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MACROSCOPIC ANATOMY OF THE LOWER RESPIRATORY TRACT OF THE NORTH AMERICAN OPOSSUM (*Didelphis virginiana*)

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ABSTRACT

This study documents the macroscopic anatomy of the lower respiratory tract of the North American opossum (*Didelphis virginiana*). The trachea consists of approximately 28 c-shaped cartilages and extends from the larynx to its bifurcation into right and left principal bronchi. The right lung consists of cranial, middle, caudal and accessory lobes which are separated from one another by interlobar fissures. The left lung consists of cranial and caudal lobes which are not separated by interlobar fissures. Lobation of the right and left lungs was verified from tracheobronchial casts.

Key words: Trachea, bronchus, lower respiratory tract, North American opossum (*Didelphis virginiana*)

INTRODUCTION

The North American opossum (*Didelphis virginiana*), has become more prominent as a patient in veterinary medicine due to advancements in wildlife rehabilitation. Therefore, it is essential to have an available source on the normal macroscopic anatomy of all the organ systems of the North American opossum especially when evaluating pathological changes.

Additionally, the North American opossum has been used in biomedical research for over twenty-five years. It has served as a model for embryogenesis [15,22,28], cytogenetic studies [20] and physiological studies [17,27]. The first anatomical descriptions on the osteology, mycology [3] and general visceral topography [29] of the North American opossum date back three hundred years. Subsequent anatomical descriptions of the North American opossum have briefly described the lung [2] and general visceral topography [5,6,24,25]. However, none provide a complete description or photographic record of the lower respiratory tract. To benefit research and medicine involving the North American opossum, complete anatomical records of the various organ systems are a necessity.

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MATERIAL AND METHODS

Eighteen North American opossums (9 males and 9 females) of various ages were used to study lower respiratory tract anatomy. The lower respiratory tracts from 6 animals were removed and air-dried with laboratory air for 48 h after which RTV silicone (Silicone Inc. P.O. Box 363, 211 Woodbine High Point, NC, 27261) was injected into the trachea to produce tracheobronchial casts [11]. The lower respiratory tracts from the remaining 12 animals were dissected and examined *in situ* and *ex vivo*. Some lungs were inflated *in situ* to mimic the inspiratory phase for documentation of intercostal landmarks of the individual lobes.

RESULTS

Trachea

The cervical trachea (pars cervicalis trachea) is located along the ventral midline of the cervical region with the esophagus (pars cervicalis esophagus) lying dorsal and to the left. The cervical trachea is covered ventrally by the right and left sternohyoideus muscles (musculi sternohyoideus) and laterally by the sternothyroideus muscles (musculi sternothyroideus). After passing through the thoracic inlet (apertura thoracis cranialis), the thoracic trachea (pars thoracica trachea) continues caudally along the dorsal midline and terminates at the tracheal bifurcation (bifurcation tracheae). The trachea maintains its orientation to the esophagus similar to that in the cervical region. The trachea bifurcates dorsal to the base of the heart (basis cordis) at the level of the third intercostal space (spatium intercostale) into the right and left principal bronchi (bronchus principalis dexter et sinister) (Fig. 1). The average distance from the first tracheal cartilage (cartilaginous tracheales) to the tracheal bifurcation *in situ* is 70.0 ± 1.28 mm. The tracheal cartilages are c-shaped and incomplete dorsally with the ends of the tracheal cartilage joined by smooth muscle (musculus tracheales). The North American opossum has 25 to 29 cartilage with the most frequent number being 28 (57% of animals). Tracheal cartilage anastomosis occurs in the middle one-third of the trachea and can involve two or three adjacent cartilage.

Lungs

Each lung (pulmo) has a costal (facies costalis), medial (facies mediales) and diaphragmatic surface (facies diaphragmatica) along with dorsal and ventral margins (margo dorsalis et ventralis). The costal surfaces are smooth, convex and in contact with the thoracic wall. The medial surfaces of the lungs are smooth and concave. Present on the medial surface of each lung is a cardiac impression (impressio cardiaca) which is created by the heart. The diaphragmatic surfaces of the lungs are smooth and concave (Fig. 2). This concavity results from the base of the lungs (basis pulmonis) lying against the convex surface of the diaphragm. The dorsal margins of the lungs are rounded and located along the ventrolateral surfaces of the thoracic vertebral bodies (corpus vertebrae thoracicae). The ventral margin of the right lung (pulmo dexter) is thin and interrupted by interlobar fissures (fissura interlobaris). The ventral margin of the cranial lobe (lobus cranialis) extends to the midline. However the ventral margin of the middle lobe (lobus medius) crosses to the left of the midline and terminates at the left fourth costochondral junction. The ventral margin of the left lung (pulmo sinister) is thin with 1 to 2 small fissures. The ventral margin of this lung does not cross the midline and only extends ventrally to the first through sixth costochondral junctions due to the ventral attachment of the mediastinal pleura to the left of the midline.

Pleura lines the thoracic wall and covers the lungs and other mediastinal structures within the thoracic cavity (cavum thoracis). The mediastinal pleura attaches dorsally along the vertebral bodies. Cranially its ventral attachment is along the midline and caudally it angles toward the left sixth costochondral junction (Fig. 3). The visceral pleura (pleura pulmonalis) is tightly adhered to the lungs. The parietal pleura (pleura parietalis) covers the medial surfaces of the ribs (costae), the internal intercostal muscles (musculi intercostales), the thoracic part of the sympathetic trunks (truncus sympathicus), the cranial surface of the diaphragm and numerous mediastinal structures. Attaching the dorsomedial border of each lung to the middle and caudal mediastinal pleura (pleura mediastinalis) is a pulmonary ligament (ligamentum pulmonale). Each pulmonary ligament extends along the medial surface of the lung from the hilus (hilus pulmonis) in a caudal direction.

The right lung consists of a cranial lobe, middle lobe, caudal lobe (lobus caudalis) and an accessory lobe (lobus accessorius). The cranial lobe extends from the first through fourth intercostal spaces in the inspiratory phase. The medial surface of this lobe covers the right cranial vena cava (vena cava cranialis) and the cranial part of the right atrium (atrium dextrum) of the heart.

The middle lobe of the right lung extends from the second through fifth intercostal spaces in the inspiratory phase. It is separated from the cranial lobe by an oblique fissure (Fig. 4). The cranial extent of the middle lobe covers the caudal part of the right atrium of the heart. This lobe curves caudoventrally around the right ventricle (ventriculus dexter) and extends past the apex of the heart (apex cordis) to the left of the median plane. Upon crossing the dorsal surface of the sternum, this elongated portion of the middle lobe inclines dorsally and terminates at the level of the left fourth costochondral junction. A small cardiac notch (incisura cardiaca) may be present between the cranial and middle lobes of the right lung opposite the right second intercostal space. However the ventral surface of the heart is exposed to the left ventral thoracic wall

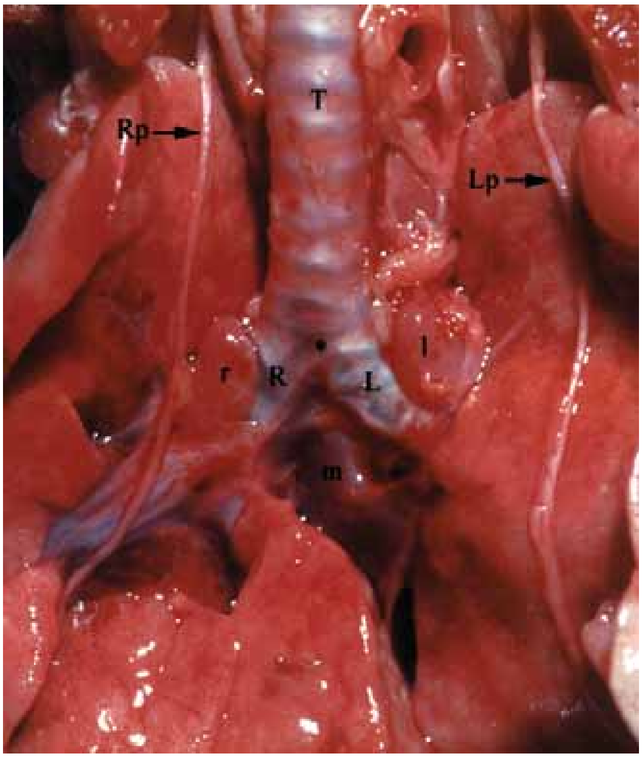

Figure 1. Ventral view of thoracic respiratory tract (heart and great vessels removed). Thoracic trachea (T), tracheal bifurcation (*), right principal bronchus (R), left principal bronchus (L), right tracheobronchial lymph node (r), left tracheobronchial lymph node (1), middle tracheobronchial lymph node (M), right phrenic nerve (Rp), left phrenic nerve (Lp), diaphragm (D).

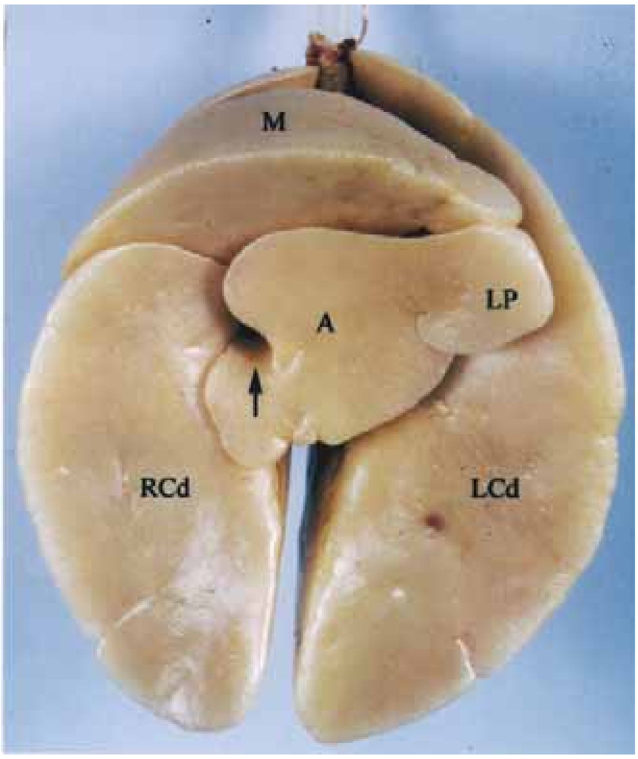

Figure 2. Caudal view of lungs. Middle lobe of right lung (M), caudal lobe of right lung (RCd), accessory lobe (A), notch for the caudal vena cava (arrow), left process of the accessory lobe (LP), caudal lobe of the left lung (LCd).

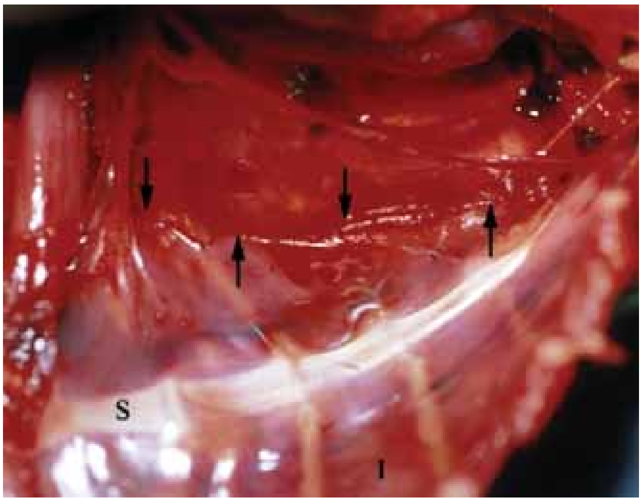

Figure 3. Dorsal view of the ventral thoracic cavity and sternum. Ventral attachment of the mediastinum (arrows), right third intercostal space (I), fifth sternabra (S).

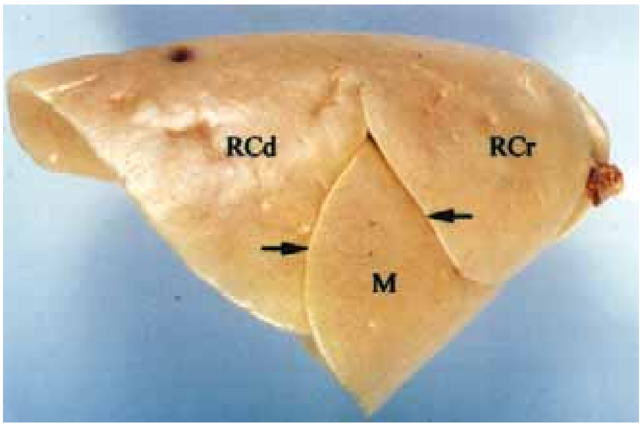

Figure 4. Lateral view of right lung. Cranial lobe (RCr), middle lobe (M), caudal lobe (RCd), interlobar fissures (arrows).

between the right and left lungs from the first to fifth intercostal spaces. The apex of the heart is directed caudoventrally and to the left of the midline (33-37^0) toward the left fourth intercostal space. A sterno-pericardial ligament (ligamentum sternopericardiacum), which is continuous with the fibrous pericardium and the pericardial mediastinal pleura, extends from the apex of the heart to the endothoracic fascia (fascia endothoracica) and the parietal pleura at the left fifth to sixth costochondral junctions.

The caudal lobe of the right lung extends from the fourth to eighth intercostal spaces in the inspiratory phase. This lobe is approximately twice as large as the middle lobe of the right lung. The caudal lobe is separated from the middle lobe by a vertical fissure (Fig. 4). Laying medial to the caudal lobe is the caudal vena cava (vena cava caudalis) and the accessory lobe of the right lung (Fig. 2).

The accessory lobe is the smallest lobe of the right lung and is shaped like an irregular pyramid. This lobe lies medial to the caudal lobes of the right and left lungs (Fig. 2). The cranial surface of this lobe rests on the caudodorsal aspect of the heart resulting in a prominent cardiac impression. The caudal surface of this lobe is molded against the convex surface of the diaphragm. The right surface of the accessory lobe has a notch (sulcus venae cava caudalis) through which the caudal vena cava passes (Fig. 2). The left process of the accessory lobe is elongated and rests within the mediastinal recess (recessus mediastini) which is a space between the plica vena cava (plica venae cavae) of the caudal vena cava and the caudal mediastinal pleura (pleura mediastinalis).

The left lung consists of cranial and caudal lobes. This lung extends from the first to eighth intercostal spaces in the inspiratory phase. The ventral margin of this lung has 1 to 2 small fissures. These fissures are located on the cranial lobe of the left lung and do not coincide with the lobar division (Fig. 5). The medial surface of this lung covers the entire left atrium (atrium sinistrum) and a portion of the left ventricle (ventriculus sinister) of the heart.

Bronchial Tree

Bifurcation of the trachea into the right and left principal bronchi marks the beginning of the bronchial tree (arbor bronchalis) (Fig. 6). The right principal bronchus is on average 13.08 ± 1.61 mm in length and the left principal bronchus is on average 11.73 ± 2.03 mm in length. The right and left principal bronchi enter the hilus of the lungs at which point they divide into lobar bronchi (bronchi loabres).

The right principal bronchus divides into cranial, middle, caudal and accessory lobar bronchi (Fig. 7). The cranial lobar bronchus originates from the dorsolateral surface of the right principal bronchus and gives off six to seven segmental bronchi (bronchi segmentales) which radiate in cranial, caudal and dorsal directions. The middle lobar bronchus originates from the ventral surface of the right principal bronchus cranial to the origin of the accessory and caudal lobar bronchi. The middle lobar bronchus gives off ten segmental bronchi which radiate cranially, caudally and laterally. The accessory lobar bronchus originates ventromedially from the right principal bronchus cranial to the origin of the caudal lobar bronchus. The accessory lobar bronchus gives off eight segmental bronchi which radiate cranially, caudally, dorsally and ventrally. The caudal lobar bronchus continues the right principal bronchus caudally and gives off nine to ten segmental bronchi which radiate into the parenchyma.

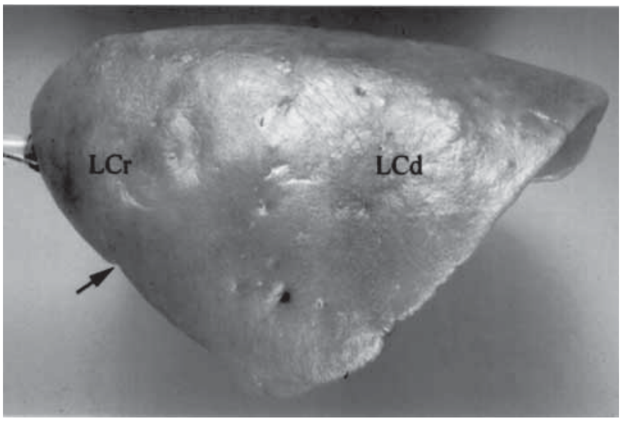

Figure 5. Lateral view of left lung. Cranial lobe (LCr), caudal lobe (LCd), marginal fissure (arrow).

Figure 6. Ventral view of tracheobronchial cast. Trachea (T), right principal bronchus (R), right cranial lobe (RCr), middle lobe (M), right caudal lobe (RCd), right caudal lobar bronchus (*), accessory lobe (A), left principal bronchus (L), left cranial lobe (LCr), left caudal lobe (LCd).

The left principal bronchus divides into cranial and caudal lobar bronchi (Fig. 6 and 7). The cranial lobar bronchus originates ventrolaterally from the left principal bronchus. The cranial lobar bronchus divides into two bronchi, cranial and caudal branches, which supply cranial and caudal parts of the left cranial lung lobe (Fig. 7). The cranial and caudal branch each give rise to four or five segmental bronchi which radiate dorsally, cranially and caudally. The caudal lobar bronchus originates caudal to the origin of the cranial lobar bronchus. Arising from the caudal lobar bronchus are six segmental bronchi which radiate into the parenchyma.

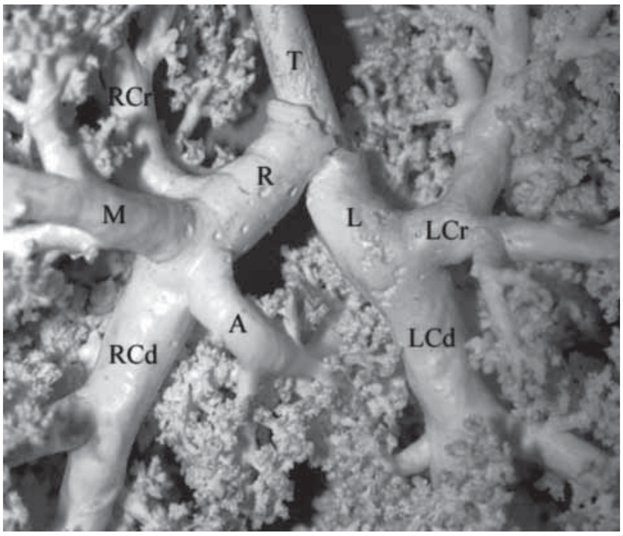

Figure 7. Ventral view of tracheobronchial cast. Trachea (T), right principal bronchus (R), right cranial lobar bronchus (RCr), middle lobar bronchus (M), right caudal lobar bronchus (RCd), accessory lobar bronchus (Ab), left principal bronchus (L), left cranial lobar bronchus (LCr), left caudal lobar bronchus (LCd).

DISCUSSION

Tracheal cartilage anastomosis, as seen in the North American opossum, has also been reported by Getty [9] to occur in domestic mammals. However, tracheal cartilage anastomosis in these mammals occurs randomly throughout the length of the trachea as opposed to only the middle third of the opossum trachea. The free ends of each tracheal cartilage in the North American opossum are joined by the trachealis muscle to form a complete ring which is also similar to many domestic mammals [4,7] .

The earliest reports on the respiratory anatomy of the North American opossum [21,29] state the right lung consist of three lobes. However a subsequent description of the lobation of the right lung of the Didelphyidae [24] reports four lobes. We found that the right lung of the North American consists of four lobes which are separated from one another by deep interlobar fissures. In addition to what we observed in the North American opossum, several of the smaller marsupials such as the brush-tailed opossum (*Trichosurus vulpecula*) [25], Phalangeridae and Phalangers [21,24], mulgara (*Dasycercus cristicauda*) [14], long nosed bandicoot (*Perameles obesula*) [24], Perameles, Petaurists and Dasyures [21] have similar lobation of the right lung. Variation in the North American opossum lung lobation in previous articles [21,24,29] may have resulted from using superficial features of the lung rather than the branching of the bronchial tree to determine lung lobation. This method of naming lobes was a common practice in previous anatomy texts and articles and has led to considerable confusion in determining lung lobation [4] .

The left lung of the North American opossum extends from the first through eighth intercostal spaces and consists of a cranial and caudal lobe. Interestingly the left lung does not have interlobar fissures demarcating the division of cranial and caudal lobes. This description of lobation of the left lung (as well as the right) is based upon the division of the bronchial tree as described by Nomina Anatomica Veterinaria [12]. Hence tracheobronchial casts were utilized to determine lobation since naming lobes based on superficial features is not reliable and should not be done [4]. A previous description of the North American opossum [21] indicates a similar lobation of the left lung. As well, the Phalangeridae, mouse opossum (*Marmosa elegans*) [24], brush-tailed opossum [25], Petaurists, Phalangers, Dasyures [21] and mulgara [14] have a similar lobation of the left lung to the North American opossum. However, no mention is made of how Owen [21], Sonntag [24,25] or Jones [14] determined lobation of the lungs. The variability in presence and location of small fissures on the ventral margin makes it difficult to accurately approximate the intercostal landmarks for the cranial and caudal lobes of the left lung in the North American opossum.

The right and left principal bronchi of the North American opossum divide into lobar bronchi to supply each lobe of the right and left lungs respectively. Within the lobe of each lung, the lobar bronchi give off numerous segmental bronchi. However the left cranial lobar bronchus divides into a cranial and caudal branch prior to the emergence of the segmental bronchi. These two branches supply the cranial and caudal parts of the left cranial lobe. Previous investigators describe a similar pattern of branching for the left cranial lobar bronchus in the canine [4,7,9], feline [1,19], sheep [10] and bovine [26]. However Hare [10], Adrian [1], Getty [9] and Nickel *et al.* [19], refer to these branches of the left cranial lobar bronchus as cranial and caudal segmental bronchi. In addition, Adrian [1] and Getty [9] state these segmental bronchi which ventilate the cranial and caudal bronchopulmonary segments, also give off numerous subsegmental bronchi. In earlier literature, Hare [10], Adrian [1] and Ishaq [13] conclude there is lack of agreement on the definition of a bronchopulmonary segment. Kramer and Glass [16], Hare [10], Getty [9], Nickel *et al.* [19], Ishaq [13] and Schaller [23] define a segmental bronchus as that which ventilates a bronchopulmonary segment and is a self-contained or independent section of lung tissue within a lobe. Also Kramer and Glass [16] and Getty [9] state the segmental bronchus supplying a bronchopulmonary segment originates from a lobar bronchus. Then, according to Nickel *et al.* [19], the segmental bronchi dispatch bronchioles. Based on these definitions, the use of cranial and caudal segmental bronchi does not seem appropriate in the canine, feline, sheep or the North American opossum. Stamp's [26] suggestion concerning the cranial and caudal branches of the left cranial lobar bronchus of the bovine lung seems to be the best description. According to him, these branches dispatch numerous segmental bronchi to supply the bronchopulmonary segments of the left cranial lobe. In addition, previous articles on the bronchial tree of domestic animals [1,10], state that the nomenclature used in these species attempted to follow that established for human anatomy. However, Hare [10] states that the nomenclature adopted for humans is not comparable when in fact it, along with Stamp's [26], seems to be the best description for the branching pattern of the left cranial lobar bronchus. According to human anatomy terminology [8,18,30] the left superior lobar bronchus divides into a superior division and an inferior division from which segmental bronchi are dispatched to the bronchopulmonary segments. This pattern is similar to what was observed in the North American opossum.

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