The Bronchial Tree and Lobular Division of the Lung of the California Sea Lion (*Zalophus californianus*)

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(Received 18 September 1992/Accepted 2 April 1993)

ABSTRACT. In the California sea lion (*Zalophus californianus*), the position of the tracheal bifurcation is fairly cranial compared with those of mammals in general. The right lung has the dorsal, ventral, medial and lateral bronchiole systems. The cranial lobe is formed by the first bronchiole of the dorsal bronchiole system. The middle lobe is formed by the first bronchiole of the lateral bronchiole system. The accessory lobe is formed by the first bronchiole of the ventral bronchiole system. The caudal lobe is formed by the remaining bronchioles of the dorsal and lateral bronchiole systems and all bronchioles of the medial bronchiole system. The left lung has the dorsal and lateral bronchiole systems. The middle lobe is formed by the first bronchiole of the lateral bronchiole system. The caudal lobe is formed by the remaining bronchioles of the lateral bronchiole system and all bronchioles of the dorsal bronchiole system.—**KEY WORDS:** bronchial tree, California sea lion, lung.

J. Vet. Med. Sci. 55(4): 669–671, 1993

Studies on comparative anatomy of the lung were initiated by Aeby [1], who examined the lungs of many mammals including man, and classified the bronchioles into the dorsal and ventral bronchiole systems. He also classified the bronchioles into the epiarterial and hypoarterial bronchioles according to the course of the pulmonary artery, and considered that the left epiarterial bronchiole, i.e. the left upper lobe bronchiole, is lacking in the human lung. Huntington [3] later examined many mammalian lungs and considered that the left cranial and left middle lobe bronchioles have a common trunk from the left bronchus. Jackson and Huber [4] divided the human lung into ten pulmonary segments on either side for the convenience of surgery. This is now widely accepted in human anatomy.

On the other hand, in veterinary anatomy, the lobular division of Ellenberger and Baum [2] was widely accepted for many years. However, Seiferle [8] maintained that the left cardiac lobe of Ellenberger and Baum [2] is a part of the apical lobe. In this way, the way of interpretation of the left lung have differed among authors.

Therefore, the present author has examined the lungs of many mammals including man to establish the fundamental structure of the bronchial ramification. From these examinations, it has been proposed that the dorsal, ventral, medial and lateral bronchiole systems arise from the dorsal, ventral, medial and lateral sides of the bronchus on either side, respectively. Furthermore, two pairs of bronchioles arise from the lateral sides of the trachea. The cranial lobe bronchioles consist of the first bronchiole of the dorsal bronchiole system (cranial lobe bronchiole I), and the two bronchioles arising from the lateral side of the trachea (cranial lobe bronchioles II and III). Thus, three kinds of cranial lobe bronchioles can be enumerated. The middle lobe bronchiole is the first bronchiole of the lateral bronchiole system, and the accessory lobe bronchiole is the first bronchiole of the ventral bronchiole system. The caudal lobe is formed by the remaining bronchioles of the dorsal, lateral and ventral bronchiole systems and all bronchioles of the medial bronchiole system [5, 6].

The lungs of two California sea lions (*Zalophus*

californianus) were used. In one specimen, a celluloid solution was injected into the bronchial tree through the trachea, and then the lung was placed in water until the celluloid solution coagulated completely. The soft tissues were treated with hydrochloric acid, and a cast model was obtained after washing in running water (Fig. 1). The other specimen was used for observation of external form. The lung of the California sea lion will be described on the basis of the foregoing proposal by the author [5, 6].

Bronchial ramification and lobular division (Figs. 1–4): The trachea of the California sea lion divides into the right and left bronchi in the thoracic cavity. However, between the tracheal bifurcation and the origin of the right cranial lobe bronchiole I, both bronchi are connected with a connective tissue. The right cranial lobe bronchiole arises from a position fairly caudal to the tracheal bifurcation, on the dorsolateral side of the right bronchus. This bronchiole corresponds to the first bronchiole (D_1) of the dorsal bronchiole system (cranial lobe bronchiole I). The main trunk of the right cranial lobe bronchiole divides into two branches, on the cranial and caudal sides, and forms the right cranial lobe. On the cranial and ventral borders of this lobe, there are shallow fissures. The right middle lobe bronchiole arises from the ventrolateral side of the right bronchus and extends in a ventrolateral direction. This bronchiole corresponds to the first bronchiole (L_1) of the lateral bronchiole system. The right accessory lobe bronchiole, i.e. the first bronchiole (V_1) of the ventral bronchiole system, arises from the ventromedial side of the right bronchus and forms an independent lobe (Figs. 1, 2). The right caudal lobe consists of the remaining bronchioles of the dorsal and lateral bronchiole systems and all bronchioles of the medial bronchiole system; the ventral bronchiole system is lacking. The lateral bronchiole system has the second (L_2) to the fifth (L_5) bronchioles. The second bronchiole (L_2) is well developed and divides into two branches, cranial and caudal, in the distal portion. The dorsal bronchiole system has the second (D_2) to the fifth (D_5) bronchioles. The second bronchiole (D_2) is well developed and divides into three branches. The medial bronchiole system has the third (M_3) and the fourth (M_4) bronchioles.

Fig. 1. Celluloid cast model of the California sea lion lung. Ventral aspect.

In the left lung, the cranial lobe bronchioles are lacking. Therefore, the left middle lobe bronchiole, i.e. the first bronchiole (L_1) of the lateral bronchiole system, is well developed. This bronchiole arises from the ventrolateral side of the left bronchus, and its origin is more cranial than that of the right middle lobe bronchiole. The left middle lobe bronchiole divides into three branches: cranial (a), middle (b) and caudal (c). Each branch area is separated by fissures, although the fissures are incomplete. Furthermore, the area of the caudal branch (c) has a fissure on the cranial margin. The left caudal lobe consists of the remaining bronchioles of the lateral bronchiole system and all bronchioles of the dorsal bronchiole system: the ventral and medial bronchiole systems are lacking. The lateral bronchiole system has the second (L_2) to the sixth (L_6) bronchioles. The second bronchiole (L_2) is well developed as in the right lung. There is a shallow fissure between the area of this bronchiole and the other portions of the left caudal lobe. The dorsal bronchiole system has the second (D_2) to the seventh (D_7) bronchioles.

The anatomical terms used in this report, i.e. the cranial lobe, middle lobe, caudal lobe and right accessory lobe correspond to the upper lobe, middle lobe, lower lobe and the right medial basal segment (S^7) of the human lung, respectively. However, in the human left lung, the upper lobe and the medial basal segment (S^7) are lacking from the viewpoint of comparative anatomy [5, 6]. The term bronchiole corresponds to a lobar bronchus arising from the right and left bronchi, or a segmental bronchus arising from the caudal lobe bronchi.

In most mammals, the right cranial lobe bronchiole (cranial lobe bronchiole I) arises from a site close to the

tracheal bifurcation, on the dorsolateral side of the right bronchus. However, in the human lung, the right upper lobe bronchiole arises from a site more caudal to the tracheal bifurcation. With regard to this phenomenon, the author has considered that the trachea of the human lung divides at a position more cranial than is generally the case in mammals [5, 6]. The author later observed the lung of the lion [7]. The right cranial lobe bronchiole of the lion arises from the right lateral side close to the end of the trachea, as the so-called tracheal bronchiole (bronchus), although this bronchiole is the first bronchiole (D_1) of the dorsal bronchiole system (cranial lobe bronchiole I). In this respect, the position of the tracheal bifurcation in the lion can be considered to be more caudal than is generally the case in mammals. However, the position of the tracheal bifurcation in the California sea lion is apparently fairly cranial compared with other mammals, and the distance between the origin of the right cranial lobe bronchiole I and the tracheal bifurcation is sufficient to include the origins of the tracheal bronchioles (bronchi), if present in the lung of the California sea lion. These phenomena show that the positions of the tracheal bifurcation are not always constant among mammals. At the same time, these facts verify the author's proposal.

In the left lung, the left middle lobe bronchiole, termed by the author, arises from a position more cranial than that of the right middle lobe bronchiole, and forms an independent lobe. Furthermore, the area of the second bronchiole (L_2) of the lateral bronchiole system is also separated from the other portions of the left caudal lobe by a fissure, although the fissure is incomplete. Therefore, the left lung tends to be interpreted as consisting of the cranial, middle and caudal lobes, since three lobes are apparent by external observation.

However, the right cranial lobe bronchiole is the first bronchiole (D_1) of the dorsal bronchiole system and arises from the dorsolateral side of the right bronchus. This bronchiole is an epiarterial bronchiole. The right middle lobe bronchiole is the first bronchiole (L_1) of the lateral bronchiole system and arises from the ventrolateral side of the right bronchus. This bronchiole is one of the hypoarterial bronchioles. In this way, the cranial lobe bronchiole and the middle lobe bronchiole differ in their origins, their relationships to the pulmonary artery and their bronchiole systems. The left middle lobe bronchiole, termed by the author, is the first bronchiole (L_1) of the lateral bronchiole system, and arises from the ventrolateral side of the left bronchus. This bronchiole is one of the hypoarterial bronchioles. The author considers that the unbalance of origins between the right and left middle lobe bronchioles might be due to the difference in growth of the two bronchi. Therefore, the left middle lobe bronchiole, termed by the author, does not correspond to the right cranial lobe bronchiole, but to the right middle lobe bronchiole. Judging from relationships among the origins of the bronchioles, the second bronchiole (L_2) of the lateral bronchiole system belongs to the left caudal lobe as in the right lung (Figs. 2-4). Accordingly, the left lung

Fig. 2. Ventral aspect of the bronchial tree of the California sea lion.

Fig. 3. Lateral aspect of the right lung.

Fig. 4. Lateral aspect of the left lung.

Abbreviations. Figs. 2-4: D-dorsal bronchiole system. L-lateral bronchiole system. V-ventral bronchiole system. M-medial bronchiole system. D₁(I)-cranial lobe bronchiole. L₁-middle lobe bronchiole. V₁-accessory lobe bronchiole. The remaining bronchioles constitute the caudal lobe. R.P.A.-right pulmonary artery. L.P.A.-left pulmonary artery.

consists of the middle and caudal lobes.

This case suggests that not only external features but also internal patterns of the bronchial tree and pulmonary arteries are necessary to take into consideration for identification of the pulmonary lobes.

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