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MACROSCOPIC ANATOMY OF THE LOWER RESPIRATORY TRACT OF THE GRAY SHORT-TAILED OPOSSUM (*Monodelphis domestica*)

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ABSTRACT

The present study describes the macroscopic anatomy of the lower respiratory tract of the gray short-tailed opossum (*Monodelphis domestica*). The trachea consists approximately 25 c-shaped tracheal cartilages and extends from the larynx to its bifurcation into right and left principal bronchi. The right lung is divided into cranial, middle, caudal and accessory lobes by interlobar fissures. The left lung consists of cranial and caudal lobes which are not divided by an interlobar fissure. Lung lobation was verified from tracheobronchial casts.

Key words: Trachea, bronchus, lower respiratory tract, gray short-tailed opossum (*Monodelphis domestica*)

INTRODUCTION

Gray short-tailed opossums have become practical for use as models in several fields of research including embryogenesis [1,8,19], reproduction, sexual differentiation, behavior, chemical communication [22,25], nervous system development, DNA repair mechanisms, cytogenetics and biochemical genetics [23]. They have also been identified as the only laboratory mammal that develops melanoma in response to ultraviolet radiation [4,9,11,17,18,24]. Despite their increasing popularity as a research animal, few anatomical descriptions of the gray short-tailed opossum exist. Peukert-Adam *et al*. [16] describe the pancreas while Koch *et al.* [7] provide a general description of the abdominal organs of the gray short-tailed opossum. Kusewitt [10] and Hubbard [4] report pathological changes in the respiratory and cardiovascular system of the gray short-tailed opossum but do not describe normal thoracic anatomy. To benefit research involving these animals, especially when pathological changes are present, this study will document the normal macroscopic anatomy of the lower respiratory tract of the gray short-tailed opossum.

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MATERIAL AND METHODS

Eighteen 2 year old, sexually mature gray short-tailed opossums of both sexes were randomly divided into two groups for study of lower respiratory tract anatomy. Following exsanguination, the lower respiratory tracts from six animals were air-dried 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 [3]. The remaining twelve animals were embalmed with 10% buffered formalin and the lower respiratory tracts were removed and utilized for gross anatomical descriptions.

RESULTS

Trachea

The trachea consists of a cervical part (pars cervicalis trachea) and a thoracic part (pars thoracica trachea). The cervical trachea is located along the midline of the neck ventral to the bodies of the cervical vertebrae (vertebrae cervicales). The cervical portion of the esophagus (pars cervicalis esophagus) is located slightly dorsal and to the left of the trachea. The cervical trachea is covered ventrally by the sternohyoideus muscles (musculi sternohyoideus) and laterally by the sternothyroideus muscles (musculi sternothyroideus). After passing through the thoracic inlet (apertura thoracis cranialis), the thoracic trachea continues caudally along the midline, with the esophagus remaining dorsal and to the left of it, and terminates at the tracheal bifurcation (bifurcatio tracheae) (Fig. 1). The trachea bifurcates dorsal to the base of the heart (basis cordis) at the level of the second to third intercostal spaces (spatium intercostale) and gives rise to the right and left principal bronchi (bronchus principalis, dexter et sinister). The trachea is made up in part by 23 to 26 tracheal cartilages (cartilagines tracheales) with the most frequent number being 25 (40% of animals). These hyaline cartilages are c-shaped and incomplete dorsally with the free ends of the cartilages joined by smooth muscle (musculus tracheales) (Fig. 2). Tracheal cartilages will frequently anastomose with adjacent cartilages in a random manner (Fig. 1). The average distance from the first tracheal cartilage to the tracheal bifurcation *in situ* is 30.27 mm with a standard deviation of ± 2.35 mm. The lumen of the trachea is round to oval on cross section with an average diameter in the cranial third of 3.18 ± 0.28 mm, in the middle third of 2.94 ± 0.20 mm and the caudal third of 2.05 ± 0.08 mm. The tracheal cartilages are approximately 1.0 mm wide in a cranial to caudal direction.

Lungs

Each lung (pulmo) has a costal (facies costalis), medial (facies medialis) and diaphragmatic (facies diaphragmatica) surface, along with dorsal (margo dorsalis) and ventral (margo ventralis) margins. The costal surfaces are smooth, convex and in contact with the thoracic wall. The medial surfaces 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. This concavity results from the base of the lungs (basis pulmonis) lying against the cranial 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 is thin and interrupted by interlobar fissures (fissura interlobaris). The ventral margin of the left lung is thin with several small fissures.

A simple squamous pleural membrane lines the thoracic wall and covers the lungs and other mediastinal structures within the thoracic cavity (cavum thoracis). 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 intercostal muscles (musculi intercostales), the thoracic portion of the sympathetic trunk (truncus sympathicus), the cranial surface of the diaphragm and numerous mediastinal structures. A pulmonary ligament (ligamentum pulmonale) attaches the dorsomedial border of each lung to the middle and caudal mediastinal pleura (pleura mediastinalis). Each ligament extends along the medial surface of the lung from the hilus (hilus pulmonis) in a caudal direction.

The right lung (pulmo dexter) consists of a cranial lobe (lobus cranialis), middle lobe (lobus medius), caudal lobe (lobus caudalis) and an accessory lobe (lobus accessorius) (Fig. 3). The cranial lobe is pyramidal. The apex of the right lung extends cranially to the thoracic inlet. During the inspiratory phase of respiration, the cranial lobe extends from the right first to fourth intercostal spaces. 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 is triangular in shape and extends ventrally toward the sternum. The cranial extent of this lobe covers the caudal part of the right atrium of the heart. The middle lobe curves caudoventrally around the right ventricle (ventriculus dextrum), extending past the apex of the heart (apex cordis), to the left of the median plane. Upon crossing the sternum, this appendage of the middle lobe inclines dorsally to terminate near the fourth to fifth costochondral junctions. The middle lobe extends from the right second through fifth intercostal spaces in the inspiratory phase and is approximately twice as large as the cranial lobe. The middle lobe is separated from the cranial lobe by a vertical fissure. A well-defined cardiac notch (incisura cardiaca pulmonis dextri) is not present between the cranial and middle lobes of the right lung. However, the auricular surface (facies auricularis) of the heart is exposed to the left ventral thoracic wall between the right and left lungs from the first to fourth intercostal spaces. The apex of the heart is directed caudoventrally, as well as 35-40^{o} to the left of the midline, and extends toward the left fourth intercostal space (Fig. 4). The sternopericardial ligament (ligamentum sternopericardiacum) connects the fibrous pericardium (pericardium fibrosum) at the apex of the heart to the endothoracic fascia (fascia endothoracica) at the left fourth intercostal space as well as to the diaphragm.

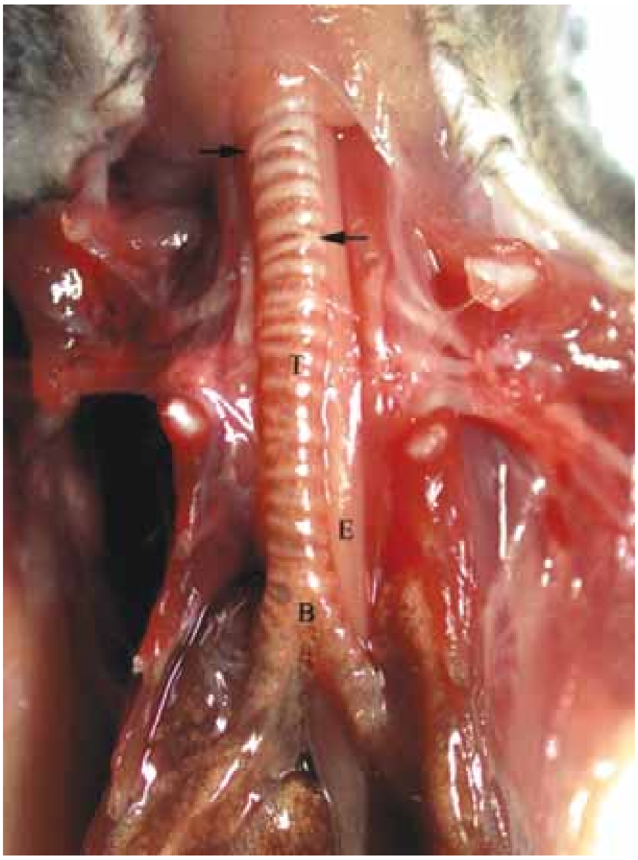

Figure 1. Ventral view of lower respiratory tract in situ. The heart and great vessels have been removed. Trachea (T), tracheal bifurcation (B), esophagus (E), tracheal ring anastomoses (arrows).

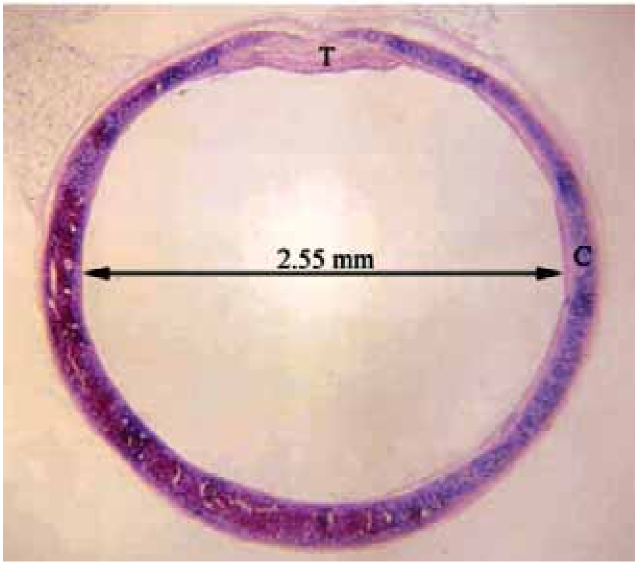

Figure 2. Cross section of trachea. Tracheal cartilage (C), trachealis muscle (T). H&E.

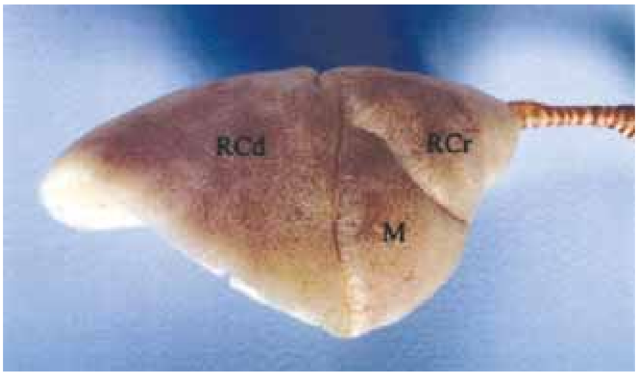

Figure 3. Lateral view of right lung. Cranial lobe (RCr), middle lobe (M), caudal lobe (RCd).

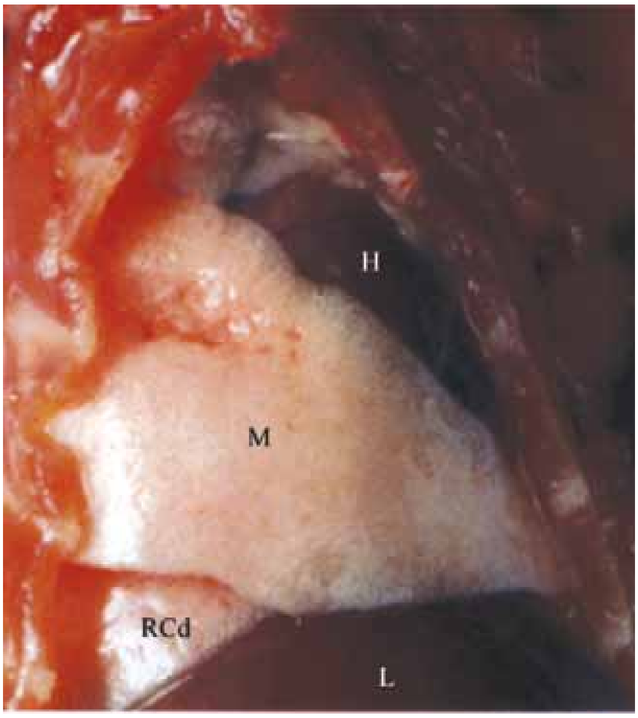

Figure 4. Ventral view of thorax. Heart (H), middle lobe of right lung (M), caudal lobe of right lung (RCd), liver (L).

The caudal lobe of the right lung extends from the right third to sixth intercostal spaces in the inspiratory phase. This lobe is triangular in shape and is approximately twice as large as the middle lobe. The caudal lobe is separated from the middle lobe by an oblique fissure. The base of the caudal lobe is in contact with the cranial surface of the diaphragm. The caudal vena cava (vena cava caudalis) and the accessory lobe are located medial to this lobe. The cranioventral margin of the caudal lobe is notched by the caudal vena cava.

The accessory lobe is the smallest lobe of the right lung and is shaped like an irregular pyramid. The cranial surface of this lobe rests on the caudodorsal aspect of the heart resulting in a prominent cardiac impression on this lobe. The caudal surface of this lobe is molded to the convex, cranial surface of the diaphragm. The right and left surfaces of the accessory lobe lie adjacent to the medial surfaces of the caudal lobes of the right and left lungs. The right surface of the accessory lobe has a notch (sulcus venae cava caudalis) through which the caudal vena cava passes. The left surface 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) and the caudal mediastinal pleura. The caudal vena cava is attached by the triangular shaped plica vena cava to the mediastinal pleura. The plica, which is a double fold of mediastinal pleura, attaches dorsally to the caudal vena cava, cranioventrally to the pericardium of the heart and caudally to the diaphragm.

The left lung (pulmo sinister) consists of cranial and caudal lobes (Fig. 5). These lobes are not separated from one another by a deep fissure. As a result, these lobes are not identifiable based on superficial features of the lung. This lung covers the left atrium (atrium sinister) and a portion of the left ventricle (ventriculus sinister) of the heart. The ventral margin of this lung typically has multiple small fissures. These fissures are randomly located and usually do not coincide with lobar division (Fig. 5). In the inspiratory phase, the left lung extends from the first through seventh intercostal spaces. An aortic impression (impressio aortica) is formed on the dorsomedial surface of the cranial and caudal lobes by the aortic arch (arcus aortae) and descending aorta (aorta descendens). The caudal lobe also has an esophageal impression (impressio esophagea) formed by the esophagus on its medial surface.

Bronchial Tree

Bifurcation of the trachea into the right and left principal bronchi marks the beginning of the bronchial tree (arbor bronchalis). The principal bronchi enter the hilus of the lungs where they divide into lobar bronchi (bronchi lobares) (Fig. 6). The left principal bronchus is on average 6.22 $\pm$ 0.69 mm in length and the right principal bronchus averages 6.57 $\pm$ 0.6 mm in length.

The right principal bronchus divides into cranial, middle, caudal and accessory lobar bronchi. The cranial lobar bronchus originates from the dorsolateral surface of the right principal bronchus and gives off five segmental bronchi (bronchi segmentales) which radiate in cranial and caudal directions from their origin. The middle lobar bronchus originates from the ventrolateral surface of the right principal bronchus cranial to the origin of the accessory and caudal lobar bronchi. The middle lobar bronchus gives off six segmental bronchi, which radiate cranially, caudally and dorsally. The accessory lobar bronchus is the last branch to arise from the right principal bronchus at which point the right principal bronchus continues caudally as the caudal lobar bronchus. The accessory lobar bronchus originates ventromedially from the right principal bronchus and gives off five to six segmental bronchi which radiate in cranial and caudal directions. Finally, the caudal lobar bronchus gives off six to seven segmental bronchi which radiate into the lung parenchyma.

The left principal bronchus divides into cranial and caudal lobar bronchi. The cranial lobar bronchus originates ventrolaterally from the left principal bronchus. The cranial lobar bronchus divides into two bronchi which supply cranial and caudal parts of the left cranial lung lobe. Arising from each of these bronchi are six segmental bronchi which radiate into the parenchyma. The caudal lobar bronchus continues the left principal bronchus caudally and has six to eight segmental bronchi which radiate into the parenchyma.

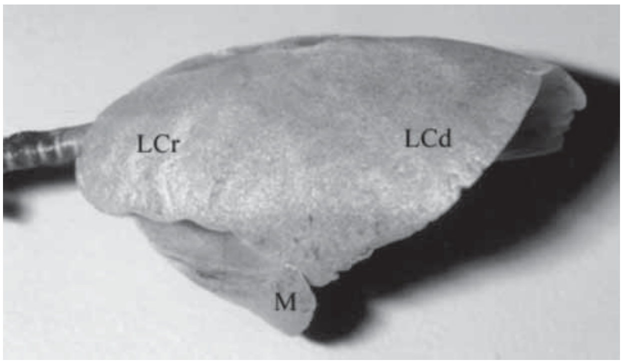

Figure 5. Lateral view of left lung. Cranial lobe of left lung (LCr), caudal lobe (LCd), middle lobe of right lung (M).

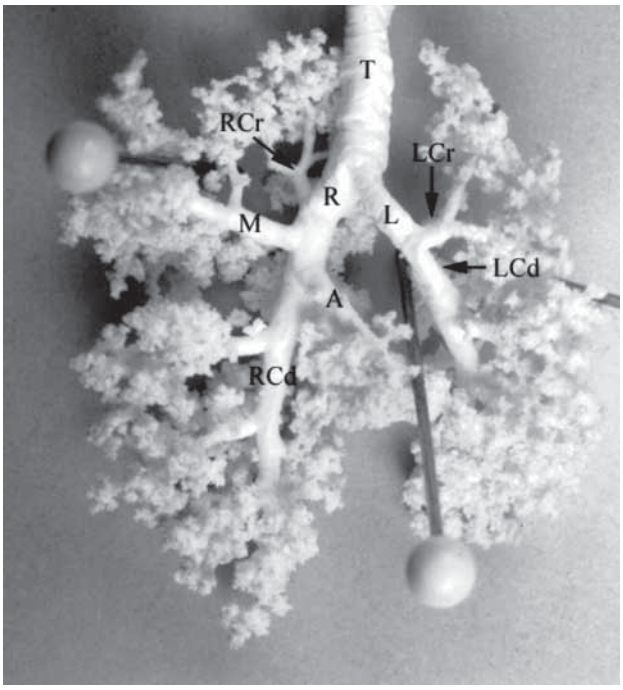

Figure 6. Ventral view of tracheobbronchial cast. Trachea (T), right principal bronchus (R), left principal bronchus (L), right cranial lobar bronchus (RCr), right middle lobar bronchus (M), right caudal lobar bronchus (RCd), accessory lobar bronchus (A), left cranial lobar bronchus (LCr), left caudal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

DISCUSSION

The trachea of the sexually mature gray short-tailed opossum consists in part of "c"-shaped tracheal cartilages with the free ends joined together by the trachealis muscle as is typical of most mammals. Tracheal cartilage number in the gray short-tailed opossum falls within the range reported in other marsupials which is nineteen rings in the gray four-eyed opossum (*Metachirus opossum)* to thirty-four in the bandicoot (*Perameles obesula)* and thirty-five in both the lesser gliding opossum (*Petaurus sciureus*) and tree kangaroo (*Dendrolagsus ursinus*) [21].

The lobation of the right lung of the gray short-tailed opossum is similar to previous descriptions of many marsupials including the mouse opossum (*Marmosa elegans*), gray four-eyed opossum, bandicoot, Phalangeridae [20], brush-tailed opossum (*Trichosurus vulpecula*) [21], Caenolestes [12], Dasyuridae [6,14], Perameles and Petaurists [14]. Owen [14] describes the right lung of Potoroo as having two to three deep fissures and an azygous lobe. This may indicate that it also has four lobes with one of them perhaps further subdivided. A right lung divided into four lobes is a common pattern found in most of the smaller marsupials.

Several other marsupials possess right lung lobation which differs from that of the gray short-tailed opossum. The right lung of the tree kangaroo, eastern grey kangaroo (*Macropus giganteus*) and wallaroo (*Macropus bennetti)*, which is trilobate, is described as having a deep median sulcus incompletely dividing the lung into anterior and posterior parts with the azygous lobe in addition [20]. Owen [14] states that the right lung of the whiptail wallaby (*Macropus parryi)* has one to two notches possibly indicating the absence of distinct divisions between lobes based on external appearance. The right lung of the American opossum (*Didelphys brachyura)* consists of three lobes and the right lung of the wombat (*Vombatus ursinus*) consists of a two lobes. The right lung of the koala (*Phascolactos cinereus)* is described by Forbes [2] as having three lobes without the azygous lobe while Sonntag [21] states that the right lung of the koala consists of only two lobes. The right lung of the common shrew opossum (*Caenolestes obscurus)* has three lobes with the anterior lobe slightly notched which corresponds to where a complete division was found in Didelphids [12]. Osgood [12] also states that in a third specimen the right lung consisted of four lobes thus indicating variability in lung lobation within this species. While a few of the smaller marsupials possess a right lung exhibiting a pattern of lobation different from that found in the gray short-tailed opossum, larger marsupials such as the kangaroos, wallabies and koala consistently have fewer attributed to the right lung. Earlier reports on marsupial respiratory anatomy often use human anatomy terms in naming the cranial lobe as the upper lobe, the middle lobe as the ventral lobe, the caudal lobe as the lower lobe and the accessory lobe as the azygous lobe or intermediate lobe.

While a cardiac notch is not present on the right lung of the gray short-tailed opossum, the angulation of the longitudinal axis of the heart to the left of the midline allows access to the heart via cardiac puncture in the left third and fourth intercostal spaces near the sternum. The longitudinal axis of the koala heart is described as being parallel to the left side of the sternum with the apex of the heart extending to the left fourth intercostal space [21]. Additional descriptions of marsupial heart angulation could not be located for further comparisons.

The left lung of the gray short-tailed opossum consists of two lobes with the cranial lobe being further sub-divided into two parts. The lobes of the left lung are not separated by an interlobar fissure as are those of the right lung. The only superficial indications which might be used for lobar demarcation are small, 1.0 – 2.0 mm fissures which are located along the ventral margin of the lung. These small fissures were found to be variable in location and number between animals with marked variation between animals obtained from different sources. Thus, the fissures were of little use in identification of the two lobes of the left lung from the surface of the organ. Due to the absence of external lobar demarcation, intercostal landmarks for the cranial and caudal lobes are difficult to define as well as the cranial and caudal parts of the cranial lobe without further study.

The left lung of the brush-tailed opossum [21], Phalangeridae [14,20], mouse opossum [20], koala [2,14], quoll (*Dasyurus*) [14], *Dasycercus cristicauda* [6] and Petaurists [14] is described as having a cranial and caudal lobe. Sonntag [20] and Owen [13] state that in *Macropodidae*, in which the tree kangaroo, wallaroo and eastern grey kangaroo were examined, the left lung has deep median sulci or clefts dividing it into anterior and posterior parts. The left lung of other marsupials such as the gray four-eyed opossum, long-nosed bandicoot [20], pig-footed bandicoot (*Choeropus castanotis*) [15], Caenolestes [12], wombat and American opossum [14] is described as being unilobate apparently based on the external appearance of the lung as branching of the bronchial tree was not mentioned. Owen [14] states that the left lung of Potoroo has a fissure on the anterior or upper ridge and the left lung of the whiptail wallaby has one to two notches and classifies the left lung of these animals as unilobate. These external markings were probably similar to what we observed in the gray short-tailed opossum giving the impression of being undivided. Lobation of the left lung across all marsupial species described it as having one or two lobes. Those described as having one lobe might actually be found to consist of two lobes should one examine tracheobronchial casts of those specimens.

Lung lobation in the gray short-tailed opossum was based upon the division of the bronchial tree as described by Nomina Anatomica Veterinaria [5] rather than on the external appearance of the lung. We accomplished this by examination of tracheobronchial casts to identify the lobar bronchi as they entered each lobe of the lung. We were unable to locate data on the branching pattern of the bronchial tree for other marsupials for comparison.

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