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Functional anatomy of bronchial veins

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Abstract

The amount of bronchial arterial blood that drains into the systemic venous system is not known. Therefore, in this study we further delineated the functional anatomy of the bronchial venous system in six adult, anesthetized, and mechanically ventilated sheep. Through a left thoracotomy, the left azygos vein was dissected and the insertion of the bronchial vein into the azygos vein was identified. A pouch was created by ligating the azygos vein on either side of the insertion of the bronchial vein. A catheter was inserted into this pouch for the measurement of bronchial venous occlusion pressure and bronchial venous blood flow. An ultrasonic flow probe was placed around the common bronchial branch of the bronchoesophageal artery to monitor the bronchial arterial blood flow. Catheters were also placed into the carotid artery and the pulmonary artery. The mean bronchial blood flow was $20.6 \pm 4.2\,ml\,min^{-1}$ (mean ± SEM) and, of this, only about 13% of the blood flow drained into the azygos vein. The mean systemic artery pressure was 72.4 ± 4.1 mmHg whereas the mean bronchial venous occlusion pressure was 38.1 ± 2.1 mmHg. The mean values for blood gas analysis were as follows: bronchial venous blood $pH = 7.54 \pm 0.02$, $PCO_2 = 35 \pm 2.6$, $PO_2 = 95 \pm 5.7$ mmHg; systemic venous blood—$pH = 7.43 \pm 0.02$, $PCO_2 = 48 \pm 3.2$, $PO_2 = 42 \pm 2.0$ mmHg; systemic arterial blood—$pH = 7.51 \pm 0.03$, $PCO_2 = 39 \pm 2.1$, $PO_2 = 169 \pm 9.8$ mmHg. We conclude that the major portion of the bronchial arterial blood flow normally drains into the pulmonary circulation and only about 13% drains into the bronchial venous system. In addition, the oxygen content of the bronchial venous blood is similar to that in the systemic arterial blood. Published by Elsevier Ltd.

Keywords: Bronchial circulation; Bronchial veins; Bronchial arteries; Bronchial blood flow

1. Introduction

The bronchial circulatory system forms a dense vascular plexus in the airway wall to supply blood and nutrients to the airways [1]. The bronchial vascular plexus is supplied blood by the bronchial arteries. The anatomy of these bronchial arteries has been well described [1–6]. It has been assumed that the major portion of bronchial arterial blood drains into the pulmonary circulation through the bronchopulmonary anastomoses and only the blood that supplies the extrapulmonary airways is drained into the systemic venous system. Although the anatomy of bronchopulmonary anastomoses as the route for drainage of bronchial arterial blood into the pulmonary circulation has been described [1], the anatomy of the bronchial veins that drain bronchial arterial blood into the systemic venous system has not been well studied. These bronchial veins may have an important role. For example, Paré et al. [7] found that systemic venous hypertension augments airway edema and postulated that this could be due to obstruction of bronchial veins that drain into the systemic venous system resulting in fluid filtration into the extravascular compartment. It is also possible that drugs that are delivered into the body through the tracheaobronchial tree, such as inhaled bronchodilators, get absorbed into the bronchial vascular plexus, and are then transported to the bronchial smooth muscles by the bronchial blood flow. If this were the case, after giving a drug by inhalation, its rate of absorption from the bronchial tree could be studied by measuring the concentration of that drug in the bronchial venous blood. Hence, knowledge of bronchial venous

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anatomy could have important implications. This research project was undertaken to delineate the anatomy of the bronchial venous drainage.

2. Material and methods

2.1. Surgical preparation

Six adult sheep of mixed breed were fasted for 24 h and then sedated with xylazine (0.25 mg/kg) about 30 min prior to surgery. Following induction of anesthesia with intravenous injection of 8–10 ml of 5% pentobarbital sodium, the sheep were intubated and connected to an anesthesia machine (Ohmeda Anesthesia System Excel 210, Madison, Wisconsin). Anesthesia was maintained with 2–2.5% isoflurane. A gastric tube was passed through the esophagus into the stomach to continuously drain the rumen. The animals were placed in a right lateral decubitus position and a left thoracotomy was performed through the fifth intercostal space. The bronchoesophageal artery and its branches were dissected and a 2-mm ultrasonic flow probe was placed around the common bronchial branch of the bronchoesophageal artery. The flow probe was connected to a blood flow meter (T201, Transonic Systems, Inc., Ithaca, NY) and bronchial blood flow was recorded continuously. The esophageal branch of the bronchoesophageal artery was cannulated and connected to an infusion pump (Fig. 1). The left azygos vein was dissected and the insertion of the bronchial vein into the azygos vein was identified. A pouch was created by ligating the azygos vein on either side of the insertion of bronchial vein. A catheter was inserted into this pouch for monitoring of bronchial venous pressure using a pressure transducer. This catheter was also used intermittently to measure bronchial venous blood flow by collecting blood in a graduated cylinder for 5 min. Blood samples were also taken intermittently for blood gas analysis. After this, the left lung was re-expanded and the chest was closed.

A catheter was placed into the left internal carotid artery for measurement of systemic arterial pressures and for collecting blood samples for blood gas analysis. A pulmonary catheter was placed for collection of mixed venous blood samples.

The sheep were ventilated with a tidal volume of $10\,ml\,kg^{-1}$, and the respiratory rate was kept between 12 and 16 breaths m^{-1}. From previous experience, we have determined that these settings maintain an optimal arterial blood gas values. Nevertheless, arterial blood gases were checked intermittently to assure that these settings were indeed correct and supplemental oxygen was given to keep arterial PO_2 above 100 mmHg.

After completing these experiments, the animals were sacrificed by infusing saturated potassium chloride solution intravenously and the bronchial vein was dissected in order to study anatomy of the bronchial vein.

3. Results

In all six sheep, we were able to identify only one bronchial vein which drained blood into the left azygos vein at the level of aortic arch. This vein drained blood from the trachea, covering the region around the main tracheal bifurcation, and proximal extrapulmonary bronchi (Fig. 2). In order to confirm that this bronchial vein indeed drained blood that was supplied by the common bronchial branch of the bronchoesophageal artery, in all six sheep we infused 5% dextrose into this artery through the esophageal branch at an infusion rate of $1.0\,ml\,min^{-1}$ for 5 min (Fig. 1). During this infusion,

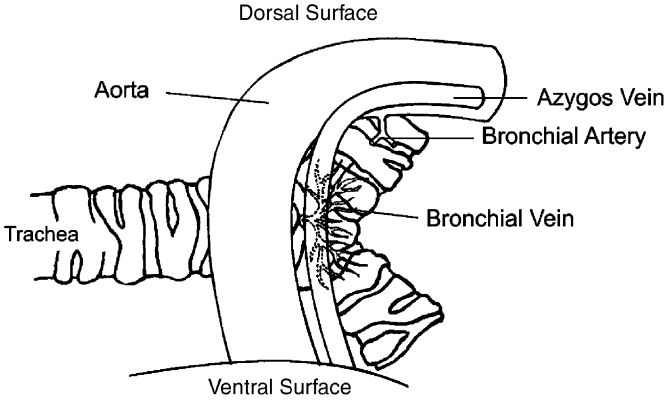

Fig. 2. Schematic diagram of bronchial vein draining into the azygos vein.

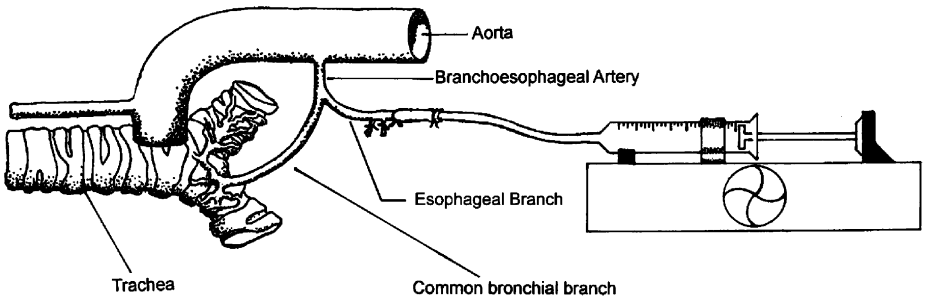

Fig. 1. Schematic diagram showing the technique of infusing 5% dextrose solution into the esophageal branch of the bronchoesophageal artery which then goes into the common bronchial branch.

Table 1
Blood gas analysis in systemic arterial, bronchial venous and mixed systemic venous blood

Blood sample	pH	PCO_2 (mmHg)	PO_2 (mmHg)
Systemic arterial blood	7.51 ± 0.03	39 ± 2.1	169 ± 9.8
Bronchial venous blood	7.54 ± 0.02	35 ± 2.6	95 ± 5.7
Mixed systemic venous blood	7.43 ± 0.02	48 ± 3.2*	42 ± 2.0*

*$p < 0.05$, compared to both bronchial venous and systemic arterial blood gas values.

bronchial venous blood glucose levels increased to $> 800\,mg\,dl^{-1}$, whereas in the systemic venous blood they were only $122\,mg\,dl^{-1}$. We did not measure bronchial or systemic venous blood glucose levels before starting 5% dextrose infusion.

The mean bronchial blood flow ($n = 6$) was 20.6 ± 4.2 ml min^{-1} (mean ± SEM) and, of this, less than 13% drained into the systemic venous system through the bronchial vein.

The mean systemic arterial pressure was 72.4 ± 4.1 mmHg whereas the bronchial venous pressure measured in the pouch was only 38.1 ± 2.1 mmHg ($n = 6$).

Blood samples were simultaneously drawn from the carotid artery, bronchial vein, and from the pulmonary artery for blood gas analysis ($n = 6$). Systemic venous blood PO_2 was only 42 mmHg, whereas bronchial venous blood PO_2 was 95 mmHg (Table 1).

4. Discussion

The major portion of the bronchial arterial blood drains into the pulmonary circulation through the bronchopulmonary anastomoses. It has been postulated that only a small portion of the bronchial arterial blood drains into the systemic venous system, however, the actual amount of blood that drains via this route has not been studied. In the present study we were able to find only a single bronchial vein. By demonstrating that the glucose concentration in the bronchial venous blood dramatically increased when 5% dextrose was infused into the bronchial artery indicates that this vein indeed drained a portion of blood supplied by the common bronchial branch of the bronchoesophageal artery. As expected, compared to bronchial venous blood, the glucose concentration in the mixed venous blood was low (only $122\,mg\,dl^{-1}$) because the bronchial venous blood got mixed with venous blood draining from other parts of the body. This study confirmed that the major portion of bronchial arterial blood is drained into the pulmonary circulation and less than 13% of the bronchial venous blood ends up in the systemic venous system.

In this model, the mean systemic arterial pressure was about 72 mmHg. We found that when the bronchial venous drainage was occluded, the mean occlusion pressure in the bronchial vein was only about 38 mmHg. This suggests that when bronchial vein is occluded, the bronchial arterial blood must have been diverted to some other venous channels thereby decreasing the bronchial venous occlusion pressure. It is likely that most of this bronchial blood was diverted into the pulmonary circulation. Hence, it is also possible that, if pulmonary venous pressures increase, some blood from the pulmonary circulation may also get diverted into the systemic venous system. This could be a mechanism which helps limiting elevation in pulmonary capillary pressure in response to elevation in left atrial pressure and hence decreasing net fluid filtration across the pulmonary capillary membrane.

We also found that when PO_2 in the systemic arterial blood was 169 mmHg, whereas it was only 95 mmHg in the bronchial venous blood. However, both these values are on the upper flat part of the oxyhaemoglobin dissociation curve suggesting that normally airway tissues extract very little oxygen. This hypothesis is supported by the fact that PCO_2 in the bronchial venous blood was much lower than the PCO_2 in the mixed systemic venous blood. In fact, it was even lower than the PCO_2 in the systemic arterial blood suggesting that some CO_2 could have been eliminated from the bronchial vascular plexus in the airways. This finding is in agreement with our previous study [8] where we showed that in sheep with unilateral pulmonary artery occlusion, CO_2 can be eliminated from the bronchial circulation.

It has been assumed that, when a drug is administered by inhalation, molecules get deposited on the surface of the bronchial mucosa, and then traverse across the airway wall to reach the bronchial smooth muscle where they exert their effects on the bronchial smooth muscles. Because there is a dense submucosal bronchial vascular plexus in the airways [1], it is also possible that inhaled drugs are first absorbed into this submucosal bronchial vascular plexus and are then transported to the bronchial smooth muscles by the bronchial blood flow. This may explain how drugs that get deposited only in the proximal airways may still influence bronchial smooth muscle tone in the distal airways. In a recent study we found that intratracheal administration of methacholine in adult anesthetized sheep results in significant bronchoconstriction [9]. However, when methacholine is infused directly into the bronchial artery, only about 3% of the inhaled dose is needed to produce a comparable degree of bronchoconstriction. These data support the notion that the bronchial circulation may play an important role in the delivery of drugs to the bronchial smooth muscles. Therefore, this knowledge of bronchial venous anatomy may be helpful to those who are studying absorption of inhaled drugs from

tracheobronchial tree because measurement of drug concentrations in the bronchial venous blood may allow them to study the pharmacokinetics of inhaled drugs in more details.

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