve the anatomical basis for experimental studies on the porcine bronchial artery circulation. The origin of the artery from the aorta is described in 32 pigs. Heart–lung blocks were perfused with saline and removed in 16 pigs, and the broncho-oesophageal orifice was identified and cannulated. In these 16 specimens the intrapulmonary ramification was studied by angiography, and the extrapulmonary distribution and supply area by injection of Evans Blue. The broncho-oesophageal artery originated from the aorta as a single trunk in 91%. Angiography showed that each principal bronchus was accompanied by 2 bronchial artery branches far into the lung parenchyma. The central branching pattern of the artery between the aorta and the principal bronchi was divided into 3 subtypes. Evans Blue showed communication with the whole mediastinum. The anatomical relations are described. It is concluded that the broncho-oesophageal artery divides to follow each bronchus with 2 bronchial branches. A nomenclature for these branches is suggested. The pig anatomy is suited for experimental investigations on the bronchial circulation.

Key words: Vasculature; lung; bronchial anatomy.

INTRODUCTION

The bronchial arteries are of interest because of their role in lung infection (Charan et al. 1985), as a substitute for the pulmonary circulation (Jandik et al. 1993), and in lung transplantation, where bronchial artery revascularisation (BAR) is a new (Couraud et al. 1992), although controversial (Patterson, 1993), option. To study further the physiological significance of the bronchial arteries in relation to BAR an experimental animal model was needed. The pig is often used in experimental designs related to lung transplantation (Aoki et al. 1991; Dubrez et al. 1995; Herold et al. 1998), but the anatomy of its bronchial artery is poorly described (Schummer et al. 1981; Christensen & Mousing, 1992; Dyce et al. 1996). The extrapulmonary course has been described earlier (Calka, 1975), but the intrapulmonary course and angiographic appearance are unknown. The purpose of this study was to establish an anatomical basis for experimental studies of the porcine bronchial branches. In veterinary anatomy the preferred term is the 'bronchial branch of the broncho-oesophageal artery', the latter usually having a single aortic origin. In human anatomy, the bronchial arteries have separate origins and are termed as such. When describing porcine anatomy in this study, the term 'bronchial branch' or 'bronchial artery branch' is often employed as the equivalent of the human 'bronchial artery'. This is shorter and more convenient than the term 'bronchial branch of the broncho-oesophageal artery'.

MATERIAL AND METHODS

Material

Thirty-two female SPF pigs of Danish landrace/Yorkshire (cross-breed, DDY) from a production

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herd, weighing 30–40 kg, were used. The heart–lung blocks were removed in 16 pigs. Of these 6 were used for angiography, 6 for Evans Blue injection, and 4 for both. The central part of the broncho-oesophageal artery was identified surgically in all 32 cases, and its origin, orifice(s), and initial branches were noted. A segment of the right and left lung hilum was taken for microscopic examination in 2 pigs.

Surgical methods

Anaesthesia was induced with thiopentone 60 mg/kg. The pigs were intubated and continuously anaesthetised with N_2O and halothane. The 16 pigs used for angiography and Evans Blue injection were operated through a median sternotomy. These pigs were anticoagulated with heparin 1000 IU/kg. The superior caval vein or the right auricle of the heart was catheterised, and both the superior and inferior caval veins were ligated. With the heart still beating, the heart and lungs were perfused with 2 l of physiological saline at room temperature to clear the blood from the pulmonary circulation. Venous drainage was performed simultaneously to avoid oedema. The heart and lungs and all mediastinal structures ventral to the spine were removed en bloc by dissection from just below the thyroid cartilage to the diaphragm. The plane of dissection was as close to the spine as possible. The descending aorta was opened, and the origin of the broncho-oesophageal artery(ies) was noted.

The other 16 pigs were operated on under similar conditions for training purposes or other experiments not conflicting with the exposure of the broncho-oesophageal artery anatomy. In these pigs the aorta was opened, the number and location of the orifice of the broncho-oesophageal artery(ies) were noted, and the first 1 cm of its course was exposed. Specimens of the left and right lung hila, including the proximal principal bronchi, were taken from 2 of these pigs.

Evans Blue injection

Evans Blue was injected into the broncho-oesophageal artery of 10 heart-lung blocks to study the distribution and supply area of the bronchial branches. Four of these were also used for angiography. Up to 20 ml of Evans Blue was gradually injected. The result was evaluated macroscopically.

Radiological methods

Angiography was performed in 10 heart-lung blocks, 4 of which were also used for Evans Blue injection. The broncho-oesophageal artery was cannulated with a buttoned cannula and ligated around the cannula. The trachea was intubated and the lungs were fully inflated. Radiographs of the blocks were performed before and after the injection of 0.5, 1, 2, 10 and 20 ml of iopromide 370 mg/ml (Ultravist) within as short intervals as possible. Radiographs were taken with a Phillips Practix x-ray apparatus set at 55 kV and 20 mA for 0.25 s. The tube was placed 80 cm from the object, and a raster was applied.

Microscopy

Specimens of the right and left lung hila of 2 pigs were fixed with 10 % buffered formaldehyde and embedded in paraffin. Sections (3–5 μm) were stained with haematoxylin-eosin.

Anatomical terms

The porcine lungs and bronchial tree are lobulated differently from those in man in 2 important ways. First, the right cranial lobe has a separate, tracheal stem bronchus. Second, after the tracheal carina the airways primarily divide into 2 principal bronchi, giving branches to the cranial and caudal lobes on the left side, and to the middle, accessory and caudal lobes on the right side.

Ethics

The animals received humane care in accordance with the Helsinki convention for the use and care of animals, and the study was approved by the Danish Inspection for Animal Experiments.

RESULTS

Angiographic anatomy

The injection of 0.5–1 ml of iopromide demonstrated the bronchial branches from the aorta to more than three quarters of the way to the lung surface (Fig. 1 *a*). Each principal bronchus was accompanied by 2 major bronchial artery branches which ramified to follow the lobar and segmental bronchi. These major branches were named the *left medial* and *left lateral bronchial branches*, and the *right medial* and *right*

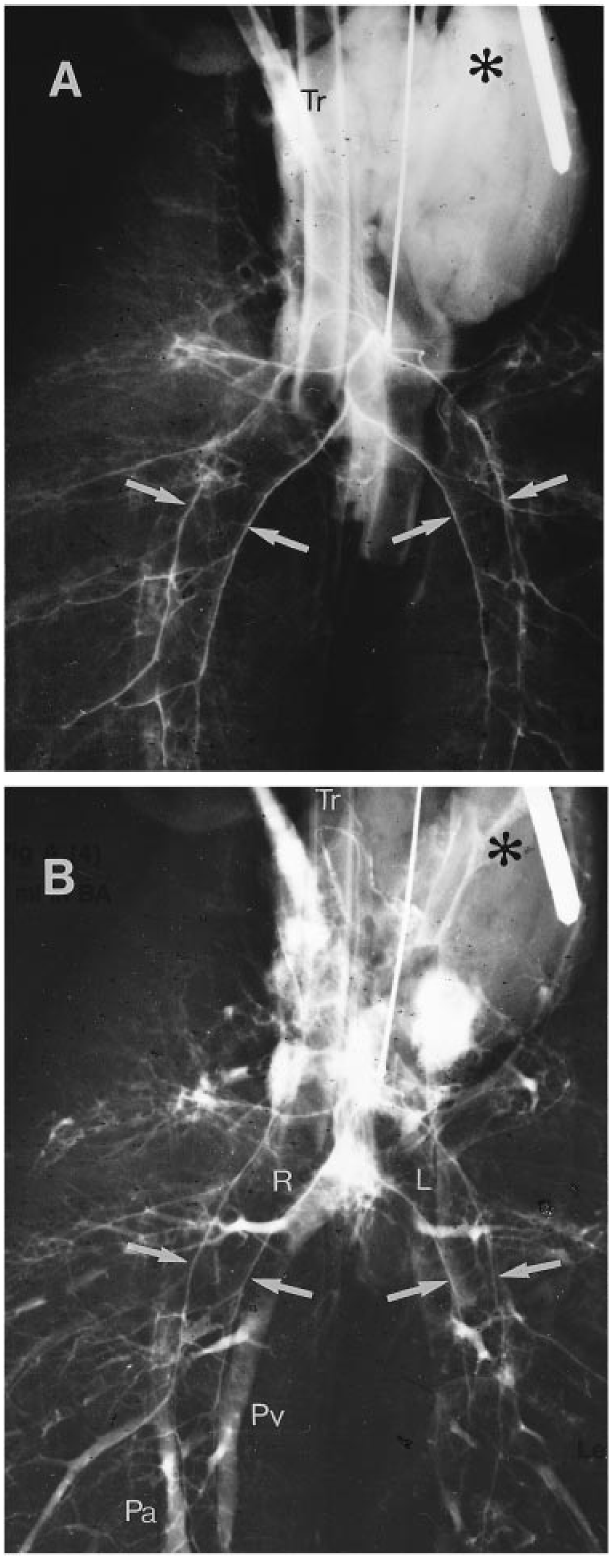

Fig. 1. Radiograph of removed heart-lung block. Anteroposterior view. (*A*) Radiograph following injection of 0.5 ml iopromide showing filling of the bronchial branches. (*B*) Radiograph of same heart–lung bloc as above after injection of 10 ml iopromide showing filling of bronchial branches as well as pulmonary arteries and veins. Arrows, bronchial branches of broncho-oesophageal artery; Pa, pulmonary artery; Pv, pulmonary vein; Tr, trachea with tube; asterisk, apex of heart turned cranially.

lateral bronchial branches of the broncho-oesophageal artery (Fig. 2). This finding was constant in all 10 pigs. When leaving the aorta the broncho-oesophageal artery trunk divided into a single large branch pointing directly towards the carina crossing the distal trachea (the 'carinal branch'; Magno et al. 1987), the left lateral branch and a minor branch for the left cranial lobe. The carinal branch ramified further into the right lateral and the right and left medial branches, whereas the left lateral branch was derived from the broncho-oesophageal trunk in 8 of 10 pigs. In the area between the origin from the aorta and the principal bronchi, 3 branching patterns were observed (Fig. 3). The bronchial branches were found close to the edge of the bronchi. The segmental bronchi were mostly accompanied by a single branch which could be visualised until it disappeared 1–2 cm before the edge of the lung.

The injection of larger amounts of contrast did not reveal further branches, but there was slight filling of the pulmonary vein after injection of 2 ml. The injection of 10 and 20 ml showed heavy filling of the pulmonary vein, and in 3 cases also of the pulmonary artery, with detectable contrast in a catheter placed in the upper caval vein (Fig. 1*b*).

Macroscopic anatomy

In 27 pigs (84%) the broncho-oesophageal artery originated from the medial or anteromedial aspect of the descending aorta just distal to the ductus arteriosus ligament, but cranial to the azygos vein crossing the aorta. The origin was more mediodorsal in 5 of 32 pigs (16%), in 2 of these also just cranial to the ductus arteriosus ligament. Twenty-nine pigs (91%) had 1 orifice and 3 pigs (9%) 2 orifices a few millimeters apart. The orifice was normally 1–2 mm wide and approximately 3 cm from the slightly larger orifices of the intercostal arteries. The broncho-oesophageal artery soon divided into 2–3 branches towards the lung hilum and the oesophagus. Injection of Evans Blue showed that there was communication with most mediastinal structures, and that the carinal branch crossed the carina ventrally. Figures 4 and 5 relate the angiographic and macroscopic appearances. Small vessels were seen in the bronchi, oesophagus, pericardium, and mediastinal lymph nodes after injection of 0.2–1.0 ml Evans Blue. This amount of dye also revealed cobwebby vessels on the aorta and the pulmonary artery, probably vasa vasorum. Colouring of the coronary arteries was seen after injection of 20 ml Evans Blue.

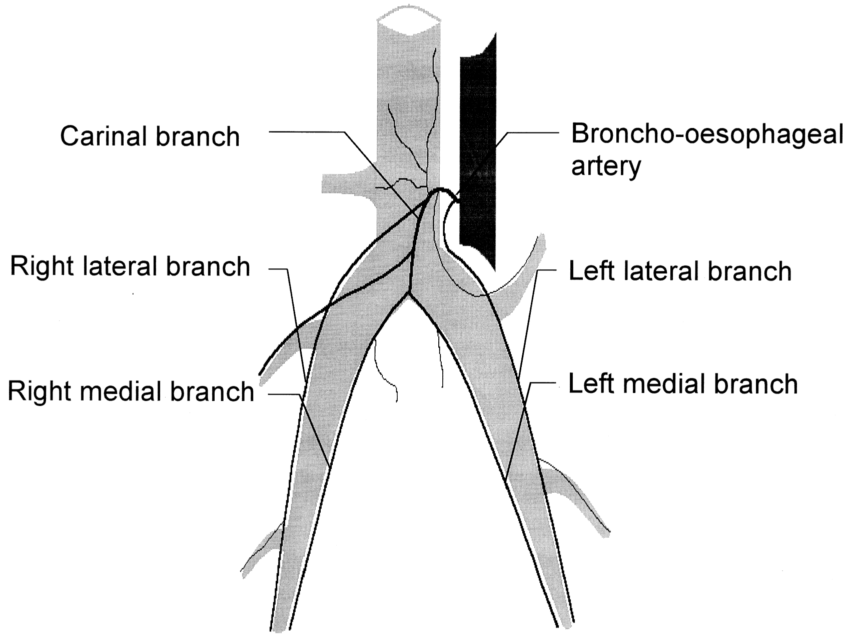

Fig. 2. Suggested nomenclature. Diagram of airways, aorta, and bronchial artery branches. Only the major, constant branches following the principal bronchi are named. For the 'carinal branch' cf. Magno et al. (1987).

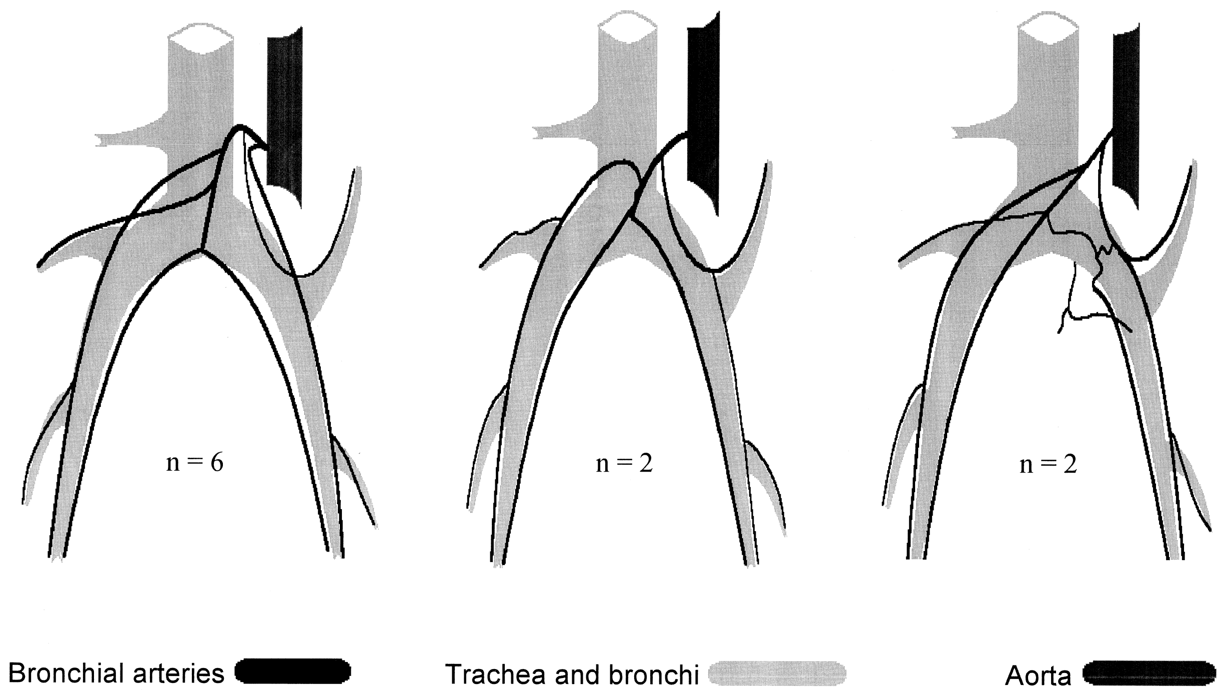

Fig. 3. Variation in branching. Diagrams showing patterns of branching, drawn from radiographs.

Microscopy

On a transverse section of the principal bronchi, there was a medium sized muscular artery measuring 0.5 mm in the peribronchial tissue on both the medial and the lateral aspects (Fig. 6). The medial vessel had the pulmonary artery ventrally and the pulmonary vein medially. The lateral vessel could not be related so closely to defined structures. These relations were in accordance with the angiographic findings. Additionally, there were a number of very small vessels, not visualised by angiography, close to the bronchial cartilage.

DISCUSSION

Although the pig has been widely used in experiments involving the bronchial circulation (Aoki et al. 1991; al Dossari et al. 1994; Berti et al. 1995; Herold et al. 1998), its broncho-oesophageal artery anatomy is

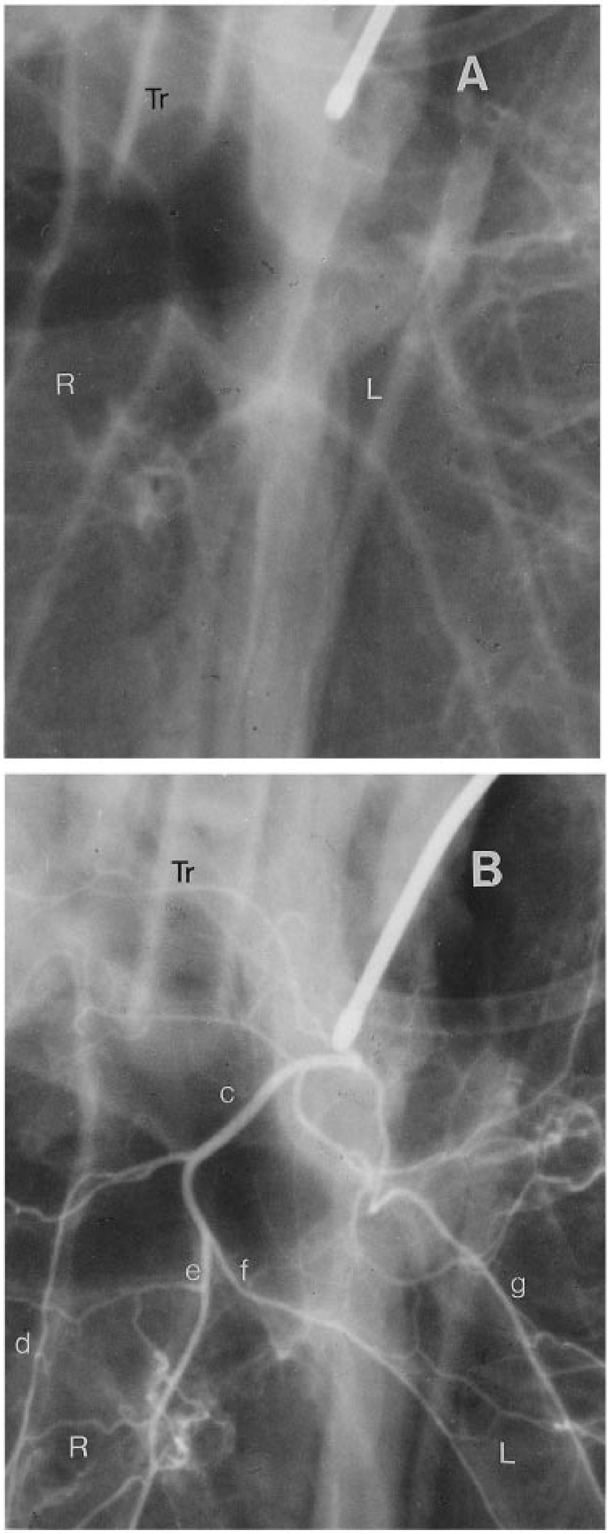

Fig. 4. Radiograph of central ramification between aorta and bronchi. Close-up anteroposterior view showing ramification and distribution of artery branches close to the edge of the bronchi. (*A*) Before injection of iopromide. (*B*) After injection of 1 ml of iopromide. c, carinal branch; d, right lateral branch; e, right medial branch; f, left medial branch; g, left lateral branch; t, trunk of broncho-oesophageal artery; Tr, trachea with tube.

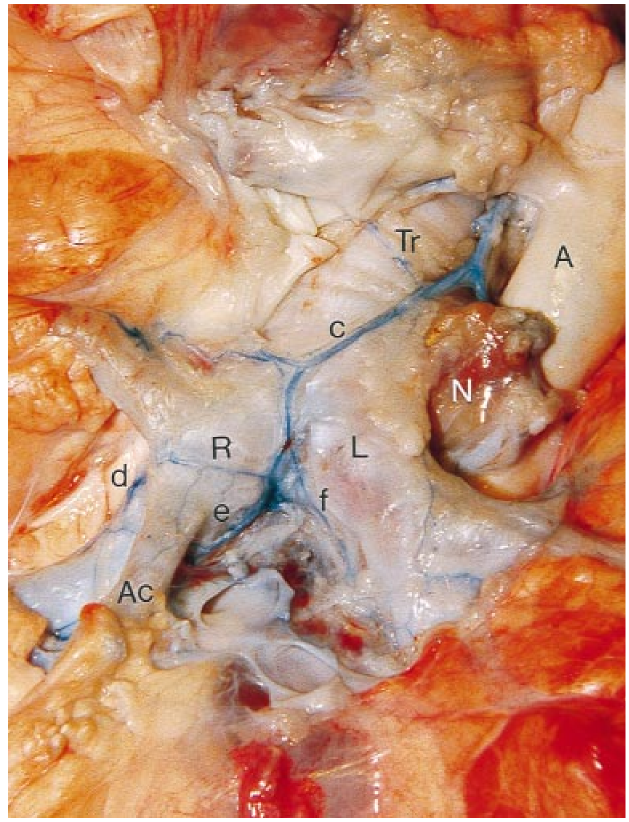

Fig. 5. Photograph of central ramification between aorta and bronchi. Dissection of same specimen as in Fig. 4. Evans Blue (2 ml) was injected into the broncho-oesophageal artery. The pericardium, the pulmonary arteries and veins, and peribronchial tissue with lymph nodes have been removed to expose the ramification. A, aorta; c, carinal branch; d, right lateral branch; e, right medial branch; f, left medial branch; Ac, bronchus of accessory lobe; N, lymph node; L, left principal bronchus; R, right principal bronchus; Tr, trachea.

poorly described. The pig has the advantage that its broncho-oesophageal artery usually originates from the aorta as a single vessel (Calka, 1975; Berg, 1976; Schummer et al. 1981). This corresponds well with the 91% found in the present study. The relative constancy of a single arterial trunk makes physiological studies of flow rates easier to perform.

Knowledge of the anatomical patterns forms an important basis for surgical and physiological experimental research, and in particular for exchange of views. One study, for example, referred to implantation of a left bronchial artery in the aorta (Aoki et al. 1991). Since there is normally no *left* bronchial artery in the pig, the meaning is unclear: if referring to a left bronchial branch, this implies anastomosis of a very small vessel (~ 0.5 mm) with the aorta, which seems unlikely. If not, implantation of the broncho-oesophageal trunk must have been performed.

It was of little surprise that variations in branching were found. Based on radiography in 10 pigs we described 3 subtypes, but other subtypes might be

Fig. 6. Photograph of specimen from left hilum showing transverse section of left bronchial wall with neighbouring tissue. $\times 5$. a, left lateral branch of bronchial artery; b, left medial branch of bronchial artery; c, minor branches; d, cartilage of bronchial wall; the porcine bronchial cartilage consists of layered plates; e, pulmonary artery; f, lung tissue.

found with larger numbers. Communications between the bronchial branches and pulmonary arteries was demonstrated. An earlier investigation on comparative anatomy failed to demonstrate bronchial to pulmonary artery shunts in the pig, although shunts have been found in many other species, including man (McLaughlin, 1983). Thus the communications we demonstrated angiographically between the 2 systems are most likely to occur via the lung capillaries, otherwise porcine broncho-pulmonary shunts must exist.

Previous investigations have studied the bronchial artery anatomy by injection of either venyl acetate or latex of different colours. The arteries could then be followed by dissection (Calka, 1975) or slicing (McLaughlin, 1983). However, these methods do not present a general view of the bronchial artery branching patterns, and especially not of the intrapulmonary part. A survey article on the bronchial artery comparing different species does not mention the intrapulmonary courses of the arteries (Magno, 1990). The finding of 2 arteries accompanying the porcine principal bronchi has not been described before. The supply of altogether 2–6 arteries for both lungs in pigs has been reported, but the intrapulmonary course was not followed (Calka, 1975). To our knowledge, angiography of the porcine bronchial branches has not previously been performed and in other species bronchial angiography has only been undertaken in dog and man (Ellis et al. 1951; Viamonte et al. 1965; Moberg, 1967; Jandik et al. 1993). The present study demonstrates that the course of the porcine bronchial branches with one branch on each side of a bronchus corresponds well with the canine anatomy (Ellis et al. 1951; Jandik et al. 1993). Two bronchial arteries for each lung is a common finding in man (Cauldwell et al. 1948; Liebow, 1965; Kasai & Chiba, 1979), but within the lungs the lobar bronchi are followed by a single artery (Viamonte et al. 1965; Norgaard et al. 1997).

An anatomical nomenclature for the bronchial artery was suggested earlier for the sheep (Magno et al. 1987). This nomenclature is also applicable to the pig. However, since the principal bronchi of the pig are each accompanied by 2 major bronchial artery branches, we suggest that these are named in accordance with their anatomical localisation (Fig. 2).

In conclusion, the course, branching pattern and distribution of the porcine bronchial arteries have been described. Each principal bronchus is followed by 2 bronchial artery branches. The findings suggest that the pig is anatomically suited for experimental physiological studies on the bronchial circulation.

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