

Computed tomographic laryngotracheal dimensions in adult domestic rabbits (*Oryctolagus cuniculus*) are positively associated with body weight and the laryngotracheal lumen is narrowest at the level of the thyroid cartilage

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OBJECTIVE

This retrospective study aimed to measure rabbit laryngotracheal dimensions at different locations on computed tomography (CT), assess the relationship of these measurements with rabbit body weight, determine the most common narrowest measurement and assess its relationship with endotracheal tube (ETT) size and body weight.

ANIMALS

66 adult domestic rabbits (*Oryctolagus cuniculus*) of different breeds and body weights.

PROCEDURES

CT laryngotracheal luminal height, width, and cross-sectional area measurements were made at the rostral thyroid cartilage at the level of the arytenoids, caudal thyroid cartilage/rostral cricoid cartilage, caudal cricoid cartilage/cranial trachea, and trachea at the level of the fifth cervical vertebra.

RESULTS

The data for every measurement of luminal airway dimensions revealed robust positive associations with body weight ($P < .001$). The narrowest laryngotracheal measurement was the width at the level of the caudal thyroid cartilage/rostral cricoid cartilage, and the smallest cross-sectional area was at the rostral thyroid cartilage at the level of the arytenoids. There was a strong association between body weight and the likelihood of appropriate ETT fit. To have at least an 80% chance of appropriate ETT fit with a 2.0, 2.5, and 3.0 mm ETT, the rabbits' weight predicted by the model (lower 95% confidence limit) were at least 2.99 (2.72) kg, 5.24 (4.65) kg, and 5.80 (5.21) kg, respectively.

CLINICAL RELEVANCE

The laryngotracheal lumen was narrowest at the level of the caudal thyroid cartilage in rabbits, which indicates this location may be the limiting factor in determining ETT size in rabbits.

Endotracheal intubation is a common practice in veterinary medicine that provides a patent airway with the ability to deliver positive pressure ventilation, offers protection from airway aspiration, and prevents environmental contamination of waste anesthetic gases in unconscious animals for procedures that require general inhalant anesthesia. However, orotracheal intubation may be challenging in rabbits due to the anatomic characteristics that limit direct visualization of the airway, including a relatively large tongue, long and narrow oropharyngeal cavity, and small glottis.^{1,2} Furthermore, sublaryngeal tracheal

injury and ulceration have been described in rabbits after orotracheal intubation with uncuffed and cuffed endotracheal tubes (ETT), suggesting that rabbits may be predisposed to serious injury from routine intubation, including subglottic and tracheal stenosis, which can increase their morbidity and mortality rate.³⁻⁵ While multiple intubations, prolonged intubation time, and using cuffed ETT likely contribute to worse outcomes, there is a paucity of literature on rabbit tracheal measurements and ETT size selection.^{3,4,6}

There is significant variation in the literature regarding the ETT size used in different rabbits.⁷⁻¹⁰



The authors acknowledge the importance of ETT size selection in rabbits with no elaboration of selection criteria.^{3,4,8,11} Some authors correlate ETT size with rabbit body weight, such as recommending uncuffed 1- to 2-mm internal diameter (ID) ETT for rabbits weighing less than 2 kg and uncuffed 2- to 3-mm ID ETT for rabbits weighing more than 3 kg,² but no reported airway measurement supports this selection. Furthermore, some recommendations suggest direct or indirect visualization (such as radiography) instead of weight cut-offs as the best way to select ETT size.¹¹

At the authors' institution, many rabbits are sedated for computed tomography (CT) before intubation and general anesthesia for a procedure (dental, emergency abdominal procedure, mass removal, etc.). This retrospective study aimed to analyze laryngotracheal luminal height, width, and cross-sectional areas at different locations using CT scans of male and female adult domestic rabbits (*Oryctolagus cuniculus*) of varying body weights, body condition scores (BCS), and breeds; assess the relationship of these measurements with rabbit body weight and determine the anatomic location of the narrowest laryngotracheal measurement. As a secondary objective, the relationship between the most common narrowest laryngotracheal measurement, ETT size, and body weight were assessed. We hypothesize that a robust population of adult rabbits will reveal a positive correlation between body weight and laryngotracheal measurements.

Materials and Methods

Animals

In this retrospective study, data were obtained from electronic medical records from rabbits that underwent head and neck CT at the veterinary teaching hospital at the University of Wisconsin - Madison School of Veterinary Medicine between July 2016 and July 2021. Inclusion criteria for study enrollment were as follows: rabbits over 12 months old, positioned in sternal (ventral) recumbency for CT scan, and no clinical signs of airway disease. Rabbits were excluded if the head and neck were incompletely included in the scan field of view, if motion artifact was present and image quality impeded assessment of the laryngotracheal region in multiplanar reconstruction (MPR), or if the patient was intubated.

CT imaging records were analyzed in reverse chronological order. As this is a retrospective study and the images were acquired for clinical purposes, an animal care and use protocol was not required.

Image acquisition

CT of the head and neck was performed using an 8-slice helical CT scanner (GE Lightspeed Ultra, GE Healthcare). The scan parameters were 120 kVp, 200 mAs, 512 X 512 matrix, 0.625–1.25 mm slice thickness, rotation time 1 second, and pitch 1. All CT studies were acquired under sedation using different combinations involving ketamine, dexmedetomidine, midazolam, and butorphanol.

Measurements

CT images were reviewed and analyzed by a veterinary student (TBA) under the guidance of an ACVR-certified veterinary radiologist (S.J.L.) on DICOM viewing software via the Philips IntelliSpace PACS system. CT images of the head and neck acquired in a bone algorithm were evaluated retrospectively in a bone window (window width [WW] of 2,000 Hounsfield units [HU], and window level [WL] of 300 HU) for optimal resolution of laryngotracheal structures. Laryngotracheal luminal height, width, and cross-sectional area were measured at the following 4 locations for each subject: the rostral thyroid cartilage (at the level of the arytenoids), caudal thyroid cartilage/rostral cricoid cartilage, caudal cricoid cartilage/cranial trachea, and trachea at the level of the fifth cervical vertebra (C5). Laryngotracheal luminal height was measured on sagittal MPR CT images (**Figure 1**) to obtain maximum luminal height measurements. A transverse MPR image optimized for the axis of the laryngotracheal region was created for laryngotracheal lumen width and cross-sectional area measurements at each anatomic site (**Figure 2**).

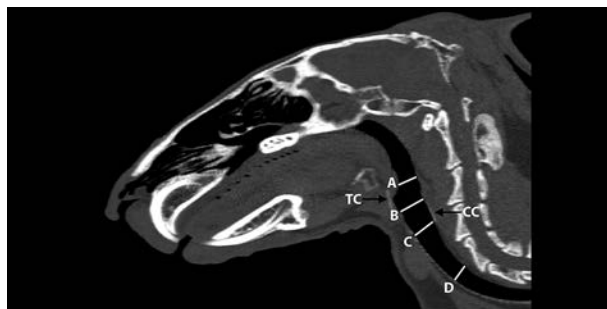


Figure 1—Sagittal multiplanar reconstructed computed tomography image of the laryngotracheal region demonstrating luminal height measurement technique at the (A) rostral thyroid cartilage, (B) caudal thyroid cartilage/rostral cricoid cartilage, (C) caudal cricoid cartilage, and (D) level of C5 vertebral body. TC = Thyroid cartilage. CC = Cricoid cartilage.

Data analysis

Statistical analyses were performed using SPSS V.28 (IBM). Measured values were tested for normality using the Kolmogorov-Smirnov test. Pearson's correlation coefficient was used to assess the relationship between weight and all 13 measurements for each rabbit. Associations were considered statistically significant at $P < .05$ and the association was described as high or very high when correlation coefficients (r) were above 0.7 or 0.8, respectively. For correlation coefficients between 0.5 and 0.7, the association was described as moderate.

Further analysis was performed in an attempt to predict appropriate ETT fit with different uncuffed ETT sizes based on the CT laryngotracheal measurements obtained during this study. Three uncuffed ETT tube sizes were considered: 2.0, 2.5, and 3.0 mm,

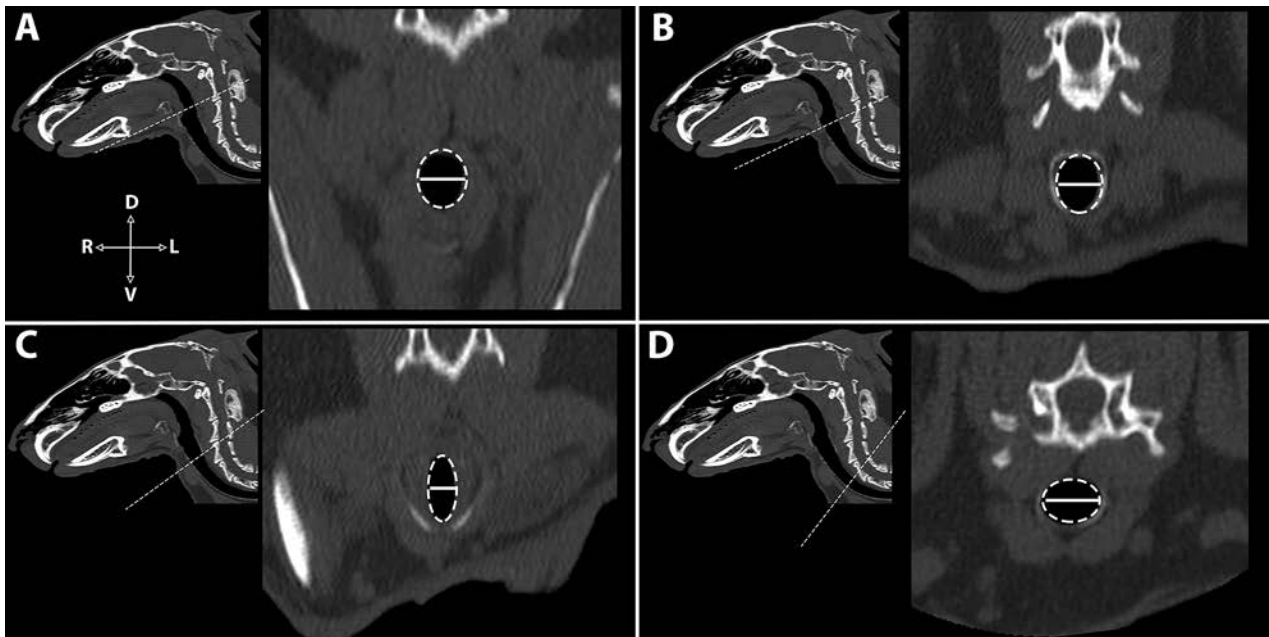


Figure 2—Transverse multiplanar reconstructed computed tomography images optimized for the laryngotracheal region demonstrating luminal width (solid line) and cross-sectional area technique (dotted ellipse) at the rostral thyroid cartilage (A), caudal thyroid cartilage/rostral cricoid cartilage (B), caudal cricoid cartilage (C), and level of C5 vertebral body (D).

with outer diameter (OD) measurements of 2.9, 3.6, and 4.2 mm, respectively (Sheridan®, Teleflex Medical). Appropriate ETT fit was defined as the OD of the ETT being less than the narrowest measurement obtained, thus, allowing the ETT to pass without restriction. Logistic regression was used to estimate the odds of appropriate ETT fit as a function of body weight and BCS (0 to 9). The model was then used to identify the weight and lower 95% confidence limit that provides a high likelihood (80% chance) for appropriate ETT fit. Logistic models were further expanded to include a factor identifying breed and the interaction between breed and body weight, which allows the association involving weight to be modified by breed. Analyses were performed using R Statistical Software (v 4.1.0).

Results

Sixty-six adult domestic rabbits (*Oryctolagus cuniculus*) between 1.0 and 13.3 years of age, with a median age of 5.6 years (IQR: 3.9–7.0 years) were included in the study. Body weight ranged between 0.86 and 6.90 kg, with a median weight of 2.34 kg (IQR: 1.67–3.72 kg), and BCS ranged from 3 to 9, with 70% of rabbits having a BCS of 4–5. Thirteen separate breeds, plus 2 “other lapine” groups defined as a mixed or unknown breed (n = 13; 20%) were identified. Lop rabbits (Holland, English, French, Mini) accounted for 30% of the sample (n = 4, 1, 5, and 10 rabbits, respectively). Other breeds included American Sable (n = 1), Angora (n = 2), Californian (n = 1), Dutch (n = 6), Flemish Giant (n = 6), Lionhead (n = 4), Netherlands Dwarf (n = 7), New Zealand (n = 1), and Rex (n = 5). For ease of reporting, subjects were

divided into 4 weight groups: group 1: ≤ 1.50 kg (n = 12); group 2: 1.51–3.00 kg (n = 30); group 3: 3.01–4.50 kg (n = 12); group 4: 4.51–7.00 kg (n = 12).

High to very high positive correlations (0.70–0.90) were identified between body weight and laryngotracheal height, width, and cross-sectional area at the 4 locations assessed (level of the rostral thyroid cartilage, caudal thyroid cartilage/rostral cricoid cartilage, caudal cricoid cartilage/cranial trachea, and trachea at the level of C5), except for width at the level of the rostral thyroid cartilage and width at the level of C5, which revealed moderate positive correlations (0.57 and 0.67, respectively; **Table 1**). Overall, there was a statistically significant, moderate to strong positive correlation between rabbit body weight and all 3 measurements taken at each of the 4 locations, $r = 0.57–0.86$, $P < .001$.

The measurements at the level of caudal thyroid cartilage/rostral cricoid cartilage had the narrowest average width in 67% (44/66) of rabbits; however, in 26% (17/66) of rabbits, the narrowest measurement was the width at the rostral thyroid cartilage. In contrast, the average height was greatest in 76% (50/66) of rabbits at the level of the caudal thyroid cartilage/rostral cricoid cartilage. The location of the overall smallest cross-sectional area was at the rostral thyroid cartilage (at the level of the arytenoids) for every weight group except group 1 (≤ 1.50 kg), whose smallest cross-sectional area was at the caudal thyroid cartilage/rostral cricoid cartilage by a margin of 0.04 mm².

Assessment of appropriate ETT fit, without considering body weight, using the caudal thyroid cartilage location revealed that the smallest tube (2.0 mm) would result in appropriate ETT fit

Table 1—Computed tomography derived laryngeal and tracheal measurements of 66 rabbits divided into 4 weight groups (group 1: ≤ 1.50 kg (n = 12); group 2: 1.51–3.00 kg (n = 30); group 3: 3.01–4.50 kg (n = 12); group 4: 4.51–7.00 kg (n = 12) at 4 different locations of the larynx and trachea.

Location	Measurements (mean \pm SD)	Weight group (kg)				Pearson correlation coefficient ^a
		< 1.50	1.51–3.00	3.01–4.50	4.51–7.00	
Rostral thyroid cartilage (level of arytenoids)	Height (mm)	3.7 \pm 0.8	4.5 \pm 0.9	5.6 \pm 1.0	6.6 \pm 1.2	0.728
	Width (mm)	2.8 \pm 0.8	3.3 \pm 0.9	3.9 \pm 1.2	5.1 \pm 1.3	0.571
	Surface area (mm ²)	7.9 \pm 3.7	10.7 \pm 4.4	16.1 \pm 7.0	24.8 \pm 8.3	0.696
Caudal thyroid cartilage/rostral cricoid cartilage	Height (mm)	4.7 \pm 0.7	5.5 \pm 0.9	6.6 \pm 1.1	8.2 \pm 1.4	0.790
	Width (mm)	2.3 \pm 0.7	2.7 \pm 0.6	3.5 \pm 0.7	4.1 \pm 0.6	0.720
	Surface area (mm ²)	7.8 \pm 2.5	11.1 \pm 3.7	18.6 \pm 6.1	24.8 \pm 6.5	0.806
Caudal cricoid cartilage/cranial trachea	Height (mm)	4.1 \pm 0.3	5.0 \pm 0.6	6.0 \pm 0.7	7.2 \pm 1.0	0.859
	Width (mm)	3.2 \pm 0.6	3.8 \pm 0.7	4.5 \pm 0.8	5.4 \pm 0.8	0.732
	Surface area (mm ²)	10.1 \pm 2.8	14.9 \pm 4.1	21.6 \pm 6.1	29.6 \pm 7.3	0.801
Trachea (level of fifth cervical vertebra)	Height (mm)	3.2 \pm 0.3	4.0 \pm 0.6	4.2 \pm 0.9	5.4 \pm 0.7	0.751
	Width (mm)	4.2 \pm 0.9	4.7 \pm 0.8	5.4 \pm 1.0	6.7 \pm 0.9	0.666
	Surface area (mm ²)	10.6 \pm 2.5	15.2 \pm 4.4	18.5 \pm 4.0	28.0 \pm 5.1	0.801

^aAll of the Pearson correlation coefficients are statistically significant ($P < .001$).

in 37/66 (56%) of the rabbits, the second smallest (2.5 mm) in 16/66 (24%) of rabbits; and the largest tube considered (3.0 mm) would result in appropriate ETT fit in 10/66 (15%) rabbits in the sample. Multivariable logistic regression revealed a strong association between body weight and the likelihood of appropriate ETT fit ($P < .001$ for each size), even after adjusting for BCS. The BCS was found not to be informative ($P = .348, .172, \text{ and } .519$ for 3 increasing ETT sizes) once body weight was considered, though BCS was retained in all models as a control variable. According to this analysis, to have at least an 80% chance of appropriate ETT fit with a 2.0, 2.5, and 3.0 mm ETT, the rabbits should weigh (lower 95% confidence limit) at least 2.99 (2.72) kg, 5.24 (4.65) kg, and 5.8 (5.21) kg, respectively.

Logistic models assessing the interaction between breed (Lop vs all others) and body weight gave no evidence to suggest that breed has any association with the likelihood of appropriate ETT fit ($P > .65$, involving simultaneous test of breed and breed X weight interaction for each ETT size).

Discussion

In the present study, the effect of increasing body weight had a significant, positive correlation with laryngotracheal measurements at every location (the level of the rostral thyroid cartilage, caudal thyroid cartilage/rostral cricoid cartilage, caudal cricoid cartilage/cranial trachea, and trachea at the level of C5). Although this positive correlation has been indirectly suggested in the literature by recommending larger ETT for larger rabbits,^{2,8,11–13} this is the first statistically meaningful dataset associating increasing rabbit body weight with increasing laryngotracheal height, width, and cross-sectional measurements.

The rabbit airway has been studied extensively as a model for subglottic stenosis in the pediatric human airway; thus, previous studies assessing CT airway measurements and gross specimen airway measurements in healthy adult New Zealand White

rabbits have been published.^{14,15} However, the tracheal CT measurements were significantly larger (anterioposterior—or “height”—tracheal diameters at the level of the cricoid averaging 8.2 ± 0.7 mm) than gross specimen tracheal heights excised immediately after euthanasia at the same location (averaged 5.8 ± 0.5 mm).^{14,15} The reason for the discrepancies, despite both studies using adult New Zealand White rabbits with similar body weights (between 3.8–4.5 kg and 2.3–5.1 kg, respectively), is likely due to different measurement techniques. One of these 2 studies characterizing the tracheal dimensions of adult New Zealand White rabbits found no significant correlation between rabbit body weight and luminal diameters, except at the level of the eighth tracheal ring.¹⁴

Loewen and Walner (2001) obtained similar measurements in their gross specimen laryngotracheal dissections compared with the present study (considering a similar weight group, 3.01–4.50 kg), especially with the height measurements at the level of the cricoid cartilage (5.8 ± 0.5 mm and 6.0 ± 0.7 mm, respectively).¹⁴ The width measurements at that location were slightly smaller in the present study. The authors reported a small positive correlation that lacked significance; therefore, luminal height and width at the cricoid level were deemed constant within their study population of 35 adult New Zealand White rabbits weighing between 2.3–5.1 kg. The lack of statistical significance may have been due to the smaller sample size, narrower weight range, and the use of only 1 breed of rabbit. Conversely, their measurements at the level of the eighth tracheal cartilage did vary significantly with body weight,¹⁴ supporting our findings that rabbit airway measurements (from the larynx to the trachea at the level of C5) increase linearly with increasing body weight.

Similar to the present study, Ajlan et al (2015)¹⁵ found the location of the smallest overall cross-sectional area to be at the level of the arytenoids; however, all CT measurements were consistently larger compared with the CT measurements obtained

in the present study (considering the weight group, 3.01–4.50 kg) and the measurements obtained in the dissection study.¹⁴ The measurements from the present study were far more congruent with those from Loewen and Walner (2001)¹⁴, despite the different measurement techniques. The discrepancies between Ajlan et al (2015)¹⁵ CT measurements and the present study are potentially due to their limited sample size (only 4 rabbits), use of a single rabbit breed (New Zealand White), and narrow body weight range (3.8–4.5 kg). Additionally, their 4 rabbits were positioned in dorsal recumbency, which is not commonly performed clinically, and the CT images were assessed in the soft tissue window whereas our study assessed images using the bone window for enhanced resolution of the laryngotracheal region, which could have contributed to the differences between the CT measurements.

A study in large animals found that in horses, the tracheal diameter is the limiting factor in determining ETT size, whereas in cattle, it is the diameter of the glottis.¹⁶ To our knowledge, there are no published data on the exact location of the narrowest laryngotracheal dimension in rabbits. For all 4 weight groups in the present study, the narrowest measurement was the width at the level of the caudal thyroid cartilage/rostral cricoid cartilage; while the rostral thyroid cartilage (at the level of the arytenoids) presented the overall smallest cross-sectional area. Nonetheless, the width measurements at these 2 locations (rostral thyroid and caudal thyroid/rostral cricoid level) are consistently the narrowest measurements of the laryngotracheal area, confirming that the thyroid cartilage is likely the limiting factor in determining ETT size in rabbits.

Knowing the ideal ETT size is helpful to allow successful intubation with minimal airway trauma, as well as to minimize increases in airway flow resistance, minimize exposure of personnel to inhaled anesthetics, minimize endotracheal tube cuff inflation, and decrease the risk of pulmonary aspiration. The development of a clinical tool to facilitate a more accurate selection of appropriate ETT size may decrease the number of unsuccessful or traumatic intubation attempts by providing a benchmark for the limiting anatomic factor based on body weight. Regression models of the data collected in this study revealed a strong association between body weight and the appropriate ETT fit, even after adjusting for BCS. However, our results were likely an underestimation of the ideal ETT to be used. The dynamic nature of the laryngotracheal structures during breathing, leading to potential changes in airway diameter depending on the respiratory phase can affect the values, and this represents a limitation to the use of CT measurements as a clinical tool for ETT selection. Furthermore, the drugs used for the sedation of the rabbits in this retrospective study, as well as the level of sedation could have also influenced the values obtained. Another potential limitation is the lack of standardization and potential influence of the neck position (extended vs neutral vs flexed) in the measurements due to the retrospective nature of

the study and the fact that the rabbits were sedated and not anesthetized. Additionally, it should be clear that the model used in the present study had the goal of identifying the rabbit weight that provides a high likelihood (80% chance) of appropriate ETT fit (allowing the ETT to pass without restriction), not successful intubation.

Furthermore, the authors' experience, confirmed by different research studies, suggests that larger ETT than those predicted by weight in the present study may be used clinically.^{7–10} However, based solely on the measurements, the reported ETT sizes would likely result in minimal airway trauma and appropriate ETT fit for the weight ranges reported. Individual anatomic differences in the oropharynx and trachea may preclude successful intubation despite a high likelihood of appropriate ETT fit as predicted by the regression models used in the present study. Furthermore, several other factors can influence the ease of intubation and the incidence of successful intubation, such as the positioning of the patient, the experience of the person performing the intubation, and the technique used during intubation (direct visualization vs blind technique).

In conclusion, increasing body weight had a significant, positive correlation with laryngotracheal height, width, and cross-sectional area in rabbits. The rostral thyroid and caudal thyroid/rostral cricoid levels are the narrowest laryngotracheal measurements in rabbits, which may indicate that the thyroid cartilage of the larynx is the limiting factor in determining ETT size in rabbits. Further studies assessing the correlation of the CT measurements with cadaveric laryngotracheal measurements and assessing the ease of orotracheal intubation in live rabbits are warranted.

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The authors declare no conflict of interest.

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