

# The porcine bronchial artery. Anastomoses with oesophageal, coronary and intercostal arteries

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## ABSTRACT

Information about the existence and anatomy of arterial anastomoses with the porcine bronchial artery is lacking in the literature. Prior to basic physiological investigations in a porcine model related to lung transplantation with bronchial artery revascularisation, this study was designed to examine the anatomy of systemic arterial anastomoses with the bronchial artery system. Twenty pigs were studied in 3 groups. In 2 groups the heart–lung block was removed with all mediastinal structures. One group served for investigation of coronary–bronchial artery anastomoses and one for investigation of oesophageal–bronchial artery anastomoses. The systemic arteries to be examined were cannulated. The inflated heart–lung block was examined macroscopically with Evans blue, and radiographically after contrast injection. In the 3rd group intercostobronchial artery anastomoses were studied radiographically with the heart–lung block in situ. Coronary–bronchial artery anastomoses were demonstrated in 3 of the 5 pigs with an aortic ‘pouch’ technique, but contrast was very limited in 2 of these 3. Oesophageal arterial anastomoses with bronchial arterial branches and/or the pulmonary veins were demonstrated in 6 of the 7 pigs and more markedly than the coronary–bronchial anastomoses. Intercostobronchial artery anastomoses could not be demonstrated angiographically. It was concluded that the existence of coronary–bronchial and oesophageal–bronchial artery anastomoses in the pig appear to establish an arterial net between the base of the heart and the distal oesophagus. The resemblance to human oesophageal–bronchial artery anastomoses supports use of a porcine model for experimental studies.

*Key words:* Vasculature; broncho–oesophageal artery; arterial anastomoses.

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## INTRODUCTION

The normal lung has a dual blood supply. The bronchial arteries are systemic arteries, providing oxygenated blood for the bronchi and extracardiac mediastinal structures (including the oesophagus, lymph nodes and the sympathetic and parasympathetic nervous system) (Cauldwell et al. 1948; Deffebach et al. 1987; Christensen & Mousing, 1992). The bronchial arteries have received increasing attention in human lung transplantation (Couraud et al. 1992; Daly & McGregor, 1994; Baudet et al. 1996; Nørgaard et al. 1997; Pettersson et al. 1997) as well as experimentally (Nazari et al. 1990; Aoki et al. 1991; Laks et al. 1991; al Dossari et al. 1994), after bronchial

artery revascularisation (BAR) has become possible. From a theoretical point of view, often based on animal studies, systemic oxygenated blood for the bronchi should avoid or reduce complications in lung transplantation related to bronchial ischaemia, i.e. poor healing (Nazari et al. 1990), infection (Charan et al. 1985) and obliterative bronchiolitis (Yousem et al. 1990; Baudet et al. 1996). However, the role of BAR is controversial (Patterson, 1993) and the physiological role of the bronchial arteries in lung transplantation is difficult to establish by clinical studies alone. This generated our interest in the experimental examination of the porcine bronchial artery.

An animal model should have a close resemblance to the situation in man, both anatomically and

physiologically. The pig is a widely used animal for experimental research in lung transplantation (Nazari et al. 1990; Aoki et al. 1991; Laks et al. 1991; al Dossari et al. 1994). In most cases the porcine bronchial artery has a single origin from the aorta (Calka, 1975; Gade et al. 1999). In veterinary anatomy the correct term is 'the bronchial branch of the broncho-oesophageal artery', the latter being an arterial trunk. It is the broncho-oesophageal artery which has only one aortic origin. In human anatomy, however, the bronchial arteries have separate origins. In the following we shall refer to 'the bronchial branch of the broncho-oesophageal artery trunk' simply as the 'bronchial branch(-es)'. This is the equivalent of the human bronchial artery(-ies). The porcine bronchial artery is easy to identify and control, which is an advantage (Nazari et al. 1990). However, if physiological studies are undertaken, not only the direct supply by the bronchial artery, but also the systemic collateral blood flow must be considered (Baile et al. 1992). Occlusion of the broncho-oesophageal artery, for example, may leave a collateral blood flow. The existence of arterial anastomoses with the bronchial artery has been described in man (Petelenz, 1965; Bjork, 1966; Moberg, 1967) and in experimental porcine and canine studies (Baile et al. 1992; White et al. 1992; Bloor & Liebow, 1965). Unfortunately, the anatomy of the porcine bronchial arterial anastomoses has not been well described (White et al. 1992). Only coronary-bronchial anastomoses have been investigated and only as a contribution to the coronary blood flow (White et al. 1992; Bloor & Liebow, 1965). As far as the lungs and the bronchi are concerned, the reverse contribution is also of interest. To our knowledge, the contribution to the porcine bronchial circulation from other mediastinal sources, such as anastomoses between arterial bronchial branches and direct aortic oesophageal arteries, which have been described in man (Hudson et al. 1932; Cauldwell et al. 1948), has not been investigated previously. Thus an important prerequisite has been missing for experimental studies of the porcine bronchial circulation. In textbooks on human anatomy, arteries supplying the oesophagus, originating directly from the aorta, are described both as 'oesophageal branches' and as 'oesophageal arteries'. In veterinary anatomy only the former term is employed. However, since the broncho-oesophageal artery in the pig also has an oesophageal branch, some confusion may be caused. We will therefore employ the term 'oesophageal artery' to describe the vessel(s) supplying the mid and distal thoracic oesophagus directly from the aorta, and the term 'oesophageal

branch' for the vessel supplying the proximal thoracic oesophagus from the 'broncho-oesophageal artery'.

This study was undertaken to describe the anatomy and sources of anastomoses with arterial bronchial branches in the pig in order to create an anatomical basis for future experimental surgical and physiological investigations, including experiments in relation to lung transplantation.

#### MATERIAL AND METHODS

Three groups of female specific pathogen free (SPF) pigs (Danish landrace/Yorkshire) weighing between 30 and 40 kg were studied. One group was used for investigation of anastomoses of bronchial branches with the coronary arteries (n = 8), one for investigation of anastomoses with the oesophageal artery (n = 7), and one for anastomoses with intercostal arteries (n = 5).

#### *Surgical technique*

Anaesthesia was induced with thiopental 60 mg/kg. After intubation, anaesthesia was maintained with NO<sub>2</sub> and pentobarbital 50 mg/ml. A perfusion catheter was placed through a sternotomy into the right auricle of the heart. The pigs were anticoagulated intravenously with 1000 IU/kg of heparin. Both the superior and inferior caval veins were ligated, and the heart and lungs were perfused with 2000 ml saline (20–22 °C) in order to clear blood from all vessels to be examined, whereby the pigs were killed. The caval veins were simultaneously transected and blood drained to avoid oedema. The heart-lung block was removed together with all the mediastinal structures from just below the thyroid cartilage to the diaphragm by careful dissection as close to the spine as possible. The aorta was opened and the orifice(s) of the broncho-oesophageal artery (and of the oesophageal artery in the group for oesophageal anastomoses) was noted.

#### *Preparation for coronary anastomoses (n = 8)*

This group was divided in 2 subgroups. In both the heart-lung block was prepared with a butted cannula in the aortic orifice of the broncho-oesophageal arterial trunk. This was the only procedure in 3 pigs. In 5 pigs the ascending aorta was additionally transected 3 cm from the aortic valves, and these were closed tightly with small haemoclips (Horizon Surgical). The ascending aorta was sutured around a butted cannula to create an aortic 'pouch' for injection into the coronary arteries. Prior to x-ray

examination 4 of the 5 specimens with an aortic pouch were injected with 10 ml Evans blue into the pouch and 2 ml into the bronchial artery. The dye distribution was recorded. In pigs with cannulation of the bronchial artery only ( $n = 3$ ) sequential radiographs of the inflated heart–lung block were made before and after the injection of 1, 2, 10 and 20 ml of iopromide 370 mg/ml (Ultravist). In pigs with an aortic pouch ( $n = 5$ ) sequential radiographs were made before and after injection of 2, 4 and 10 ml iopromide 370 mg/ml into the pouch. To confirm normal anatomy of bronchial branches, 2 ml contrast was afterwards injected into the broncho–oesophageal artery and an additional radiograph was taken. Efforts were made to diminish problems with contrast leakage by ligation of all visible open ends of vessels cut during removal of the block.

#### *Preparation for oesophageal anastomoses ( $n = 7$ )*

The heart–lung block was removed as described above. The aorta was opened and the orifices of the broncho–oesophageal and oesophageal arteries were cannulated. In 4 pigs, 2 ml of Evans blue was injected into the oesophageal artery. In all the pigs iopromide 370 mg/ml was injected first into the oesophageal artery. Radiographs were taken when 2 and 10 ml had been injected. To confirm normal anatomy of bronchial branches, 2 ml iopromide was afterwards injected into the bronchial artery and a radiograph was taken.

#### *Preparation for intercostal anastomoses ( $n = 5$ )*

The pigs were treated under general anaesthesia. Two pigs were operated through a sternotomy and perfused with saline as described above, but the heart–lung block was left in situ. Two pigs were heparinised with 100 IU/kg of heparin and killed by exsanguination. The 5th pig was heparinised with 1000 IU/kg of heparin and then killed by a pentobarbital overdose. The aorta was opened in all pigs and the orifices of the upper 3 intercostal arteries were cannulated, because the observations in the other groups had identified these arteries as possible anastomosing vessels. To visualise such anastomoses contrast (iopromide 370 mg/ml) was injected sequentially with 2 and 4 ml into each of the cannulated arteries, and radiographs were taken sequentially after each injection.

#### *Angiography*

In groups A and B radiographs of the heart–lung specimen were taken with a Phillips Practix, set at

20 mA and 55 kV for 0.25 s with 80 cm tube distance and a raster applied. In the pigs of group C (whole body) the apparatus was set at 20 mA and 100 kV for 0–4 s. Iopromide 370 mg/ml (Ultravist) was used as contrast and pictures were taken after each injection with as short intervals as possible.

#### *Ethics*

The animals received humane care in compliance with the Danish national regulations for animal experiments. Settings were approved by the Danish Inspectorate for Animal Experiments.

## RESULTS

### *Coronary-bronchial arterial anastomoses*

Injection of Evans blue into the aortic pouch showed colouring of the heart and pericardium and many cobwebby vessels superficially on the lung hila and mediastinal lymph nodes, but the dye was not seen in the bronchial arteries or distally to the lung hila. Injection into the broncho–oesophageal artery further coloured the whole mediastinum including the oesophagus and the mediastinal pleura, and also the visceral pleura. Leakage of Evans blue through one or more of the upper 3 intercostal arteries was occasionally observed following injection into the broncho–oesophageal artery.

In pigs with cannulation of the broncho–oesophageal artery only, angiography showed a normal anatomy of bronchial branches. After the injection of 2 ml iopromide traces of contrast were seen in the coronary arteries of 1 pig, and after 10 and 20 ml contrast in the coronary arteries was seen in all 3 pigs. In 2 pigs the area of communication could be localised. In 3 of the 5 pigs, where an aortic pouch was employed, contrast was seen in the bronchial branches. In one of these the upper halves of the bronchial branches were filled with contrast after injection of 10 ml iopromide, but no contrast was seen in the pulmonary veins (Fig. 1). In this pig the anastomoses between the 2 arterial systems apparently traversed the pericardial reflection in 2 places, one from the right posterior descending artery via the right atrial branches, and the other directly from the circumflex artery. In the 2 other pigs the amount of contrast in anastomosing vessels was very limited and the anastomoses were not easily identified. Contrast never passed through the valves into the left ventricle. Subsequent injection into the broncho–oesophageal artery did not add further information, but normal filling of the bronchial arteries was demonstrated in all 5 pigs.

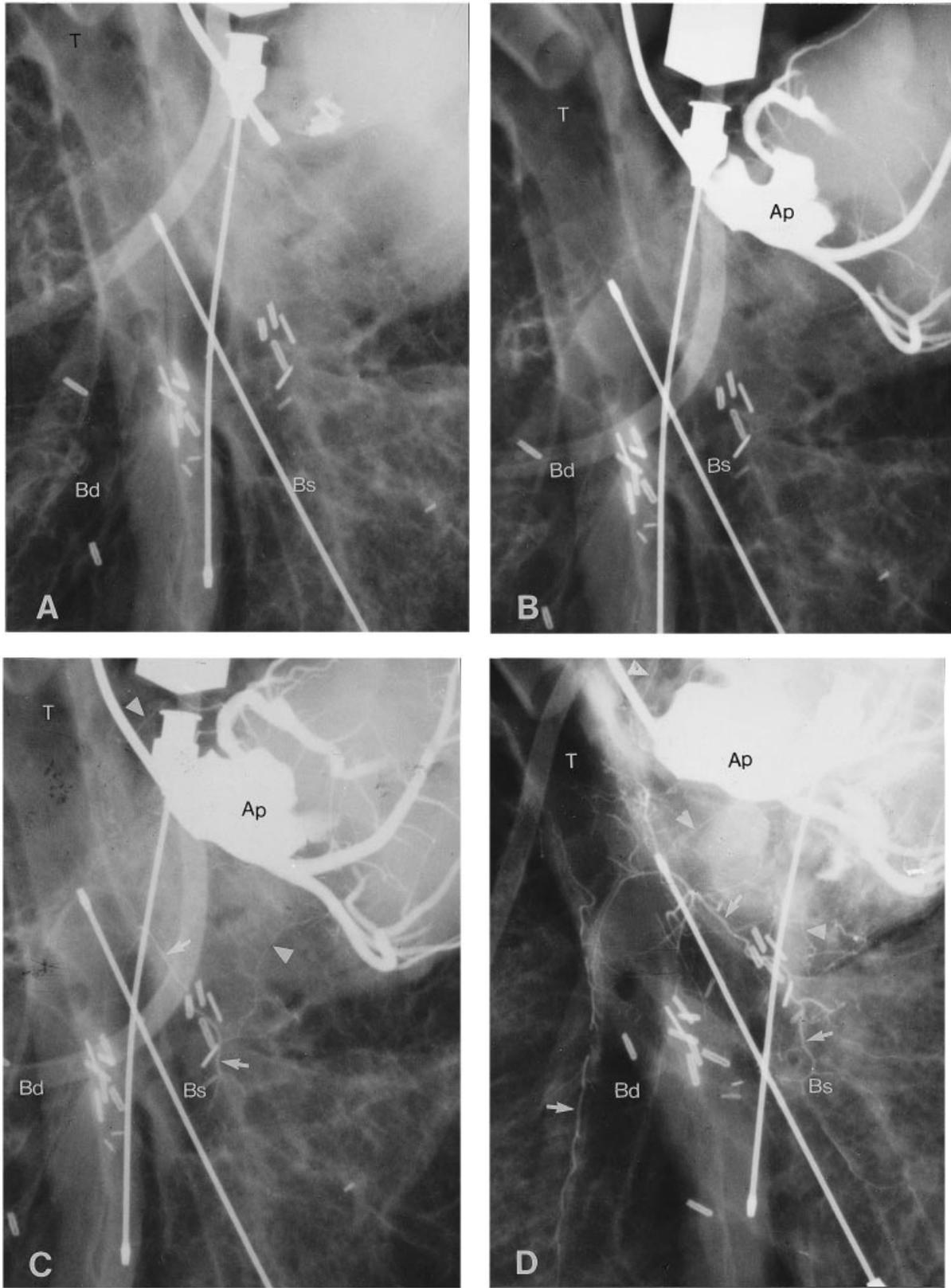


Fig. 1. Coronary-bronchial anastomoses. Angiography of inflated heart-lung block showing distribution of contrast following sequential injection of iopromide into an 'aortic pouch'. *A*, Before injection of iopromide. *B*, After 2 ml iopromide. Coronary arteries are partly filled and traces of contrast occur in arterial anastomoses. *C*, After 4 ml iopromide. Coronary arteries are almost filled, the arterial anastomoses are seen, and contrast has reached bronchial arterial branches. *D*, After 10 ml iopromide. The upper half of the bronchial arterial branches are filled with contrast. Ap, aortic pouch; Bd, right principal bronchus; Bs, left principal bronchus; T, trachea with tube; arrows, bronchial arterial branches; arrowheads, coronary-bronchial anastomoses.

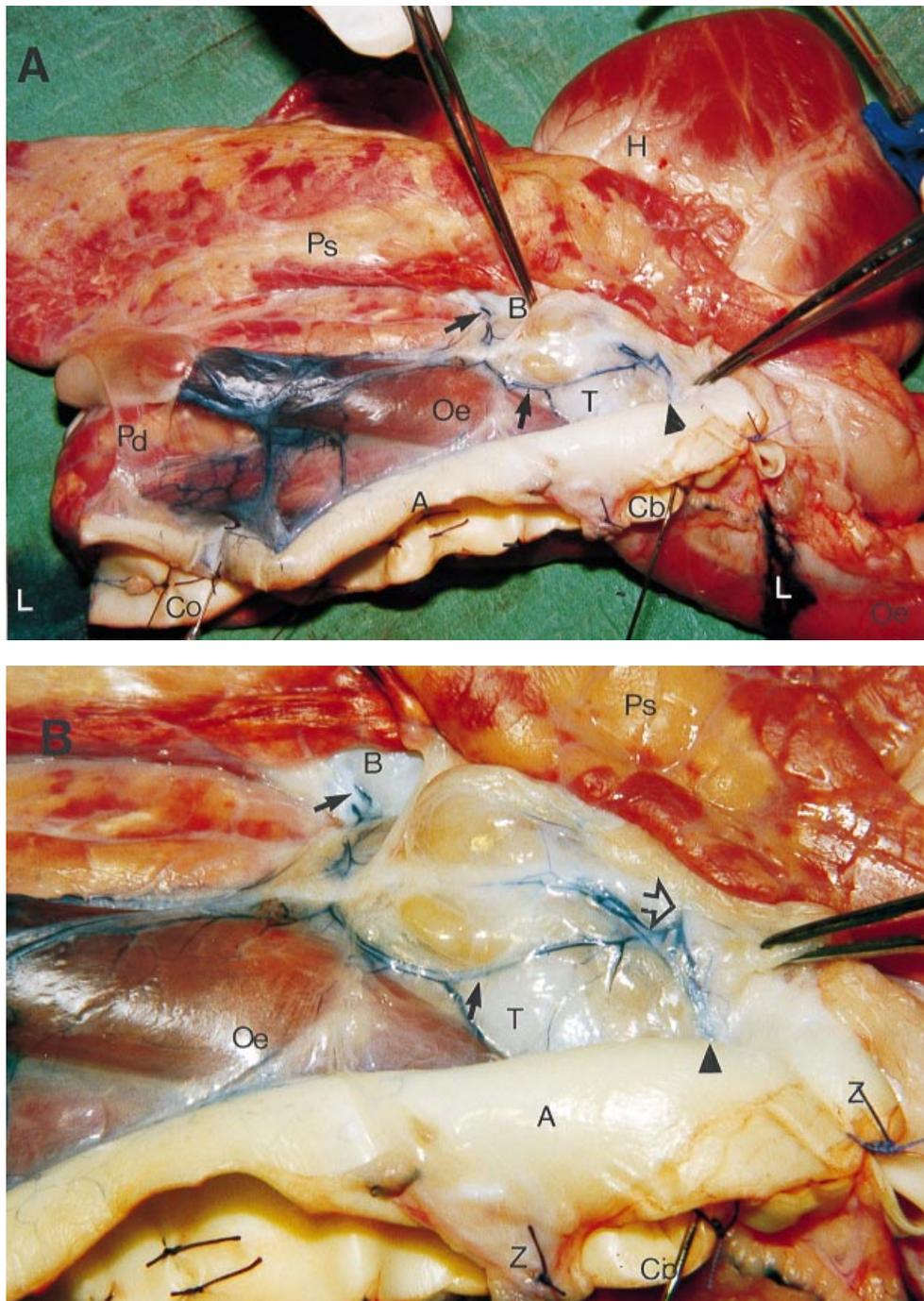


Fig. 2. Dissection of oesophageal-bronchial anastomoses. Dissection of removed heart-lung block. The oesophagus was exposed and the aorta opened longitudinally. Two oesophageal arteries were found. The larger oesophageal artery and the bronchial artery were cannulated. Evans blue (2 ml) was injected into the oesophageal artery. Lateral and anterolateral view. *A*, Overview of heart-lung block with the disclosed oesophagus and branches of oesophageal artery. The cannulas are placed in the orifices of the oesophageal and broncho-oesophageal arteries. *B*, Detailed view of the area of anastomoses. *A*, aorta; *B*, left bronchus; *Cb*, cannula in broncho-oesophageal artery; *Co*, cannula in oesophageal artery; *H*, heart; *L*, leakage of Evans blue; *Oe*, oesophagus; *Ps*, left lung; *Pd*, right lung; *T*, trachea; *Z*, arrows, left lateral bronchial branch (cf. Gade et al. 1999); open arrow, carinal branch; arrowhead, origin of broncho-oesophageal artery.

*Oesophageal-bronchial arterial anastomoses*

An oesophageal artery was found in all 7 pigs. The location of origin from the medial or anteromedial aspect of the aorta varied from close to the diaphragm to the level of the orifice of the second intercostal

artery trunk. One artery was present in 5 pigs, and 2 in 2 pigs.

Injection of Evans blue showed communication both directly with the bronchial branches and with the broncho-oesophageal artery via oesophageal branches (Fig. 2). The anastomoses with the bronchial

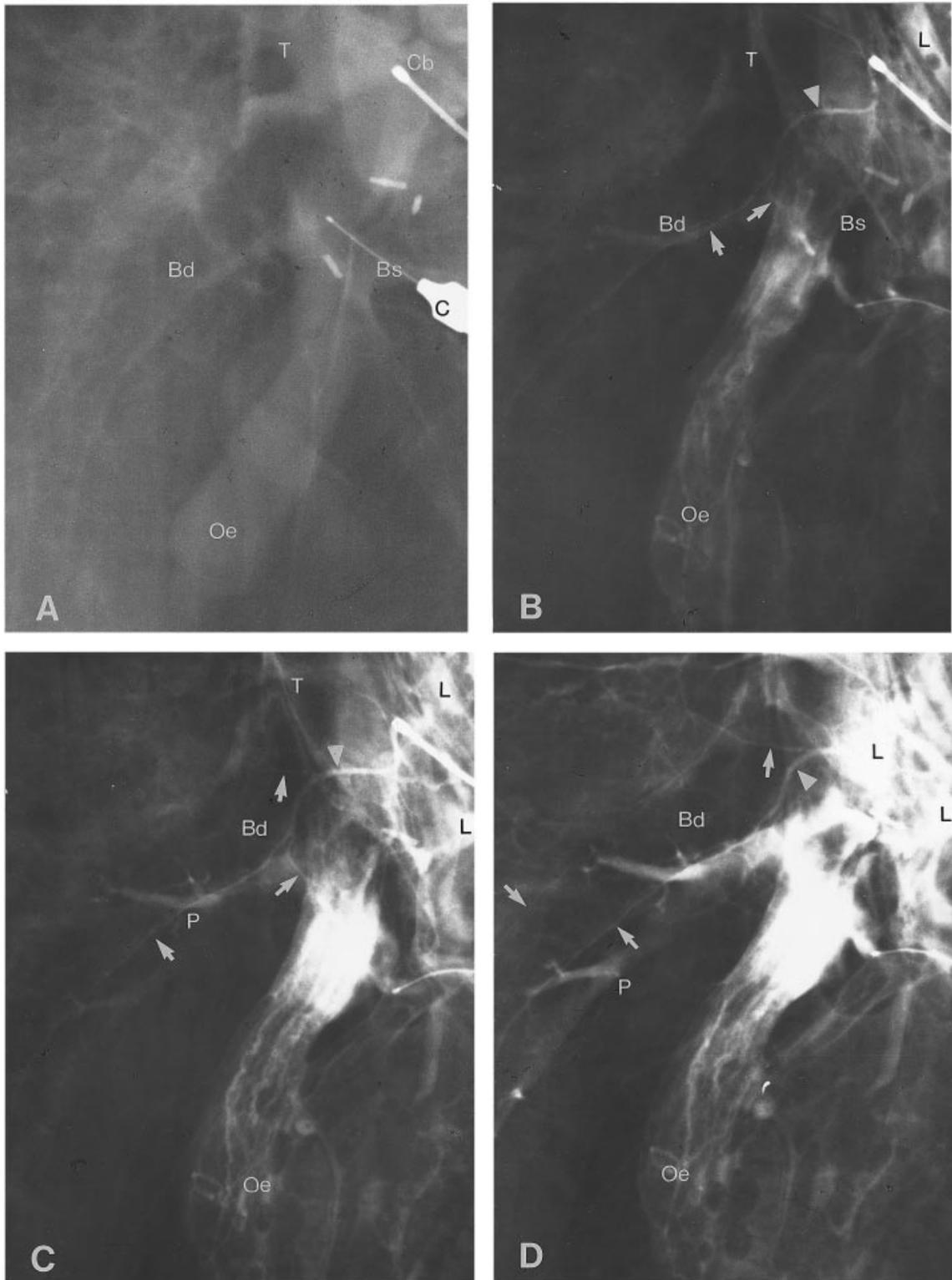


Fig. 3. Oesophageal-bronchial anastomoses. Angiography of inflated heart-lung block showing distribution of contrast following sequential injection of iopromide into the oesophageal and broncho-oesophageal arteries. *A*, Before contrast injection. *B*, After injection of 2 ml iopromide into oesophageal artery. Contrast is seen in the oesophageal tissue, in the carinal branch, and in the left and right medial bronchial branches. *C*, After injection of 5 ml iopromide into oesophageal artery (10 ml was intended, but not carried out due to excessive leakage). The bronchial arterial branches are seen as in *B*, but filling of a right pulmonary vein has occurred. *D*, After injection of 2 ml iopromide into the broncho-oesophageal artery the normal right medial and lateral bronchial branches are seen together with further filling of the pulmonary vein. The left bronchial branches are not visible due to contrast leakage. Bd, right principal bronchus; Bs, left principal bronchus; C, cannula is oesophageal artery; Cb, cannula in broncho-oesophageal artery; L, leakage of contrast. Oe, oesophagus; P, pulmonary vein; T, trachea; arrows, bronchial branches; arrowhead; carinal branch.

branches took place via 1 or 2 small arteries ( $\frac{1}{2}$ –1 mm) on the oesophageal surface running parallel to the vagus nerve and meeting branches from the broncho–oesophageal artery on a level with the carina (Fig. 2).

Radiographically the oesophageal tissue gradually filled with contrast in all 7 pigs. Following injection of 2 ml of contrast, filling of a bronchial branch was seen in 4 of the 7 pigs (Fig. 3). Additional contrast did not fill the bronchial branches further, but contrast was seen in the pulmonary veins. In 1 pig contrast could not be seen in the bronchial branches, but contrast was evident in a pulmonary vein and in the left atrium. The anastomoses between the bronchial branches and oesophageal arteries appeared to be on a level with the tracheal carina and the proximal principal bronchi, but details could not be studied due to contrast in the oesophageal wall and contrast leakage. In 2 pigs no oesophageal–bronchial anastomoses could be demonstrated. Subsequent injection of contrast into the broncho–oesophageal artery did not add further information, but angiography of bronchial branches was normal in all 7 pigs, including the 2 pigs with no visible oesophageal arterial anastomoses.

#### *Intercostal-bronchial arterial anastomoses*

After injection of iopromide the intercostal arteries were filled with contrast, but anastomoses with the bronchial artery system could not be demonstrated.

#### DISCUSSION

To study the arterial blood supply of the lungs and its importance for the bronchi, lung parenchyma, and mediastinal tissues, it is necessary to take into account not only the bronchial artery itself, but also possible arterial anastomoses. It is not known, how much collateral circulation contributes to the porcine bronchial circulation. Investigations must be based on knowledge about possible collateral sources and their anatomical course. Our study indicates 3 sources of bronchial collateral circulation: the coronary arteries, the oesophageal artery, and possibly the intercostal arteries. The existence of bronchial–coronary anastomoses has been reported in man (Petelenz, 1965; Bjørk, 1966; Moberg, 1967) and in pigs (White et al. 1992). Bronchial–oesophageal arterial anastomoses and intercostobronchial arteries are also found in man (Hudson et al. 1932; Cauldwell et al. 1948; Kasai & Chiba, 1979; Nørgaard et al. 1997), and in cattle (Calka, 1969), but we found no reports of such anastomoses in pigs or other species. If physiological or other functional investigations of the bronchial

artery are to be undertaken, account must be taken of the collateral sources mentioned above. This is in accordance with a physiological canine study, where the collateral systemic flow could not be ignored (Baile et al. 1992). Although less common, it should be mentioned that pleural adhesions, mostly surgically-induced, may provide a fourth systemic source of flow to the lungs (Cockett & Vass, 1950; Remy-Jardin & Remy, 1990).

Our finding of porcine oesophageal arterial anastomoses with the bronchial arteries was in contrast to Shummer et al. (1982), who stated that the oesophageal branch of the bronchial artery in the pig does not supply the oesophagus more distally than the base of the heart and that the oesophageal artery supplies only the distal thoracic oesophagus. The present study showed that the distal oesophageal artery has anastomoses with the broncho–oesophageal artery (Figs 2, 3). In our study the anatomical course of such anastomoses both from the oesophageal and intercostal arteries seemed to be via arteries running along the oesophagus. It may be that these arteries constitute the actual nutrient artery of the oesophagus and receive contributions from oesophageal, bronchial, and probably intercostal arteries. We showed anastomoses both via the oesophageal branch of the broncho–oesophageal artery, and more directly to the bronchi and lungs (Fig. 2). The existence of porcine oesophageal–bronchial artery anastomoses and their similarity with human anatomy may support use of the pig as a model in physiological studies.

Our method for investigation of anastomoses with bronchial branches basically consisted of anticoagulation, perfusion of heart–lung block with saline, and en bloc removal of lungs with all mediastinal structures. Different methods to visualise the vessels could then be applied, such as x-ray examination and injection of Evans blue. The model offered some advantages. Intravascular coagulation was very unlikely to take place, which assured free contrast distribution and allowed us to conclude that filling of the pulmonary vein was also via bronchial branches in the case where no bronchial branches were visualised, since contrast in the pulmonary vein is a normal phenomenon following contrast injection into the bronchial artery itself. Removal of the heart–lung block, creation of an aortic pouch, and cannulation of the bronchial and oesophageal arteries made it possible to examine one artery system at a time and x-ray quality was improved. Sequential injections made it possible to follow contrast distribution and thereby describe the source and course of arterial anastomoses. A disadvantage was leakage of contrast,

which has also been reported in other studies (Petelenz, 1965; Moberg, 1967).

The model was not suitable for investigation of intercostal anastomoses, since the intercostal arteries were cut during removal. For this reason we chose to perform investigations on the intercostal arteries with in situ cannulation. Although injection of Evans blue in the other studies had suggested the existence of collaterals, these could not be identified by direct methods. Since radiographs were of the whole thorax of the pigs, small anastomoses may have been overlooked with this method. In all circumstances we believe this procedure is inferior to the isolated heart–lung block method.

In conclusion, this study has shown that the porcine bronchial arteries and their branches anastomose with the coronary as well as oesophageal, and, possibly, intercostal arteries with which they seem to constitute an arterial net from the base of the heart to the distal oesophagus. Thus to study the bronchial artery, 3 sources of collateral blood flow should be accounted for. The supply from the porcine oesophageal artery may be considerable. The resemblance to human oesophageal–bronchial anastomoses supports the use of porcine models in studies on the bronchial circulation.

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