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The macroscopical anatomy of the lungs and thorax of the African lion (*Panthera leo*)

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Abstract

The left and right lungs extend from the second rib to the 13th, while only a small portion is present cranial to the 4th rib. The basal border of the left lung extends horizontally from the second costochondral junction (CCJ) to just ventral to the seventh CCJ, and then dorso-caudally to the angle of the 13th rib. The right lung has a similar configuration except for the basal border, which is located above the fifth to the sixth CCJ. The cardiac incisure is more prominent in the right lung and is formed by the notched space between the ventral margins of the cranial and middle lobes. The lungs are well-lobated, with complete fissures laterally but none medially. The trachea and primary bronchi are large and have a wide, thin membranous part. The muscular front limbs could limit cranial thoracic expansion, with the result that the bulk of the functional lung capacity is present caudal to the tricipital line. Recommended sites for intracardiac injections are on either side of the fifth CCJ, and for thoracocentesis, just dorsal to the seventh or eighth CCJ. Care is needed while intubating a lion's trachea because of the delicate membranous part.

KEYWORDS

anatomy, lion, lungs, thorax, veterinary

1 | INTRODUCTION

The anatomy of the domestic cat (*Felis silvestris catus*) is extensively researched (see below) and is a crucial component in the companion animal veterinary industry. "The cat is not a small dog" (Anon). This well-known expression in veterinary medicine is key in explaining why the anatomy of Felidae and Canidae should be considered separately. Owing to the status of the domestic cat as a widely owned pet, there has been extensive research on the lung anatomy for veterinary purposes (Dyce et al., 2010; Hudson & Hamilton, 1993). Despite the large number of lions in captivity, the anatomic structure of their lungs has not been described in detail. Lions use social hunting to accommodate for their reduced stamina and high energy cost of locomotion (Chassin et al., 1976). It is unknown whether an altered morphology of the lungs account for their limited athletic ability. From the limited studies on the respiratory tract of the lion, it is apparent that there are some anatomical

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differences between the lion and domestic cat pertaining to the upper respiratory tract, thus confirming that the anatomy of the lion is not just an enlarged version of that of the domestic cat (Luckhaus, 1969; Peters & Hast, 1994; Weissengruber et al., 2002). The problems associated with assuming similarities between species (such as the domestic cat and lion (*Panthera leo*)) have been recently highlighted (Marais & Crole, 2022).

The lion has received newfound attention in research circles after four lions tested positive for SARS-CoV-2 at a Barcelona Zoo during the recent COVID-19 pandemic (Fernández-Bellon et al., 2021). While dogs and cats are usually compared and regarded as similar, it was interesting to note that dogs were not as susceptible to SARS-CoV-2 as domestic and non-domestic cats (Mathavarajah & Dellaire, 2020). Symptoms in lions were predominantly respiratory in nature and presented as a dry cough and abnormal lung sounds (Gollakner & Capua, 2020). SARS-CoV-2 infection has also been confirmed in the Asiatic lion (*Panthera leo persicus*) in India, of which two lions died (Mishra et al., 2021). This is concerning as Asian lions have a much smaller population compared to African lions and are considered critically endangered by the IUCN red list and Appendix 1 of CITES (Harrington, 2004). Due to the very low population numbers of the Asiatic lion, the African lion could be used as a model, with possible extrapolation to the Asiatic species (Zahmel et al., 2021). Tuberculosis caused by *Mycobacterium bovis* has been reported since the 1990s to spill over from the host species of domestic cattle (*Bos taurus*) to other species such as the lion (Michel et al., 2006). It is now an important cause of respiratory disease in the lion, as it causes dyspnoea (Morris et al., 1996) and granulomatous lesions in the lungs (Ayele et al., 2004).

It is clinically relevant to know the branching pattern of the bronchial tree in healthy animals. Any deviation from the normal may indicate pathological conditions (Dyce et al., 2010). Domestic cats display fewer bronchial markings in comparison to dogs (*Canis familiaris*), and if a cat displays the same amount of bronchial markings as a normal dog, it could be indicative of disease (Thrall & Robertson, 2011). The most notable lung features on radiographs are the bronchi and blood vessels (Dyce et al., 2010). The bronchial anatomy of the domestic cat is well described and this knowledge can be used to ensure the entire airway is explored during bronchoscopies and the evaluation of thoracic radiographs (Caccamo et al., 2007).

Lions are listed by the International Union for the Conservation of Nature (IUCN) as vulnerable with decreasing numbers (IUCN, 2020). As a consequence, increasing numbers of lions are present in captivity in zoological gardens, private conservancies and captive-breeding facilities. For this reason, the need for veterinary interventions is increasing. In this investigation, we focussed on the lungs and associated structures to ensure that the entire airway is assessed during auscultation, bronchoscopy and the evaluation of thoracic radiographs (Caccamo et al., 2007). Knowledge of the bronchial anatomy of the lungs of lions will also contribute to the accuracy of radiographic evaluations and other procedures in this species. The aim of this article is to provide a topographical and anatomical description of the lungs, pleurae and mediastinum of the lion.

2 | MATERIALS AND METHODS

The carcasses of five lions, three females and two males, obtained and embalmed previously (Hartman et al., 2013; Marais & Crole, 2022), were used in this study.

Prior to dissection, the lion carcasses were rinsed in running tap water for 5–7 days. The two male lions were radiographed for a separate study prior to dissections. In these two specimens, the ventral neck region was skinned, and the sternohyoid muscle (*M. sternohyoideus*) and sternocephalic muscle (*M. sternocephalicus*) were transected to expose the trachea directly caudal to the larynx. A circular piece of trachea was removed to allow the size 18 endotracheal (ET) tube to be inserted into the trachea. The cuff of the ET tube was inflated with 120 cc of air, and air was forced into the lungs using an ambubag. The ambubag was removed after each inflation to allow the formalin and fluid to drain from the lungs and airways. The fluid drainage was assisted either by forcefully pressing on the thorax with the lion in lateral recumbency or by gravity, by positioning the hind limbs higher than the head. The inflation of the embalmed lungs in these two specimens allowed for a comparison between the borders and topography of the "inflated" lungs in comparison to the "deflated" lungs (representing the resting state of the lungs). In all five specimens, as described by Marais and Crole (2022), the thorax of the carcass was skinned from the neck to the 13th rib, simultaneously removing all the cutaneous muscles. After the removal of the thoracic limbs, the remaining muscles of the thorax (including the iliocostal muscle (*M. iliocostalis*)) were sequentially removed. The straight abdominal muscle (*M. rectus abdominis*) and external abdominal oblique muscle (*M. obliquus abdominis externus*) were reflected caudally. A small window was cut in the intercostal muscles, and the costal pleura was penetrated and removed to allow the insertion of a dissection probe to determine the caudo-ventral extent of the pleural cavity. After the extent of the pleural cavity was established, the incision was extended ventrally in order to determine the level of the diaphragmatic line of pleural reflection and dorsally to the border of the thoracic longissimus muscle (*M. longissimus thoracis*).

The basal edge of the lungs, dome of the diaphragm and diaphragmatic line of pleural reflection were determined

with the ribs in situ, and each line was individually drawn on the ribs with different coloured chalk (Figures 1 and 2). After these landmarks were established, the ribs were individually cut with gardening shears, except for the eighth rib in one specimen and the 3rd, 7th and 11th ribs in another specimen. These ribs were only removed when the lungs were removed. Before the removal of the lung, the cranial lung lobe was reflected to expose the cranial mediastinum. The nerves and blood vessels of the thorax were dissected from the connective tissue and mediastinal pleura. The lungs were removed by transecting the left and right pulmonary ligaments (*Lig. pulmonale sinister* and *dexter*) and the pulmonary hilus (*Hilus pulmonalis*). This procedure was used for both sides of the two male lion carcasses.

In the three female carcasses, the thoracic cavity (*Cavum thoracis*) was opened on the right or left side only. All the content of the thoracic cavity was removed intact by transecting the caudal vena cava (*Vena cava caudalis*), oesophagus and the left and right pulmonary ligaments. The ligament between the heart, sternum and diaphragm (Marais & Crole, 2022) was cut as close to the thoracic wall as possible. In the cranial part of the thoracic cavity the trachea, oesophagus and all the blood vessels and nerves cranial to the heart were severed just cranial to the first rib, and from there, all connective tissue was separated from the thoracic wall caudo-ventrally and caudo-dorsally. In the three lioness carcasses, the lungs were separated from the heart and dissected individually. One of the lungs was dissected to expose the entire bronchial tree by removing lung parenchyma from the pulmonary hilus region and from there into the lung to expose the bronchi and the blood vessels supplying each lung lobe.

Images of the dissections were digitally recorded using a Canon IXUS 115 HS Full HD (Japan) 12.1-megapixel camera and a Samsung Galaxy S9+ and Samsung Galaxy S6 smartphone (Samsung Electronics, Vietnam). The terminology used is that of the Illustrated Veterinary Anatomical Nomenclature (Schaller, 2007) and the Nomina Anatomica Veterinaria 5th Edition (Revised) (ICVGAN, 2012).

3 | RESULTS

3.1 | Thoracic cavity and pleura

The plural cupulae (*Cupula pleurae*) (Marais & Crole, 2022) (Figures 1 and 2) are functionally insignificant, and the

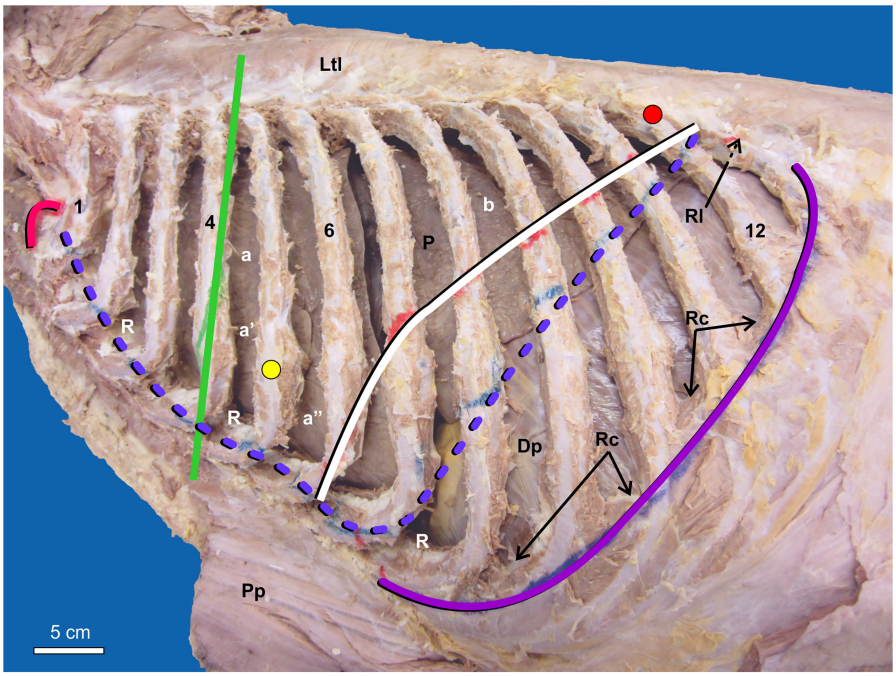

FIGURE 1 Left lateral view of the thorax (thoracic limb removed). The thoracic and intercostal muscles have been removed to reveal the topography of the *Pulmo sinister* (P) with the ribs in situ. The *Cavum thoracis* spans ribs 1–13 with the small *Cupula pleura* that extends 1.5 cm cranial to rib 1. The left cranial lung lobe spans ribs 2–7 and the *Lobus caudalis* spans ribs 8–13. Glossary: *Angulus costae* of rib 12 (red circle), *Art. costochondralis* of rib 5 (yellow circle), *Cupula pleura* (pink line), *Diaphragma* (Dp) covered by *Pleura diaphragmatica*, diaphragmatic line of pleural reflection (violet line), dome of the diaphragm (white line), *Lobus cranialis pulmonis sinistri* (a): *Pars cranialis* (a'), *Pars caudalis* (a"); *Lobus caudalis* (b), *Margo acutus* (purple dotted line), *Margo tricipitalis* (green line), *M. longissimus thoracis et lumborum* (Ltl), *M. pectoralis profundus* (reflected ventrally) (Pp), *Recessus costodiaphragmaticus* (Rc), *Recessus costomediastinalis* (R), *Recessus lumbodiaphragmaticus* (Rl), ribs 1 (1), 4 (4), 6 (6) and 12 (12). [Colour figure can be viewed at wileyonlinelibrary.com]

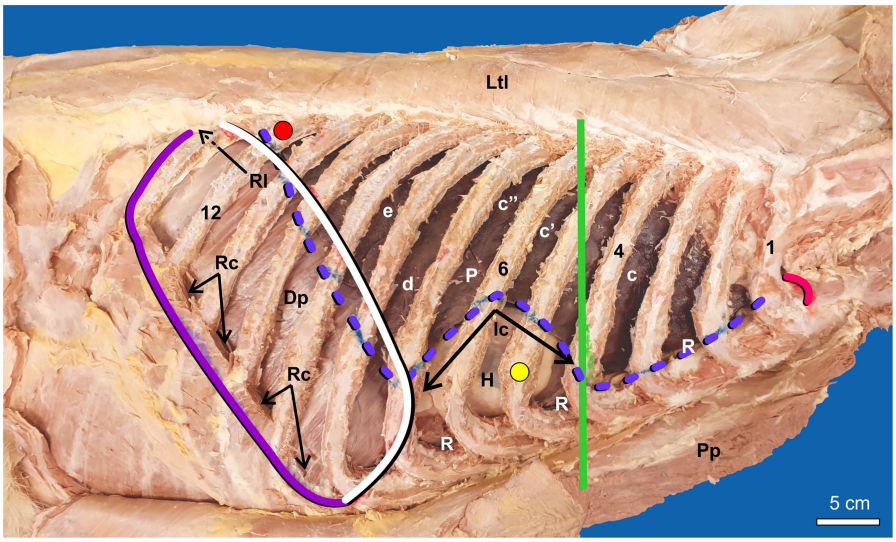

FIGURE 2 Right lateral view of the thorax (thoracic limb removed). The thoracic and intercostal muscles have been removed to reveal the topography of the *Pulmo dexter* (P) and heart with the ribs in situ. The *Cavum thoracis* spans ribs 1–13 with the *Cupula pleura* slightly smaller than the left side (see Figure 1) and extends 1 cm cranial to rib 1. Note that the *Insisura cardiaca pulmonis dextri* is large and prominent. Glossary: *Angulus costae* of rib 12 (red circle), *Art. costochondralis* of rib 5 (yellow circle), *Cupula pleura* (pink line), *Diaphragma* (Dp) covered by *Pleura diaphragmatica*, diaphragmatic line of pleural reflection (violet line), dome of the diaphragm (white line), Heart (H) covered by *Pleura pericardiaca*, *Insisura cardiaca pulmonis dextri* (Ic and black arrows), *Lobus cranialis pulmonis dextri* (c): *Pars cranialis* (c'), *Pars caudalis* (c"); *Lobus medius pulmonis dextri* (d), *Lobus caudalis* (e), *Margo acutus* (purple dotted line), *Margo tricipitalis* (green line), *M. longissimus thoracis et lumborum* (Ltl), *M. pectoralis profundus* (transected) (Pp), *Recessus costodiaphragmaticus* (Rc), *Recessus costomediastinalis* (R), *Recessus lumbodiaphragmaticus* (Rl), ribs 1 (1), 4 (4), 6 (6) and 12 (12). [Colour figure can be viewed at wileyonlinelibrary.com]

lung tissue did not occupy this space. Pleura (*Pleura*) covers the thoracic cavity, which is divided by the mediastinum into the left and right pleural cavities (*Cavum pleurae*). The visceral pleura (*Pleura visceralis*) covers the lungs (pulmonary pleura (*Pleura pulmonalis*)), and the nomenclature of the parietal pleura (*Pleura parietalis*) depends on the associated structures, namely, the costal pleura (*Pleura costalis*) (ribs), diaphragmatic pleura (*Pleura diaphragmatica*) (diaphragm) and mediastinal pleura (*Pleura mediastinalis*) (mediastinum), including the pericardial pleura (*Pleura pericardiaca*) (heart). The costodiaphragmatic recess (*Recessus costodiaphragmaticus*) marks the diaphragmatic line of pleural reflection (Figures 1 and 2), extending from ribs 8 to 13. On the eighth rib, the attachment is at the bend in the costal cartilage (*Cartilago costalis*) on the caudal border of the cartilage; caudo-dorsally, it is attached to the dorsal aspect of the ribs (9–12) at a level dorsal to the bend in the costal cartilage; and on rib 13, the line of pleural reflection is at the level of the ventral end of the floating rib (*Costae fluctuantes*). The *Recessus costomediastinalis* (Figures 1 and 2) is the recommended location for thoracocentesis of fluids. The junction of the pleura between the diaphragm and the dorsal aspect of the plural cavities represents the lumbodiaphragmatic recess (*Recessus lumbodiaphragmaticus*) (Figures 1 and 2).

3.2 | Blood supply and innervation

Branching directly from the pulmonary trunk (*Tr. pulmonalis*), the right pulmonary artery (*A. pulmonalis dextra*) is larger than the left pulmonary artery (*A. pulmonalis sinistra*) (Figure 3b). One artery supplies each lung lobe; however, some lobes are drained by numerous veins that course close to the arteries (Figure 3a). The lungs have a dual nerve supply. The sympathetic supply arises from the cervicothoracic ganglion (*Gl. cervicothoracicum*) (Figure 4), which runs dorsal to the parasympathetic supply from the vagus nerve (*N. vagus*) (Figures 3a and 4). The cervicothoracic ganglion has multiple branches, which anastomose with the vagus nerve. On the left, the vagus nerve courses over the aortic arch (*Arcus aortae*) (Figure 4a), and on the right, it passes ventral to the right azygos vein (*V. azygos dextra*) (Figure 4b). Both the left and right vagal nerves pass dorsal to the pulmonary hilus as they extend caudally.

3.3 | Mediastinum

The mediastinum is thin but not perforated, and there is no communication between the left and right pleural cavities. The mediastinal recess (*Recessus mediastini*)

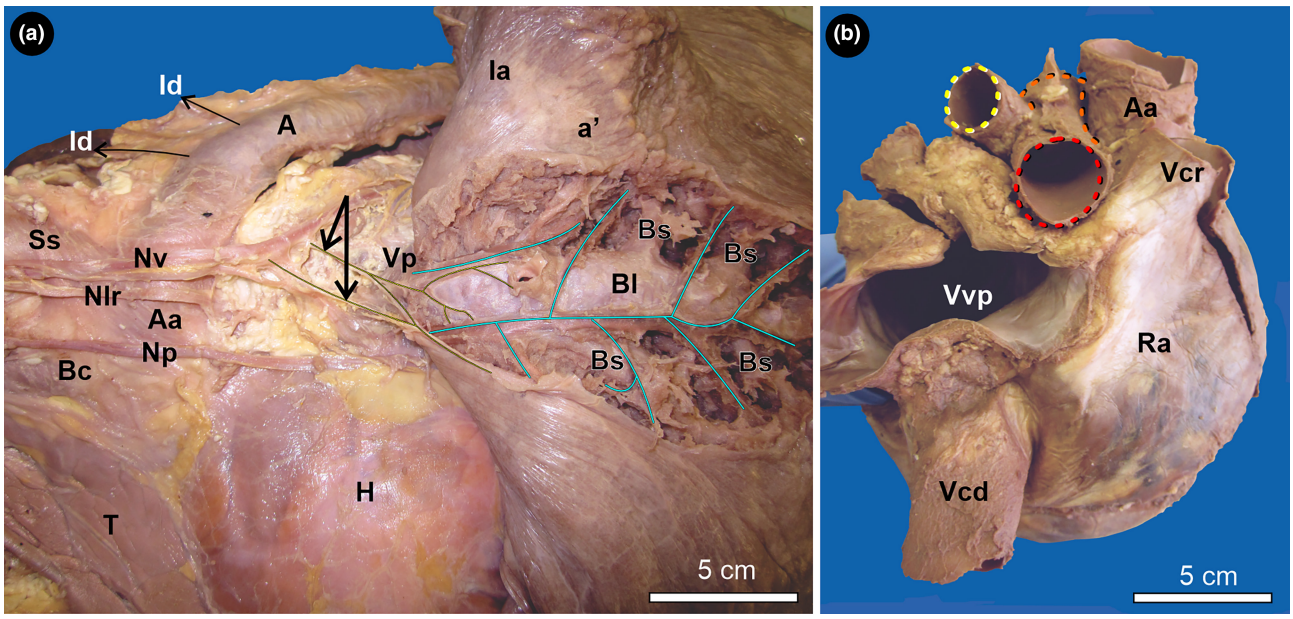

FIGURE 3 (a): Thoracic organs. *Lobus cranialis pulmonis sinistri Pars cranialis* reflected caudally and partially dissected in situ to the level of the *Bronchi lobares* and *Bronchi segmentales*. The *N. vagus* is clearly seen in this view. (b): Caudo-dorsal view of the heart base. Note that the *A. pulmonalis dextra* is larger than the *A. pulmonalis sinister*. The pulmonary arteries originate from the *Tr. pulmonalis*. Glossary: *Arcus aortae* (Aa), *Tr. brachiocephalicus* (Bc), *A. subclavia sinistra* (Ss), *Aorta thoracica* (A), *Aa. intercostales dorsales* (Id); *Tr. pulmonalis* (orange dotted outline): *A. pulmonalis dextra* (red dotted circle), *A. pulmonalis sinister* (yellow dotted circle), *Atrium dextrum* (Ra), *Bronchi lobares* (Bl), *Bronchi segmentales* (Bs), Heart (H) covered by *Pleura pericardiaca*, *Impressio aortica* (Ia), *Lobus cranialis pulmonis sinistri Pars cranialis* (a'), *N. vagus* (Nv): *N. laryngeus recurrens* (Nlr), *Rr. bronchales* (yellow lines and black arrows); *N. phrenicus* (Np), Thymus (T), *Vena cava caudalis* (Vcd), *Vena cava cranialis* (Vcr), *Venae pulmonales* (Vvp) and *V. pulmonalis lobi cranialis sinistri* (Vp and blue outlines). [Colour figure can be viewed at wileyonlinelibrary.com]

(Figure 4b) is in the right pleural cavity between the caudal part of the mediastinum and the vena caval fold (*Plica venae cavae*) and houses the ventral part of the right accessory lung lobe (*Lobus accessorius pulmonis dextri*) (see below). The left mediastinal diaphragmatic recess (*Recessus mediastinodiaphragmaticus sinister*) is a left lateral deviation of the mediastinal recess where the caudal mediastinum attaches to the diaphragm. The lungs are the only thoracic viscera not contained within the mediastinum. The following structures are present within the various regions of the cranial, middle and caudal mediastinum (*Mediastinum craniale/medium/caudale*). In the dorso-cranial mediastinum (Figures 3a and 4) the thoracic part of the trachea (*Trachea Pars thoracica*), oesophagus, cranial mediastinal lymph nodes (*Lnn. mediastinales craniales*), nerves and ganglia (cervicothoracic ganglion, middle cervical ganglion (*Gl. cervicale medium*), phrenic nerve (*N. phrenicus*), vertebral nerve (*N. vertebralis*), vagus nerve, recurrent laryngeal nerve (*N. laryngeus recurrens*), *Ansa subclavia* and sympathetic trunk (*Tr. sympathicus*)) and blood vessels (brachiocephalic trunk (*Tr. brachiocephalicus*), left and right subclavian arteries (*A. subclavia sinistra/dextra*), vertebral artery (*A. vertebralis*), costocervical trunk (*Tr. costocervicalis*), superficial cervical artery (*A. superficialis cervicalis*), cranial vena cava (*Vena cava cranialis*)) and in the ventro-cranial mediastinum (Figures 3a and 4) the internal thoracic artery (*A. thoracica interna*) and the thymus. The dorsal, middle mediastinum, oesophagus, tracheal bifurcation (*Bifurcatio tracheae*), aortic arch, pulmonary arteries (*Aa. pulmonales*), pulmonary veins (*Vv. pulmonales*), thoracic duct (*Duct. thoracicus*), tracheobronchial lymph nodes (*Lnn. tracheobronchales*), vagus nerves and right azygos vein. The ventral two-thirds of the middle mediastinum are occupied by the heart. The continuation of the internal thoracic artery extends caudally on the ventral aspects of the middle and caudal mediastinum, which also contain the pericardial ligaments. The dorsal aspect of the caudal mediastinum contains the caudal vena cava, descending aorta (*Aorta descendens*), vagal nerves, oesophagus and thoracic duct.

3.4 | Topography

In the embalmed lion carcass, the left cranial lung lobe (*Lobus cranialis pulmonis sinistri*) (Figure 1) extends from ribs two to seven and, when inflated, the left caudal lung lobe (*Lobus caudalis pulmonis sinistri*) from ribs seven to 13. When deflated, the left caudal lung lobe extends caudally to the 12th rib (Figure 1). The most ventral parts of the cranial (*Pars cranialis*) and caudal parts (*Pars caudalis*)

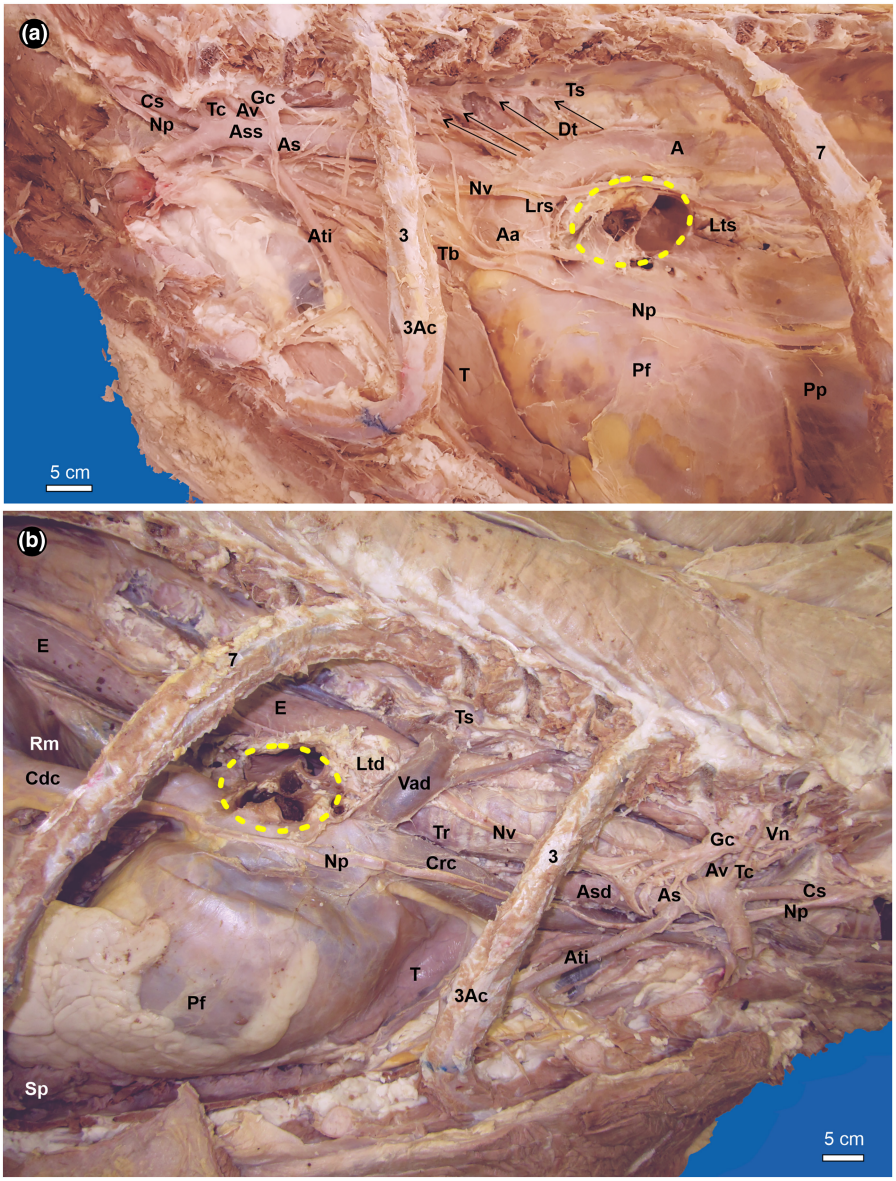

FIGURE 4 (a): Viscera within the left mediastinum (ribs and lungs removed). (b): Viscera within the right mediastinum (ribs and lungs removed). Glossary: Left and right side: *Ansa subclavia* (As), *A. cervicalis superficialis* (Cs), *A. thoracica interna* (Ati), *A. vertebralis* (Av), *Art. costochondralis* of rib 3 (3Ac), *Gl. cervicothoracicum* (Gc), *Hilus pulmonis* (yellow dashed circle), *N. phrenicus* (Np), *N. vagus* (Nv), *Pericardium fibrosum* (Fp), rib 3 (3), rib 7 (7), thymus (T), *Tr. costocervicalis* (Tc) and *Tr. sympathicus* (Ts). Left side only: *Aa. intercostales dorsales* (black arrows), *Aorta thoracica* (A), *Arcus aortae* (Aa), *A. subclavia sinistra* (Ass), *Duct. thoracicus* (Dt), *Lig. phrenicopericardiacum* (Pp), *Ln. tracheobronchalis sinistra* (Lts), *Tr. brachiocephalicus* (Tb). Right side only: *A. subclavia dextra* (Asd), oesophagus (E), *Ln. tracheobronchalis dextra* (Ltd), *N. vertebralis* (Vn), *Recessus mediastini* (Rm), Trachea (Tr), *Vena azygos dextra* (Vad), *Vena cava caudalis* (Cdc) and *Vena cava cranialis* (Crc). [Colour figure can be viewed at wileyonlinelibrary.com]

of the left cranial lung lobe cover the left atrium (*Atrium sinistrum*) and most of the left ventricle (*Ventriculus sinister*) (the auricular surface (*Facies auricularis*) of the heart) (Figure 3a), except for that portion not covered by a small left pulmonary cardiac incisure (*Incisura cardiaca pulmonis sinistri*), which forms in the ventral margin (*Margo ventralis*) of the left lung (*Pulmo sinister*) (Figure 6a). The caudal part of the left cranial lung lobe is the most ventrally situated and extends to the sternum between ribs six and seven (ventral part of the 6th intercostal space). The right cranial lung lobe (*Lobus cranialis pulmonis dextri*) (Figure 2) extends from the first rib caudally to the seventh intercostal space. The cranial part (*Pars cranialis*) of the right cranial lung lobe is much larger (extends from ribs one to six) in comparison to the caudal part (spans intercostal spaces six to seven dorsally) (Figure 2). The right middle lung lobe (*Lobus medius pulmonis dextri*) is situated between the sixth and seventh intercostal spaces and is ventral to the caudal part of the right cranial lung lobe (Figure 2). The ventral margin of the caudal part of the right cranial

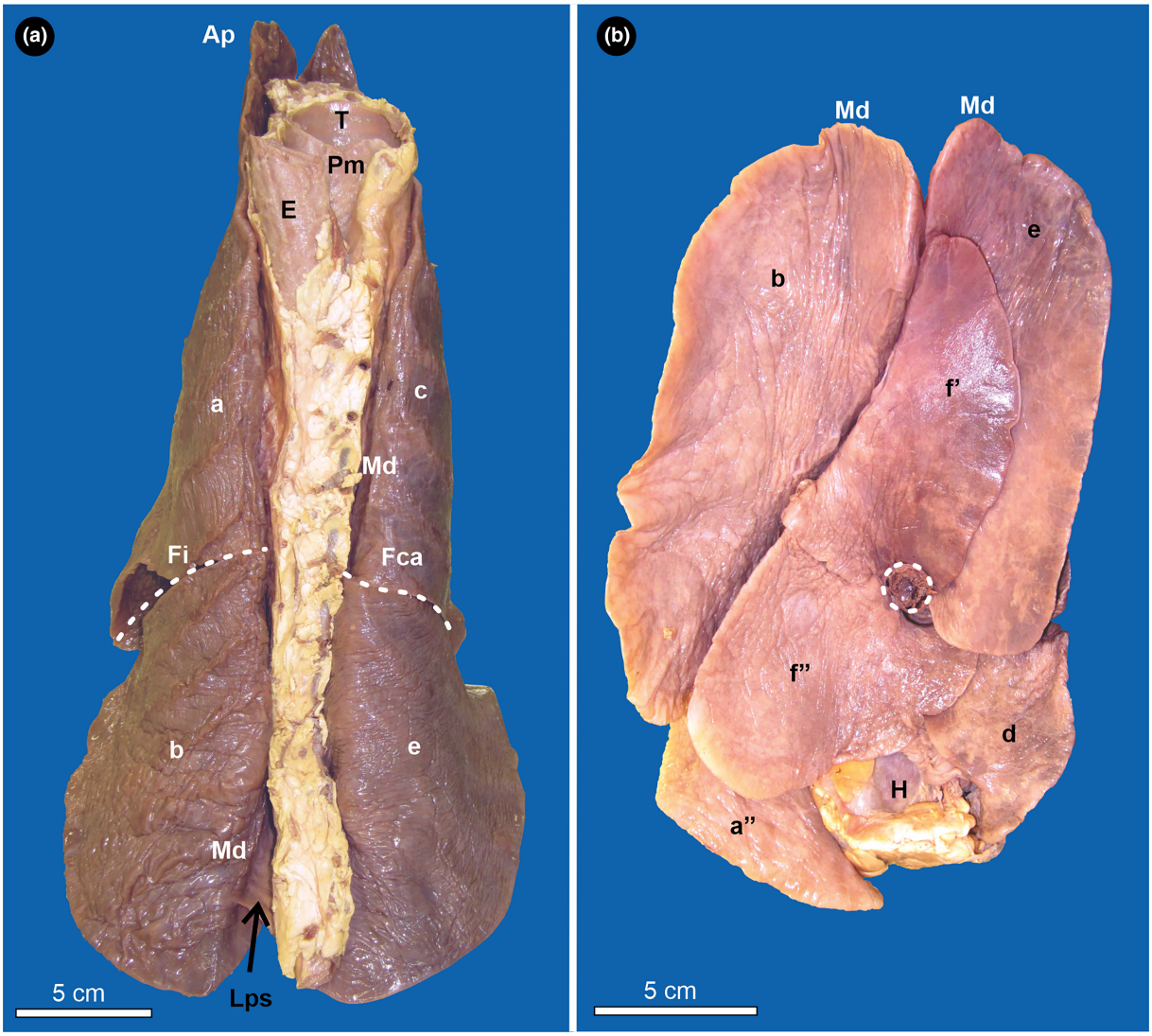

FIGURE 5 (a): Dorsal view of the excised lungs, *Trachea Pars thoracica* and oesophagus. The cranial lobes of the lungs are narrow, and the caudal lobes increase in diameter, cranio-caudally. (b): Caudal view (*Facies diaphragmatica*) of the lungs and heart. Glossary: *Apex pulmonis* (Ap), oesophagus (e), left *Fissura interlobaris caudalis* (Fi, white dotted line), right *Fissura interlobaris caudalis* (Fca, white dotted line), Heart (H), *Lig. pulmonale sinister* (Lps), *Lobus cranialis pulmonis sinistri* (a), *Lobus caudalis* (b), *Lobus cranialis pulmonis dextri* (c), *Lobus medius pulmonis dextri* (d), *Lobus caudalis* (e), *Lobus accessorius pulmonis dextri* dorsal part (f') and ventral part (f''), *Margo dorsalis* (Md), *Paries membranaceus* (Pm), *Trachea Pars thoracica* (T) and *Vena cava caudalis* (white dotted circle). [Colour figure can be viewed at wileyonlinelibrary.com]

lung lobe and right middle lung lobe form the cardiac incisure of the right lung (*Incisura cardiaca pulmonis dextri*) (Figures 2 and 7a), which exposes part of the right ventricle (*Ventriculus dexter*). The remainder of the right side of the heart (atrial surface) (*Facies atrialis*) is covered by the ventral part of the right cranial lung lobe. The cardiac incisure of the right lung is larger than the left. The right caudal lung lobe (*Lobus caudalis pulmonis dextri*) extends from the seventh intercostal space to the 13th rib. When deflated, the caudal lobe only extends to the angle of the 12th rib (Figure 2). Viewed dorsally, the left and right cranial lung lobes of the lion are narrow compared to the caudal lung lobes (Figure 5a). There is a marked increase in width from about the region of the fourth rib proceeding caudally.

3.4.1 | Basal edge of the lung

The most cranial part of the basal edge of the left lung (Figure 1) begins at the costochondral junction (CCJ) of the second rib. The basal edge then extends ventrally to the seventh rib, just ventral to its CCJ. After the seventh rib, the basal edge of the lung inclines obliquely dorsally until it reaches the angle of the 13th rib. The dorsal border of the left lung extends from the second rib to the 13th rib (rib 12, if not inflated). The basal edge of the right lung (*Pulmo dexter*) (Figure 2) follows a similar path as the left one. However, the left and right lung differ at the cardiac incisure. The basal border on the left is ventral to (Figure 1), and the basal border on the right is

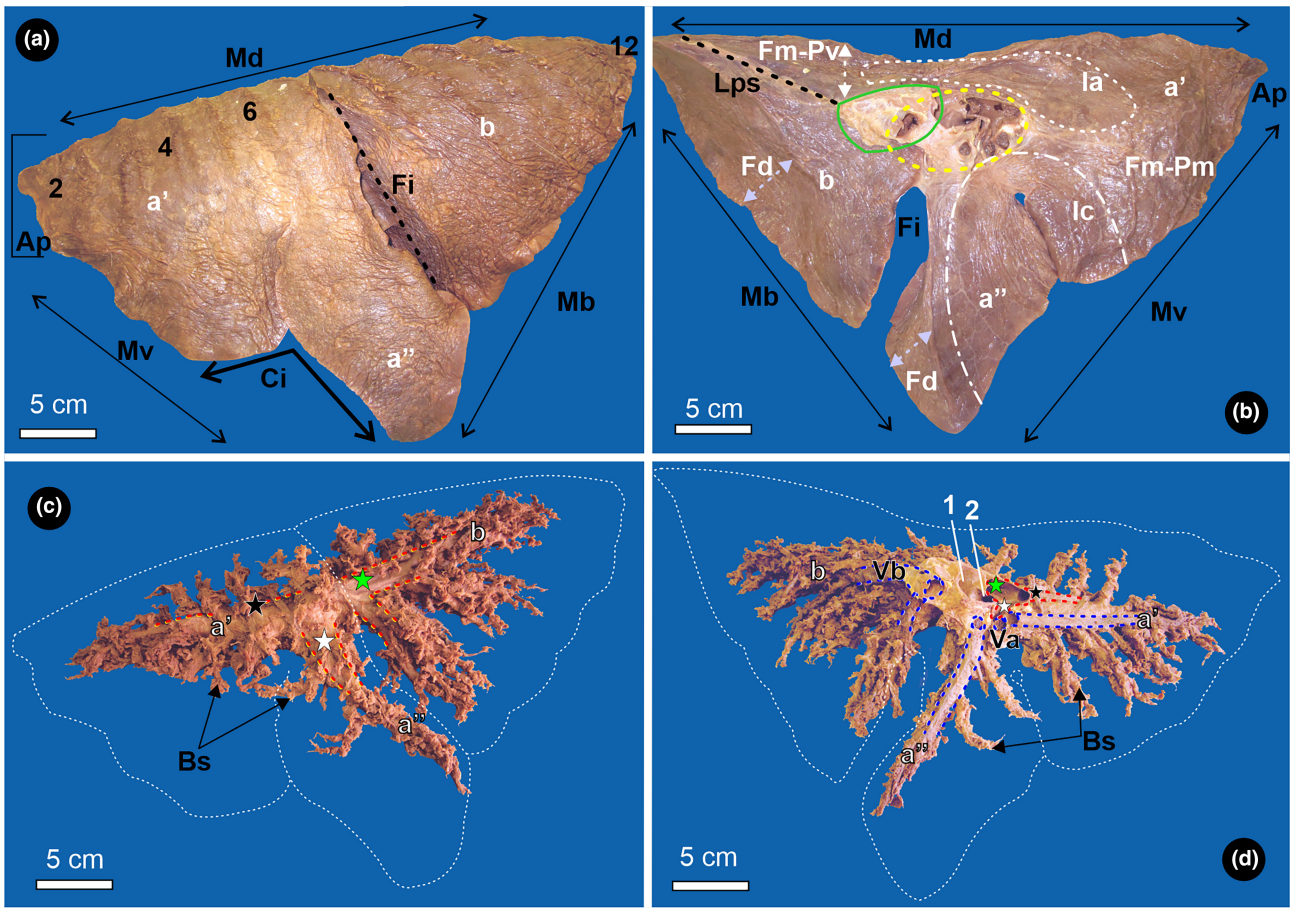

FIGURE 6 (a): Excised *Pulmo sinister*. Lateral view (*Facies costalis*). The pointed *Apex pulmonis*, the ventrally positioned *Lobus cranialis pulmonis sinistri Pars caudalis*, the long *Margo basalis* and the *Margo dorsalis* confer a triangular shape to the *Pulmo sinister*. The rib impressions left by ribs 2, 4, 6 and 12 are annotated as such. (b): Excised *Pulmo sinister*. Medial view. The *Lig. pulmonale sinister* suspends the *Lobus caudalis* and extends from the caudal edge of the *Lobus caudalis* to the *Hilus pulmonis*. (c): Dissected *Arbor bronchales* with the white dotted outline of the *Pulmo sinister* (Figure 6a) approximately placed. Lateral view. Note that most arteries are positioned lateral to the veins. (d): Dissected *Arbor bronchales* with the white dotted outline of the *Pulmo sinister* (Figure 6b) approximately placed. Medial view. The arteries originate medially and move laterally through the lung parenchyma. Glossary: *Apex pulmonis* (Ap), *A. pulmonalis sinistra* (red dotted lines): *R. lobi cranialis*: *R. ascendens* (black star), *R. descendens* (white star), *R. lobi caudalis* (green star); *Bronchi lobares* supplying the *Lobus caudalis* (1) and supplying the *Lobus cranialis pulmonis sinistri* (2), *Bronchi segmentales* (Bs), *Facies diaphragmatica* (Fd), *Facies interlobares* (Fi), *Facies medialis* (Fm): *Pars mediastinalis* (Pm), *Pars vertebralis* (Pv), *Impressio aortica* (Ia), *Impressio cardiaca* (Ic); *Fissura interlobaris caudalis* (black dashed line), *Hilus pulmonis* (yellow dotted circle), *Incisura cardiaca pulmonis sinistra* (Ci), *Lig. pulmonale sinister* (Lps, black dotted line), *Lobus cranialis pulmonis sinistri* (a): *Pars cranialis* (a'), *Pars caudalis* (a"); *Lobus caudalis* (b), *Ln. tracheobronchalis sinistra* (green circle), *Margo basalis* (Mb), *Margo dorsalis* (Md), *Margo ventralis* (Mv), *Vv. pulmonales* (blue dotted lines): *V. pulmonalis lobi cranialis sinistri* (Va) and *V. pulmonalis lobi caudalis sinistri* (Vb). [Colour figure can be viewed at wileyonlinelibrary.com]

dorsal to (Figure 2), the respective CCJ of the fifth and sixth ribs.

3.4.2 | Cardiac incisure

Both cardiac incisures are pronounced in the lion. The cardiac incisure of the left side is formed by the notched ventral margin of the junction of the cranial part and caudal part of the cranial lobe (Figure 6a). The cardiac incisure is larger on the right side and is formed by the notched space between the ventral margins of the cranial part of the right cranial lung lobe and the right middle lung lobe (Figures 2 and 7a).

3.5 | Macroscopic anatomy of the lungs

3.5.1 | Lung surfaces, borders and impressions

The apex (*Apex pulmonis*) of the left lung is small and rounded (Figure 6a) and occupies the angle between the left subclavian artery and internal thoracic artery. The

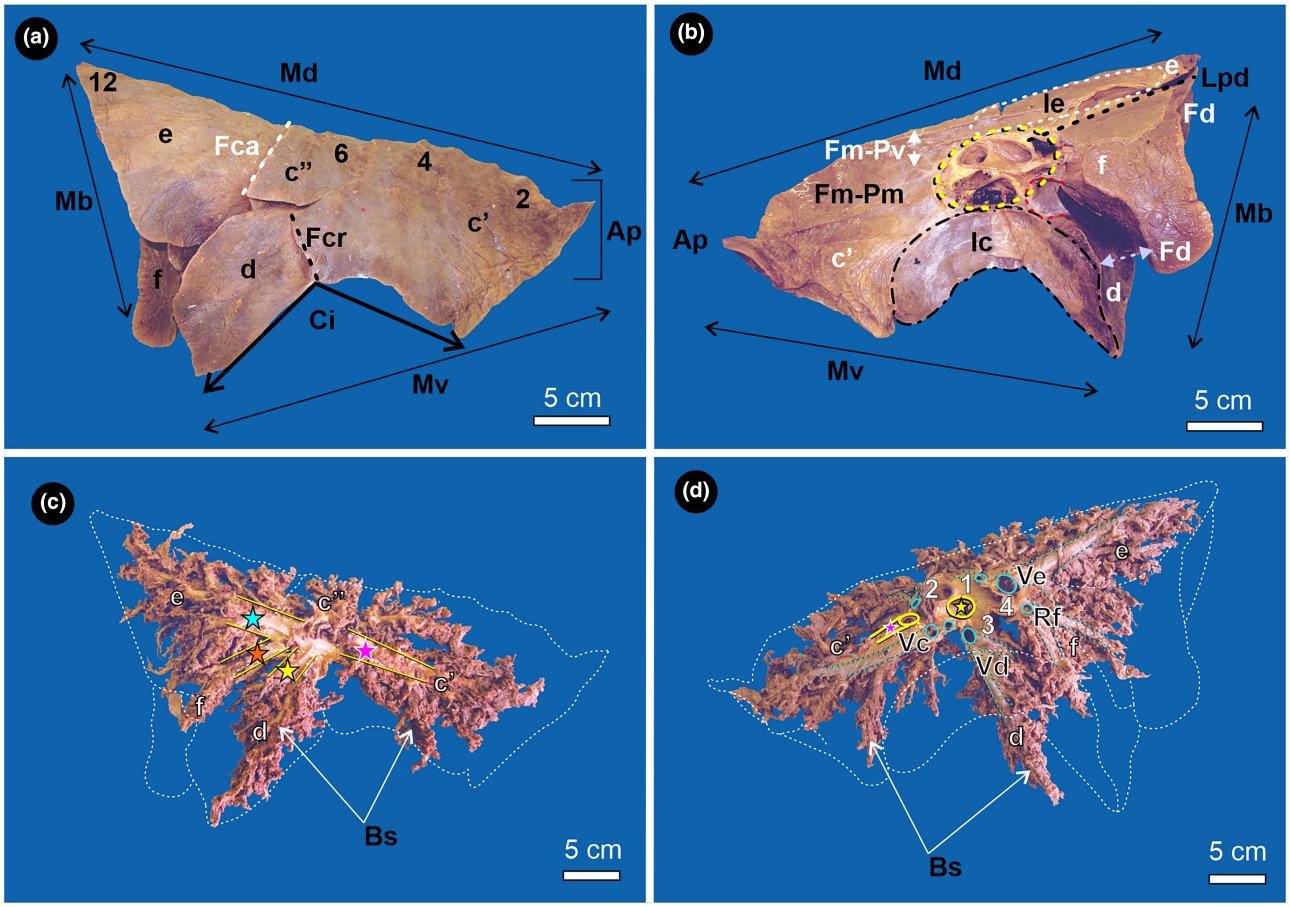

FIGURE 7 (a): Excised *Pulmo dexter*. Lateral view (*Facies costalis*). The rib impressions left by ribs 2, 4, 6 and 12 are annotated accordingly. (b): Excised *Pulmo dexter*. Medial view. The medial view of the right lung shows the *Lig. pulmonale dexter* (Lpd), which suspends the caudal lung lobe and extends from the caudal edge of the caudal lung lobe to the *Hilus pulmonis*. (c): Dissected *Arbor bronchales* with the white dotted outline of the *Pulmo dexter* (Figure 7a) approximately placed. Lateral view. Note that most arteries are positioned lateral to the veins. (d): Dissected *Arbor bronchales* with the white dotted outline of the *Pulmo dexter* (Figure 7b) approximately placed. Medial view. The arteries originate medially and move laterally through the lung parenchyma. Glossary: *A. pulmonalis dextra*: *R. lobi cranialis*: *R. ascendens* (pink star); *R. lobi medii* (yellow star), *R. lobi caudalis* (blue star), *R. lobi accessorii* (orange star); *Apex pulmonis* (Ap), Arteries (yellow lines), *Bronchi lobares* supplying the *Lobus caudalis* (1), the *Lobus cranialis pulmonis dextri Pars cranialis* (2), *Lobus medius pulmonis dextri* (3), *Lobus accessorius pulmonis dextri* (4); B*ronchi segmentales* (Bs), *Facies diaphragmatica* (Fd), *Facies interlobares* (Fi), *Facies medialis* (Fm): *Pars mediastinalis* (Pm), *Pars vertebralis* (Pv), *Impressio cardiaca* (Ic), *Impressio esophagea* (Ie); *Fissura interlobaris caudalis* (Fca, white dotted line), *Fissura interlobaris cranialis* (Fcr, black dotted line), *Hilus pulmonis* (yellow dotted circle), *Incisura cardiaca pulmonis dextra* (Ci), *Lig. pulmonale dexter* (Lpd, black dotted line), *Lobus cranialis pulmonis dextri*: *Pars cranialis* (c'), *Pars caudalis* (c"); *Lobus medius pulmonis dextri* (d), *Lobus caudalis* (e), *Lobus accessorius pulmonis dextri* (f), *Margo basalis* (Mb), *Margo dorsalis* (Md), *Margo ventralis* (Mv), *Sulcus venae cavae caudalis* (red dotted line), *Vv. pulmonales* (blue dotted lines): *V. pulmonalis lobi cranialis dextri* (Vc), *V. pulmonalis lobi medii* (Vd), *V. pulmonalis lobi caudalis dextri* (Ve): *Ramus lobi accessorii* (Rf). [Colour figure can be viewed at wileyonlinelibrary.com]

apex of the right lung is well defined and sharply pointed (Figure 7a). It covers part of the internal thoracic artery. The lung base (*Basis pulmonis*) (Figures 6a and 7a) is broad and contacts the diaphragm, forming the diaphragmatic surface (*Facies diaphragmatica*) (Figures 5b, 6b and 7b). The diaphragmatic surface is formed by part of the caudal part of the left cranial lung lobe, the right and left caudal lung lobes and the accessory lung lobe (Figure 5b). The medial surface (*Facies medialis*) is divided into the smaller, dorsal vertebral part (*Pars vertebralis*) and the larger, ventral mediastinal part (*Pars mediastinalis*) (Figures 6b and 7b). From the costal surface (*Facies costalis*) (Figures 6a and 7a), the dorsal border of the lungs (*Margo dorsalis*) slope dorso-caudally (Figures 5, 6a,b and 7a,b). The ventral and basal borders (*Margo basalis*) (Figures 6a,b and 7a,b) form the acute border (*Margo acutus*) (Figures 1 and 2).

The various impressions can be viewed medially. On the left lung, the oval-shaped cardiac impression (*Impressio cardiaca*) (Figures 3a and 6b) can be seen on the ventral parts of the cranial part and the caudal part of the left cranial lung lobe. The cardiac impression is prominent on the right lung (Figure 7b) and extends from the ventral part of

the cranial part of the cranial lobe to the middle lobe. The aortic impression on the left lung (*Impressio aortica pulmonis sinistri*) (Figures 3a and 6b) is seen as a slight indentation on the dorso-medial side, originating dorsal to the pulmonary hilus and extending caudally over the caudal lobe. The oesophageal impression (*Impressio esophagea*) (Figure 7b) is located on the medial surface of the caudal, dorso-medial right lung, originates just dorsal to the pulmonary hilus and extends over the dorsal part of the caudal lobe. The caudal vena caval groove (*Sulcus venae cavae caudalis*) (Figures 5b and 7b) runs between the accessory lobe and the caudal and medial lung lobes. It originates caudally from the pulmonary hilus on the middle lobe and extends to the lateral side of the accessory lobe.

3.5.2 | Lung lobation

The lungs are heavily lobated with deep and complete fissures (cranial interlobar fissure of the right lung (*Fissura interlobalis cranialis pulmonis dextri*) (Figure 7a) and caudal interlobar fissure (*Fissura interlobalis caudalis*)) (Figures 5a and 7a) on the costal surface (Figures 6a and 7a) and no fissures on the medial surface (Figures 5, 6b and 7b). The lungs are not macroscopically lobulated and display a smooth, silky appearance. The left lung is divided into the cranial and caudal lobes (Figures 5 and 6a,b). The right lung is divided into the cranial, middle, caudal and accessory lobes (Figures 5 and 7a,b). The accessory lung lobe is further divided into a dorsal and ventral part (Figure 5b). The left lung is triangular (Figure 6a), and the right lung is trapezoid in shape (Figure 7a).

3.5.3 | Pulmonary ligaments

The left (Figure 6b) and right (Figure 7b) pulmonary ligaments are well-developed, long and attach the caudal lobes to the mediastinum that suspends them in the pleural cavities. On the right side, the pulmonary ligament originates from the caudal edge of the pulmonary hilus at the eighth rib and extends dorsally to rib 12. The right pulmonary ligament is situated dorsal to the aorta and ventral to the right azygos vein. The left pulmonary ligament has similar attachments extending from the 8th to 12th ribs.

3.5.4 | Trachea and bronchi

The thoracic part of the trachea and the left and right principal bronchi (*Bronchus principalis dexter et sinistra*) of the lion are large. The membranous part (*Paries membranaceus*) on the dorsal aspect of the trachea is broad and flimsy. The principal bronchi branch off the trachea caudo-dorsal to the base of the heart. The left principal bronchus divides into two lobar bronchi (*Bronchi lobares*), one for each lobe (Figures 5 and 6c,d), while the right principal bronchus branches into four lobar bronchi (Figure 7c,d). The lobar bronchi of the left lung correspond to the size of the lung lobes; the lobar bronchus of the caudal lobe is larger than that of the cranial lung lobe. There are multiple segmental bronchi (*Bronchi segmentales*) that branch off the lobar bronchi. The shape and distribution of the bronchial tree (*Arbor bronchalis*) are similar between the right and left lungs. The caudal part of the left cranial lung lobe possesses large segmental bronchi that resemble those of the right middle lung lobe. The left caudal lung lobe has two distinct bronchial divisions that appear similar to those of the right caudal lung lobe and accessory lobe. Although the lungs differ slightly in shape, the bronchial tree is, for the most part, similar.

4 | DISCUSSION

The thoracic cavity and lungs in lions have a typical mammalian structure and conformation. However, some specific structural characteristics of the thoracic cavity and the lungs that have clinical implications for lions are highlighted and discussed below.

4.1 | Thoracic cavity

The shape of the thoracic cavity is determined by the very large and muscular front legs of African lions. It is characterised by a thin frontal section extending from the first to the fourth ribs, with most of the functional lung mass, with a very large accessory lobe in particular, towards the caudal thoracic cavity. The conformation of the thorax also causes the heart to be situated further caudally than in, for example the dog and ungulates (Marais & Crole, 2022). This conformation reduces the space available for the lungs to expand maximally during strenuous exercise when hunting. The available functional thoracic space may be further reduced by a full stomach pressing on the diaphragm, as lions consume up to 20% of their body weight at a time (AZA, 2012).

4.1.1 | Immobilisation

Reducing the pressure on the cranial thoracic space is of clinical importance since immobilisation of lions with certain drugs may cause significant impairment of cardiopulmonary function (Fyumagwa et al., 2012). Particularly if a lion is darted with its stomach full and placed in lateral

recumbency, it is recommended that the upper front limb be suspended to lessen its pressure on the thorax. Placing the animal in sternal recumbency may also be beneficial (West et al., 2014). Immobilising a lion with an empty stomach will not only improve breathing under anaesthesia but will also reduce the risk of aspiration pneumonia (West et al., 2014).

4.1.2 | Auscultation

The differences in the thoracic structure of lions also have an impact on detecting respiratory sounds by auscultation. In practice, a line approximately 3–4 cm above the basal edge of the lung is used for auscultation and determination of the clinical lung field because the basal border is too thin to allow detecting significant respiratory sounds (Budras & Habel, 2011). The area available in the various species for auscultation of the lungs is limited to the auscultation triangle. In domestic cats, this triangle is formed by the caudal border of the thoracic limb muscles, the lateral border of the epaxial muscles and an oblique line from the CCJ of the sixth rib to the 11th intercostal space (Hudson & Hamilton, 1993). In dogs and cats, the area for auscultation would thus be more towards the axillary region, but normal breathing sounds can also be heard over the lateral thoracic wall (Vijayaragavan & Prasad, 1992). In ruminants where the lungs project into the pleural cupulae, respiratory sounds are also audible in the pre-scapular region (Dyce et al., 2010). However, the musculature cranial to the pleural cupula in the pre-scapular region would make auscultation in this area difficult for lions.

The clinically detectable lung field and preferred sites for auscultation in lions are caudal to the tricipital line that crosses the fourth rib. While the lateral edge of the epaxial muscles forms the dorsal margin for percussion and auscultation in all species (Vijayaragavan & Prasad, 1992), the preferred location on the lateral thoracic wall in lions is halfway between the CCJ and the dorsal part of the fifth to the eighth ribs, and just ventral to the dorsal part of the more caudal ribs.

4.1.3 | Pleural cupula

The extent of the pleural cupula in lions is similar to that reported for domestic dogs and cats. Although the pleural cupula extended only 1–1.5 cm cranial to the first rib, there would be sufficient space for air to enter into the pleural cavity that may cause the lung to collapse following injury or a surgical procedure in that area (Dyce et al., 2010).

4.1.4 | Clinical interventions

The basal edge of the lung of the lions in this study was determined with formalin-fixed organs, and thus the basal border was not necessarily determined after maximal expiration. The basal border of the lungs and the line of pleural reflection are of clinical importance (Habel, 1978), as any surgical incision or puncture wound caudal to the line of pleural reflection will penetrate the peritoneal cavity. The location of the line of pleural reflection is very similar in most species (Vijayaragavan & Prasad, 1992). In dogs and cats, it starts at the CCJ of the eighth rib, crossing the 11th rib just above the CCJ towards the dorsal part of the 13th rib (Habel, 1978). The configuration in lions is different, in that this line crosses the caudal ribs at a lower level than in domestic cats and dogs. In lions, the line of pleural reflection commences at the caudal edge of the eighth rib below the CCJ and extends obliquely caudo-dorsally up to the 13th rib. This allows for a larger costodiaphragmatic recess in the lion and a slightly larger caudal extension of the pleural cavity, thus creating space for the large caudal portion of the lungs located in the caudal part of the thorax.

Thoracocentesis, by which fluid is drained from the pleural cavities, can safely be performed by using knowledge of where the basal border of the lungs and the line of pleural reflection are situated (King, 1999). It is recommended that thoracocentesis be performed in the seventh intercostal space in sternal recumbent lions, just below the CCJ of the eighth rib. This is very similar to the sites in dogs (7th and 8th intercostal spaces) and cats (8th intercostal space) (Habel, 1978).

The cardiac notch on the basal border of the lung allows the heart to be in contact with the costal pleura and is the preferred site for intracardiac injections. The cardiac incisure is more pronounced in both lions and domestic cats (Hudson & Hamilton, 1993), and, thus, in both species, intracardiac injections should preferentially be performed on the right-hand side of the thorax. In lions, intracardiac injections are recommended in the fifth intercostal space, just caudal to the CCJ of the fifth rib.

Thoracoscopy is performed in domestic cats to replace the need for open thoracotomies for procedures such as lobectomies. The landmarks described for the procedure include using the fourth and fifth intercostal spaces for cranial and middle lung lobe lobectomies and the fifth and sixth intercostal spaces for the caudal and accessory lung lobes (Scott et al., 2019). In lions, the large thoracic limb impedes access to the fourth intercostal space. The best surgical access to the cranial and middle lobes in the lion would be through the fifth and sixth intercostal spaces, and for the caudal and accessory lobes, through the seventh and eighth intercostal spaces. These are

recommendations based on the anatomical findings in this study, but these sites need to be further evaluated in fresh lion carcasses where the extent of pulmonary inflation is known and taken into consideration.

4.2 | Anatomy of the lungs

4.2.1 | Trachea and bronchi

The large trachea and bronchi show adaptation for rapid airflow in the lion; however, for the size of the animal, the restricted lung volume would potentially not support sustained muscular activity. When a lion accelerates, the airflow in the trachea, as described in humans, will increase, and it will become turbulent, creating resistance to inspiration (Brand-Saberi & Schafer, 2014). This turbulence may result in less air reaching the lungs for gas exchange, thus contributing to the limited ability for sustained muscular activity in the lion when hunting (Chassin et al., 1976).

4.2.2 | Lung lobation and lobulation

The fissures of the lion's lung are only complete on the costal surface. This differs from that of dogs, in which fissures are complete and, in some cases, the lobes of the lung are only connected by the branching bronchial tree and vessels (Dyce et al., 2010). Fissures facilitate movement of lung lobes in relation to other lobes, which allows for greater distention of the lower lobes (in the case of animals—the caudal lobe) during respiration (Meenakshi et al., 2004). The lion's lung is a combination of complete and incomplete interlobar fissures. The complete fissures on the costal surface allow uniform expansion and increased filling of the caudal lobes, while the incomplete fissures on the mediastinal surface are likely to facilitate the spread of infection between the lung lobes due to enhanced interlobar and collateral ventilation (Koster & Slebos, 2016). Compared to cattle, sheep and pigs, in which the lungs are clearly lobulated and lobated (Tyler, 1983), the lungs of carnivores, which include those of lions (the present study), show few macroscopic signs of lobulation (König & Liebich, 2020). These structural differences seen in cattle and pigs are due to the large amount of connective tissue that forms complete interlobar septa (Tyler, 1983). The lack of these complete interlobar septa in dogs and lions (present study) allows for ample collateral ventilation (Tyler, 1983), and air can flow freely between lobules if they are located in the same lobe (Van Allen et al., 1931). This allows air to enter a collection of lobules (in the same lobe) via different routes when some of the bronchi supplying those lobules are obstructed (Van Allen et al., 1931).

4.2.3 | Pulmonary ligament

The pulmonary ligament in lions is exceptionally long. The pulmonary ligament suspends the caudal lung lobes, which are equivalent to the inferior lobes in humans. In humans, this ligament restricts the extent of movement of the inferior lobe (Bu et al., 2016). The function of the ligament is likely to be similar in animals, particularly in lions with their unusually large caudal lung lobes, to prevent excessive movement of the lobes within the thoracic cavity and the possibility of lobar torsion while running.

4.2.4 | Intubation

During intubation, the thin, membranous part of the trachea in lions can easily be damaged, and care should be taken to insert the endotracheal tube in a ventrally directed direction to decrease the chances of injury occurring.

5 | CONCLUSION

This study outlines the important landmarks and features of the lungs and thoracic cavity of relevance for veterinary procedures in African lions. Considering the reduced space within the thoracic cavity that the lungs in the lion occupy, future research is recommended to study the microscopic anatomy to better understand ventilation. This may inform decisions relating to thoracic surgery and anaesthesia in lions.

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