Changes in tracheal dimensions during inspiration and expiration in healthy dogs as detected via computed tomography

Caroline D. Leonard, BA; Lynelle R. Johnson, DVM, PhD; Cecily M. Bonadio, BS; Rachel E. Pollard, DVM, PhD

Objective—To determine the degree of fluctuation in tracheal dimensions between forced inspiration and passive expiration in healthy dogs of various sizes.

Animals—10 client-owned dogs with no evidence of respiratory disease or tracheal collapse.

Procedures—Anesthetized dogs underwent a computed tomographic examination during forced inspiration and passive expiration to assess tracheal dimensions. Tracheal height, width, and cross-sectional area were measured at inspiration and expiration and percentage change in dimension was calculated for each variable.

Results—Measurements were acquired in 10 dogs that ranged in body weight from 3.5 to 47.8 kg. Tracheal cross-sectional area at inspiration and expiration was associated with body weight at all 3 tracheal regions. The percentage change in tracheal height and cross-sectional area was associated with body weight in the cervical but not the thoracic-inlet or thoracic regions. The tracheal cross-sectional area changed by as much as 24.2% (mean, 5.5%), 20.0% (mean, 6.0%), and 18.6% (mean, 6.0%) in the cervical, thoracic-inlet, and thoracic regions, respectively.

Conclusions and Clinical Relevance—The change in tracheal cross-sectional area from inspiration to expiration was as great as 24% in healthy dogs, and the area was associated with body weight. Respiratory fluctuations appeared to result in changes in tracheal dimension during respiration similar to those reported for humans. (Am J Vet Res 2009;70:986–991)

Tracheal dimensions are determined by the difference in pressures between the tracheal lumen and an external region. For example, in the cervical portion of the trachea, size is determined by the gradient between atmospheric and intratracheal pressure, whereas in the thoracic portion of the trachea, size is determined by the difference between intrapleural pressure and intratracheal pressure. In a study of healthy humans, CT was used to identify a 35% change in tracheal cross-sectional area at the level of the aortic arch between maximal inspiration and forced expiration. The change in area was primarily related to a decrease in tracheal height, and an associated change in tracheal shape was detected. Human and canine tracheas are anatomically similar in that both have semicircular cartilaginous rings that are connected dorsally by a dorsal tracheal membrane. These anatomic similarities suggest there may also be considerable fluctuation in the tracheal dimensions in healthy dogs between inspiration and expiration.

In dogs, the severity of tracheal collapse is evaluated on the basis of a grading scheme developed in 1982 by use of tracheoscopy, by which the percentage of tracheal obstruction is compared with an estimation of typical tracheal diameter in the dog if it were healthy. Grades range from I, which corresponds to a decrease in tracheal diameter of < 25%, to IV, which signifies that < 10% of the trachea remains patent. However, if tracheal diameter in healthy dogs fluctuates as it does in healthy humans, then a 35% change in dimension could actually be clinically normal.

Dynamic changes in tracheal dimension are most important in identifying tracheal collapse, which is a problem that affects humans as well as small- and toy-breed dogs. In humans, CT is the imaging method of choice for defining tracheal collapse and a change in tracheal diameter of 70% to 100% can be evident in affected individuals.
The purpose of the study reported here was to measure induced changes in tracheal height, width, and cross-sectional area during forced inspiration and end expiration in healthy dogs to determine the degree of change possible at 3 regions of the trachea: cervical, thoracic inlet, and thoracic. Computed tomography was used rather than radiography or fluoroscopy because of the usefulness of CT images for measuring height, width, and cross-sectional area changes. To the authors’ knowledge, there is no information available regarding fluctuations in tracheal dimensions between inspiration and expiration in healthy anesthetized dogs. This lack of reference data could result in misinterpretation of regular changes in the trachea throughout respiration and inappropriate diagnosis of tracheal collapse, particularly in dogs undergoing cervical and thoracic CT. We hypothesized that tracheal diameter in healthy dogs would vary by < 25% at any tracheal location between phases of respiration in a manner similar to the changes that occur in humans.

**Materials and Methods**

**Animals**—All procedures were approved by the Institutional Animal Care and Use Committee at the University of California, and owner consent was obtained. Dogs that were admitted to the University of California Veterinary Medical Teaching Hospital and scheduled for CT scans between April and September 2007 for conditions unrelated to thoracic or airway disease were considered for inclusion in the study. Of these dogs, only those without a prior history of respiratory disease and without physical examination findings indicative of tracheal abnormalities or chronic respiratory conditions were included. Thoracic radiographs were reviewed to exclude dogs with gross tracheal abnormalities.

**Thoracic imaging procedures**—Dogs were anesthetized by use of standard institutional protocols and positioned in sternal recumbency within the CT gantry, with the endotracheal tube oriented within the trachea as far cranially as possible. Dogs were positioned with the head extended and supported so that the trachea was parallel to the CT table, thereby minimizing potential obliquity to the scan plane.

A survey scan of the thorax was obtained during maximal inspiration, which was created by manually compressing the reservoir bag of the anesthetic machine to achieve an airway pressure of 15 cm H₂O. This is the standard breath-hold procedure used for all thoracic CT-imaging sequences at our institution. Technical settings used for all thoracic series were 120 kVp, 150 mA, 1-second acquisition time, and a 512 × 512 matrix. The smallest field of view that included the entire thorax was used in each instance. Images were reconstructed for viewing by use of an algorithm for thoracic imaging. Slice thickness for the survey scan was 5 or 7 mm, depending on dog size. Additional images were obtained for the cervical trachea, thoracic inlet, and thoracic trachea. The region of the cervical trachea was defined by the caudal end plate of C5. The head of the first and fourth rib defined the boundaries for measurements at the thoracic inlet and thoracic trachea, respectively. A board-certified veterinary radiologist (REP) selected each specific region on the survey scan that corresponded to these anatomic locations, and 3 additional inspiratory scans were obtained by use of 1-mm-thick slices at the 3 chosen locations to improve image resolution.

The second series of CT images was obtained during a simulated expiratory phase created by hyperventilating the dogs to induce a short-term apnea. During expiration, a survey scan (5- to 7-mm slice thickness, with the same acquisition values as for the inspiratory phase) was performed to relocate the specific anatomic regions of interest. This second survey scan was necessary to compensate for the variable amount of thoracic movement during the expiratory phase of respiration. After identifying slice locations that corresponded to tracheal locations defined during inspiratory scans, a second expiratory scan was obtained by use of 1-mm-thick slices at the 3 chosen locations.

**Data processing**—The 1-mm-thick slices from inspiratory and expiratory scans at the 3 anatomic locations were analyzed by use of commercially available software on a dedicated processing station. Images were viewed at a window width of 1,700 and level of −600. Height, width, and cross-sectional area of the trachea were measured, and percentage change in these dimensions between inspiration and expiration was calculated by 1 individual (CDL), who was unaware of the identities of the dogs and the phases of respiration. Percentage change was defined as the inspiratory dimension minus the expiratory dimension, divided by the inspiratory dimension. A board-certified veterinary radiologist (REP) subjectively assessed tracheal shape by comparing inspiratory to expiratory CT images.

**Statistical analysis**—Tracheal cross-sectional areas at inspiration and expiration were evaluated for relat-

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Table 1—Percentage changes in tracheal dimensions at 3 tracheal regions between inspiration and expiration in 10 healthy client-owned dogs evaluated via CT.

<table>
<thead>
<tr>
<th>Tracheal region</th>
<th>Height Mean ± SD</th>
<th>Range</th>
<th>Width Mean ± SD</th>
<th>Range</th>
<th>Cross-sectional area Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>6.2 ± 7.7</td>
<td>−5.3 to 16.4</td>
<td>0.7 ± 4.6</td>
<td>−10.0 to 7.3</td>
<td>5.5 ± 10.8</td>
<td>−1.5 to 24.2</td>
</tr>
<tr>
<td>Thoracic inlet</td>
<td>5.7 ± 5.8</td>
<td>−1.1 to 15.7</td>
<td>1.1 ± 5.8</td>
<td>−4.3 to 12.7</td>
<td>6.0 ± 8.2</td>
<td>−5.8 to 20.0</td>
</tr>
<tr>
<td>Thoracic</td>
<td>10.1 ± 9.7</td>
<td>−3.7 to 18.8</td>
<td>2.2 ± 6.5</td>
<td>−11.5 to 12.1</td>
<td>6.0 ± 8.9</td>
<td>−3.4 to 18.6</td>
</tr>
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</table>

A positive value indicates that the tracheal dimension was greater at inspiration than at expiration, and a negative value indicates that the tracheal dimension was less at inspiration than at expiration.

*The region of the cervical trachea was defined by the caudal end plate of the C5 vertebra. The head of the first and fourth rib defined the boundaries for measurements at the thoracic inlet and thoracic trachea, respectively.
tionships with body weight by means of linear regression to determine the coefficient of determination. Linear regression was also used to evaluate relationships between body weight and percentage changes in tracheal height and cross-sectional area in the cervical, thoracic-inlet, and thoracic regions. For all analyses, a value of \( P \leq 0.05 \) was considered significant. Results are reported as mean ± SD.

**Results**

Ten dogs met the inclusion criteria for the study. Results of thoracic radiography were unremarkable in all dogs. The mean ± SD age of dogs was 7.5 ± 4.1 years, and the mean body weight was 16.9 ± 13.7 kg (range, 3.5 to 47.8 kg). Breeds included 1 each of Golden Retriever, Boxer, Labrador Retriever, Australian Cattle Dog, Pembroke Welsh Corgi, Jack Russell Terrier, Pug, West Highland White Terrier, Italian Greyhound, and Spaniel cross. Percentage changes in tracheal height, width, and cross-sectional area were summarized (Table 1). Some dogs had an increase in tracheal dimensions at expiration, and some had a decrease. All dogs that had an increase in tracheal diameter during expiration were large-breed dogs.

Tracheal cross-sectional area during inspiration and expiration was associated with body weight at all 3 tracheal regions (cervical, thoracic-inlet, and thoracic; Figure 1). The percentage change in tracheal cross-sectional area and height was associated with body weight in the cervical region but not in the thoracic-inlet or thoracic regions (Figure 2).

Subjective analysis of alterations in tracheal shape that occurred from inspiration to expiration in the 3 anatomic locations identified fairly consistent changes. In each anatomic region, all dogs maintained a nearly round-shaped trachea during inspiration. However, during expiration, the trachea of some dogs underwent invagination of the dorsal tracheal membrane or became ovoid (Figure 3). In the cervical region, 2 of the 10 dogs had an ovoid trachea at expiration, and both dogs weighed < 15 kg. In the thoracic-inlet region, 2 dogs had an ovoid trachea. In the thoracic region, 7 dogs had invagination of the dorsal tracheal membrane at expiration; 5 of those dogs weighed < 15 kg.

**Discussion**

In the present study, CT was used to assess changes in tracheal dimensions between phases of respiration induced by application of positive inspiratory pressure and simulated end expiration. During inspiration, intrapleural pressure typically becomes more negative and the pressure gradient that develops from the mouth toward the alveoli results in airflow. In healthy dogs, spontaneous inspiration creates negative intrathoracic pressure that can range from 30 to 58 cm H\(_2\)O. In spontaneously breathing dogs, the intratracheal pressure is negative rather than positive. Therefore, it is uncertain whether the measurements obtained in the present study would be similar to those of spontaneously breathing dogs, in which measurements would be made during voluntary rather than forced inspiration. Results of the present study indicated that the tracheal cross-sectional area of healthy dogs can change by up to 24% (mean, 5.5%) between inspiration and passive expiration in the cervical region. Tracheal cross-sectional area changed by up to 20% (mean, 6.0%) in the thoracic-inlet region and 18.6% (mean, 6.0%) in the thoracic region.
region. These results suggested an inherent ability of canine tracheas to change dimension during respiration, with the degree of change closely resembling that in humans.6

Various dog breeds were included in the present study to evaluate regular fluctuations in tracheal diameter during induced respiration and to assess body weight–related changes in tracheal diameter in dogs lacking respiratory signs of disease. It is unknown whether the findings apply to dogs of breeds commonly affected by tracheal collapse because of the natural variation in severity of that disease, rigidity of tracheal cartilage, and dynamic nature of dorsal tracheal membrane prolapse. Results cannot be predicted for subclinically affected dogs that typically develop tracheal collapse (eg, Yorkshire Terrier and Pomeranian). Additional studies are needed to determine the degree of regular fluctuation in tracheal dimensions in dog breeds susceptible to tracheal collapse; however, such studies would require large numbers of unaffected dogs, and it is possible that breed differences exist.

The largest percentage change in tracheal dimensions between inspiration and expiration in the present study was in tracheal height, whereas tracheal width
As anticipated, tracheal cross-sectional area was associated with body weight, and large dogs had a greater cross-sectional area in all tracheal regions than did small dogs in the present study. However, percentage change in tracheal cross-sectional area between inspiration and expiration was associated with body weight only in the cervical region and not in the thoracic-inlet or intrathoracic region. It is possible that the methods used in this study to simulate maximum inspiration artificially created a distinction between small and large dogs. An airway pressure of 15 cm H₂O is the amount of pressure applied during routine thoracic CT evaluations at our institution because attainment of this pressure effectively avoids atelectasis. In small dogs, this pressure may have overdistended the trachea, whereas in large dogs, it may have underdistended the trachea. Perhaps maximal inspiration was not achieved in large dogs, therefore creating an artificially smaller percentage change in that group. This effect would be expected to be more pronounced in the cervical region, where surrounding tissues would not limit tracheal expansion as might occur within the thorax.

Several of the large dogs in the present study had an increase in tracheal diameter during expiration. This effect was greatest in the cervical tracheal region. Other studies of anesthetized dogs have revealed that the cervical trachea has the greatest and the thoracic inlet has the smallest cross-sectional area during passive expiration. Perhaps in large dogs, forced inspiration has little effect on the cervical trachea for the aforementioned reasons and because the driving force of airway pressure during expiration results in passive distention of the cervical trachea, effectively causing an increase in tracheal dimensions with expiration. In the study reported here, small (<5%) increases in tracheal dimensions were evident in the thoracic-inlet and thoracic regions at expiration. We suspect that the tracheas in these dogs did not actually change dimensions and that the small change detected was attributable to error inherent to the measurement system.

Methods for evaluating tracheal diameter in dogs include radiography, ultrasonography, fluoroscopy, and bronchoscopy. Because of the widespread availability, ease of use, and low risk associated with the procedure, thoracic and cervical radiography are the most common imaging methods used to assess the trachea. However, there is a paucity of information in the veterinary literature regarding the appearance of tracheas of healthy dogs by use of traditional imaging techniques. Radiographically, the canine trachea is reportedly of uniform diameter and does not vary appreciably with phase of respiration. Slight narrowing of the tracheal lumen with expiration has been detected bronchoscopically. Although fluoroscopy is widely regarded as a useful method for tracheal assessment, there are no published guidelines for typical fluctuation in tracheal dimensions in dogs. The results of our study indicated that there is likely more variation in tracheal dimensions during expiration than that which has been reported. The improved detection of changes in tracheal dimensions may be a result of the superior resolution of CT, the lack of superimposition of tissues, or a combination of both.

 Whereas availability and cost prohibit use of CT as a routine method for evaluating changes in tracheal dimensions, there are many merits to this modality, which perhaps contribute to its usefulness as the gold standard for imaging airways in human medicine. For example, the precise anatomic detail and resolution yielded by CT allow for accurate measurement of tracheal cross-sectional area. That said, we are not suggesting that CT replace radiography or fluoroscopy as the main method for evaluating tracheal collapse in dogs. This is particularly important in the situation of a dog with clinical signs related to tracheal collapse, in which the risk associated with anesthesia is substantial. Rather, our intent was to use a highly precise method for quantifying

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Figure 3—Cross-sectional CT images and diagrams of tracheas of healthy dogs during inspiration (top row) and expiration (middle and bottom rows). As a general rule, tracheas appeared round at inspiration, but various changes in tracheal shape were evident at expiration. Column A—Thoracic region of the trachea in a large dog with no change in tracheal shape from inspiration to expiration. Column B—Cervical region of the trachea in a small dog in which the trachea became ovoid at expiration. Column C—Thoracic region of the trachea in a small dog in which the dorsal tracheal membrane invaginated slightly at expiration. Column D—Thoracic-inlet region of the trachea in a small dog in which the dorsal tracheal membrane invaginated more prominently at expiration. See Figure 1 for remainder of key.
changes in luminal dimensions in healthy dogs. Potential clinical applications of tracheal CT in dogs are yet unknown but likely include helping to determine the size of tracheal stents and guiding stent placement in dogs with tracheal collapse. The ability to reformat data gathered in different planes by use of CT is useful for determining the length and degree of tracheal collapse in affected dogs, particularly when this information is used in conjunction with information obtained via bronchoscopy. The results of the study reported here can be used as reference data in future CT studies of tracheas in dogs.

References