Morphometry of the thorax and three-dimensional modelling of the lower respiratory tracts with computed tomography in Van cats

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Abstract

This study was conducted to produce a three-dimensional model of the thorax and lower respiratory tract in Van cats, to reveal their morphometric properties, and to investigate the anatomical structure of this region in more detail. A total of 16 adult Van cats (8 males and 8 females) were used in the study. The thoracic region of the cats was scanned using multi-detector computed tomography device. The images of the scanned region were transferred to the MIMICS 20.1 software that creates three-dimensional reconstruction in order to produce the models. The morphometric measurements were obtained from these models and the index values were calculated. When the data were analysed in terms of sexual dimorphism, significant differences were determined between the sexes in terms of transverse diameter of the thoracic cavity in apertura thoracis cranialis (T2) ($P < 0.05$), minimum width of apertura thoracis cranialis (T3), and height of the thoracic cavity in thoracis cranialis (H1) ($P < 0.01$). The index values of the data revealed a significant difference between the sexes only in terms of the thoracic index 2 ($P < 0.05$). The 7th sternebra was shorter and more flattened than the other sternebrae in Van cats. In conclusion, three-dimensional models of the thorax and lower respiratory tracts of Van cats were produced in the study. It is thought that the data of the study may be useful in clinical practice and academic studies in the field of veterinary medicine.

Feline, 3D model, thoracic cavity, sexual dimorphism

The Van cat is a native domestic cat breed in Türkiye and endemic to the province of Van, which it is named after. Van cats hold an important place among cat breeds. Van cats enjoy playing in the water, are highly intelligent and have a triangular face shape; a distinctive feature is that their eyes are of different colours (both eyes can be amber or blue, or heterochromic) (Odabaşıoğlu and Ateş 2000). Due to their special physical characteristics, researchers have approached these cats with interest throughout history (Cak 2017). Their physical differences are thought to be related only to the external appearance (Uslu and Yörük 2015).

Respiratory infections are common in cats (Harbour et al. 1991). Viral and bacterial lower respiratory tract infections have a high rate of morbidity especially in adolescent cats and kittens and in shelter conditions (Bannasch and Foley 2005; Coyne et al. 2007). It is crucial to know the normal anatomy of the lower respiratory tract and thorax in identifying pathological changes. There are various studies investigating the lung trachea and thorax of cats using radiological, cast, and endoscopy methods (Vladova et al. 2005; Caccamo et al. 2007; Mirhish and Nassar 2013; Sak and Pazvant 2021). However, the number of studies examining the lower respiratory tract and thorax via computed tomography (CT) and producing their three-dimensional models is very limited.

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Radiography is an affordable and accessible method used to establish the diagnosis of respiratory system diseases. However, radiography may remain insufficient in diagnosing complicated cases of lower respiratory tract. Computed tomography, which is a widespread tool in veterinary medicine, is employed to diagnose such cases (Ballegeer et al. 2010; Schwarz and Saunders 2011; Fina et al. 2014). It is an ideal examination method for pulmonary embolism, pneumonia, mediastinal tumours, traumatic thorax injury, pleuritis, and emphysema (Prokop 2000; Prokop 2003).

The aim of this study was to produce the three-dimensional models of the thorax and lower respiratory tracts in Van cats, to reveal their morphometric properties, and to determine the anatomical structure of this region in more detail. It also aimed to determine differences between sexes by taking measurements of the studied indicators on these 3D models and thus to contribute to the little information available in literature to date.

Materials and Methods

A total of 16 adult Van cats (8 males, 8 females) were obtained for the study from the Van Yüzüncü Yıl University Van Cat Research and Application Centre. Their mean age was 5 years and their mean weight was 4.91 and 3.6 kg for males and females, respectively. The cats were fasted the day before they were scanned via CT. They were anaesthetized with the combined administration of ketamine (15 mg/kg, IM, Ketasol® 10% injectable) and xylazine (1–2 mg/kg, IM, Alfazyne® 2% injectable). Computed tomography images of the cats were obtained using a 16-slide multi-detector CT device (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany) with kV/Effective mAs/Rotation time (s) values of 20/120/0.75, gantry rotation time of 420 ms, physical detector collimation of 16 × 0.6 mm, section thickness of 0.75 mm, final section collimation of 32 × 0.63 mm, feed/rotation of 6 mm, Kernel of U90u, increment of 0.5 mm, and resolution of 512 × 512 pixels. Dosage parameters and scanning were performed on the basis of standard protocols found in the literature (Prokop 2003; Kalra et al. 2004). A study by Caccamo et al. (2007) was used as a reference to name the bronchial tree.

The images were saved in the format of DICOM (Digital Imaging and Communications in Medicine). Computed tomography images were transferred to the MIMICS 20.1 (The Materialize Group, Leuven, Belgium) software that creates three-dimensional models. The "Hounsfield Scale" range of −600 to −900 was chosen for modelling the images. After creating models and taking measurements in the MIMICS software, the images were improved by using the multi-resolution option of the Blender 2.92.0 software.

An approval was obtained from the Van Yüzüncü Yıl University Animal Experiments Local Ethics Committee (Date: 25/02/2021 and Decision no: 2021/02-03). The terminology of the study was based on Nomina Anatomica Veterinaria (NAV 2005).

To conduct statistical analysis, SPSS (22.0) software was employed. Independent samples *t*-test was used for the normally distributed data and Mann Whitney U test was applied for the non-normally distributed data. Levene's test was employed for the homogeneous distribution of variances.

Results

Tables 1 and 2 show the measurement points, index values and abbreviations of the morphometric data of the thorax and lungs. Table 3 shows the statistical analyses, standard deviations, and sexual dimorphisms of the data. Figures 1, 2 (Plate V) and 3, 4 (Plate VI) illustrate the measurement points. Tables 4 and 5 show pulmonary, thoracic, and sternal index values and sexual dimorphisms. Significant differences were determined between the sexes in terms of transverse diameter of the thoracic cavity (T2) ($P < 0.05$), apertura thoracis cranialis minimum width (T3) and height of thoracic cavity (H1) ($P < 0.005$) data (Table 3). No sexual dimorphism was observed among the other data ($P > 0.05$). When the index values of the data were analysed, no sexual dimorphism was observed in pulmonary index 1, pulmonary index 2, pulmonary index 3, sternal index 1, sternal index 2 and thoracic index 1 ($P > 0.05$). However, a significant difference was determined between the sexes in terms of thoracic index 2 ($P < 0.05$).

It was observed that the 7th sternebra which forms the ventral part of the thorax, was shorter and more flattened in Van cats than the other sternebrae, and the manubrium sterni had the shape of a cross and a convex shape. Based on lung morphology, it was determined that the right lung was positioned slightly in front of the left lung. Radiological examination revealed that the right lung was divided into cranial, medial, and caudal lobes and the left lung was divided into cranial and caudal lobes. The cranial lobe was divided into pars cranialis and pars caudalis.

It was determined that the trachea was located closer to the dorsal part of the cavum thoracis. The trachea was divided into its right and left branches at the level of the 5^{th}–6^{th} sternebrae, the 4^{th}–6^{th} intercostal spaces, and the 6^{th}–7^{th} thoracic vertebrae. When the bronchial branching of the trachea was examined (Plate VII, Fig. 5), it was observed that it was divided into two main branches as right principal bronchi (RPB) and left principal bronchi (LPB). After splitting into right and left branches, the RPB branch was divided into four bronchi (RB1, RB2, RB3, and RB4). These bronchi were divided into bronchi by taking dorsal and ventral roots. Likewise, the LPB branch was divided as left bronchus 1 (LB1) and left bronchus 2 (LB2). These branches were also divided into bronchi by taking dorsal and ventral branches.

Table 1. List of abbreviations of the indicators measured in the Van cat.

Abbreviation	Definition
TDL	Transverse diameter of the lung (the greatest distance of the lung from medial to lateral on the horizontal axis)
SDL	Sagittal diameter of the lung (the greatest distance between the cranial and caudal edges of the lung)
HL	Height of the lung (the greatest distance measured from dorsal to ventral)
T1	TDTC (transverse diameter of the thoracic cavity) in apertura thoracis caudalis
T2	TDTC (transverse diameter of the thoracic cavity) in apertura thoracis cranialis
T3	Apertura thoracis cranialis minimum width
H1	HTC (height of the thoracic cavity) in apertura thoracis cranialis
H2	HTC (height of the thoracic cavity) in apertura thoracis caudalis
S1	SDTC (sagittal diameter of the thoracic cavity) at its base
S2	SDTC (sagittal diameter of the thoracic cavity) in the tab of the apertura thoracis caudalis
LM	Length of the manubrium sterni
LWM	Lateral width of the manubrium sterni
HM	Height of the manubrium sterni
StH	Height of the sternebra
StL	Length of the sternebra
LSB	Length of the sternal body
LMB	Length of the manubrium body (sum of the length of the manubrium and the length of the sternal body)
LX	Length of the processus xiphoideus
HX	Height of the processus xiphoideus

Table 2. Indices and formulas of the lung and thorax used in study of the Van cat.

Index	Formulas
Pulmonary index 1	Transverse diameter / sagittal diameter × 100
Pulmonary index 2	Transverse diameter / height of the lung × 100
Pulmonary index 3	Sagittal diameter / height of the lung × 100
Thoracic index 1	Transverse diameter of the apertura thoracis cranialis/ transverse diameter of the apertura thoracis caudalis × 100
Thoracic index 2	Height of the apertura thoracis cranialis/ Height of the apertura thoracis caudalis × 100
Sternal index 1	Length of the manubrium / length of the sternal body × 100
Sternal index 2	Length of the proc. xiphoideus / length of the sternal body × 100

Table 3. The mean and standard deviation (SD) of the thorax and lung in the Van cat.

Indicator	Sex	n	Mean	SD	*P*
TDL - left (mm)	Male	8	42.27	6.42	0.126¥
	Female	8	38.14	3.23	
TDL - right (mm)	Male	8	35.95	6.56	0.094¥
	Female	8	31.38	2.94	
SDL - left (mm)	Male	8	151.87	12.65	0.199¥
	Female	8	145.08	5.84	
SDL - right (mm)	Male	8	152.84	6.04	0.072¥
	Female	8	146.42	7.09	
HL (mm)	Male	8	61.13	5.74	0.893¥
	Female	8	60.80	3.74	
T1 (mm)	Male	8	87.70	6.22	0.172¥
	Female	8	83.42	5.64	
T2 (mm)	Male	8	23.77	1.21	0.002**,¥
	Female	8	22.07	1.02	
T3 (mm)	Male	8	21.15	2.53	0.009*,¥
	Female	8	16.32	2.47	
H1 (mm)	Male	8	27.10	2.47	0.002**,¥
	Female	8	22.30	2.55	
H2 (mm)	Male	8	68.90	7.21	0.675¥
	Female	8	67.63	4.36	
S1 (mm)	Male	8	122.45	7.80	0.137¥
	Female	8	116.82	6.43	
S2 (mm)	Male	8	149.70	5.42	0.119¥
	Female	8	144.26	7.52	
LM (mm)	Male	8	22.27	2.95	0.968¥
	Female	8	22.22	1.72	
LWM (mm)	Male	8	8.81	0.76	0.038*,φ
	Female	8	8.36	0.43	
HM (mm)	Male	8	6.36	0.67	0.376¥
	Female	8	6.04	0.75	
St2L (mm)	Male	8	14.58	1.07	0.100¥
	Female	8	13.73	0.83	
St2H (mm)	Male	8	6.52	0.62	0.282¥
	Female	8	6.20	0.53	
St3L (mm)	Male	8	14.54	0.83	0.949¥
	Female	8	14.52	0.52	
St3H (mm)	Male	8	6.81	0.83	0.146¥
	Female	8	6.31	0.40	
St4L (mm)	Male	8	13.89	1.09	0.898¥
	Female	8	13.95	0.86	
St4H (mm)	Male	8	6.78	0.69	0.020*,¥
	Female	8	6.04	0.30	
St5L (mm)	Male	8	13.44	0.91	0.562¥
	Female	8	13.11	1.26	
St5H (mm)	Male	8	6.28	0.57	0.068¥
	Female	8	5.84	0.27	
St6L (mm)	Male	8	12.39	1.0	0.724¥
	Female	8	12.21	0.99	
St6H (mm)	Male	8	5.98	0.58	0.090¥
	Female	8	5.50	0.45	
St7L (mm)	Male	8	10.66	1.82	0.468¥
	Female	8	11.24	1.24	
St7H (mm)	Male	8	6.07	0.65	0.032*¥
	Female	8	5.43	0.35	
LX (mm)	Male	8	22.91	1.92	0.320¥
	Female	8	22.02	1.50	
HX (mm)	Male	8	4.16	0.61	0.038*,φ
	Female	8	3.74	0.32	
LSB (mm)	Male	8	90.18	8.0	0.090¥
	Female	8	84.55	1.95	
LMB (mm)	Male	8	113.62	6.37	0.66¥
	Female	8	108.57	3.32	

*$P < 0.05$; **$P < 0.01$; ¥ Independent *t*-test; φ Mann-Whitney U test

Table 4. The mean and standard deviation (SD) of the pulmonary indices in the Van cat.

Indicator	Direction	Sex	Mean	SD	*P*
Pulmonary index 1	Left	Male	27.79	3.20	0.272¥
		Female	26.29	1.89	
	Right	Male	23.53	4.30	0.250¥
		Female	21.47	2.20	
Pulmonary index 2	Left	Male	68.97	7.05	0.075¥
		Female	62.86	5.57	
	Right	Male	58.44	6.90	0.081¥
		Female	51.91	6.98	
Pulmonary index 3	Left	Male	249.00	14.64	0.298¥
		Female	239.58	19.82	
	Right	Male	251.92	24.88	0.293¥
		Female	241.25	12.06	

$*P < 0.05$; $**P < 0.01$); ¥ Independent *t*-test; φ Mann-Whitney U test

Table 5. The mean and standard deviation (SD) of the thoracic indices in the Van cat.

Indicator	Sex	Mean	SD	*P*
Thoracic index 1	Male	27.19	1.96	0.521¥
	Female	26.54	1.98	
Thoracic index 2	Male	41.61	3.39	0.025*,¥
	Female	36.40	4.79	
Sternal index1	Male	25.97	4.65	0.328φ
	Female	26.59	1.71	
Sternal index 2	Male	25.25	2.78	0.505φ
	Female	25.59	1.58	

$*P < 0.05$; ¥ Independent *t*-test; φ Mann-Whitney U test

Discussion

Computed tomography is frequently used to diagnose respiratory diseases and thoracic pathologies in companion animals. For this reason, examining the anatomical structures of this region via CT is crucial for clinical practice. Studies have been conducted using various methods such as cast technique (Mirhish and Nassar 2013), radiometric examination (Sak and Pazvant 2021), endoscopic examination (Caccamo et al. 2007), and cross-sectional examination (Vladova et al. 2005) on the respiratory tract of cats. However, we did not find a study on detailed three-dimensional examination of the lower respiratory tract and thorax. This limited literature data is the most apparent limitation of the study.

In the study, it was determined that the trachea was separated at the level of the 4th–6th intercostal spaces, the 5th–6th sternebrae, and the 6th–7th thoracic vertebrae. This result is compatible with the study conducted by Mirhish and Nassar (2013) on a local cat breed.

The lung lobes of Van cats are parallel to the reported lung anatomy of other cat breeds (Samii et al. 1998; König and Liebich 2004; Hudson and Hamilton 2011).

The trachea branching and pulmonary lobes found in the study are supported by Caccamo et al. (2007) and Mirhish and Nassar (2013). The tracheal bronchus branching in the species such as pigs (Kalita 2014), Japanese deer (Nakakuki 1993), and sheep (Özüdoğru and Özdemir 2019) was not detected in this study.

In the study conducted by Özkadif et al. (2018) on mongoose, it was reported that while the transverse diameter of the lung (TDL) value was 37.88 mm in the right lung and 29.23 mm in the left lung in the males, it was 35.20 mm in the right lung and 33.16 mm in the left lung in the females. Also, Özkadif et al. (2018) reported that while the sagittal diameter of the lung (SDL) value was 94.04 mm in the right lung and 91.01 mm in the left lung in the males, it was 122.17 mm in the right lung and 119.21 mm in the left lung in the females. Szpinda et al. (2015) reported finding a difference between the right and left lungs of human foetuses but no difference between the sexes. In the present study, lung measurements revealed no difference between the sexes and between the right and left lungs in Van cats ($P > 0.05$).

Singh et al. (2012) and Ramadan et al. (2010) found a difference in terms of sexual dimorphism in their morphometric studies on the human sternum. In the present study, no difference was determined in the indicators related to the sternum in terms of sexual dimorphism.

Özkadif et al. (2018) determined that the sagittal diameters of the thoracic cavity 1 (S1) value and sagittal diameter of the thoracic cavity 2 (S2) were 93.35 mm and 119.3 mm, respectively, in males, and 96.44 mm and 131.08 mm, respectively, in females. In the present study, S1 was determined as 122.45 ± 7.80 mm and 116.82 ± 6.43 mm, respectively, in males and females, and the S2 value was 149.70 ± 5.42 mm and 144.26 ± 7.52 mm, respectively, in males and females. No significant difference was found in these indicators in terms of sexual dimorphism ($P > 0.05$).

Inspiration and expiration were not performed in a controlled manner while taking the tomography images of Van cats in the study and therefore, motion artifacts distorted the cross-sectional images. These artifacts prevented three-dimensional reconstruction of bronchial branching in more detail, as well. In the study, the image and size were not affected much because CT shortened the shooting time very much. In such cases, noise artifacts often occur, which complicates the interpretation of the image. Since no anomaly or disease diagnosis was studied in our study, this situation was not affected (Şentürk and Akay 2008).

In conclusion, three-dimensional models were created and morphometric indicators of the thorax and lower respiratory tract in healthy adult Van cats were determined using CT images. It is believed that the obtained 3D models and measurements may aid veterinary medicine professionals in the examination and clinical interpretation of the thorax anatomy. It is considered that the data of the study may be useful in practice as well as in academic studies of the thorax and lower respiratory tract.

Conflict of interest

There is no conflict of interest in the present form of the manuscript.

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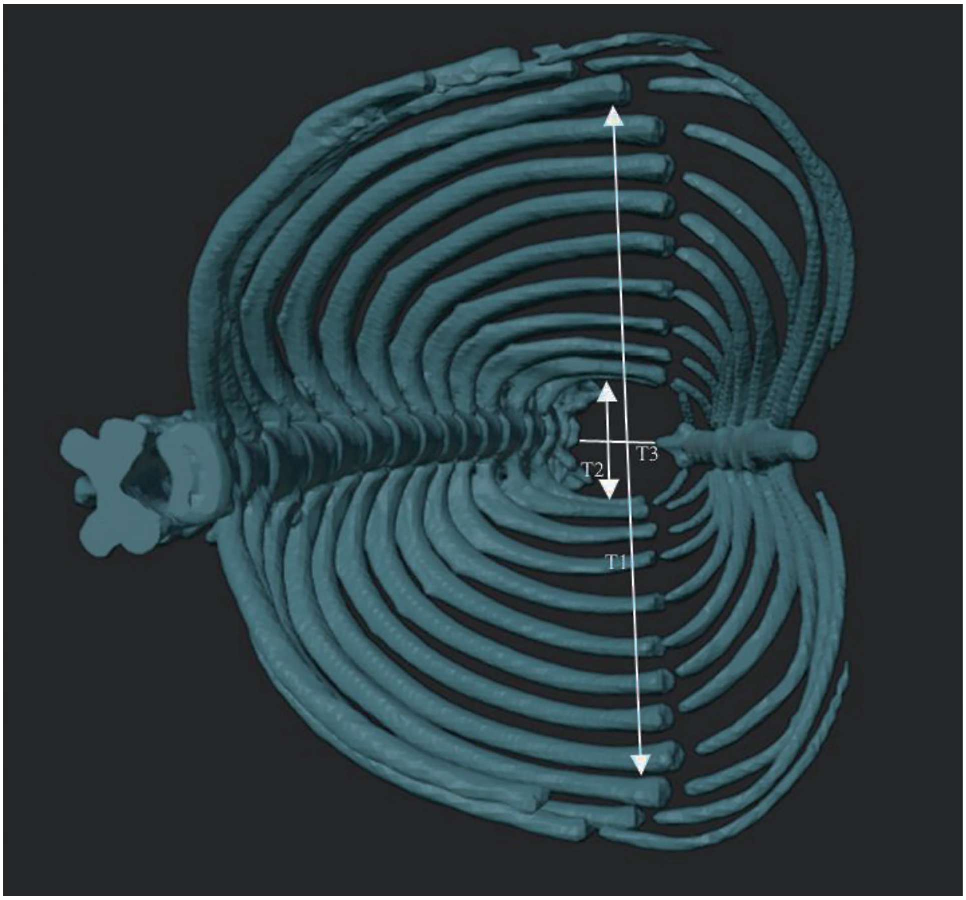

Fig. 1. Three-dimensional modelling of cavum thoracis and the measurement points in the Van cat (caudocranial view)

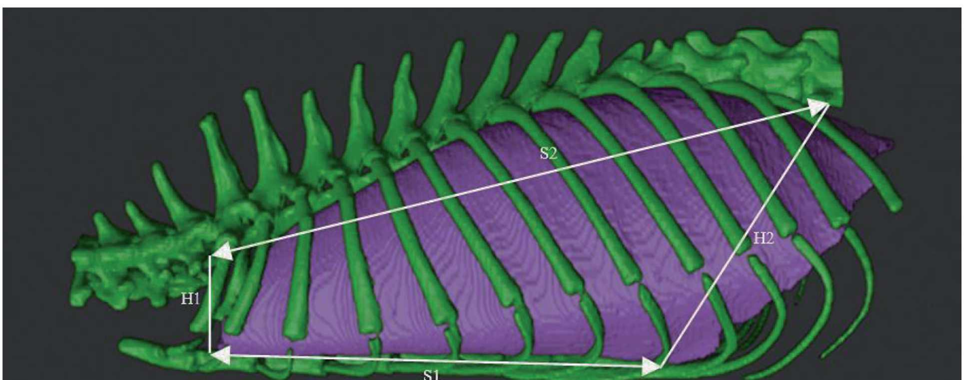

Fig. 2. Three-dimensional modelling of the thorax and the measurement points in the Van cat (lateral view).

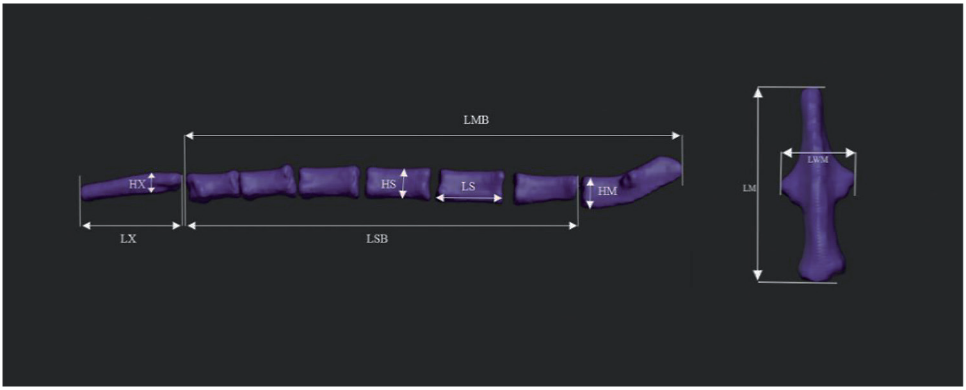

Fig. 3. Three-dimensional modelling of the sternum and the measurement points taken from the sternebrae in the Van cat.

LS: length of the sternebrae; LSB: length of the sternal body; LMB: length of manubrium body; HS: height of the sternebrae; LX: length of the processus xiphoideus; HX: height of the processus xiphoideus; LM: length of the manubrium sterni; HM: height of the manubrium sterni

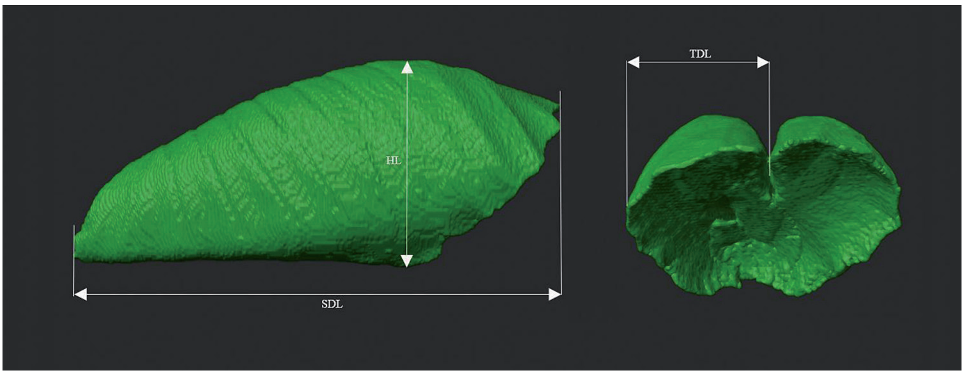

Fig. 4. Three-dimensional modelling of the lung and the measurement points in the Van cat.

HL: height of the lung; SDL: sagittal diameter of the lung; TDL: transverse diameter of the lung

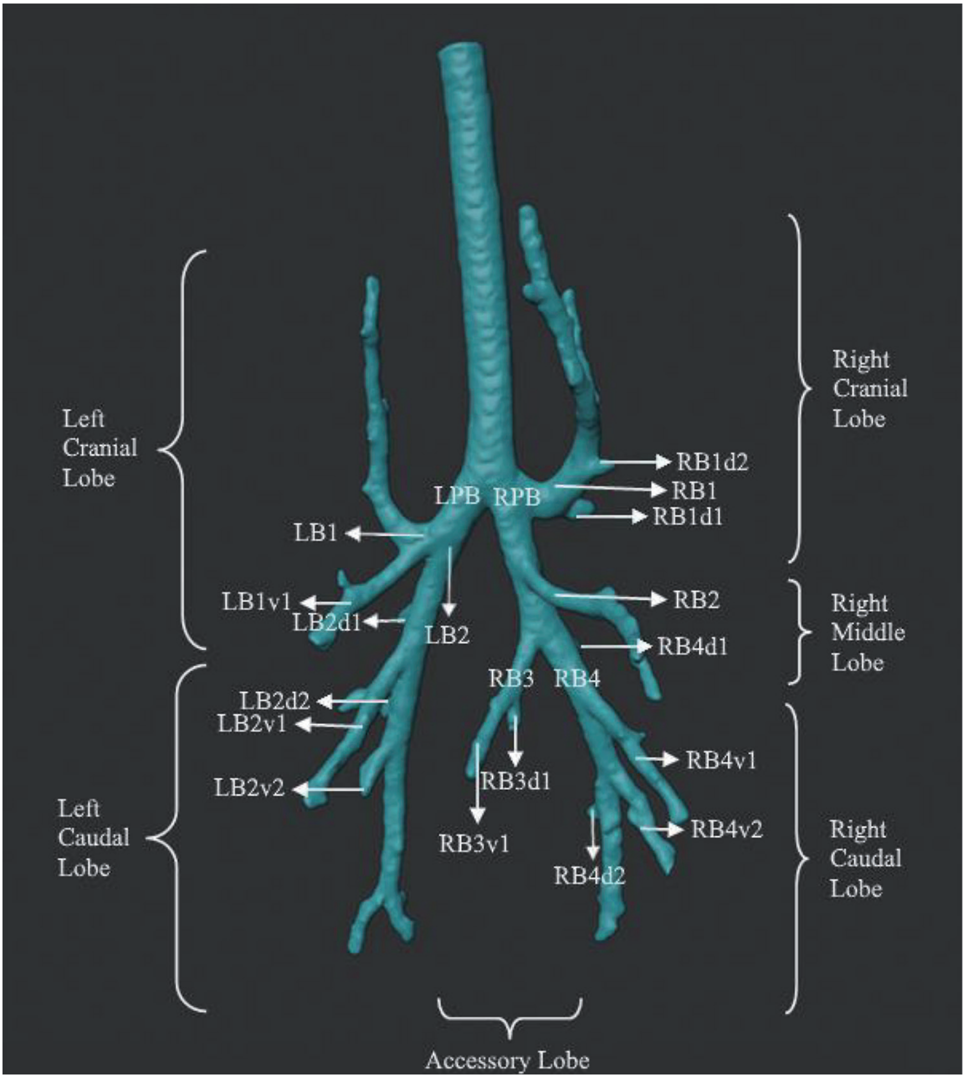

Fig. 5. Bronchial branching of the trachea in the Van cat.

RPB: right principal bronchi; RB1: right bronchus 1; RB2: right bronchus 2; RB3: right bronchus 3; RB4: right bronchus 4; RB1d1: right bronchus 1 dorsal segmental bronchi 1; RB1d2: right bronchus 1 dorsal segmental bronchi 2; RB3d1: right bronchus 3 dorsal segmental bronchi 1; RB3v1: right bronchus 3 ventral segmental bronchi 1; RB4d1: right bronchus 4 dorsal segmental bronchi 1; RB4d2: right bronchus 4 dorsal segmental bronchi 2; RB4v1: right bronchus 4 ventral segmental bronchi 1; RB4v2: right bronchus 4 ventral segmental bronchi 2; LPB: left principal bronchi; LB1: left bronchus 1; LB2: left bronchus 2; LB1v1: left bronchus 1 ventral segmental bronchi 1; LB2d1: left bronchus 2 dorsal segmental bronchi 1; LB2d2: left bronchus 2 dorsal segmental bronchi 2; LB2v1: left bronchus 2 ventral segmental bronchi 1; LB2v2: left bronchus 2 ventral segmental bronchi 2