Original Article

Computed Tomographic Anatomy and Topography of the Lower Respiratory System of the Mature Rat (*Rattus norvegicus*)

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ABSTRACT

Among various mammals, the laboratory rat (*Rattus norvegicus*) is widely used for experimental purposes and belongs to the order Rodentia, family Muridae, and genus *Rattus*. The lack of comprehensive studies on the topography and CT anatomy of thoracic structures in this species necessitates further investigation. This study aims to accurately describe the topography of the lungs, trachea, and heart in rats based on CT scan findings compared with anatomical observations. CT scan images were obtained from 10 adult male rats at 1 mm intervals using a Siemens Somatom Spirit CT Scanner, followed by anatomical studies through autopsy. Morphometric measurements were taken from the CT images, and the thorax, lungs, heart, and intrathoracic trachea, along with the spatial relationships of the organs, were meticulously examined during the anatomical studies. Detailed descriptions were compiled from both the CT scan images and autopsy findings. The tracheal bifurcation was consistently located between the fourth and fifth ribs in all samples. The right lung was larger and more voluminous than the left lung. The heart was oriented toward the left, and the right bronchus was shorter than the left. The results confirmed that the right lung was more voluminous than the left lung in *R. norvegicus*, as evidenced by precise measurements. It was also found to be longer than the left lung, although both lungs exhibited similar width and height. Notably, the use of CT scans enables anatomical examination of living and active body structures, which can be practically beneficial. In general, the lungs extend from the second rib to the last rib, with the right lung occupying slightly more space both anteriorly and dorsally. Regarding lobulation, the left lung consists of one lobe, while the right lung has four lobes. This study underscores the value of CT imaging in facilitating anatomical assessments in vivo, enhancing its practical applicability.

Keywords: Anatomy, Lung, Trachea, CT Scan, Laboratory Rat

1. Introduction

Rodents represent the largest order of mammals, comprising approximately 3,000 species. Like all rodents, the laboratory rat (*Rattus norvegicus*) belongs to the order Rodentia and, along with mice (*Mus musculus*), is a member of the family Muridae. The term "murine" specifically refers to laboratory rats and mice. Laboratory rats are of great interest in research and as pets due to their smaller size compared to rabbits and monkeys, short gestation period, and ease of maintenance. However, the use of rats in biological research is somewhat limited by certain diseases, including chronic respiratory diseases that can lead to severe pneumonia (1). In *R. norvegicus*, the thorax contains 13 pairs of ribs, which include six true ribs, four false ribs, and three floating ribs (2). The thorax in this species is laterally wide and has a larger volume compared to its body size. Similar to the respiratory system of mice, the right lung consists of four lobes, while the left lung has one lobe (3). Diagnostic imaging techniques have long been recognized as effective methods for anatomical studies of living animals and have been employed in various veterinary anatomy studies for many years. In the thoraxes of carnivores, Perissodactyla, ruminants, and most rodents, the margins of the lungs are flat but not straight, as also observed in a previous study (4). For instance, thoracic arteries in goats were examined using computerized tomography (CT) scans (5). Anatomical features can be investigated using various diagnostic imaging techniques, including radiography, sonography, MRI, and CT scans, alongside traditional methods such as autopsy and cross-sectional analyses. CT scanning is particularly useful for studying the anatomical structures of the respiratory tract and for examining the anatomy, topography, radiography, and CT images of non-respiratory organs within the coelomic cavity of the European pond turtle (6, 7). Smallwood and Georgell (1993) prepared an atlas of CT images (with a slice thickness of 13 mm) of the dog's pelvis (8). Another study presented a detailed analysis of heart structure that correlated with anatomical data from the human heart (9, 10). The conventional use of CT scans in human medicine has spurred interest in their application in veterinary medicine. The advantages of CT scans as diagnostic and anatomical tools are widely acknowledged, particularly in the pathology of the thorax and heart in carnivores, leading to increased anatomical studies in these areas (11). In all mammals, the base of the heart is formed solely by the left ventricle; however, differences exist in the orientation of the heart. In quadrupedal animals, the longitudinal axis of the heart is oblique, caudoventral, and slightly leftward. Due to their standing posture, the tip of the heart in quadrupeds is more inclined toward the ventral and sternal sides compared to humans. The heart of all mammals is situated in the middle mediastinum and is surrounded by the pericardium (12). De Rycke et al. (2005) studied the thorax of dogs using CT scans with a slice thickness of 5 mm. Anatomical differences in the shape and structure of the heart and thorax in dogs and cats indicate that CT scan images of one species should not be interpreted in the same manner as those of another species; instead, new images should be generated to accurately examine each species and ascertain their specific anatomy (13). Additional studies have shown that CT scans are the most accurate method for volumetry. In a study evaluating cat kidney volumetry, both ultrasonography and CT scanning were compared to real measurements obtained through autopsy, demonstrating that CT scan data closely matched actual volume (14). CT scans were also employed to examine the anatomy of a gazelle's abdominal cavity, accurately identifying the liver, spleen, stomach, large intestine, and small intestine, with ribs and vertebrae serving as landmarks for these structures (15). The laboratory rat is a widely used model organism for experimental purposes among various mammals. Given the lack of thorough investigations into the topography of thoracic structures in rats, this study aimed to accurately describe the topography of the lungs, trachea, and heart in rat samples based on CT scan findings, compared with anatomical observations. Additional parameters examined included the position of the bronchi, the level of the tracheal bifurcation, and the entry of the trachea into the thorax. The volumes of various structures, including the heart and lungs, were also measured in this investigation.

2. Materials and Methods

2.1. Individuals

In this study, 10 adult male rats (*Rattus norvegicus*) with an average weight of 350 ± 0.51 g were obtained from the Small Animal Hospital (Faculty of Veterinary Medicine, University of Tehran). Each rat was anesthetized via intraperitoneal injection of ketamine at a dose of 75 mg/kg, combined with 5 mg/kg of xylazine (16).

2.2. Computed Tomography (CT) Scanning

To prepare the CT scan images, all rats were placed in ventral recumbency on a CT scan table (Siemens Somatom Spirit, Germany). The vertical positioning significantly affected lung volumes and could potentially influence the interpretation of the radiographs obtained in these positions (17). Scans began at the front of the jaw and progressed toward the back of the body to encompass all respiratory surfaces of the animal. Images were captured transversely, perpendicular to the longitudinal axis of the body (spine), at 1 mm intervals.

2.3. Technical factors of CT Scan

Each section was analyzed by selecting appropriate window width (WW) and window level (WL) settings. The X-ray irradiation factors and CT scan technique are detailed below: Rotation time: 1s, slice thickness: 1mm, reconstruction interval: 0.5–1 mm, pitch: 1, X-ray tube potential: 120 kV, and X-ray tube current: 130 mA.

2.4 Morphometric Studies

Thoracic tracheal volume, left and right bronchi, left and right lungs, and heart dimensions, as well as the lengths of the right and left trachea and bronchi, were measured using Syngo MMWP VE40A software on the CT scanner. All relevant parameters were analyzed using the Student's t-test in SPSS 16 software ($P < 0.05$).

2.5. Gross anatomical Studies

The bodies of rats that had been euthanized for non-respiratory issues and were preserved under appropriate conditions were utilized for this phase of the study. No samples from the previous stages were euthanized specifically for this part. To perform the thoracic autopsy, an incision was made from the ventral thorax below the throat and extended to the back of the last rib. The sternum was fully opened to facilitate access to the thoracic cavity and examine the anatomical positions of the heart and lungs. These organs were studied through various sections and limits.

3. Results

Table 1 presents the locations of the trachea, bronchi, lungs, and heart, as examined using both conventional anatomical methods and 2D/3D CT scans (Figure 1), along with the relationships between these organs. The results of the measurements are shown in Table 2.

3.1 Results of anatomical studies and CT scan images

Different structures are described in this section based on the order of their observation during the autopsy procedure. The trachea begins at the throat and lies along the midline; it then deviates to the right of the midline around the fourth cervical vertebra and continues posteriorly until it enters the thorax between the first two ribs. The trachea, as it passes the first rib, maintains an inclination to the right of the midline and bifurcates at the level of the fourth and fifth ribs (Figure 2). The right lung was more anterior and started near the cranial border of the second rib (Figure 2). The right lung appeared larger than the left lung (Figures. 3, 4, 5) and was more caudal continued until before the 13^{th} rib (Figures. 2 and 6). The bronchi extended caudodorsally to enter the lungs. The right bronchus entered the right lung near the sixth rib. The length of the right bronchus was shorter (Figures 2 and 3). The right lung consisted of four apical, cardiac, diaphragmatic, and accessory lobes. The inter-lobar fissures in the right lung were fully deep so that the lobes were not connected to each other (Figure 7). The structures in this section are described based on the order of their observation during the autopsy procedure. The left lung begins near the caudal border of the second rib and terminates near the eleventh rib (Figure 2). The left bronchus is notably longer, entering the left lung at approximately the seventh rib (Figures 2, 3). The borders of the left lung are not incised and do not exhibit lobulation.

3.2 Results of morphometric studies

The results of the measurements (Table 2) indicate a statistically significant difference in length between the right and left lungs, with the right lung being longer ($p < 0.05$). The widths of the right and left lungs are equal, showing no significant difference (Table 2). Similarly, the heights of the right and left lungs are equal, lacking statistical significance (Table 2). The difference in lung length on each side is significantly distinct from the height of the corresponding lung, with the height on each side exceeding the length (Table 2). There are significant volume differences between the right and left lungs, with the right lung exhibiting a larger volume (Table 2). The length of the left bronchus is significantly longer than that of the right bronchus (Table 2). The volume of the bronchi differs significantly, with the left bronchus possessing a larger volume (Table 2). Additionally, there is a significant difference between the heart volume and that of both lungs, with the heart volume being smaller compared to the volume of each lung (Table 2).

4. Discussion

Like other rodents, rats have four lobes in their right lung, while the left lung lacks distinct lobulation. Species differences in lung lobe formation can be attributed to evolutionary adaptations (2), and similar patterns were observed in the present study. In large mammals, the heart is situated in the middle ventral mediastinum, with its long axis oriented obliquely downward compared to humans, exhibiting a slight leftward orientation (18). Moreover, the heart is elongated and has a pointed apex in most animals. The conical, elongated heart with a pointed apex in rabbits resembles that of guinea pigs (19), while dogs possess elliptical hearts with rounded apices (20). In rats, the heart is oval with a narrow apex oriented to the left, occupying a significant portion of the thorax. In all mammals, the base of the heart is formed solely by the left ventricle, although differences exist in heart orientation. In quadrupeds, the long axis of the heart is oblique, oriented ventro-dorsally and slightly to the left. Due to the standing posture of quadrupeds compared to humans, the apex of the heart is inclined more ventrally towards the sternum (12). Previous studies on the thorax (4) indicated that the margins of the lungs are flat in carnivores, perissodactyla, ruminants, and most rodents, but do not follow straight lines, as also observed in this investigation. Reports suggest that the interlobular duct in rodents is deeper, and the lobes of the right lung are completely separate. Accordingly, the right lung comprises four lobes: apical, cardiac, diaphragmatic, and accessory (21, 22). This separation of lobes was also noted in our examination of rat lungs. Additionally, the anterior part of the right lung, or apex, in rats starts earlier than that of the left lung, and the dorsal or diaphragmatic lobe of the right lung is positioned more dorsally than that of the left lung. Given this observation and the location of the heart on the left side of the thorax, it can be concluded that the right lung is larger and occupies more space within the thorax. In a study examining the anatomy of the lower respiratory tract in mole rats (*Spalax leucodon*), it was reported that the lungs of this species comprise 1.29% of body weight, with the right lung being heavier than the left (23). Our experimental rats also exhibited a larger volume in the right lung compared to the left. Reports on male rats indicated that the inter-lobar fissures were deep and completely separated the lung lobes, a finding consistent with our observations. An investigation into the anatomy

Table 1. Organs and their limited area the thoracic cavity

Explanation	13	12	11	10	9	8	7	6	5	4	3	2	1	Rib organ
From the first up to 4th- 5th rib, Rightward									*	*	*	*	*	Trachea
From the second rib ends up at the beginning of the13th rib		*	*	*	*	*	*	*	*	*	*	*		Right lung
The end of the second rib up to the 11th rib			*	*	*	*	*	*	*	*	*			Left lung
From the third up to the 10th rib				*	*	*	*	*	*	*	*			Heart

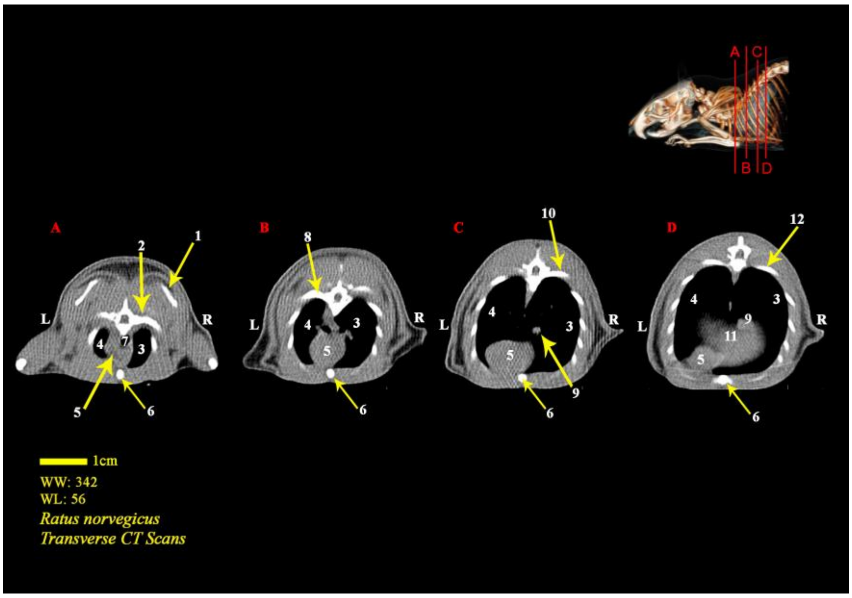

Figure 1. (A-D) Two- dimensional computed tomography images of the *Rattus noevegicus* Transverse plane – Chest/Abdomen window. 1. Scapula, 2. Third rib, 3. Right lung, 4. Left lung, 5. Heart, 6. Sternum, 7. Trachea, 8. Sixth rib, 9. Caudal vena cava, 10. Ninth rib, 11. Diaphragm, 12. Tenth rib.

Table 2. Results of morphometric studies (cm, cm^3, g).

Parameters	**Mean±standard deviation (Left)**	**Mean±standard deviation (Right)**
Lung, length	2.04±0.98a	2.74±0.74b
Lung, width	1.44±0.74c	1.65±0.44c
Lung, high	2.95±0.23d	3.04±0.54d
Lung, volume	6.84±0.54e	7.54±0.51f
Bronchus, length	1.04±0.54h	0.54±0.06i
Bronchus, volume	0.03±0.001j	0.02±0.002k
Thoracic trachea, length	0.51±0.07i	
Thoracic trachea, Volume	0.06±0.002k	
Heart, volume	3.60±0.98g	
Heart, length	2.62±0.55	
Heart, width	1.94±0.85	

The different words represent meaningfulness differently between right and left parameters (P<0.05)

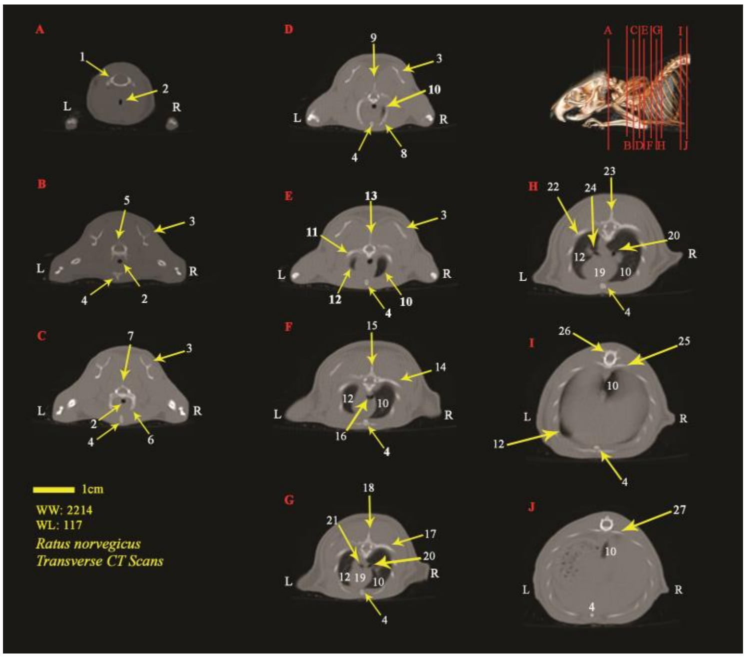

Figure 2. (A-J) Two- dimensional computed tomography images of the *Rattus noevegicus* Transverse plane- Bone window.
1. Atlas, 2. Trachea, 3. Scapula, 4. Sternum, 5. Sixth cervical vertebra, 6. First rib, 7. Seventh cervical vertebra, 8. Second rib, 9. Eighth vertebra, 10. Right lung, 11. Third rib, 12. Left lung, 13. Ninth vertebra, 14. Fourth rib, 15. Tenth vertebra, 16. The place where that the trachea divides into primary bronchi, 17. Fifth rib, 18. Eleventh vertebra, 19. Heart, 20. Right bronchial / shows the place it enters the right lung, 21. Left bronchial, 22. Sixth rib, 23. Twelfth vertebra, 24. Shows the place left bronchial enters the left lung, 25. Eleventh rib, 26. Seventh vertebra, 27. Twelfth rib.

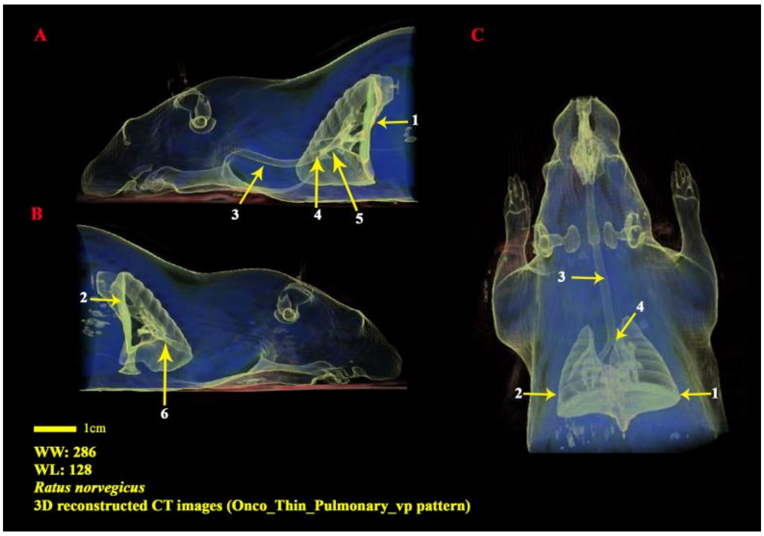

Figure3. 3D reconstructed Computed tomography images of the *Rattus noevegicus* – Onco_ Thin_Pulmonary_vp pattern.
A. Medial view of right paramedian, B. Medial view of left paramedian, C. Ventral view
1. Right lung, 2. Left lung, 3. Trachea, 4. The place where that the trachea divides into primary bronchi, 5. Right bronchus, 6. Left bronchus.

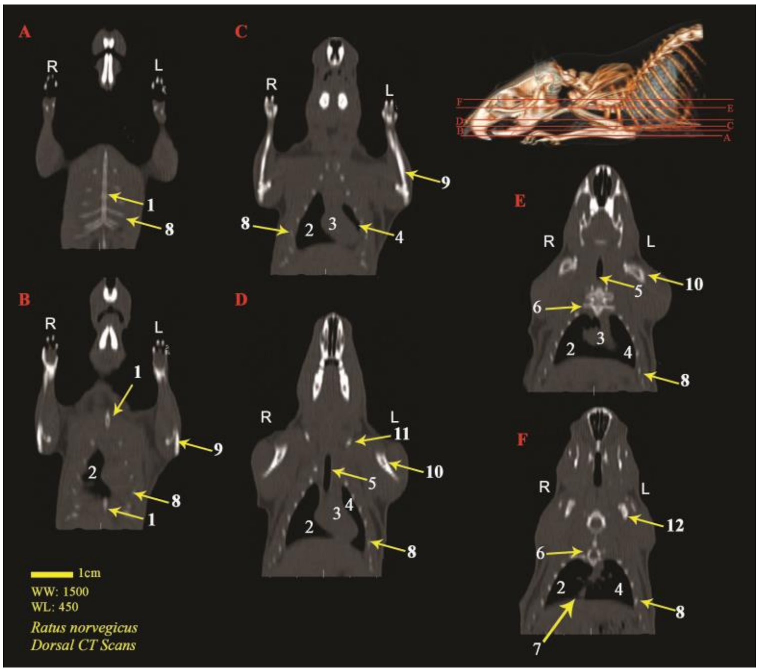

Figure 4. (A-F) Two- dimensional computed tomography images of the *Rattus noevegicus* dorsal plane - bone window.
1. Sternum, 2. Right lung, 3. Heart, 4. Left lung, 5. Trachea, 6. Cervical vertebrae, 7. Caudal vena cava, 8. Ribs, 9. Ulna, 10. Humerus, 11. Clavicle, 12. Scapula.

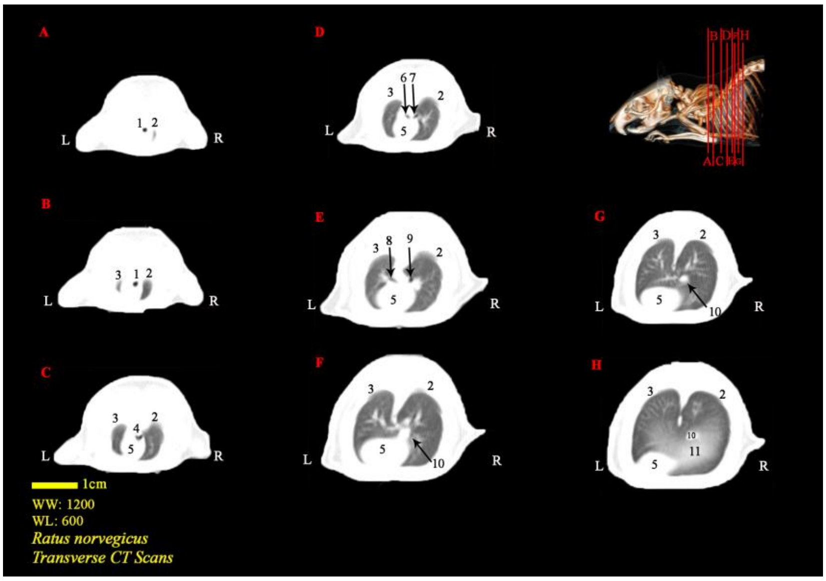

Figure 5. (A-H) Computed tomography images of the *Rattus norvegicus*, Transverse planes – lung window.
1. Trachea, 2. Right lung, 3. Left lung, 4. The place where that the trachea divides into primary bronchi, 5. Heart, 6. Left bronchial, 7. Right bronchial / shows the place it enters the right lung, 8. Shows the place left bronchial enters the left lung, 9. Shows the place it enters the right lung, 10. Caudal vena cava, 11. Diaphragm.

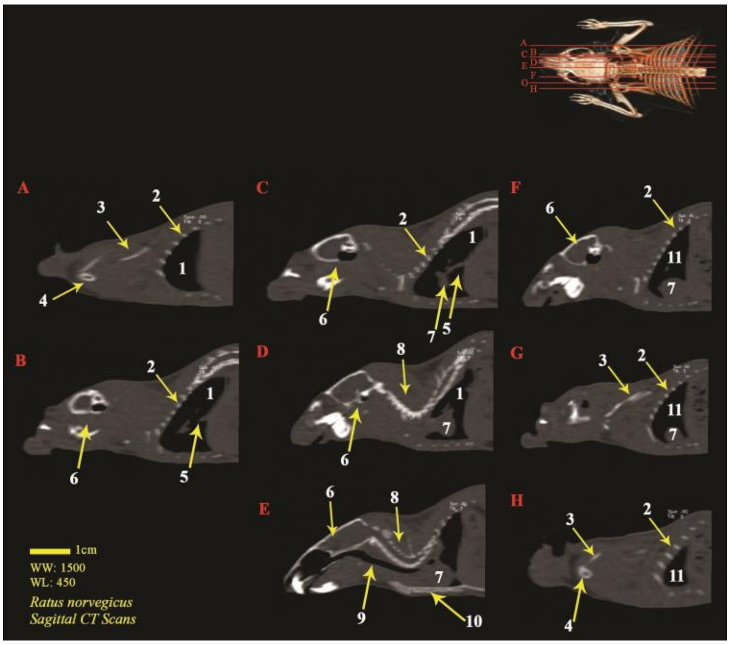

Figure 6. (A-H) Two- dimensional computed tomography images of the *Rattus noevegicus* Sagittal plane - bone window.
1. Right lung, 2. Ribs, 3. Scapula, 4. Humerus, 5. Caudal vena cava, 6. Skull, 7. Heart, 8. Vertebral column, 9. Trachea, 10. Sternum, 11. Left lung.

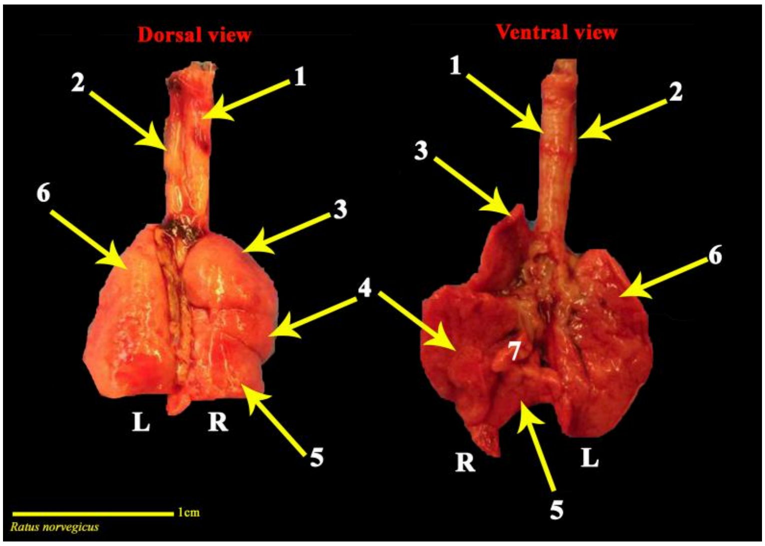

Figure 7. *Rattus norvegicus* lung dissection.
1. Trachea, 2. Esophagus, 3. Cranial lobe of the right lung, 4. Medial lobe of the right lung, 5. Caudal lobe of the right lung, 6. Left lung, 7. Accessory lobe of the right lung.

of the lower respiratory tract in the African giant pouched rat (*Cricetomys gambianus*) revealed that the right lung consists of four lobes while the left lung remains undivided (24). In this study, inter-lobar fissures were absent in the right lung, except for the ventral border separating the cranial lobe from the caudal lobe. In our rats, however, the right lung lobes were fully separated due to deep fissures. Laakkonen and Jernvall (2016) studied the anatomy of the lower respiratory tract in the Saimaa ringed seal (*Phoca hispida saimensis*), observing that the right lung contained incomplete inter-lobar fissures and was divided into cranial, middle, caudal, and accessory lobes, while the left lung was divided into cranial, middle, and caudal lobes (25). The volume of the right lung in our rat samples was consistently larger than that of the left lung, as confirmed by accurate measurements. Furthermore, the right lung was longer than the left lung, though both exhibited equal widths and heights. Generally, the lungs extend from the second rib to the last rib, with the right lung occupying slightly more anterior and dorsal space. In terms of lobulation, the left lung consists of one lobe while the right lung comprises four lobes. The right bronchus is shorter than the left bronchus, as the tracheal bifurcation level is slightly tilted to the right of the midline. Both bronchi enter the lungs caudo-dorsally, with the entrance of the left bronchus positioned slightly more dorsally than that of the right bronchus. This rightward tilt of the bifurcation explains the greater length of the left bronchus compared to the right. This method is among the most effective diagnostic techniques for pets and laboratory animals due to its high sensitivity in detecting normal and abnormal structural features in CT scans. Thus, it is recommended for obtaining information on rare and endangered animals where autopsy examinations may not be feasible. Since the examination of internal organs is fraught with limitations, the use of diagnostic imaging methods for these organs is invaluable for diagnosing various conditions. This study's examination of the structural features and positions of various organs in the thorax of *Rattus norvegicus* provides a foundation for further exploration.

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Authors' Contribution
Data collection, and analysis: T. R.
Supervisors for the study, and writing of the article: M. H. Y., and M. M.
Methodology and writing the article: O. Z., and S. J. A.

Ethics
It is hereby stated that all ethical considerations were taken into account in the preparation of the submitted manuscript.

Conflict of Interest
The authors declared that they have no conflict of interest.

Data Availability
The data that support the findings of this study are available on request from the corresponding author.

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