Short Communication

A preliminary study of tracheal morphology in mixed-breed dog cadavers: Anatomical variation of tracheal cartilaginous rings

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Abstract

Anatomical abnormalities of the trachea leading to respiratory distress. Few reports describe the morphological characterization of the dog's trachea, particularly in the tracheal cartilaginous rings. In this study, twelve tracheas from mixed-breed dog cadavers were obtained to investigate their features across three anatomical tracheal regions: cervical, thoracic inlet, and intrathoracic trachea. The average length of the trachea was 18.92 ± 0.67 cm. Each trachea contained a different number of tracheal rings, ranging from 32 to 41 rings (37.42 ± 0.81 rings). A significant reduction in both outer transverse diameter (OTD) and outer vertical diameter (OVD) was observed from the cervical to the thoracic inlet trachea (P<0.007 and P<0.003, respectively). The intraluminal tracheal cross-section shapes observed at the thoracic inlet trachea were horseshoe (50%), crescent (25%), dorsal focal invagination (16.7%), and oval (8.3%) respectively. Surprisingly, a circular shape could not be observed in the thoracic inlet trachea. Additionally, a single straight band with a parallel border throughout the tracheal cartilaginous ring is a typical configuration in all dog's trachea (93.3%). Conversely, atypical patterns of cartilaginous rings were less observed (6.7%). This study provides valuable novel insights into the anatomical structure and morphological variability of the tracheal ring in dogs.

Keywords: Cartilaginous ring patterns, Dog's cadavers, Intraluminal tracheal cross-section shapes, Tracheal dimensions

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Introduction

The trachea is a flexible cartilaginous tubular airway structure responsible for conducting air in the respiratory system. It originates from the caudal aspect of the cricoid cartilage and extends to the mainstem bronchi. Each tracheal ring, composed of incomplete hyaline cartilage, is connected by annular ligaments. The bilateral and ventral borders of these tracheal rings are primarily supported by the cartilage, stabilizing and maintaining the large tubular airway structure (Rains *et al*., 1992). The dorsal border of each tracheal ring is formed by the trachealis muscle, facilitating food passage through the esophagus during the feeding state (Iber and Mederacke, 2022). The trachea is divided into three regions based on its location: cervical, thoracic inlet, and intrathoracic trachea. It usually undergoes a reduction in size from the cervical trachea to the thoracic inlet, which has been reported as the narrowest point of tracheal diameter in dogs (Dabanoğlu *et al*., 2001; Kara *et al*., 2004). Notably, the tracheal cartilage is avascular tissue with a small number of cell populations, thereby leading to poor regenerative potential in case of tracheal damage (Igai *et al*., 2007).

In the clinical context, the examination of the trachea focused on three main aspects: dimensions, intraluminal shapes, and cartilaginous ring morphology. In-depth knowledge of the tracheal luminal dimension is crucial for various medical procedures, including selecting appropriate endotracheal tube size and an endotracheal stent. Understanding variations in intraluminal shapes could assist clinicians in diagnosing tracheal abnormalities. Meanwhile, a thorough comprehension of the individual anatomical tracheal ring is essential for tracheal reconstruction. Currently, 3D printing is employed to create substitute rings for tracheal transplantation in humans, however, only simple designs have been implemented (Etienne *et al*., 2018; Frejo & Grande, 2019). Therefore, exploring the anatomical characteristics of individual cartilaginous rings may enhance the design of prosthetic tracheal rings. Hence, our study aimed to investigate the tracheal length, the number of trachea rings, tracheal dimensions, intraluminal tracheal cross-section shapes, and anatomical characteristics of individual cartilaginous rings.

Materials and Methods

This present study was carried out at the Gross Anatomical Laboratory, Department of Veterinary Anatomy, Faculty of Veterinary Medicine, Kasetsart University, Thailand. The Animal Care and Use for Scientific Research Committee of Kasetsart University, Thailand approved the study protocol. (Protocol ID # ACKU66-VET-057). Dog carcasses were derived post-mortem from the owner's donation. Adults over 1 year old dog's carcasses were included. Based on their medical recording, dogs with a clinical appearance of respiratory disease before death were excluded. Furthermore, dogs with a history that indicated goose honking or chronic coughing were excluded from this study. The tracheas were obtained from the twelve, mixed-breed dog cadavers after the dissection session of veterinary anatomy courses. There were 4 male and 8 female dog cadavers with ranges of age from 9 years to 17 years. The metal ruler and digital vernier caliper (Metric and Inch Series 500-196-30, Mitutoyo, Japan) were used for the measurement of tracheal length and dimension, respectively. The total length of the trachea was measured from the caudal border of the cricoid cartilage to the mainstem bronchi. The number of tracheal rings was counted in the medial view. Both typical and atypical shapes of cartilaginous rings were observed in each trachea, making it troublesome to count the number of tracheal rings. Consequently, abnormal characteristics of tracheal cartilaginous rings, such as fusion rings, were counted as one ring. Tracheal dimensions were measured across three anatomical regions- cervical, thoracic inlet, and intrathoracic trachea. The diameters of the cervical, thoracic inlet, and intrathoracic trachea were assessed at the locations corresponding to the first tracheal ring, level of the first rib, and cranial to tracheal bifurcation, respectively (Fig. 1A). The parameters for tracheal dimensions, including the inner transverse diameter (ITD), inner vertical diameter (IVD), ITD/IVD ratio, outer transverse diameter (OTD), outer vertical diameter (OVD), and OTD/OVD ratio, were measured (Fig 1B). The cross-sectional luminal area (CSA) of the trachea was calculated using the method outlined in the previous report by Dabanoğlu (2001). Furthermore, the intraluminal tracheal cross-section shapes among three tracheal regions were examined. Finally, the patterns of individual cartilaginous tracheal rings were recorded. All parameters were analyzed by the Statistical Package for Social Sciences (SPSS Statistics Version 26 software, SPSS Inc., Chicago, IL, USA). Normality was assessed using the Shapiro-Wilks test. Differences in tracheal dimensions among the cervical, thoracic inlet, and intrathoracic region were examined using one-way ANOVA. Statistical significance was considered at a *P*-value of less than 0.05.

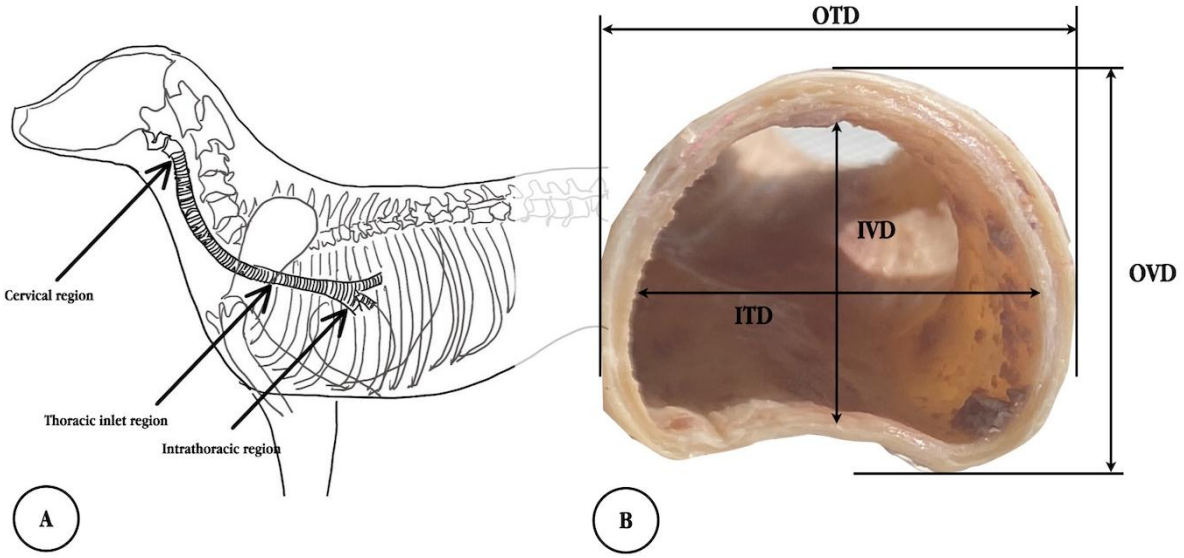


Figure 1 Image representation of the trachea showing (A) the cervical, thoracic inlet, and intrathoracic regions (B) the trachea indicating where measurements for inner transverse diameter (ITD), inner vertical diameter (IVD), outer transverse diameter (OTD), and outer vertical diameter (OVD), which were measured in this study.

Results and Discussion

The average length of the trachea from twelve mixed-breed dog cadavers in this study was 18.92 ± 0.67 cm. Each trachea contains a varying number of cartilaginous rings, ranging from 32 to 41, with a mean of 37.42 ± 0.81 rings. The tracheal length in this study is slightly shorter than in previous reports (Dallman and Brown, 1984; Dabanoğlu *et al*., 2001), possibly due to the different breeds of dog cadavers and long-term preservation. Formalin fixation, a well-documented shrinkage phenomenon in several tissues (Kansu *et al*., 2017), is known to cause alterations in mucosal length. The dimensions of the cervical, the thoracic inlet, and the intrathoracic trachea are presented in Table 1. A significant difference in both OTD (P<0.007) and OVD (P<0.003) was observed between the cervical and thoracic inlet tracheas. Similar to ITD, IVD, and CSA, a reduction was observed from the cervical to thoracic inlet regions, although these differences were not statistically significant. These findings together support the narrowing of the trachea from the cervical to thoracic inlet region, similar to the findings reported by Violette *et al*. (2019). This information is crucial for veterinary practitioners in selecting the appropriate endotracheal tube or endotracheal stent for anesthetic and emergency situations. Although five shapes of intraluminal tracheal cross-section shapes, including horseshoe, dorsal focal invagination, crescent, oval, and circular were identified throughout this study (Fig. 2), none of the dog cadavers had a history of respiratory problems. In all tracheal regions, the predominant shapes were horseshoes while the circular and oval were rarely observed in this study (Table 2). This contrasts with the findings by Lim *et al*. (2018), where the circular shape was commonly observed in awake dogs undergoing computed tomography scans. The difference in tracheal luminal cross-section shapes may be associated with the laxity of the dorsal trachealis muscle and the stability of cartilaginous tracheal rings (Violette *et al*., 2019).

Notably, we are the first to report the characterization of cartilaginous ring patterns in the dog trachea (Fig. 3). Nine patterns of cartilaginous tracheal rings are shown in Table 3. Our results align with our expectations. We observed a single straight band with a parallel border throughout the tracheal cartilaginous ring, referred to as the C-shaped cartilaginous ring, as a major patterns. This observation was consistent across all examined dog tracheas and also in human tracheas (Premakumar *et al*., 2018). The differences in the patterns of each tracheal cartilaginous ring may alter their biomechanical composition and mechanical properties, such as stress-strain (Hamaide *et al*., 1998; Teng *et al*., 2009; Hoffman *et al*., 2016) and relaxation of hyaline cartilage in the trachea (Han *et al*., 2022), leading to changes in elasticity and diameter of the trachea. There are some limitations in this present study, such as the small sample sizes of dog cadavers, encompassing a wide range of ages. Additionally, the samples were preserved in a fixative for a year. Further examination with a larger sample size is needed, and future studies will focus on the impact of each cartilaginous pattern on the mechanical properties of the trachea in dogs.

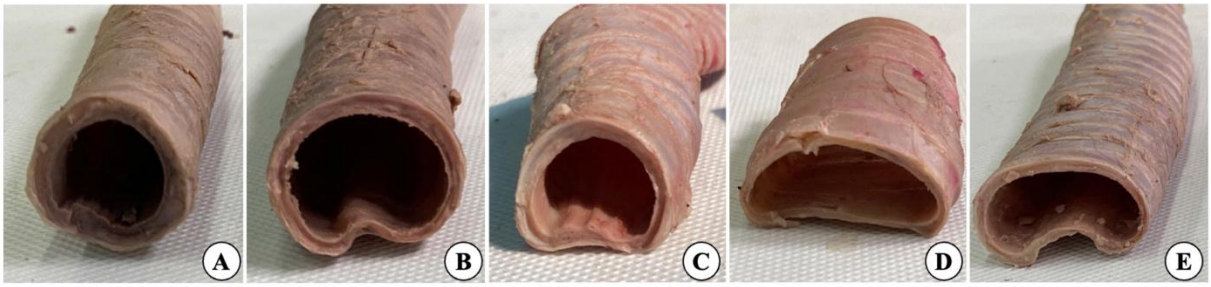


Figure 2 Five different patterns of tracheal luminal cross-section, (A); Circular shape, (B); Dorsal focal invagination shape, (C); Horseshoe shape, (D); Oval shape and (E); Crescent shape

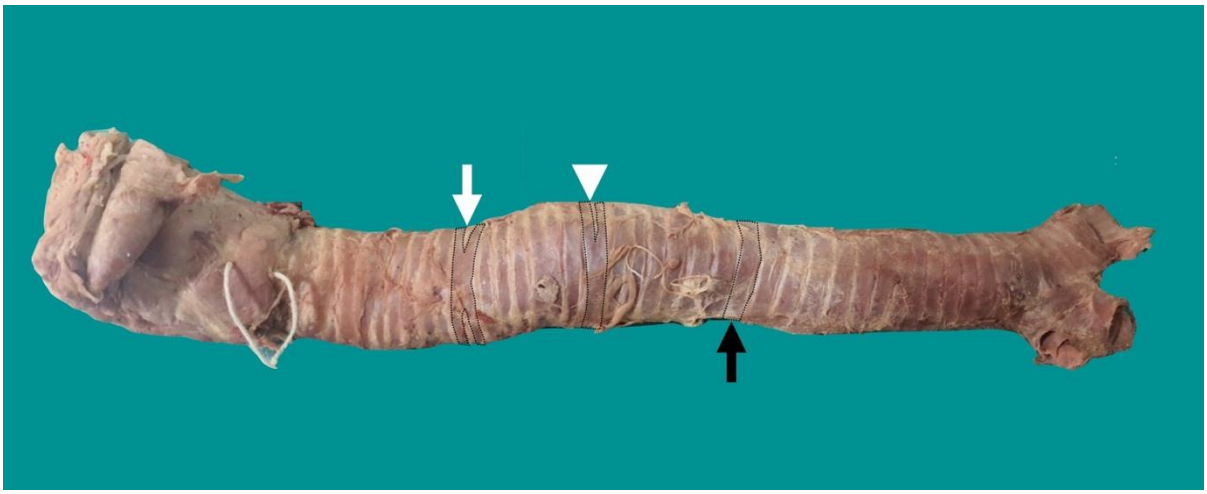


Figure 3 The variety shape of cartilaginous ring in the dog trachea: The compound of two adjacent cartilaginous rings at mid central area (white arrow), a straight band of tracheal cartilaginous ring runs from the right side of the tracheal ring, and divided into two bands at the left end (white arrowhead), and typical shape, a single straight band with parallel border entire tracheal cartilaginous ring (black arrow)

Table 1 The dimensions of the trachea among three anatomical regions of dog cadavers.

Diameter	Tracheal region			*P*-value
	Cervical	Thoracic inlet	Intrathoracic	
	Mean ± SE	Mean ± SE	Mean ± SE	
ITD (mm)	18.19 ± 0.72 [a]	17.03 ± 0.93[a]	16.44 ± 0.75 [a]	0.310
IVD (mm)	11.62 ± 0.62 [a]	9.58 ± 0.73 [a]	11.18 ± 0.88 [a]	0.146
ITD/IVD	1.62 ± 0.12 [a]	1.85 ± 0.12 [a]	1.58 ± 0.15 [a]	0.302
OTD (mm)	22.38 ± 0.85 [a]	19.23 ± 0.87 [b]	18.78 ± 0.72 [b]	0.007**
OVD (mm)	15.07 ± 0.41[a]	11.62 ± 0.64 [b]	14.01 ± 0.85 [a]	0.003**
OTD/OVD	1.50 ± 0.07 [a]	1.69 ± 0.09 [a,b]	1.40 ± 0.10 [a,c]	0.070
CSA (cm^2)	166.19 ± 11.58 [a]	130.65 ± 14.44 [a]	146 ± 14.70 [a]	0.197

ITD: inner transverse diameter, IVD: inner vertical diameter, OTD: outer transverse diameter, OVD: outer vertical diameter, CSA: cross-sectional lumen areas, SE: standard error of the mean. Statistical difference between tracheal regions (One-way ANOVA) *P < 0.05, **P < 0.01, and ***P < 0.001

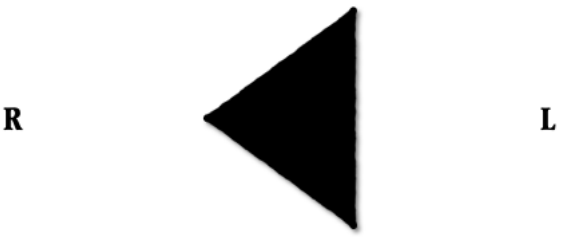
[abc]Within a column mean without a common superscript differs (P<0.05)

Table 2 Frequency of the intraluminal cross-section shape at cervical, thoracic inlet, and intrathoracic region

Cross-section shape (n=12)	Tracheal region		
	Cervical	Thoracic inlet	Intrathoracic
Circular	8.3% (1)	0% (0)	0% (0)
Dorsal focal invagination	41.7% (5)	16.7% (2)	25% (3)
Horseshoe	41.7% (5)	50% (6)	58.3% (7)
Oval	0% (0)	8.3% (1)	0% (0)
Crescent	8.3% (1)	25% (3)	16.7% (2)

Table 3 Characterization of the cartilaginous ring in the dog trachea

The tracheal cartilaginous ring patterns	Description of each cartilaginous ring patterns	Number of cadavers found the patterns (from 12 cadavers)	Percent (%) tracheal ring patterns (total of 446 rings from 12 cadavers)
	A singular straight band with parallel borders throughout.	12	93.3% (416 rings)
	A straight band of tracheal cartilaginous ring runs from the right side of the tracheal ring and divides into two bands at the left end.	7	2.5% (11 rings)
	A compound of two adjacent straight bands of cartilaginous rings in the mid-central area.	7	1.8% (8 rings)
	A straight band of tracheal cartilaginous ring runs from the left side of the tracheal ring and divides into two bands at the right end.	4	0.9% (4 rings)
	A single straight band with a concave at the center of the tracheal cartilaginous ring	3	0.7% (3 rings)
	A single straight band with an apex pointing to the center of the cranial adjacent tracheal cartilaginous ring.	1	0.2% (1 rings)

	Two adjacent tracheal cartilaginous band connected by singular band directed caudolateral from the right upper ring to left lower ring	1	0.2% (1 rings)
	A small wedge-shaped piece of tracheal cartilaginous ring on the left side.	1	0.2% (1 rings)
	A small wedge-shaped piece of tracheal cartilaginous ring on the right side.	1	0.2% (1 rings)

R stands for the Right side of the trachea, and L stands for the Left side of the trachea

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Author contributions: NS and MK contribute to the concept and study design. NS, MK, ST, SP, MP, and NL were involved in sample collection, investigation, and measurement. NS, ST, and MK performed data analysis and interpretation. NS and MK were involved in manuscript drafting and editing. All authors contribute and approve the final manuscript.

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