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Comparison of Fluoroscopy and Computed Tomography for Tracheal Lumen Diameter Measurement and Determination of Intraluminal Stent Size in Healthy Dogs

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Abstract

Tracheal collapse is a progressive airway disease that can ultimately result in complete airway obstruction. Intraluminal tracheal stents are a minimally invasive and viable treatment for tracheal collapse once the disease becomes refractory to medical management. Intraluminal stent size is chosen based on the maximum measured tracheal diameter during maximum inflation. The purpose of this prospective, cross-sectional study was to compare tracheal lumen diameter measurements and subsequent selected stent size using both fluoroscopy and CT and to evaluate inter- and intraobserver variability of the measurements. Seventeen healthy Beagles were anesthetized and imaged with fluoroscopy and CT with positive pressure ventilation to 20 cm H_2O. Fluoroscopic and CT maximum tracheal diameters were measured by 3 readers. Three individual measurements were made at 8 pre-determined tracheal sites for dorsoventral (height) and laterolateral (width) dimensions. Tracheal diameters and stent sizes (based on the maximum tracheal diameter + 10%) were analyzed using a linear mixed model. CT tracheal lumen diameters were larger compared to fluoroscopy at all locations. When comparing modalities, fluoroscopic and CT stent sizes were statistically different. Greater overall variation in tracheal diameter measurement (height or width) existed for fluoroscopy compared to CT, both within and among observers. The greater tracheal diameter and lower measurement variability supported the use of CT for appropriate stent selection to minimize complications in veterinary patients.

Keywords

trachea; stent; fluoroscopy; computed tomography; diameter

Introduction

Tracheal collapse, characterized by weakening tracheal cartilages leading to luminal collapse, is a progressive disease with a multifactorial etiology.[1–3] Although a large

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percentage of affected dogs respond to medical management, surgical treatment represents a final method of palliation and can be associated with many complications such as tracheal necrosis and laryngeal paralysis.[4–10] Intraluminal stenting is an alternative method of treatment that has advantages of shorter anesthetic and recovery times and immediate improvement in clinical signs with a fair to good outcome.[8,11–14]

Radiography is the most widely used imaging modality in veterinary medicine for evaluation of tracheal lumen diameter or area.[6,15–19] Tracheal assessment for determining appropriate stent size includes measurement of the maximum tracheal diameter (while under positive pressure ventilation) using radiography or fluoroscopy as well as the length of affected trachea.[8,14] A stent is typically chosen that has a diameter that is 10–20% greater than the largest tracheal diameter during maximal inflation in an effort to accommodate stretching of the dorsal tracheal membrane and to prevent migration.[11,20] Exact measurements of the tracheal diameter are problematic with radiography owing to the absence of sharp luminal borders due to overlying soft tissues.[21]

In human medicine, computed tomography (CT) is the imaging modality of choice for stenting as it provides information prior to and after tracheal stent implantation.[22–27] CT affords determination of accurate tracheal diameter and length in combination with identification of optimal location and number of required stents.[28–29] Additional diagnostic bronchoscopic procedures can also be avoided. As tracheal stents maintain position through a radial force applied to the tracheal wall, appropriate tracheal dimensions and stent sizes are crucial to avoid mucosal ischemia, irritation, granuloma formation, rupture, migration, or other reported complications.[30–32] CT is considered to provide accurate dimensions through its multiplanar reconstruction and virtual bronchoscopic capabilities, and it has shown to reduce complications in people.[28–29] In the post-stenting period, multidetector computed tomography (MDCT) exhibited 88–100% sensitivity and 100% specificity in identifying stent complications.[29] The use of CT for tracheal evaluation has been suggested in veterinary medicine in cases of intraluminal stenting, and a morphometric study of the trachea of the German Shepherd dog has been reported.[33–35] However, radiography remains the modality of choice for tracheal measurement and determination of stent size in all published reports of tracheal stenting in veterinary patients.[1,8,11,13–14]

In a study using direct comparison of tracheal diameter measured on radiographic and CT studies in 146 humans for the selection of appropriate endotracheal tube sizes, weak correlation coefficients were calculated, and radiographic studies overestimated tracheal diameter.[36] Ultimately, the authors concluded that radiographic measurements would not be useful for determining the appropriate size of an endotracheal tube.[36] A recent veterinary cadaveric study comparing radiographic and computed tomographic studies for determination of tracheal diameter in normal dogs showed that radiographic measurements underestimate tracheal size.[35]

The purpose of this study is three-fold: (1) to directly compare tracheal diameters as measured with fluoroscopy and CT in anesthetized healthy dogs, (2) to directly compare selected stent sizes based on the fluoroscopy and CT measurements, and (3) to assess inter- and intraobserver variability in tracheal diameter measurements using both modalities. Our

hypothesis was that fluoroscopic measurements would underestimate tracheal dimensions, leading to selection of a smaller stent compared to CT-based measurements. In considering variability in measurements, we hypothesized that fluoroscopy would produce greater inter- and intraobserver variability due to the absence of sharp luminal margins.

Materials and Methods

The study design was observational, cross-sectional and prospective. All procedures were conducted according to a protocol approved by the Iowa State University Institutional Animal Care and Use Committee. Seventeen healthy purpose-bred Beagles without clinical signs of respiratory disease underwent awake dynamic fluoroscopy (66 kVp, 5 mAs) of the entire trachea prior to tracheal dimension measurements (Philips Veradius mobile C-arm, Philips Healthcare, Andover, MA). Imaging was performed without sedation to rule out overt tracheal collapse. Prior to anesthesia, dogs were pre-medicated with 0.2 mg/kg butorphanol and 0.05 mg/kg acepromazine administered intravenously. Dogs were then induced using propofol bolus to effect (4–6 mg/kg), maintained on isoflurane, and imaged in sternal recumbency using a 16 slice helical CT scanner (Aquilion™ LB, Toshiba Medical Systems, Tustin, CA). Technique settings included 0.5 mm thick slices, a pitch of 11, and 1 mm thick slice reconstructions. For the purposes of anesthesia, the endotracheal tube was placed in each patient with the cuff located in the most proximal aspect of the trachea without being located within the larynx.

Patients were scanned from the tip of the nose to the diaphragm during positive pressure ventilation (20 cm H_2O). No contrast medium was utilized, and CT scans were completed at 120 kVp and 200 mA. Each scan lasted approximately 15 seconds.

Following computed tomography, the entire length of the trachea in each patient was imaged with fluoroscopy in right lateral and dorsal recumbency. The sizes of the patients permitted the entire trachea to be captured in one image. A 65 cm 5 French metallic marker catheter (Infiniti Medical, LLC, Menlo Park, CA) labeled in 1 cm increments for calibration of tracheal measurement was placed in each dog’s esophagus, and digital images were obtained in both body positions with the patient under positive pressure ventilation (20 cm H_2O).

The authors standardized the location of tracheal measurements in both fluoroscopic projections and CT images. The selected sites of measurements included the caudal endplate of C4, cranial endplate of C7, mid-body of T1, mid-body of T3, and 1 cm cranial to the tracheal bifurcation on the right lateral projections (Figure 1A). Standardized sites for measurement on the ventrodorsal projections were the mid-body of T1, the mid-body of T3, and 1 cm cranial to the tracheal bifurcation (Figure 1B). Cervical tracheal width measurements were not performed due to superimposition of the endotracheal tube and overlying soft tissues. In an effort to ensure that all measurements were made at the same location across observers on the CT studies, single transverse slices of the trachea imaged with CT at each location were obtained and converted to jpeg format. All images were loaded into commercially available diagnostic image viewing software (OsiriX 4.1 DICOM viewer, Pixmeo, Geneva. Switzerland). The single slice CT images in jpeg format were converted back into DICOM format within the viewing software. For the fluoroscopic

measurements, the electronic calipers were calibrated against the esophageal marker catheter. For the CT measurements, no calibration was necessary.

The tracheal height (dorsoventral dimension) was measured at each site on both lateral fluoroscopic and CT images (5 sites) (Figures 1A and 2). Measurements were all made perpendicular to the tracheal lumen and did not include the tracheal wall. The tracheal width (laterolateral dimension) was measured on the ventrodorsal fluoroscopic images as well as the same CT images where tracheal height was measured (Figure 1B). Three individual measurements were made at each site by three observers (a third year radiology resident, a small animal surgeon, and a board-certified radiologist) to test both interobserver and intraobserver variability. Each observer entered data into individual spreadsheets, and the average of each set of 3 measurements was calculated. For each of the three observers, the tracheal site of both maximum height and width based on the averaged value (regardless of a cervical or intrathoracic location) was used as the measurement from which to determine tracheal stent size, as would be performed in a clinical setting. Separate stent sizes were chosen based on both the height and width measurements by one of the authors (IAK) by adding an additional 10% to the maximum diameter and using the conversion chart specifically developed for the self-expanding Nitinol Vet Stent-Trachea® (Infiniti Medical, LLC, Menlo Park, CA).

Descriptive statistics were performed to summarize mean tracheal height and width by tracheal location, dog, and modality. Tracheal diameters and stent sizes were analyzed using a linear mixed model where modality (fluoroscopy vs. CT) was treated as a fixed effect and dog, observer, and location were treated as random effects. For interobserver variability, coefficient of variation (CV) was calculated using the mean and standard deviation for all of three observers repeat measurements averaged together. For intraobserver variability, CV was calculated using the mean and standard deviation for each observers' three replicate measurements of diameter. The coefficients of variation were then analyzed using the same linear mixed model described above. Bonferroni adjustment was made for multiple comparisons when comparing the inter- and intraobserver variability by each tracheal site. P-value ≤ 0.05 was considered significant, and all statistical analyses were performed using commercial statistical software (SAS version 9.4, SAS Institute, Inc, Cary, NC).

Results

The Beagle population included 4 intact males and 13 intact females with an average age of 1.7 ± 0.6 years and an average weight of 11.1 ± 2.4 kg. No dogs were excluded from the study due to abnormal dynamic fluoroscopic imaging. Tracheal lumen diameters measured from CT were larger compared to those made with fluoroscopy at all tracheal locations ($p < 0.0001$) (Table 1). The mean difference in diameter over all sites was 0.21 mm (both height and width, 95% CI 0.19, 0.23).

Direct comparison of fluoroscopic and CT height and width dimensions as well as stent sizes indicated a statistically significant difference between the two modalities (Table 1). This finding was true for both the height ($p < 0.0001$) and width ($p < 0.0001$) dimensions, including when an average diameter was calculated over all tracheal sites and when only

maximum height or width was considered. Statistically different stent sizes (based on height and width) were obtained when using measurements made by fluoroscopy versus those made by CT; selected stents were smaller in size based on fluoroscopic measurements. As maximum height was greater than maximum width regardless of the modality used, larger stent sizes were calculated based on height measurements compared to width measurements.

Greater inter- and intraobserver variability existed for fluoroscopic measurements compared to CT measurements (Tables 2 and 3, respectively). This finding was true for both tracheal height and width dimensions. Table 2 shows the differences in coefficients of variation (variability) among the three observers for fluoroscopy and CT at each of the tracheal locations, including height and width dimensions. Fluoroscopic measurements exhibited higher interobserver variability compared to CT measurements, and when using fluoroscopy, width measurements of the intrathoracic trachea produced greater interobserver variability compared to intrathoracic height. No statistically significant interobserver variability existed for fluoroscopy or CT at two tracheal sites. These included the cranial aspect of C7 (height) and the mid-body of T3 (width). Statistically significant interobserver variability existed at the remaining tracheal sites for both modalities.

Table 3 shows the differences in coefficients of variation within the three observers' measurements for fluoroscopy and CT at each tracheal site. Height and width dimensions are included, and statistically significant variation existed at every tracheal site. Similar to interobserver variability, fluoroscopic measurements exhibited larger intraobserver variability compared to CT. Fluoroscopic tracheal width measurements also exhibited greater variability compared to height measurements.

Discussion

Fluoroscopy underestimated tracheal height and width by 0.21 mm compared to CT. This finding is similar to a recent study that measured tracheal height in cadaver dogs using radiography and CT.[35] The magnitude of the difference is smaller in the current study (0.21 mm vs. 1.03 mm), and the effect of measurement modality (radiography vs. fluoroscopy) is unknown. More importantly, based on measurements made from fluoroscopy and CT, stent sizes chosen based on each modality are statistically different. Larger stent sizes were selected based on CT measurements. Accurate maximum tracheal diameter and subsequent stent size are crucial parameters in clinical cases of tracheal collapse. As the stents maintain position by radial force against the airway wall, undersized stents provide less force and create risk for migration. Conversely, oversized stents may apply excessive radial force against the airway wall with the possibility of inducing ischemia, irritation, granuloma formation, hemoptysis, or stent rupture.[8,13,28] The capacity for self-expanding stents to resist compressive forces induced by coughing is limited to a predetermined maximum diameter.[8] In addition, stent size (diameter) is intimately involved with stent length as stent shortening occurs after stent expansion.[8,11,13]

Fluoroscopic measurements did prove to exhibit higher inter- and intraobserver variability compared to CT measurements across all tracheal sites. Differences in measurement orientation and sequence may account for overall measurement variability. It is possible that

measurements were not obtained at a perfect 90° angle to the long axis of the trachea in either fluoroscopic or CT images. For fluoroscopic measurements, observers made the three separate measurements at each tracheal site differently as this portion of the measurement procedure was not standardized. Some observers made a single measurement at all sites sequentially, repeating this procedure three times on each image, while others measured at each site three times prior to moving on to the next tracheal site within the same image. The latter technique was also used when evaluating CT images. In this case, observer bias may have been created based on the absolute diameter for either modality. The tip of the endotracheal tube was located near the site of the cranial cervical tracheal location in some dogs; this may have overestimated the measured diameter with either modality, but its contribution to measurement variability is uncertain.

Computed tomography had the added benefit of potentially reducing measurement variability in two ways: (1) selecting the location of diameter measurement and (2) lack of calibration. Computed tomography images were single transverse slices provided to each observer, ensuring that cross-sectional measurements were made in the exact same location. Selection of the exact same site of measurement with fluoroscopy among observers could not be ensured when using anatomic landmarks. The need to calibrate all fluoroscopic measurements against the esophageal marker catheter added an additional opportunity for measurement variability, as each observer's calibration likely differed slightly.

Computed tomography has been suggested for use in intraluminal stenting applications because of its superior resolution and elimination of superimposition of structures.[11] In our study, minor undulations within the dorsal tracheal membrane inherent to each patient or created by differences in patient neck position may explain the measurement variability with CT. Significant interobserver variability was noted in a recent cadaveric study measuring tracheal diameter from CT, yet specific locations within the trachea where variability was highest were not indicated.[35] Another consideration for the CT measurement differences at varying tracheal sites is that the trachea may not be perfectly round in shape along its length. The trachea has been shown to be nearly circular in shape in mixed breeds (ex-vivo study) and German Shepherd dogs (CT study).[33,37] Additionally, the trachea is nearly circular during forced inspiration via positive pressure ventilation at 15 cm H_2O in varying breeds.[34] The effect of breed chosen for our study population (Beagle) on tracheal shape, if any, is unknown.

In human medicine, pre-stent planning via CT has been suggested to provide optimal size, thus avoiding invasive diagnostic bronchoscopic procedures and reducing complications.[28] A complication rate of 10.1% was reported within the first 48 hours after stent placement when measurements were made via CT, and only two stent fractures occurred out of 69 patients with malignant airway obstruction.[28] This result is in comparison to other studies' reported complications rates (40%, 34%, and 19% within the first 48 hours) where bronchoscopy was used for stent measurement.[30–32] Additional complications reported in these studies included stent migration along with granuloma formation, infection, and hemoptysis. Two long-term studies in veterinary patients report a stent fracture rate of 5 of 12 dogs[8] and 4 of 18 dogs[14] with similar complications of migration, infection, and coughing. Additional complications associated specifically with the stent included collapse

and deformation.[14] In both veterinary studies, stent size was determined from thoracic radiography.

Tracheal collapse is classically defined as collapse in a dorsoventral manner.[8,14] Width measurements were included this study in an effort to define the largest dimension of the trachea based on the protocol for stent selection, despite the convention for measuring tracheal height. According to descriptive statistics, the stent sizes selected based on width measurements were equal to or less than those based on height measurements. Based on the greater measurement variability that was generally exhibited by tracheal width measurements, particularly for fluoroscopy, tracheal height measurements remain the appropriate qualifier for determining stent size.

To maximize tracheal dimension, positive pressure ventilation to 20 cm H_2O was used in all fluoroscopic studies and CT scans.[8,14,38] This is the standard airway pressure used in breath-hold procedures at our institution. The effect of varying airway pressures on tracheal dimensions is unknown. Healthy Beagles were chosen for our study population in an effort to reduce and/or eliminate any breed and size variability in tracheal dimensions. However, our population of dogs was larger in size compared to those breeds typically affected by tracheal collapse. A breed that is not commonly affected with tracheal collapse was also chosen for our study population to validate purely the effect of measurement modality on tracheal diameter. The next step would be to apply this study protocol to breeds that are known to suffer from tracheal collapse to further validate the use of CT in clinical cases.

In conclusion, use of CT for tracheal diameter measurement translates into different intraluminal stent size selection compared to diameter measurements made from fluoroscopy. This finding may have clinical significance as appropriately sized stents are expected to reduce complications such as stent migration and fracture. In addition, as stent size is chosen from maximum tracheal diameter, CT measurements have proven to be larger compared to fluoroscopy and radiography,[35] and measurement variability (inter- and intraobserver) is lower from CT. Despite the CT limitations of added cost, availability, and need for additional anesthesia time, the results of this study suggest that CT may be a better modality to use for pre-stent planning in veterinary patients. Additional studies are needed that assess outcome of clinical patients whose stents were selected and placed based on radiographic/fluoroscopic measurements compared to CT methods of measurement to further evaluate any potential benefit of CT over traditional forms of tracheal diameter measurement in veterinary medicine.

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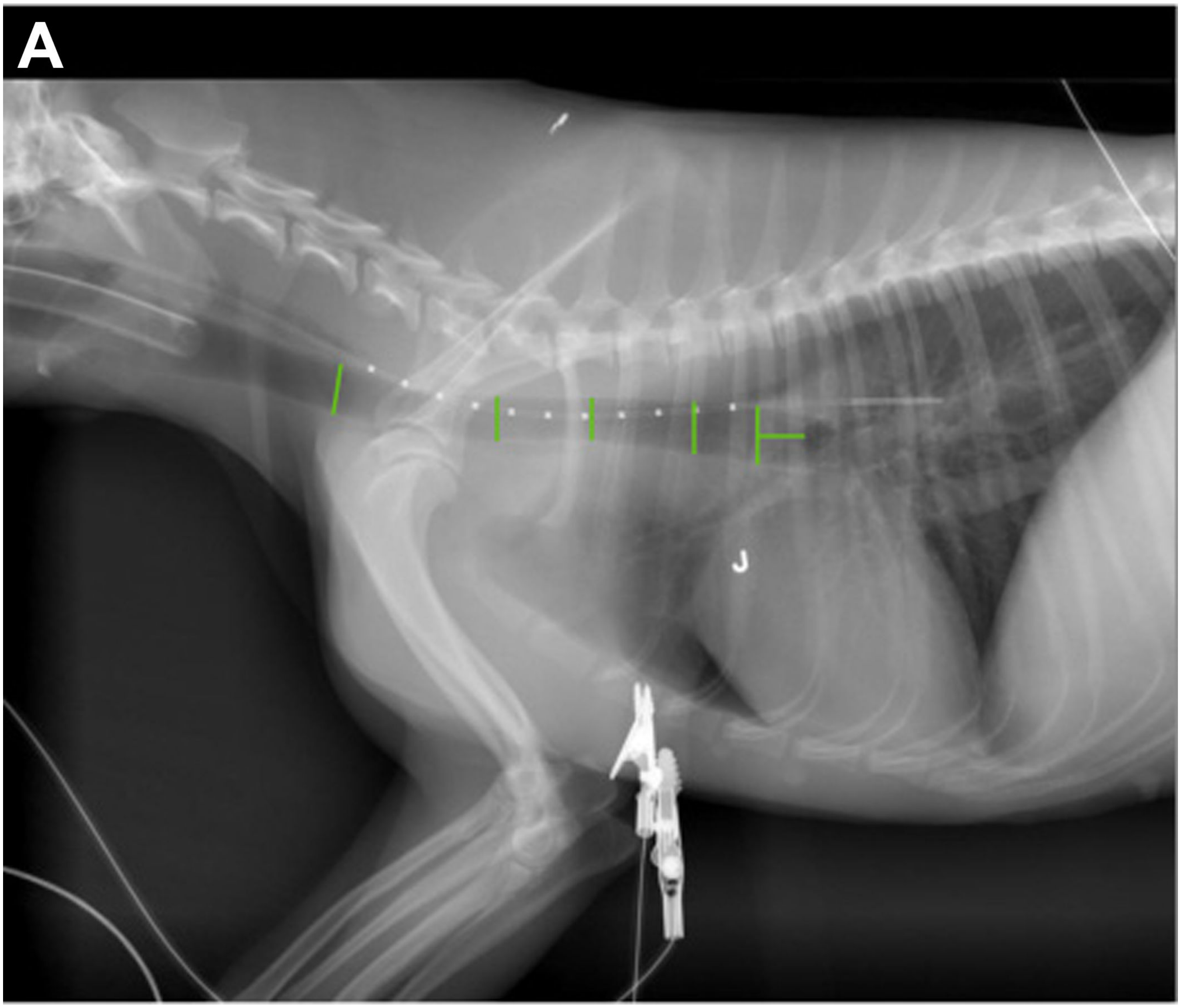
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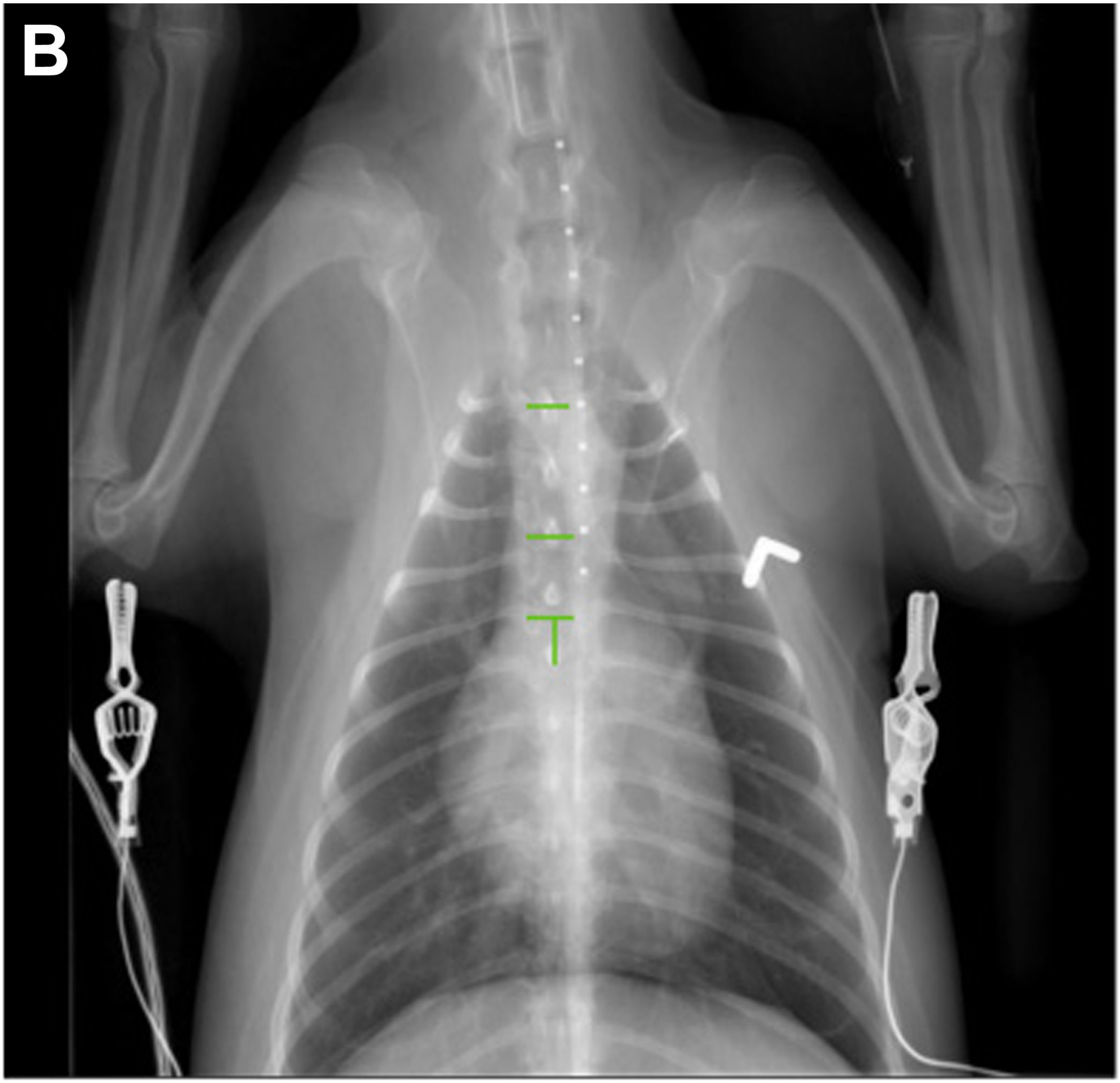

Figure 1.

Right lateral and ventrodorsal fluoroscopic projections indicating locations of tracheal diameter measurements made perpendicular to the tracheal lumen. A radiopaque marker catheter was placed within the patient's esophagus for calibration. The distance between two metallic increments represents 1 cm. A) Measurements in the dorsoventral dimension (height) were made at 5 locations within the trachea. B) Measurements in the laterolateral dimension (width) were made at 3 locations within the trachea.

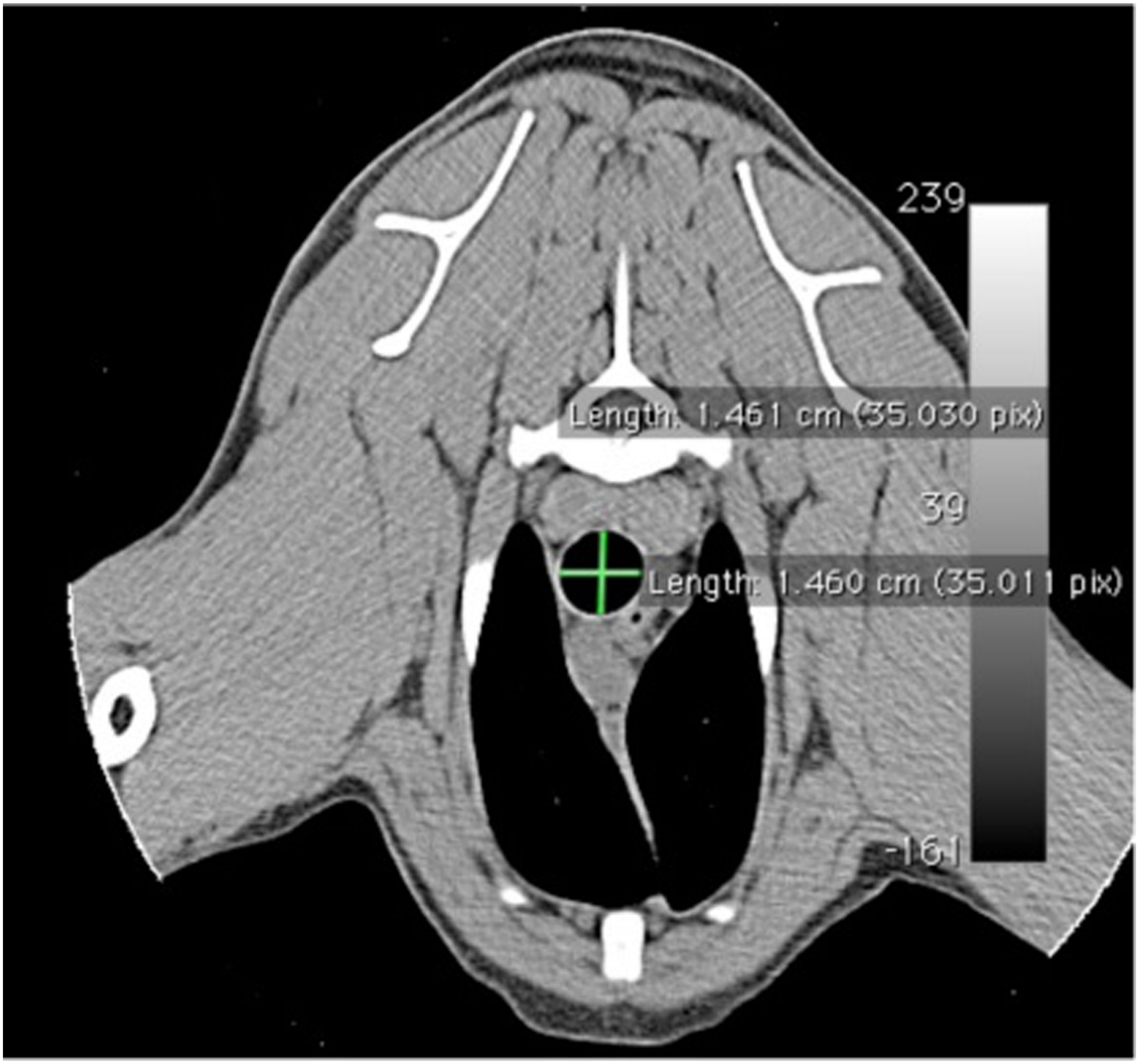

Figure 2.
Transverse CT image (window width: 400, window level: 40) of the trachea at the level of the mid-body of T1 showing tracheal diameter measurement via electronic calipers in the height (1.461 cm) and width (1.460 cm) dimensions.

Table 1

Comparison of Height and Width Measurements and Subsequent Intraluminal Stent Sizes* Using Fluoroscopy and CT

	Fluoroscopy		CT		Difference (CT-Fluoroscopy)				
	LSM	SE	LSM	SE	LSM	SE	95% UCI	95% LCI	p-value
Average Diameter	1.36	0.04	1.58	0.04	0.21	0.01	0.19	0.23	< 0.0001
Maximum height	1.57	0.05	1.74	0.05	0.17	0.02	0.12	0.21	< 0.0001
Stent size height	18.27	0.55	20.08	0.55	1.8	0.28	1.25	2.36	< 0.0001
Maximum width	1.41	0.04	1.60	0.04	0.18	0.03	0.12	0.24	< 0.0001
Stent size width	16.39	0.48	18.31	0.48	1.92	0.37	1.18	2.66	< 0.0001

LSM = least square means; SE = standard error; Average Diameter includes all height and width measurements across all tracheal sites

*Based on the Vet Stent-Trachea® sizing chart (Infiniti Medical, LLC, Menlo Park, CA)

Table 2

Interobserver Coefficients of Variation of Tracheal Diameter Measurements Using Fluoroscopy and CT.

	Fluoroscopy		CT		
Tracheal Location	LSM	SE	LSM	SE	p-value
Overall	5.58	0.76	0.80	0.76	< 0.0001
Caudal C4	3.52	0.42	1.11	0.42	0.0016
Cranial C7	3.26	0.54	0.89	0.54	0.0544
Mid-body T1	2.84	0.30	0.74	0.30	< 0.0001
Mid-body T3	2.73	0.23	0.64	0.23	< 0.0001
Cranial to Carina	3.20	0.26	0.66	0.26	< 0.0001
T1 (Width)	10.53	1.64	0.78	1.64	0.0048
T3 (Width)	9.84	2.15	0.82	2.15	0.0688
Cranial to Carina (Width)	8.76	1.27	0.76	1.27	0.0032

LSM = least square means; SE = standard error

Table 3

Intraobserver Coefficients of Variation of Tracheal Diameter Measurements Using Fluoroscopy and CT.

	Fluoroscopy		CT		
Tracheal Location	**LSM**	**SE**	**LSM**	**SE**	**p-value**
Overall	3.67	0.63	0.83	0.63	< 0.0001
Caudal C4	2.19	0.45	1.03	0.45	< 0.0001
Cranial C7	2.69	0.42	1.03	0.42	< 0.0001
Mid-body T1	3.09	0.58	0.79	0.58	< 0.0001
Mid-body T3	2.21	0.38	0.82	0.38	< 0.0001
Cranial to Carina	2.48	0.42	0.73	0.42	< 0.0001
T1 (Width)	5.04	0.67	0.75	0.67	< 0.0001
T3 (Width)	5.71	1.19	0.75	1.19	< 0.0001
Cranial to Carina (Width)	5.93	0.78	0.78	0.78	< 0.0001

LSM = least square means; SE = standard error