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Immediate, short-, and long-term changes in tracheal stent diameter, length, and positioning after placement in dogs with tracheal collapse syndrome

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Background: Intraluminal tracheal stenting is a minimally invasive procedure shown to have variable degrees of success in managing clinical signs associated with tracheal collapse syndrome (CTCS) in dogs.

Objectives: Identify immediate post-stent changes in tracheal diameter, determine the extent of stent migration, and stent shortening after stent placement in the immediate-, short-, and long-term periods, and evaluate inter-observer reliability of radiographic measurements.

Animals: Fifty client-owned dogs.

Methods: Retrospective study in which medical records were reviewed in dogs with CTCS treated with an intraluminal tracheal stent. Data collected included signalment, location, and type of collapse, stent diameter and length, and post-stent placement radiographic follow-up times. Radiographs were used to obtain pre-stent tracheal measurements and post-stent placement measurements.

Results: Immediate mean percentage change was 5.14%, 5.49%, and 21.64% for cervical, thoracic inlet, and intra-thoracic tracheal diameters, respectively. Ultimate mean follow-up time was 446 days, with mean percentage change of 2.55%, 15.09%, and 8.65% for cervical, thoracic inlet, and intra-thoracic tracheal diameters, respectively. Initial mean stent length was 26.72% higher than nominal length and ultimate long-term tracheal mean stent shortening was only 9.90%. No significant stent migration was identified in the immediate, short-, or long-term periods. Good inter-observer agreement of radiographic measurements was found among observers of variable experience level.

Conclusions and Clinical Importance: Use of an intraluminal tracheal stent for CTCS is associated with minimal stent shortening with no clinically relevant stent migration after fluoroscopic placement. Precise stent sizing and placement techniques likely play important roles in avoiding these reported complications.

KEYWORDS
canine, collapsing trachea, fluoroscopy, interventional radiology

Abbreviations: C7, 7th, cervical vertebra; CTCS, canine tracheal collapse syndrome; CT, computed tomography; ELR, extra-luminal rings; ET, endotracheal tube; SD, standard deviation; T4, 4th, thoracic vertebra.

The work was completed at the Animal Medical Center, New York, NY in the Interventional Radiology Department.

A poster presentation was presented at the 2014 ACVS conference in San Diego, CA.

1 | INTRODUCTION

Canine tracheal collapse syndrome (CTCS) in dogs is a common irreversible, progressive disease of the large airways that predominately occurs in middle-aged small and toy breed dogs.[1–3] It encompasses a variety of conditions including tracheomalacia, dorsal membrane weakness, cartilage ring malformation, or some combination of these leading to variable degrees of raspy, honking breathing, coughing, and dyspnea.[4] The initial treatment of choice is conservative medical therapy that often includes weight loss, decreased activity, minimization of environmental factors that cause anxiety and excitement, and a combination of medications such as corticosteroids, anti-tussives, antibiotics, bronchodilators, tranquilizers or sedatives, anti-histamines, or some combination of these.[5,6] In 1 report, 71% of dogs with tracheal collapse responded well to initial medical therapy and management of secondary causes and remained asymptomatic for 12 months.[6] Surgery is recommended when medical therapy options have failed or in acute, unstable cases.

Two commonly performed surgeries for CTCS to restore the narrowed or obstructed lumen include placement of extra-luminal rings (ELR) and intraluminal stents. Most dogs show immediate clinical improvement after either of these surgeries, and complications are associated with both,[7] but stenting has become a more common treatment because fewer perioperative complications may be associated with stenting.[4] Serious complications have been reported after surgical placement of ELR, including laryngeal paralysis.[7–10] Intraluminal tracheal stenting is a minimally invasive, image-guided treatment option. Advantages of stents include the ability to be used in any region of the trachea, short surgery and anesthesia times, and noninvasive placement,[2,7,10,11] but complications are not uncommon. Tracheal stenting is a technically demanding procedure and advanced training is recommended to prevent avoidable errors. Acute complications often are associated with improper stent sizing or deployment leading to stent migration or stent misplacement into the carina, mainstem bronchus, or larynx.[4] Some of the most commonly reported complications include inflammatory or bacterial tracheitis (up to 58%),[7,12,13] stent fracture (up to 42%),[7,12-14] stent migration (up to 37%),[7,12,15] and stent shortening (up to 27%).[12,16] We have experienced some of these complications, but stent migration and shortening are uncommonly encountered compared to rates previously reported.[7,12,15,16] We suspect that different tracheal measuring and stent placement techniques may account for fewer episodes of stent migration and shortening. In addition, these techniques may help properly predict appropriate stent diameter and length at the time of placement, decreasing the risk of stent misplacement within the cricoid or carina regions.

The purposes of our retrospective study were: (1) to identify immediate post-stent changes in tracheal diameters for prediction of stent length during the procedure, (2) to determine the incidence of stent migration and the degree of stent shortening that occurs after stent placement in the immediate-, short-, and long-term periods during the management of these patients by an interventional radiology service, and (3) to evaluate the inter-observer reliability of radiographic measurements among observers with varying levels of experience. We hypothesized that precise stent sizing and appropriate stent placement techniques would minimize the extent of stent migration and stent shortening over time.

2 | MATERIALS AND METHODS

Medical records of all dogs diagnosed with CTCS by the Animal Medical Center Interventional Radiology service between March 2009 and January 2014 were retrospectively reviewed. Dogs were included if a single Vet Stent-Trachea (Infiniti Medical, Menlo Park, California) stent initially was placed by the Animal Medical Center Interventional Radiology Service and both pre-stent and immediate post-deployment radiographs were available. Patients were excluded if there was a history of previous tracheal surgery or medical records were incomplete.

Data collected included patient signalment and weight, location and type of tracheal collapse, stent diameter and length, and post-stent placement radiographic follow-up times. Types of tracheal collapse were documented as traditional (tracheomalacia, weakened dorsal tracheal membrane or both) or malformation (firm "W"-shaped rather than "C"-shaped tracheal cartilage rings).[4] Radiography, fluoroscopy (both positive- and negative-pressure ventilation images), and endoscopy were used to determine the type of collapse present.

2.1 | Stent sizing and placement

Measurements for stent selection were performed as previously described.[4] Briefly, dogs under general anesthesia were placed in right lateral recumbency with the neck flexed to ensure the trachea was as straight as possible. An esophageal marker catheter (5fr Marker Diagnostic Catheter, Infiniti Medical, Menlo Park, California) was placed over a guide wire to span the entire length of the trachea for calibration of measurements accounting for radiographic magnification. The endotracheal (ET) tube was withdrawn until the cuff was at the level of the cricoid cartilage, and the positive- and negative-pressure ventilation device was attached to the ET tube. Positive-pressure ventilation at 20 cm H_2O was used to achieve maximal tracheal diameter to obtain maximum cervical, thoracic inlet, and intra-thoracic tracheal diameter and length measurements, followed by negative-pressure ventilation at -10 to -15 cm H_2O to confirm precise location and extent of collapse. In general, a nominal (relaxed) tracheal stent diameter approximately 2–3 mm larger than the maximal tracheal diameter measured was selected. Tracheal stent length subsequently was determined using a sizing chart provided by the stent manufacturer such that the final stent length achieved would span approximately 10 mm caudal to the cricoid cartilage and 10 mm cranial to the carina. As the stent expands, it simultaneously shortens. By oversizing the stent diameter, the stent will remain in place and not completely expand, and therefore be longer. For example, a stent with nominal dimensions of 14 mm × 58 mm that expands to 10 mm will be 85 mm long. An appropriately sized Vet Stent-Trachea stent was placed under fluoroscopic guidance as previously described.[4] Briefly, the leading (caudal) edge of the stent was positioned approximately 10 mm cranial to the carina and held stationary as the nose cone was advanced down the trachea during deployment. After approximately $^1/_3$ length deployment, gentle manipulation

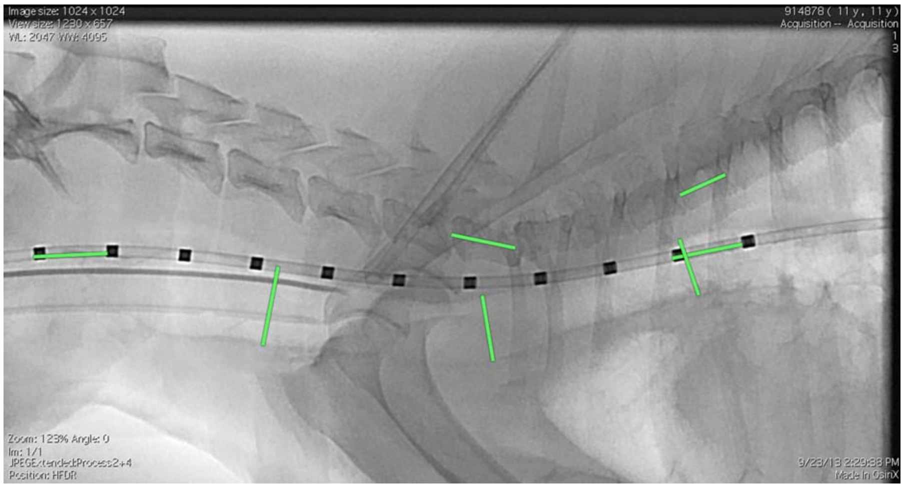

FIGURE 1 Right lateral 20 cm H_2O positive-pressure fluoroscopic image with esophageal marker catheter in place performed for determining maximal tracheal diameter and length of stent necessary. Measurement from the beginning of one marker to the next is 10 mm. Maximum cervical, thoracic inlet, and intra-thoracic diameters of the trachea are determined as well as the length of the dorsal cricoid cartilage and vertebral bodies of 7th cervical vertebra (C7) and 4th thoracic vertebra (T4) to be used for calibration in future radiographs when an esophageal marker is not present

of the stent delivery system back and forth confirmed that the deployed stent had engaged the trachea sufficiently before continuing deployment. During stent deployment, periodic, gentle, forward (caudal) pressure was applied to the entire delivery system to encourage stent expansion before complete deployment. All stents were placed by, or under the guidance of, a single board-certified veterinary surgeon (C. Weisse). Tracheoscopy was performed after stent placement to confirm appropriate stent position and wall contact.

2.2 | Radiographic measurements

Radiographic images were used to determine tracheal measurements preoperatively, immediately post-deployment, and at follow-up examinations. Measurements obtained from pre-stent lateral 20 cm H_2O positive-pressure fluoroscopic images included maximum cervical, thoracic inlet, and intra-thoracic tracheal diameters and tracheal length (Figure 1). The maximum diameters were measured at each representative location of the trachea where the margins were easily visualized. The thoracic inlet was measured approximately at the level of the first rib. For all radiographs with radiographic markers present, measurements also included lengths of the dorsal cricoid cartilage, and the 7th cervical (C7) and 4th thoracic (T4) vertebral bodies when the margins were identifiable. These measurements later were used to adjust for radiographic magnification in subsequent images obtained without radiographic markers in place. Measurements obtained from immediate post-deployment lateral fluoroscopic images (without positive-pressure ventilation) included the distance from the cricoid cartilage to the cranial aspect of the stent, distance from the carina to the caudal aspect of the stent, stent length, and maximum cervical, thoracic inlet, and intra-thoracic diameters (Figure 2). Post-stent measurements obtained

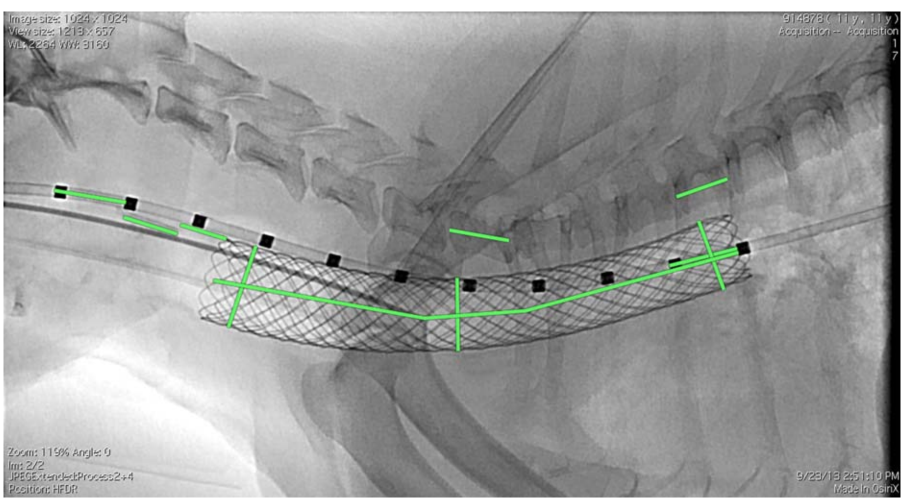

FIGURE 2 Right lateral fluoroscopic image with esophageal marker catheter in place immediate post-stent placement to determine distance from the cricoid cartilage to the cranial aspect of the stent and the carina to the caudal aspect of the stent (not measured here), stent length, and maximum cervical, thoracic inlet, and intra-thoracic tracheal diameters immediately after stent placement

from right lateral thoracic radiographs in the awake state at follow-up examinations included the same measurements as previously mentioned for immediate post-deployment (Figure 3). Radiographs taken at follow-up examination were calibrated for magnification using either the lengths of the C7 or T4 vertebral bodies, or the dorsal cricoid cartilage. The individual performing the measurements chose which of these structures was mostly clearly defined on the radiographs for calibration. All measurements were calculated with commercially available imaging analysis software (OsiriX version 4.1.2, Pixmeo, Bernex, Switzerland). Ideally, radiographs were performed at follow-up examinations at 4 weeks, 12 weeks, and every 3–6 months thereafter, unless complications occurred. However, because of considerable variability in days to follow-up radiographic examination for each dog, these durations were distributed into pre-stent (T0) and 6 post-stent categories as follows: (1) Immediate post-stent placement (<1 day; $T<1$), (2) ≥ 1 and <90 days (T1–89), (3) ≥ 90 and <180 days (T90–179), (4) ≥ 180 and <365 days (T180–364), (5) ≥ 365 and <730 days (T365–729), and (6) ≥ 730 days ($T\geq 730$). Follow-up measurements performed at any time for an individual patient were recorded, and all measurements were compared to the immediate post-stent radiographic measurements ($T<1$). In terms of follow-up, the time categories (T1–89) and (T90–179) were considered short term, and the remaining time categories were considered long term. Ultimate mean follow-up time was calculated for dogs that presented for follow-up, using the longest follow-up time for each dog.

The observers performing measurements for inter-observer variability of measurements consisted of 1 diplomate of the American College of Veterinary Surgery with >10 years of experience performing tracheal stent measurement and placement (C. Weisse) and 1 third-year surgical resident with preliminary measurement and placement experience (M. Raske). Inter-observer reliability comparing measurements was determined for post-stent length; maximum cervical, thoracic inlet, and intra-thoracic diameter; distance from cricoid; distance from carina; length of C7; length of T4; and, length of dorsal cricoid cartilage. Only the measurements by the diplomate of the American College of Veterinary Surgery were used to determine statistical significance comparing initial stent placement measurements to follow-up radiographic measurements for the previously mentioned time categories.

2.3 | Statistical analysis

Baseline descriptive statistics are presented as mean and standard deviation (SD) for normally distributed variables whereas non-normally distributed variables are presented as median and range. Ultimate percentage change values were calculated by finding the mean of ([the last follow-up measurement – stent placement measurement]/stent placement measurement) $\times$ 100, for the dogs that had at least 1 follow-up. Between groups, analyses of baseline variables were performed using analysis of variance (ANOVA) or the Wilcoxon test as appropriate for the data distribution. The normality of the error residuals was analyzed by the Kolmogorov-Smirnoff test for descriptive and multivariate models. Dependent variables were modeled separately in a mixed model repeated measures ANOVA. Subject was assigned as a random effect, and the covariance structure was assigned as compound symmetry and variance component method when appropriate. Least squares means generated by the models were evaluated by a Tukey's or Dunnett's adjustment test where appropriate. Analysis for proportions of categorical variables was evaluated by Chi-Square analysis. Inter-observer analysis was carried out to assess the agreement between 2 methods of clinical measurement as described previously.[17] The agreement scale was defined as percentage outliers exceeding 2 SDs from the mean. The defined scale of percentage within the limits was defined as follows: $\geq 90\%$ as strong, $\geq 80\%$ as good, $\geq 70\%$ as moderate, $\geq 60\%$ moderately weak, and $\leq 50\%$ as weak agreement. Hypothesized mean analyses were carried out by way of a Student's *t* test if normality of data were achieved. All analyses were deemed significant at $P\leq .05$ and carried out using SAS 9.3 (SAS version 9.3; SAS Institute Inc., Cary, North Carolina).

3 | RESULTS

Although 67 dogs were identified as having received single tracheal stents during the study period, only 50 met the inclusion criteria. The

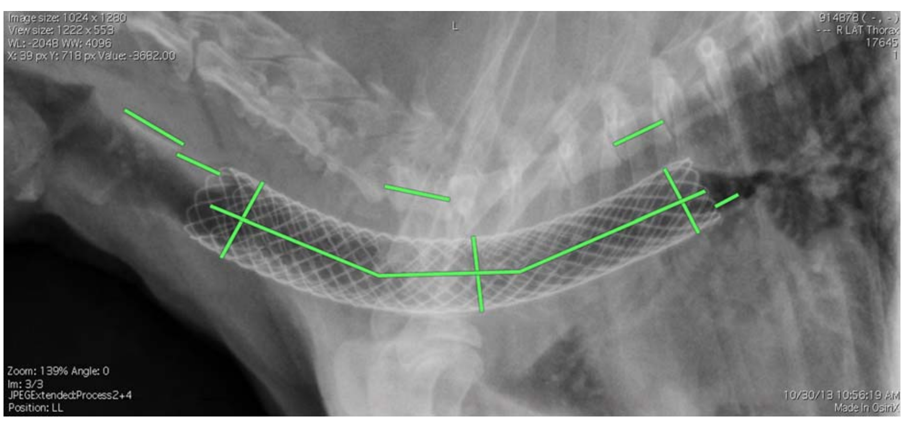

FIGURE 3 Right lateral thoracic radiograph 5 weeks post-stent placement portraying the measurement technique to determine length of the stent at time of follow-up, distance from the cricoid cartilage to the cranial aspect of the stent and the carina to the caudal aspect of the stent, as well as maximum cervical, thoracic inlet, and intra-thoracic tracheal diameters

TABLE 1 Percentage change in tracheal diameter for each follow-up time block and total ultimate percent change

	Follow-up time (Number of dogs)	% Change in cervical diameter (± standard deviation)	% Change in thoracic inlet diameter (± standard deviation)	% Change in intra-thoracic diameter (± standard deviation)
Pre-stent to placement	Immediate post placement (n = 50)	5.14 (±10.26)	5.49 (±19.31)	21.64 (±12.62)
Post-stent placement to follow-up	≥ 1 day & <90 days (n = 45)	1.99 (±9.60)	10.04 (±11.08)	5.07 (±10.09)[a]
Post-stent placement to follow-up	≥90 days & < 180 days (n = 11)	4.36 (±11.49)	15.33 (±18.47)	1.12 (±14.54)[a]
Post-stent placement to follow-up	≥180 days & < 365 days (n = 9)	1.86 (±6.92)	12.43 (±14.66)	1.26 (±11.31)[a]
Post-stent placement to follow-up	≥365 days & < 730 days (n = 14)	4.71 (±14.69)	20.45 (±15.22)[a]	20.24 (±13.65)
Post-stent placement to follow-up	≥730 days (n = 18)	0.22 (±9.02)	12.93 (±8.72)	13.45 (±8.16)
	Ultimate mean follow-up 446 days (n = 46)	**2.55**	**15.09**	**8.65**

[a]Significant difference from immediate post placement.

Yorkshire Terrier was the most commonly represented breed accounting for 34 of the 50 dogs in the study (68%) followed by the Pomeranian (11/50; 22%), Maltese (4/50; 8%) and 1 (2%) Shih Tzu. Mean age at time of stent placement was 7.8 years (SD, 3.3 years). Mean body weight was 3.3 kg (SD, 1.1 kg). Twenty-six of the dogs were spayed females, 20 castrated males, 2 intact males, and 2 intact females.

The distribution of the collapse within the trachea was 39 cervical (78%), 45 thoracic inlet (90%), 35 intra-thoracic (70%), and 28 bronchial (56%). Twenty-nine of the 50 dogs (58%) had traditional tracheal collapse, 18 (36%) had tracheal malformation, and collapse type was unclear in 3 (6%). Stent sizes ranged from 8 to 14 mm in diameter and 32 to 85 mm in length; the 3 most commonly used stents were 12 × 52 (13/50; 26%), 14 × 58 (12/50; 24%), and 12 × 65 (10/50; 20%).

Forty-six of the 50 dogs (92%) had at least 1 follow-up radiographic evaluation, with an ultimate mean follow-up time of 446.1 days (range, 15-1,424 days). Twenty-four dogs had at least 1 measurement in 2 follow-up time categories and 4 dogs had at least 1 measurement in 3 follow-up time categories. No dogs had at least 1 measurement in 4 or all 5 follow-up time categories. The number of measurements in each time category were as follows: T < 1 had 50 measurements of 50 dogs, T1–89 had 45 measurements of 37 dogs, T90–179 had 11 measurements of 11 dogs, T180–364 had 9 measurements of 8 dogs, T365–729 had 14 measurements of 13 dogs, and T ≥ 730 had 18 measurements of 10 dogs.

3.1 | Measurements immediate post-stenting and follow-up

Percentage change in tracheal diameters, tracheal length changes, and change in distance from cricoid and carina for the 6 post stent categories are summarized in Tables 1 and 2.

Initial mean stent length was 26.72% higher than nominal length immediately post-stent placement, 15.89% higher than nominal length at short-term follow-up, 13.00% higher than nominal at long-term follow-up and overall 14.55% higher than nominal length at an ultimate mean follow-up of 446 days. Ultimate overall mean tracheal stent shortening was 9.90%, with 9.44% and 9.74% shortening at short-term and long-term follow-up, respectively.

A significant difference was observed for stent length between immediate post-stent placement and all-time categories, specifically

TABLE 2 Percentage change in tracheal dimensions and change in distance from cricoid and carina for each follow-up time block and total ultimate percent change

Follow-up time	% Length achieved by stent (# of dogs)	% Change in stent length over time (# of dogs)	Change (mm) in distance from cricoid (# of dogs)	Change (mm) in distance from carina (# of dogs)
Immediate post placement	126.72% (n = 50)	N/A	N/A	N/A
≥ 1 day & < 90 days	121.94%[a] (n = 45)	−6.98%[b] (n = 45)	0.02 (n = 23)	−0.42 (n = 40)
≥90 days & < 180 days	109.84%[a] (n = 11)	−11.89%[b] (n = 11)	2.20 (n = 6)	3.19 (n = 9)
≥180 days & < 365 days	123.14%[a] (n = 9)	−7.88%[b] (n = 9)	−1.07 (n = 4)	1.34 (n = 7)
≥365 days & < 730 days	110.31%[a] (n = 14)	−11.20%[b] (n = 14)	0.40 (n = 5)	0.33 (n = 12)
≥730 days	105.56%[a] (n = 18)	−10.16%[b] (n = 18)	2.58 (n = 11)	1.26 (n = 18)
Ultimate mean follow-up 446 days	**114.55% (n = 46)**	**−9.90% (n = 46)**	**1.1 (n = 25)**	**1.9 (n = 44)**

[a]Significant difference from immediate post placement.
[b]Percent change was significantly different from a null mean of zero.

between baseline and T1–89 ($P < .0001$), T90–179 ($P < .0001$), T180–364 ($P = .004$), T365–729 ($P < .0001$), and T ≥ 730 ($P < .0001$). Compared with immediately after stent placement, a significant difference observed for percentage length achieved by stent at T1–89 ($P = .034$), T90–179 ($P < .0001$), T180–364 ($P = .014$), T365–729 ($P < .0001$), and T ≥ 730 ($P < .0001$). Percentage change in length of stent over time was significantly different from a null mean of 0 at T1–89 ($P < .0001$), T90–179 ($P = .0003$), T180–364 ($P = .0037$), T365–729 ($P = .0002$), and T ≥ 730 ($P < .0001$).

A significant difference was observed between time comparisons for thoracic inlet diameter between baseline and all time comparisons, specifically T1–89 ($P = .0012$), T90–179 ($P = .014$), T180–364 ($P = .0153$), T365–729 ($P = .0001$), and T ≥ 730 ($P = .0068$), and intra-thoracic diameter between baseline and T365–729 ($P < .0001$) and T ≥ 730 ($P = .0037$). No significant differences were observed among time comparisons for cervical tracheal diameter.

A significant difference was identified for percentage change of thoracic inlet diameter between baseline and T365–729 ($P = .019$), as well as percent change of intra-thoracic between baseline and T1–89 ($P < .0001$), T90–179 ($P < .0001$), and T180–364 ($P = .0001$), but the percentage change of cervical diameter was not significant for any of the pairwise comparisons.

The distance (mm) from cricoid cartilage to the cranial aspect of the stent was not significant for any of the pairwise comparisons, nor was the distance from the carina to the caudal aspect of the stent.

3.2 | Traditional versus malformation types

A significant difference was observed for stent length between baseline and all-time comparisons for traditional types, specifically T1–89 ($P = .0002$), T90–179 ($P = .0002$), T180–364 ($P = .015$), T365–729 ($P = .022$), and T ≥ 730 ($P = .01$). For malformation types, a significant difference was observed only for stent length from baseline to T90–179 ($P = .001$) and T365–729 ($P = .005$).

For traditional types, no significant differences were observed between baseline and time comparisons for cervical or intra-thoracic diameter. A significant difference was observed for thoracic inlet diameter between time comparisons, specifically for baseline compared to T1–89 ($P = .004$) and T365–729 ($P = .01$). For malformation types, a significant difference was observed between time comparisons for intra-thoracic diameter specifically for baseline compared to T365–729 ($P = .001$).

There was a significant difference for percentage change of intra-thoracic diameter between time comparisons for traditional types, specifically for baseline compared to T1–89 ($P < .0001$), T90–179 ($P < .0001$), and T180–364 ($P = .0012$), but the percentage change of cervical and thoracic inlet diameter was not significant and no significant differences were identified for malformation types.

The distance from cricoid cartilage to the cranial aspect of the stent was not significant for any of the pairwise comparisons, nor was the distance from the carina to the caudal aspect of the stent for either traditional or malformation types.

3.3 | Inter-observer reliability

Radiographic projections of 50 dogs were evaluated by the 2 observers (C. Weisse and M. Raske) to make paired comparisons of the previously mentioned variables at each of the specified time categories that were available. When all times were grouped together, analysis indicated acceptable agreement between the 2 raters for all variables evaluated (Figure 4a-i). Rare instances of inter-observer differences falling outside of the confidence limits were observed for all variables. Specifically, there was 1 violation for length of T4, 2 violations for distance from the cricoid cartilage to the cranial aspect of the stent, 3 violations each for length of dorsal cricoid cartilage, length of C7, maximum cervical diameter, maximum thoracic inlet diameter and maximum intra-thoracic diameter, 4 violations each for length of the stent after placement, and distance from the carina cartilage to the caudal aspect of the stent. In all cases, these violations were observed at higher mean values distant from where the majority of data was clustered together.

4 | DISCUSSION

To our knowledge, ours is the first report of tracheal stenting investigating the immediate, short- and long-term dimensional changes and positioning of stents in a large group of dogs. Our results suggest that use of an intraluminal tracheal stent for CTCS is associated with minimal, acceptable, and predictable stent shortening with no relevant stent migration after fluoroscopic placement using the measurement and placement guidelines employed by our interventional radiology service. Using these guidelines, initial stent length was 26.72% higher than nominal length, and ultimate long-term tracheal stent shortening was only 9.90%. Additionally, good inter-observer reliability was found for all measurements between 2 observers of different experience level.

To investigate changes that occurred over time, differences were observed from immediate stent placement to the established follow-up time categories. Evidence of stent migration over time was minimal as evidenced from the minimal change and lack of significant difference in the distance from cricoid cartilage and carina to the cranial and caudal aspect of the stent, respectively, at any of the follow-up time categories compared to immediate post-stent placement. Of these minimal and nonsignificant changes, the largest changes in distance from cricoid and carina occurred in 1 of the short-term follow-up periods (T90–179) and 1 of the long-term follow-up periods (T ≥ 730), but the implications of these changes with regard to clinical signs and complications are unknown because this aspect was beyond the scope of our study.

Significant difference was seen for mean stent length and percentage length achieved by the stent between immediate stent placement and all 5 follow-up categories, but the ultimate mean percentage change in stent length was only 9.90%. The change in stent length occurred fairly quickly, and the majority of stent shortening occurred by the T90–179 time period. It appears that the stent length was not likely to shorten beyond this short-term period and this finding is valuable information for clinicians, because it is important to know when and how long to anticipate stent shortening. This finding is in contrast to a previous study of 24 dogs treated with a biliary Wallstent (Boston

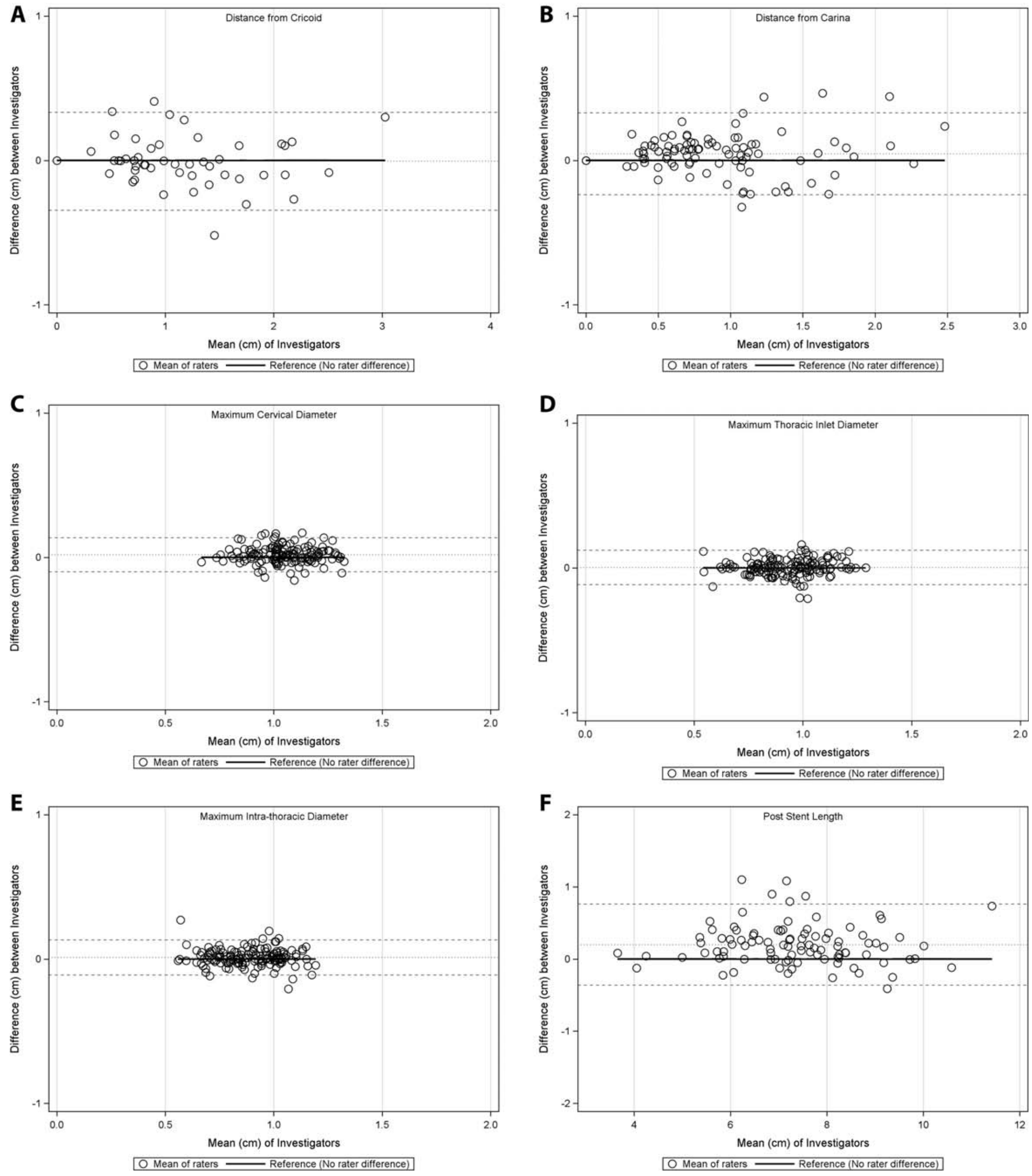

FIGURE 4 Inter-observer reliability comparing post stent placement to follow-up for (A) distance from cricoid cartilage to the cranial aspect of the stent, (B) distance from carina to the caudal aspect of the stent (C) maximum cervical tracheal diameter, (D) maximum thoracic inlet tracheal diameter, (E) maximum intra-thoracic tracheal diameter, (F) post stent length, (G) length of the vertebral body of 7th cervical vertebra (C7), (H) length of the vertebral body of 4th thoracic vertebra (T4), and (I) length of dorsal cricoid cartilage

Scientific Corporation, Marlborough, Massachusetts), that reported a median shortening of 27% within a median of 175 days after stent placement under fluoroscopy with 2 cases associated with a recurrence of clinical signs because of severe collapse cranial to the stent.[16] The stent type and diameter used along with the placement technique may account for these differences.

Complications have been noted with the use of airway stents for the treatment of malignant and benign airway obstruction in human medicine, similar to those seen in dogs, including stent migration, granulation tissue formation around the stent, problems with mucociliary clearance, poor patient tolerance, problems with placement and removal, and stent fracture.[18–20] Although complications are similar, the differences between airway collapse in humans and dogs preclude direct comparisons from being made. Advances in stent designs, improvements in stent placement techniques, and understanding and addressing the diversity of CTCS will likely lead to a decrease in these complications.

When appropriately sized diameter stents are used, migration is minimal. Using the maximal cervical and intra-thoracic tracheal diameters is important to anticipate the degree of stent expansion that will occur.[4] No significant differences for mean percentage change in

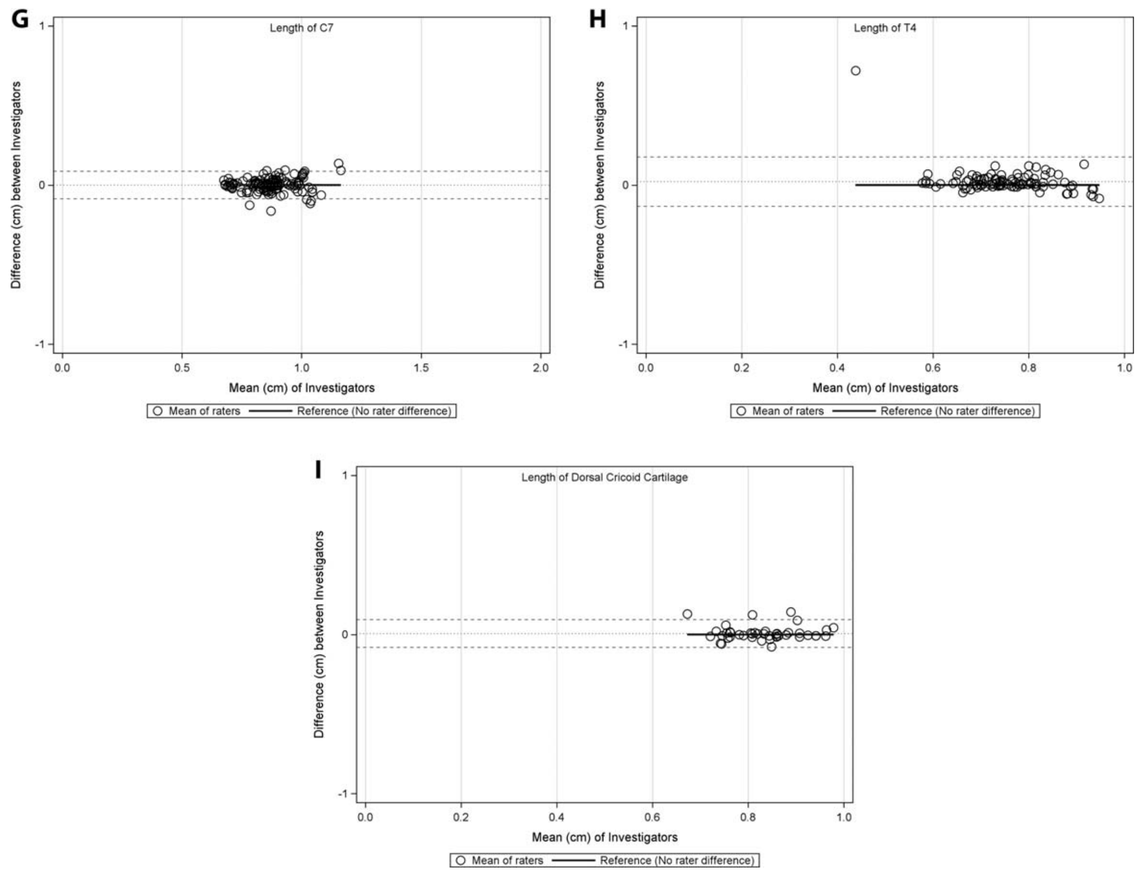

FIGURE 4 Continued

cervical diameter were observed from immediate post-stent placement and any of the follow-up categories. A significant difference from immediate post-stent placement in percentage change of thoracic inlet diameter occurred in 1 long-term follow-up category and in percentage change in intra-thoracic diameter from immediate post-stent placement in both short-term follow-up categories and 1 long-term follow-up category (T180–364). A previously reported cases series of 18 dogs using a rigid bronchoscope for placement of nitinol stents found that percentage change in minimum tracheal diameter was significantly increased after stent placement, whereas no significant difference was observed in the percentage change of maximum tracheal diameter after stenting.[13] Our study differed in the fact that maximum tracheal diameter was investigated for all 3 segments in each case to more closely investigate specific changes taking place throughout the entire length of the trachea.

Tracheal malformations were present in 36% of the dogs in our study. The abnormal ("W"-shaped) tracheal cartilage rings complicate endoluminal stenting because an incompletely expanded stent may leave an area lacking tracheal wall contact in the region of the misshapen cartilage rings. Although extensive comparisons between traditional and malformation types of tracheal collapse were beyond the scope of our study, some similarities and differences between the 2 groups were identified suggesting future studies will be necessary to potentially differentiate 2 patient populations. In our study, both traditional and malformation tracheal collapse groups demonstrated no significant difference between the distance from the cricoid cartilage and carina to the cranial and caudal aspect of the stent, respectively, indicating lack of stent migration in both groups. However, although both malformation and traditional type tracheal collapse patients had significant differences observed for mean stent length between time comparisons, traditional types had significant differences between baseline and all-time comparisons, whereas malformation types only had a significant difference between baseline and 1 of the short-term and 1 of the long-term time comparisons. One possible explanation is that malformed cartilage rings may limit maximum stent expansion and therefore the stents may remain longer in length. Partially compressed stents may exert less outward radial force, limiting ultimate expansion, as well as leading to gaps between the stent and tracheal wall. These gaps from lack of contact allow for mucus accumulation leading to infection and tissue ingrowth.[21] In malformation cases, good wall apposition should be confirmed using post-stent tracheoscopy and, if gaps exist, gentle expansion of the stent using the ET tube cuff or careful use of a balloon dilatation catheter should be performed.[4]

Accurate measurement of tracheal diameter is essential for the selection of an appropriate stent size. In human medicine, computed tomography (CT) is the imaging modality of choice for evaluation of the airways because of superior resolution and lack of tissue superimposition. The expense of CT may limit its use in veterinary medicine for assessing tracheal measurements, although it has been questioned whether measurements from 3-dimensional imaging would be a more accurate means for determining tracheal dimensions. In 1 study, CT tracheal diameter measurements were approximately 7% larger than the corresponding radiographic (straight lateral, 15° oblique lateral, and 45° oblique) measurements in normal cadaver dogs ventilated to 20 cm H_2O during imaging.[22] However, calculations suggest that adding 2–3 mm to the maximum diameter of the trachea when selecting stent size based on positive-pressure ventilation radiographs should compensate for this difference and minimize chances of stent migration.[23] A study evaluating the accuracy of segmental measuring techniques to predict immediate post-deployment stent lengths found a trend towards decreasing percentage and average absolute differences between the prediction and overall stent length when using 2, 3, or 4 segments versus just using the single widest point of the trachea.[24] However, it was noted that there was a high percentage of underestimation of stent length from the prediction techniques used in that study, which ultimately could lead to an inappropriate fit of the stent and increased risk for potential complications.[24] In our study, we found the stent sizing and placement techniques described as critical to limit subsequent stent shortening and migration.

Experience level did not have an effect on tracheal measurements in our study, as good agreement was found between the 2 observers. Only rare instances of inter-observer differences were identified. The good agreement could be attributed to the systematic way that the measurements were taken in our study. The use of the lengths of the dorsal cricoid cartilage and of the C7 and T4 vertebral bodies appeared to provide an accurate means of measurement to adjust for radiographic magnification in subsequent images that did not have radiographic markers in place. Comparatively, the previously mentioned study evaluating accuracy of segmental measurement techniques found good to high intra- and inter-observer reliability for all segmental measurements among 4 observers of different experience level.[24]

Our study had several limitations including its retrospective nature. Although there was a recommended time for follow-up after stent placement, the number of follow-up examinations and the time between these examinations varied considerably among the dogs. Future prospective studies with uniform follow-up times are warranted. Because of the retrospective nature of our study, we could not determine why some dogs were not returned for follow-up at the suggested time intervals. Sample size was small, and fewer than half of the dogs had a follow-up time >90 days, which may have resulted in a low power of detection for significant differences. Additionally, not all dogs contributed a measurement in each time category and individual dogs accounted for >1 measurement during some time periods. For example, time period T1–89 had 45 measurements of 37 dogs. Another limitation is that not all follow-up radiographs included the calibration marker. In these cases, calibration of the radiograph depended on either using the length of the vertebral body of C7 or T4 or the dorsal cricoid cartilage that was measured during stent placement. Using these measurements for some cases could have added more variability to the stent diameter and length measurements, because the individual performing the measurements chose which structure (C7, T4, or dorsal cricoid cartilage) was most clearly defined on the radiographs for calibration. This factor also could have led to some variability in measurements. However, based on the good agreement between the observers, we do not believe this factor had an adverse effect. Also, although inter-observer reliability was investigated, repeated measurements performed by the same individual were not investigated to determine the contribution of intra-observer variability.

In conclusion, treatment of CTCS by fluoroscopic placement of intraluminal tracheal stents in dogs resulted in minimal and acceptable mean stent shortening with no evidence of substantial migration in the immediate, short-, or long- term. Inter-observer reliability of radiographic measurements was good. With appropriate sizing and deployment techniques, minor stent shortening appears to occur in the short-term without progression, and migration should be minimal during any time period. Future prospective studies are needed to further assess long-term changes in tracheal stent diameter, length, and position, as well as the clinical relevance of any of these changes for traditional and malformation types of CTCS.

CONFLICT OF INTEREST DECLARATION

Dr. Weisse is a consultant for Infiniti Medical, LLC.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed.

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