RESEARCH ARTICLE

Gross Morphology and Morphometry of Bronchial Tree using Casting Method in Domestic Sheep (*Ovis aries*)

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Abstract

The bronchial tree of sheep (*Ovis aries*) demonstrated species-specific anatomical features that reflect adaptation to ruminant physiology and grazing behaviour. The lung was composed of right and left lobes, with four and two sub-lobes each, respectively. The apical lobe and accessory lobes were present in the right lobe while cardiac and diaphragmatic lobes were seen in both right and left lobes. The cardiac notch was prominent in right lobe than in left lung cardiac lobe. A distinctive feature of the ovine bronchial tree was the presence of anapical bronchus supplying the right cranial lobe. The bronchial architecture exhibited both monopodial and dichotomous branching pattern, where the principal bronchus on right side showed four ventral, 5 dorsal and 3 lateral and 3 medial lobar (secondary) bronchi while that of left one emitted 5 dorsal, 6 lateral, 4 ventral, and 3 medial segmental bronchi but with a more consistent order of origin which thereafter continued as terminal segment. The morphometry revealed that the circumference of trachea before giving rise to apical bronchus was more (6.99 ± 0.93 cm) than after origin of apical bronchus (6.53 ± 1.12 cm), which increased at the level of bifurcation (7.10 ± 0.91 cm). The circumference of left principal bronchus (5.68 ± 0.70 cm) was higher and that of apical bronchus was least (3.03 ± 0.44 cm).

Key words: Bronchial tree, Bronchus, Cast technique, Lung, Sheep.

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Introduction

Corrosion casting is a conventional method employed in the fields of anatomy and pathology to create precise copies of vascular and airway structures (Gupta and Sangeetha, 2025). Lungs serve the essential function of providing a conduit for gas exchange, which allows for oxygenation of tissues (Mulka *et al*., 2026). The bronchial tree forms the conducting portion of the lower respiratory tract and ensures distribution of inspired air to alveolar gas exchange units. There are about 15 generations of conducting airways and about 8 generations of gas exchange spaces, with considerable species and individual differences (Weibel, 2013). Sheep are small ruminants widely used in agriculture and biomedical research. Because of the many similarities in the sheep and human respiratory systems and their unique attributes as experimental animals, sheep have been used as models for a wide range of human respiratory diseases (Meeusen *et al*., 2009). According to the 20th Livestock Census of 2019, India had 74.26 million sheep. This represented a significant increase of 14.1% compared to the previous census in 2012 (Choubisa, 2025).

Unlike humans, ruminants exhibit a tracheal bronchus and a highly lobulated lung structure. These features influence both physiological airflow patterns and the localization of pulmonary disease. This article provides a detailed anatomical and histological analysis of the ovine bronchial tree, emphasizing structural organization and clinical implications. Understanding the detailed anatomy of the ovine bronchial tree is essential for diagnostic imaging, pathology, anaesthesia, and comparative biomedical research.

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Materials and Methods

The work was conducted at College of Veterinary Science, Korutla, Jagtial, PVNRTVU, Telangana (India). The lung samples were collected from 12 sheep aged between 6 months to 3 years from local slaughter house. The samples were cleaned thoroughly and fixed in 10% formalin for one week, which were dissected to study the gross morphological features. The fresh samples were injected with commercially available silicon sealant into the trachea little above the origin of apical bronchus using a silicon gun to obtain bronchial casts. The specimens were then left to dry for 48 h for curing, so that the sealant got solidified. The surrounding lung tissue was then removed by putting the specimen in 10% HCl for 5 days to digest the lung tissue. There after remnants of lung tissue if any was removed carefully to obtain the luminal cast. Silicon cast was then cleaned by washing with fresh running water and air dried as per Sinha *et al*. (2021), with slight modification. The obtained silicone model of lung was used to study the tracheal bifurcation and bronchial ramification pattern in sheep. Gross morphometry of trachea and bronchi was recorded with the help of thread and scale.

Results and Discussion

Macroscopic Features of the Lungs

The sheep lung comprised of right and left lobes similar to highly segmented lungs of cattle and pigs (Meeusen *et al*., 2009) and was voluminous as mentioned by Sinha *et al.* (2021) in Garole sheep, but contrast to their studies, left lobe was made up of two lobes, as described by Nickel *et al*. (1979), left lungs of large ruminants, goats and sheep composed of two lobes, but differed from pig lung (Jayachitra *et al*., 2021) that comprised of three lobes. However, the right lung showed four lobes which is in akin with Sinha *et al*. (2021) in Galore sheep and Black Bengal goat. The lung lobes in the present study were well separated by tissue septa with limited connectivity between compartments as in sheep (Kirschvink and Reinhold *et al*., 2008). The fissures were prominent and lobes were clearly demarcated on the ventral aspect than on the dorsal side. The mediastinal surface behind the hilum consisted of dorsal aortic and ventral esophageal impressions (Fig. 1) as in domestic animals (Nickel *et al*., 1979) and pigs (Jayachitra *et al*., 2021). Recurrent laryngeal nerves were observed of which right was associated with trachea while the left one was situated little farther (Fig. 2). The dorsal border was long, thick, and rounded, whereas the ventral border was short and thin. The base of the lung was concave, lying against the thoracic surface of the diaphragm. The apex was narrow and prismatic, forming the cranial pole of the lobe (Dyce *et al.,* 2002).

Right lobe consisted of apical lobe, cardiac, diaphragmatic lobes and an accessory lobe called mediastinal lobe while the left lobe was devoid of apical and mediastinal lobe as in Japanese Deer (Nakakuki, 1993), but Albert *et al*. (2009) demonstrated cranial and diaphragmatic lobes in left lung of deer. Sinha *et al* (2021) expressed that the impartial separation lead to ambiguity in number of lobes in left lung of Black Bengal goat and Garole sheep. The hilum was located towards the mediastinal surface and more ventrally positioned. Pulmonary artery, pulmonary veins, bronchial artery, bronchial veins, nerves and lymphatics were observed. Lungs of the study specimen belonged to Type I as categorization given by Mulka *et al*. (2026) in cattle, pigs, and sheep with well-developed secondary lobules with thick interlobular septa and found few or no respiratory bronchioles. The pulmonary artery and vein were in close proximity within the broncho-vascular sheath (Fig. 3).

Lung Lobes

The right apical lobe was longer and second largest among the four lobes with small fissure in anterior and posterior borders. It was clearly demarcated from the cardiac lobe by a fissure extended to the root on ventral aspect but dorsally it ended midway the root as in Japanese deer (Nakakuki, 1993). The ventral border of apical border showed a notch towards the distal third resulting in posterior part overlapping the

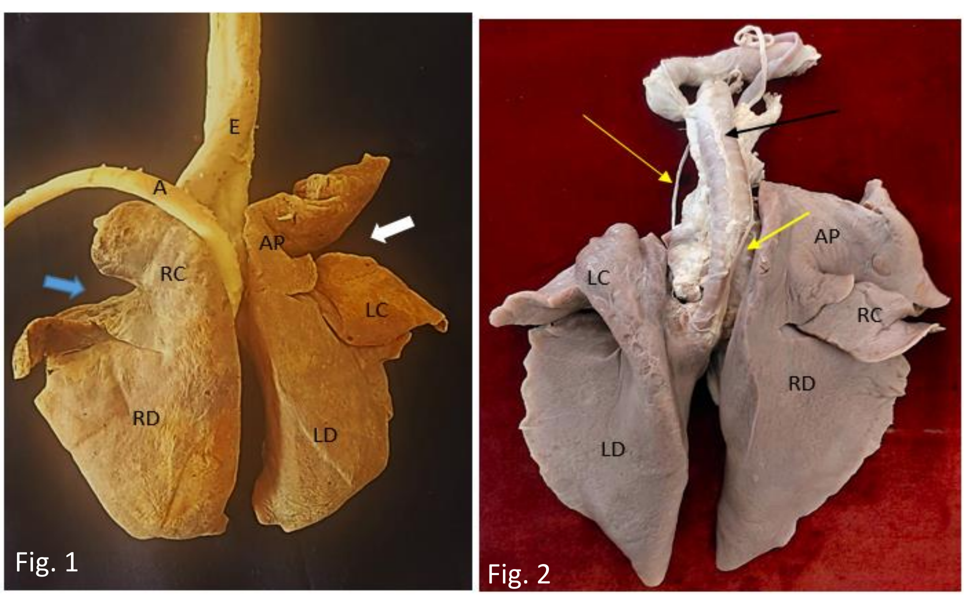

Fig. 1, 2: Dorsal view of sheep lung indicating the Aorta (A), Trachea (Black arrow), Esophagus (E), Recurrent laryngeal nerve (yellow arrows), Right Apical lobe (AP), Right Cardiac lobe (RC), Right Diaphragmatic lobe (RD), Left Cardiac lobe (LC), Left Diaphragmatic lobe (LD), Right (White arrow) and Left (Blue arrow) cardiac notch.

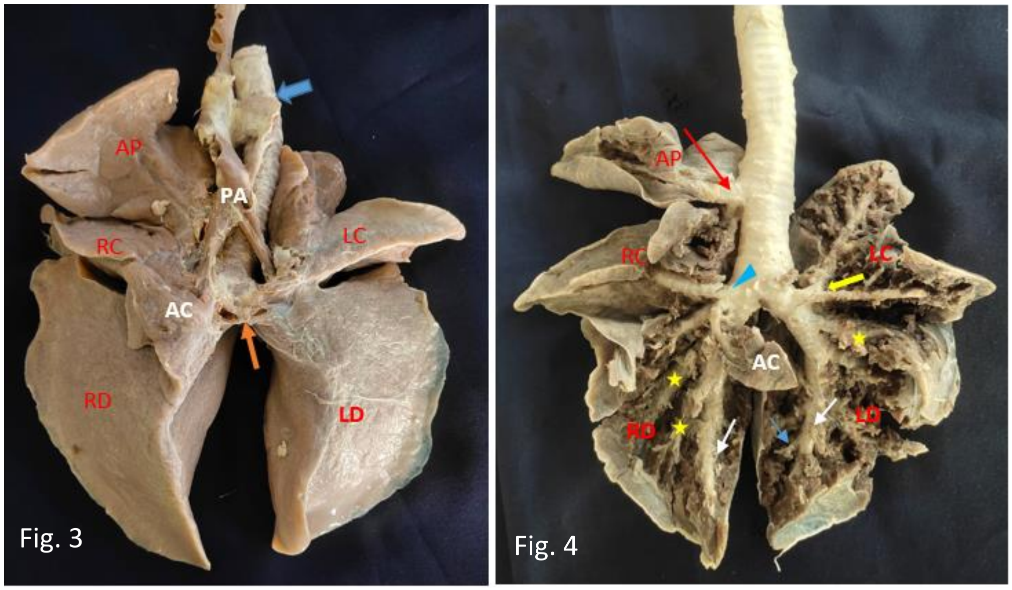

Fig. 3, 4: Showing the ventral aspect of lung indicating the Right Apical lobe (AP), Right cardiac lobe (RC), Accessory lobe (AC), Right Diaphragmatic lobe (RD), Left cardiac lobe (LC), left Diaphragmatic lobe (LD), Pulmonary artery (PA), Pulmonary vein (orange arrow), Trachea (blue arrow), Apical bronchi (Red arrow) lobar divisions supplying apical Right Apical lobe and Right cardiac lobe, First ventral lobar bronchi dividing into segmental bronchi to Accessory lobe and Right cardiac lobe (Blue arrow head), First left ventral lobar bronchi supplying two divisions of Left cardiac lobe (Yellow arrow), Medial lobar bronchi, Lateral lobar bronchi to Diaphragmatic lobe (*) and Continuing part of principal bronchi (White arrow)

cardiac lobe. Cranially, it showed a projection which curved medially with a cardiac impression on the ventro-medial aspect, which support the studies of Sinha *et al*. (2021) in Garole sheep, who stated that it occupied the cranial aspect of the mediastinum and placed cranial to the anterior border of the heart occupied the cranial aspect of the mediastinum. Cardiac notch was present between the apical and cardiac lobe and was prominent than in the left lung (Fig. 1).

The cardiac lobe was the middle lobe with apical lobe cranially and diaphragmatic lobe caudally placed in right lung. It was continuous with caudal lobe as in Japanese deer (Nakakuki, 1993) as it was concealed by the caudal part of apical lobe towards the dorsal border. However, it was clearly partitioned from apical and diaphragmatic lobe by deep fissures. The left cardiac lobe was longer and larger than right with cardiac notch on cranial border. The fissure between it and diaphragmatic lobe was incomplete dorsally giving impression that both lobes were connected with each other on dorsal aspect (Fig. 2).

The diaphragmatic lobe was largest of all the lobes in both right and left lobes while the mediastinal lobe was the smallest. As indicated by Nakakuki (1994) in Holstein cow, the apical and diaphragmatic lobes were united in the dorsal aspect while the cardiac lobe was separated both ventrally and dorsally. Similarly, the left cardiac and diaphragmatic lobes were united in the dorsal aspect but fissures extended till the root dividing them completely (Fig.3). The accessory lobe was located on the ventro-medial aspect of right lung lobe which was the smallest of all the lobes of both sides. It shared a common bronchi with the cardiac lobe which was originated on the ventral side of the right principal bronchus similar to goats and sheep (Sinha *et al*., 2021) where the medial division of first ventral lobar bronchi supplied the accessory lobe (Fig. 4).

Bronchus

As expressed by Mulka *et al*. (2026) it became difficult to analyze the branching pattern of sheep in present study as, the dichotomous branching was described as each airway tube giving rise to 2 daughter branches (Weibel *et al*., 2005; Pinkerton *et al*., 2015), while, dichotomous branching system as a parent airway dividing into 2 smaller daughter segments of approximately equal diameter, whereas monopodial branching refers to the parent airway dividing into daughter airways of unequal diameter (Harkema, *et al*., 2000; Peake and Pinkerton, 2015; Meyerholz and Suarez, 2018). The airways of most species branch in an asymmetric fashion of various degrees, with humans being the most symmetric. Two principal (primary) bronchi were given further below at the level of 4^{th} to 6^{th} intercostal space similar to goats (Kumar *et al*., 1992; Singh *et al*., 1992). Each principal (primary) bronchus gave rise to a number of secondary (lobar) bronchi further divided into tertiary (segmental) bronchi. All the bronchi and bronchioles were directed in different directions in both lungs (Sinha *et al*., 2021), which resembled fine bristle-like, structures (Ananya *et al*., 2019). The right and left principal bronchi and lobar bronchi terminated by dichotomy which was in accordance with Monteiro and Smith (2014), who stated that bronchial division ended in terminal bifurcation in Holstein cow. However, the lobar, segmental, sub-segmental bronchi and bronchioles originated alternately in a monopodial pattern, which was in partial akin with Pathak and Rajput (2018) in Gaddi sheep. The monopodial pattern may be associated with posture as animals are quadrupeds with a horizontal disposition of airways while humans are bipeds with vertical body and disposition of airways (Monteiro and Smith, 2014**)**. The ambiguity of monopodial and dichotomy in sheep lung in present study was clarified by Kirschvink and Reinhold (2008) and Scheerlinck *et al*. (2008), who expressed that the sheep tracheobronchial tree has an irregular dichotomous branching pattern as seen in humans and other large mammals (Fig.5).

Apical Bronchus

The apical bronchus of the right lobe was originated directly from the trachea (Meeusen *et al*., 2009), at the level of 3rd rib as stated by Kalita and Battacharya (2004) in Zebu cattle. As per the studies by Nakakuki, (1993) in Japanese deer, the right apical bronchus in present study arouse` from lateral aspect from right face of trachea which soon after divided into cranial and caudal bronchi innervating the apical (cranial) lobe which further divided into two branches each, similar to Holstein Friesian cow (Nakakuki, 1994). The cranial division of apical bronchus as a whole detached into seven secondary bronchioles, among which two dorsal, two ventral, two cranial and one caudal in position. Caudal division gave rise to two dorsal and one ventral bronchiole before bifurcating. The branches, originated towards the edge of the secondary bronchi diminished in diameter compared to one which was close to the hilum which was clarified by Tawhai *et al*. (2004), who opined that the monopodial branching pattern produces a more asymmetric bronchial tree with respect to the rate of increase of the number of branches and the rates of decrease of branch length and diameter with each branch division (Fig. 5, 6).

Right Principal Bronchus

The right principal bronchi supplied lobar (secondary) bronchi to cardiac, diaphragmatic and accessory lobes. The principal bronchus on right side showed 4 ventral, 5 dorsal and 3 lateral and 3 medial lobar (secondary) bronchi which thereafter continued as terminal segment, similar to the observations of Pathak and Rajput (2018) in Garole sheep. Jayachitra *et al*. (2021) in pigs found 5 ventro-lateral, 4 ventro-medial, 3 dorso-medial and 2 dorsal secondary branches in the right primary bronchus, but Sinha *et al*. (2021) observed 4 dorsal, 5 lateral, 4 ventral and 2 medial bronchus from right principal bronchus in sheep. Lateral bronchi were well developed than dorsal, ventral and medial ones, while the first dorsal lobar bronchi further emitted two dorsal, two lateral, two ventral and one medial segmental bronchiole.

The cardiac and accessory lobes were supplied by a single lobar bronchus that positioned ventrally, which immediately divided into two segmental bronchi, among which one was dorsally directed and other curved ventrally to ventilate the cardiac and accessory lobes, respectively (Fig. 4, 6) similar to the findings of Sinha *et al*. (2021) in goats and sheep. Also it was large branch among the ventral branches. The first dorsal bronchi was divided into 2 branches supplying the apical part of the diaphragmatic (caudal) lobe which was united with the apical lobe (Fig. 5)

Left Principal Bronchus

The left principal bronchus divided in to 5 dorsal, 6 lateral, 4 ventral, and 3 medial segmental bronchi but with a more consistent order of origin. The segmental bronchi further divided into sub-segmental bronchi, bronchioles which terminated into respiratory bronchioles. The principal bronchi after distributing branches continued as a terminal segment. Similar pattern was observed in pigs, where after

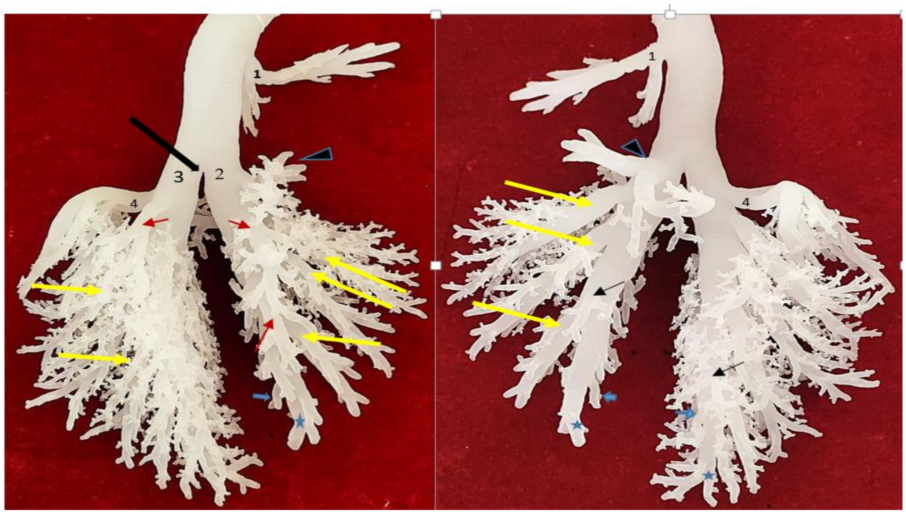

Fig. 5: Dorsal view **Fig. 6:** Ventral view of sheep lung cast indicating the apical bronchus (1), Right principal (primary) bronchus (2), Left principal (primary) bronchus (3), First left lateral lobar bronchus to cardiac lobe (4), Tracheal bifurcation (Bold arrow), first right ventral lobar bronchi diving into dorsal segmental bronchi to diaphragmatic lobe and ventro-medial branch to accessory lobe (arrow head), lateral lobar bronchi (yellow arrows), Ventral lobar bronchi (black arrow), dorsal lobar bronchi (Red arrow), medial lobar bronchi (Blue arrow) and continuing bronchi to diaphragmatic lobe)

distributing secondary bronchi to cardio-apical lobe, four ventro-lateral, three dorsal, two ventro-medial branches, the left principal bronchus which then continued as terminal branch to ventilate the diaphragmatic lobe (Jayachitra *et al*., 2021). The first lateral lobar bronchus was the largest of lateral branches and was divided into cranially and caudally directed branches as described by Pathak and Rajput (2018) in Garole sheep, who mentioned it as apico-cardiac lobar branch. However, two divisions of first lateral lobar bronchi of sheep lung supplied the parts of the cardiac lobe located cranial and caudal to the cardiac notch, respectively (Fig. 5, 6).

Morphometry

The morphometry revealed that the mean length of trachea between the origin of apical bronchus and tracheal bifurcation in to right and left principal bronchi was 4.93 ± 0.33 cm. The circumference of trachea before giving rise to apical bronchus was 6.99 ± 0.93 cm and after origin of apical bronchus was 6.53 ± 1.12 cm. The circumference of trachea increased at the level of bifurcation (7.10 ± 0.91 cm), which is justified by Pathak and Rajput (2018) in Gaddi sheep, who stated that the increase can be attributed the change in principal bronchus shape at the level of bifurcation. However, in contrast the overall traverse circumference of trachea decreased in caudal part in Iraqi goat (Al-Umeri, 2015). The circumference of left principal bronchus (5.68 ± 0.70 cm) was higher and that of apical bronchus (3.03 ± 0.44 cm) was the least (Table 1).

Table 1: Morphometry of trachea and bronchi in centimeters

S.No.	Anatomical feature	(Mean ± SD, cm)
1	Length of trachea between the right apical bronchi to the tracheal bifurcation.	4.93 ± 0.33
2	Circumference of trachea before origin of apical bronchus	6.99 ± 0.93
3	Circumference of trachea between the apical bronchus and bifurcation	6.53 ± 1.12
4	Circumference of trachea at the level of bifurcation	7.10 ± 0.91
5	Circumference of right apical bronchi at its origin.	3.03 ± 0.44
6	Circumference of the right principal bronchi at the level of origin.	5.12 ± 0.86
7	Circumference of the left principal bronchi at the level of tracheal bifurcation	5.68 ± 0.70

Conclusion

The bronchial tree of sheep exhibits distinct anatomical and morphometric characteristics that reflect species-specific adaptations. The presence of asymmetrical lung lobation, with a more complex right lung, and the occurrence of a unique apical bronchus supplying the right cranial lobe are notable features. The branching pattern shows a combination of monopodial and dichotomous arrangements, indicating an organized yet flexible airway distribution. Additionally, variations in tracheal and bronchial circumference highlight structural adaptations that may support efficient airflow and respiratory function in ruminants. Overall, these findings provide valuable baseline data for comparative anatomy, clinical diagnosis, and veterinary interventions involving the ovine respiratory system.

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