Effect of Variations in Stent Placement on Outcome of Endoluminal Stenting for Canine Tracheal Collapse

Stephanie Rosenheck, DVM, DACVS-SA*, Garrett Davis, DVM, DACVS, Carl D. Sammarco, BVSc, MRCVS, DACVIM (Cardiology), Richard Bastian, PhD

ABSTRACT

The study's objective was to determine effects of relative size and placement location of endoluminal stents on incidence of complications and survival for canine tracheal collapse. Measurements were obtained on lateral radiographs before and after stenting to determine percent of the trachea occupied by the stent. These values were monitored over time and compared to complication rates and survival. Overall median survival time was 502 days. Six month survival rate was 78%, 1 yr survival was 60%, and 2 yr survival was 26%. Median percent of trachea occupied by the stent at initial placement was 79% (range, 41–93%). Percent of the trachea occupied by the stent at the time of placement did not significantly correlate to complication rate (0.397) or survival time (0.853). Incidence of serious complications was 37%, including granuloma formation, pneumonia, material failure, and stent migration. For patients experiencing serious complications, median survival was shorter, at 208 days, but was not significantly different from survival without serious complications. Within the margins of the data from this study, the proportion of the trachea occupied by the stent at the time of placement does not appear to impact incidence of complications or survival time in dogs with tracheal collapse. (*J Am Anim Hosp Assoc* 2017; 53:150–158. DOI 10.5326/JAAHA-MS-6485)

Introduction

Tracheal collapse is a respiratory condition that commonly affects small and toy breed dogs. With this condition, the integrity of the tracheal cartilage progressively weakens, there is laxity of the dorsal tracheal membrane that causes increased upper airway resistance, and this ultimately progresses to partial or complete airway obstruction.[1,2] This can further be exacerbated by development of chronic tracheal and/or small airway inflammation, fibrosis, and the loss of the mucociliary apparatus.[1] History and clinical signs usually involve a characteristic "goose honk" cough that is often accompanied by intermittent or worsening episodes of respiratory difficulty. Commonly affected breeds include the Yorkshire terrier, Chihuahua, Pomeranian, miniature poodle, and pug, with no sex predilection reported.[3–6]

Diagnosis is made based on history and physical exam findings, followed by documenting the collapse with imaging. Severity of tracheal collapse is typically graded on a scale of I to IV, associated with 25, 50, 75, and 100% luminal collapse, respectively.[7,8]

Surgery for tracheal collapse is considered by some to be a last resort since medical management using a combination of anti-inflammatories, antitussives, bronchodilators, antibiotics, and sedatives or tranquilizers can provide acceptable amelioration of signs for a protracted time period, and risks of surgical intervention are typically not benign.[3,9–11] A 71% rate of resolution of clinical

From the Department of Surgery, Center For Animal Referral and Emergency Services, Langhorne, Pennsylvania (S.R.); Red Bank Veterinary Hospital, Tinton Falls, New Jersey (S.R., G.D., C.D.S.); and Monmouth University, West Long Branch, New Jersey (R.B.).

Correspondence: srosenheck@gmail.com (S.R.)

* S. Rosenheck's present affiliation is the Center for Animal Referral and Emergency Services, Langhorne, Pennsylvania.

signs with medical management for greater than 12 mo in a survey of 100 cases has been reported.[8]

Surgery for tracheal collapse may be indicated in cases that are no longer responsive to conservative management. Reported surgical techniques have included dorsal tracheal membrane plication, tracheal resection and anastomosis, and extraluminal prostheses.[3,4,9–11] Surgery, however, is of limited value in cases of significant intrathoracic tracheal collapse since associated surgical morbidity to treat intrathoracic tracheal disease is considered by some to be prohibitive.[1,6,12] Results of surgical treatment for tracheal collapse are variable and can precipitate serious and sometimes fatal complications, including laryngeal paralysis, tracheal necrosis, and pneumothorax.[2,3,11]

Endoluminal tracheal stenting has become an important and promising alternative to conventional surgical techniques. This approach to treating tracheal collapse has the advantages of shortening anesthetic time, providing immediate relief of respiratory distress, and allowing minimally invasive access to the intrathoracic trachea.[5,2,13] Potential complications for this method include stent fracture, stent collapse or deformation, stent migration, stent shortening, tracheal perforation during placement, exuberant granulation tissue formation, bacterial or sterile tracheitis, pneumonia, and persistent coughing.[1,6,14–17] It should be noted that persistent coughing, while partially a consequence of direct tracheal irritation by the stent, is also likely a result of progressive bronchial collapse, tracheitis, lower airway inflammation, and/or mucosal hyperplasia. Client education should emphasize that endoluminal stenting is intended to ameliorate the collapse and not, necessarily, the cough itself.[4,5,16]

Factors contributing to survival, treatment success, and long-term outcome remain difficult to determine. Studies have demonstrated that 11–25% of patients with tracheal stents die within 6 mo of placement, with stent fracture being one of the most commonly reported serious complications, occurring in 22–41% of cases.[5,18] Recently, it has been shown that 89% of stents will shorten in dimension over time, though this finding has not been found to correlate with outcome.[5] To date, no study has identified specific factors associated with a better or worse long-term outcome and survival with endoluminal stenting.

Some studies describe an aim to support as much of the working length of the trachea as possible with the stent without impinging on the larynx and carina.[5,16] The optimal location of the stent within the trachea, however, has not yet been determined. The purpose of this study was to evaluate cases of tracheal collapse treated with endoluminal stenting. We specifically determined the percent of tracheal length occupied by the stent, the distance from the stent to the larynx and carina, respectively, and the changes in stent length over time. These values were then compared to complications and survival time. The hypothesis of the study herein was that a larger initial percent coverage of the trachea by the stent would correlate to improved survival. Additionally, it was hypothesized that cases in which the stent shortened over time would have a shorter survival time.

Materials and Methods

Medical records for patients with tracheal collapse that were treated with intraluminal tracheal stent placement between February 1, 2005 and October 1, 2013 at the Red Bank Veterinary Hospital were reviewed. For study inclusion, patients were required to have a complete medical record, including history, physical exam findings, cervicothoracic radiographs available for review both prior to stent placement and immediately after placement, as well as a written account of the stent placement procedure performed. Data collected included breed, age at presentation, onset and duration of clinical signs, any complications that occurred following stent placement, and cause and date of death. Serious complications were defined as any event directly related to the stent that resulted in hospitalization, and/or a second procedure, and/or death.

Stent Selection and Placement

Patients were candidates for treatment with endoluminal stenting if (1) they had been previously managed medically for tracheal collapse and became refractory to conservative treatment or (2) if they experienced an episode of respiratory distress secondary to tracheal collapse necessitating intubation, and clinical judgment dictated that stenting was indicated. Once stent placement was elected, stent size selection was based on a combination of radiographic measurements, fluoroscopic measurements, and stent inventory. Preoperative thoracic radiographs were used to assess any concurrent cardiac and/or pulmonary abnormalities as well as to estimate tracheal size for stent selection. Measurements of tracheal length and maximum diameter were taken from a lateral view. Tracheal length measurements were taken from the caudal-most aspect of the cricoid cartilage, extending down to the level of the tracheal bifurcation. Multiple tracheal diameter measurements were taken to determine the widest portion of the trachea, which was typically found immediately caudal to cricoid cartilage. These measurements were obtained in awake patients and were used to approximate dimensions and evaluate inventory to select the most appropriate options. Once the patient was anesthetized, additional measurements of tracheal dimensions were taken using the fluoroscopy unit, and were obtained at 20 cm H_2O positive pressure ventilation. Either an intraesophageal measuring device or a ruler with radiopaque graduations rested on the dog at the

cervicothoracic region was used during fluoroscopy to measure tracheal length and width. Stent diameter was selected by adding 10–20% of the maximum tracheal width measured, and stent length was chosen based on the shortening chart, aiming to span the entire length of the trachea without overlapping with the larynx or the tracheal bifurcation, respectively. Only the measurements obtained with positive pressure ventilation were used for ultimate stent selection, so as to avoid selecting an inadequately sized stent. Specific stent selection was based on the manufacturer shortening charts, according to maximal or sub-maximal stent expansion. For example, for patients with a longer tracheal length, a stent with a larger potential diameter may be selected, assuming sub-maximal expansion and corresponding increased stent length.

The standard anesthetic protocol included premedication with hydromorphone at 0.1 mg/kg via intramuscular injection. An intravenous catheter was then placed in a cephalic vein, followed by induction using diazepam at 0.2 mg/kg IV and propofol IV, titrated to effect. Patients were intubated with an appropriately sized endotracheal tube and maintained under anesthesia using isoflurane. In cases where the patient was intubated emergently due to respiratory distress, premedication and/or induction agents were not always used.

The patient was then positioned in left lateral recumbency for fluoroscopy-guided stent placement. Stents placed were one of two commercially available brands[a,b], and the decision to use one over another was based primarily on inventory and variations in stent sizes between manufacturers. The stent delivery system was introduced through a T-port attached to the endotracheal tube with the inhalant temporarily turned off and was inserted until the farthest aspect of the stent was visualized at the level of the carina. This was typically at the level of the fourth intercostal space, at which point stent deployment was initiated. As the stent was deployed within the trachea, the patient was simultaneously slowly extubated until the stent was fully deployed or it was determined that a different stent length was required. If the stent size was deemed inappropriate, the stent was recaptured and a different size was selected and placed. If clinical judgment deemed stent size selection to be adequate, the stent was deployed completely, and the empty delivery system was retracted as the patient was simultaneously completely extubated. Because the inhalant anesthetic was not administered during stent delivery through the T-port, propofol was administered intravenously when necessary, titrated to effect. The patient was not reintubated as to prevent dislodgement of the stent, and was allowed to fully recover from anesthesia under close monitoring. Ventrodorsal and lateral cervicothoracic radiographs were taken in all cases for confirmation and documentation of appropriate stent placement

Postplacement Care

Following radiography the patients were monitored during recovery from anesthesia. Patients were treated with 0.5–1 mg/kg of prednisolone acetate subcutaneously, and respiratory rate and effort were recorded hourly peri-operatively. Patients remained on a maintenance fluid rate of physiologic isotonic crystalloids, and broad spectrum oral antibiotics were initiated upon full recovery from anesthesia. Excitement or anxiety with associated respiratory distress was treated with butorphanol at 0.2 mg/kg IV, as indicated. In the absence of postoperative complications, most patients were discharged on amoxicillin/clavulinic acid (twice daily for 6 wk), and an anti-inflammatory dose of prednisone (0.25–0.5 mg/kg twice daily) for 6 wk, with instructions to taper thereafter over 3 wk. Cough suppressants (hydrocodone/homatropine, butorphanol, diphenoxylate/atropine) were also used as needed.

Tracheal and Stent Dimensions

Measurements were taken retrospectively to assess tracheal dimensions both before and after stenting. Preoperative tracheal measurements were taken from the radiographs obtained closest to the time of stenting, typically on the same day of the procedure. Radiographs obtained immediately following tracheal stent placement were used to determine stent position and percent of the trachea covered. When possible, tracheal and stent dimensions were followed over time and recorded. Measurements were obtained using the electronic measurement tools provided by the radiograph viewing software used. All measurements were taken in triplicate by a single observer (S.R.), using the mean for data analysis. These values were then converted to a percentage of total tracheal length.

Prestent tracheal length measurements were obtained from the caudal-most aspect of the cricoid cartilage to the level of the tracheal bifurcation. In most cases, due to the curvilinear orientation of the trachea, a single measurement was taken from the cricoid to the level of the thoracic inlet, and an additional measurement was taken from the inlet to the carina, and these measurements were added to generate a tracheal length.

Poststent placement measurements were obtained on the lateral projection from the caudal aspect of the cricoid cartilage to the cranial aspect of the stent, and from the caudal aspect of the stent to the level of the tracheal bifurcation. These measurements determined distances from the stent to the larynx and the carina, respectively. In order to control for magnification, these values were then subtracted from the total tracheal length, and the result expressed as a percentage representing the proportion of the trachea supported by the stent. An example of a lateral post-stent radiograph with annotated measurements can be found in **Figure 1**.

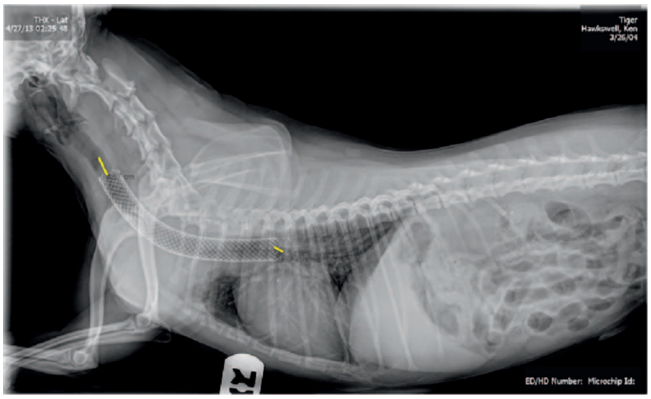

FIGURE 1 *Right lateral cervicothoracic projection taken immediately following tracheal stent placement. Distances from the stent to the larynx and carina are annotated in yellow.*

When available, follow-up radiographs were used to obtain the same measurements. The percent of tracheal coverage at initial placement was compared to the percent tracheal coverage at follow-up visits; change in stent length was determined and expressed as a percentage. If more than one radiographic study was available from follow-up visits, then the most recent radiographs obtained were used to compare to those taken after initial stent placement. All radiographs included in data analysis contained a marker in the projection for purposes of magnification calibration.

Follow Up

Initial recheck examinations were performed 2 wk after initial stent placement and again at 6 wk to adjust medications if indicated. Thereafter, appointments were recommended every 6 mo.

Data Collection

Several variables were examined to determine how the percent of trachea covered by the stent affected outcome. Patients were categorized according to their cause of death; specifically, whether or not death was directly due to respiratory disease. Specific inquiries included initial percent tracheal coverage, changes in stent dimension over time, as well as distances from the cranial and caudal aspects of the stent to the larynx and carina, respectively. These variables were then analyzed in relation to incidence of complications as well as overall survival time. Initial percent tracheal coverage was also examined as a potential risk factor for death due to respiratory disease.

Statistical Analysis

Quantitative descriptive data for metric variables are presented as medians and range or as mean +/- standard deviation for normally distributed data. Associations between categorical variables were tested using Pearson's chi-square test of independence or Fisher's exact test. Tests of association between categorical variables and metric variables used tests of two or more medians (Mann-Whitney, Kruskall-Wallis) or two or more means (for normally distributed data, e.g., t-tests, analysis of variance), with appropriate Bonferroni corrections as needed.

Scale variables investigated included age, tracheal length, stent length, stent placement relative to larynx or carina, percent trachea covered by the stent, and percent shortening or lengthening of the stent. Stent diameter was treated as an ordinal variable with values of 10, 12, and 14.

For some of the statistical analyses, several categorical variables were created from the scale variables. These were as follows: Stent Shortening (Yes for stents that shortened, No otherwise), Stent Lengthening (Yes for stents that lengthened, No otherwise), or Stent Change (Yes for either Shortening or Lengthening, No otherwise). In addition, a new variable was created: Serious Complications (Yes if criteria met [see results section for criteria], No otherwise). A final categorical variable denoted whether or not the patient had multiple stents.

Curves for survival time were generated using the Kaplan-Meier product-limit method. Dogs were censored in the analysis if they were alive at the time of statistical analysis, lost to follow-up, or died of causes unrelated to respiratory disease. Variables examined for predictors of survival time in the univariate analysis included each of the categorical variables above as well as each of the scale variables individually. Multivariate analysis was performed using the guidelines in Hosmer, Lemeshow, and May, involving backward elimination and assumption assessment in Cox regression.[19] Beginning with all variables with univariate P values of .3 or less in the regression model, the P values of the Wald statistic of each variable, as well as the P value of the partial likelihood ratio test for the overall model, was used to eliminate variables from the model one at a time and then to determine whether or not the removed variable was a confounder. If the variable was a confounder, it would be added back into the model. For all univariate analyses, a value of $P < .05$ was considered significant. For multivariate analysis, a value of $P = .1$ was used to remove a variable from the model. All analyses were performed using SPSS statistical software[c].

Results

Twenty-nine patients were treated for tracheal collapse at Red Bank Veterinary Hospital with endoluminal tracheal stents between February 1, 2005 and October 1, 2013. Among these patients, two did not meet the inclusion criteria, and twenty-seven patients were included in this study. The most common breed represented was

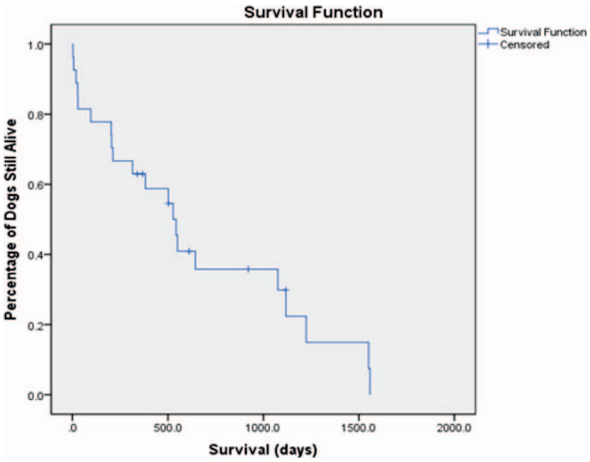

FIGURE 2 *Kaplan Meier survival curve representing the number of patients still alive over time after stent placement.*

the Yorkshire terrier (14/27), followed by the Pomeranian (5/27), Chihuahua (4/27), Silky terrier (2/27), Papillon (1/27), and Maltese (1/27). Age at the time of stenting ranged from 3 to 14 yr old, and the median age was 8 yr old.

Overall, prescription medications varied among patients both before and after stent placement. In general, a combination of oral antibiotics, antitussives, corticosteroids, sedatives/tranquilizers, and bronchodilators were used. Selection of individual medications prescribed was at the discretion of the attending clinician. For two patients, colchicine was added to the treatment protocol after stenting. The vast majority of the patients received stents made by a single manufacturer[a]. Only one patient received a stent by an alternative manufacturer[b] during the final 2 yr of data collection.

Median survival time for all 27 patients was 502 days (range 3 to 1558 days). Five patients (18.5%) died within the first mo after stent placement. Median survival for patients who lived beyond 1 mo was 535 days. These survival time differences were not statistically significant. Twenty-one out of 27 patients (78%) survived at least 6 mo, 16/27 patients (60%) survived >1 yr, and 7/27 patients (26%) lived >2 yr. **Figure 2** depicts overall survival time.

Thirteen out of 27 patients (48%) ultimately died due to respiratory disease, 6/27 (22%) patients died of unrelated causes, 2/27 (7%) patients died due to unknown causes, 5/27 (19%) patients were still alive at the time of study completion, and 1 patient was lost to follow-up (4%).

Serious complications were defined as any complication directly related to the stent that resulted in hospitalization, a second procedure, or death. These included granuloma formation (5/27), pneumonia (4/27), stent deformation (1/27), stent fracture (1/27), and stent migration (1/27). Serious complications occurred in 10 patients (37%), and 2 of these patients experienced more than one complication.

The median survival time for dogs that did not exhibit serious complications was 543 days. Those who did experience serious complications had a median survival of 208 days. This difference was not found to be statistically significant, with a P value of .072. However, this variable was found to have a reliable ability to predict survival, with a P value of .039.

Initial percent coverage of the trachea was investigated as a potential corollary to the development of complications and to survival time, as well as to the incidence of death due to respiratory disease. Median initial percent tracheal coverage was 79% with a range of 41–93%. Patients who experienced serious complications did not have a significantly different value for initial percent tracheal coverage than those who did not experience serious complications ($P = .397$). In addition, initial percent tracheal coverage did not correlate to survival time ($P = .853$). Similarly, dogs that died from respiratory disease did not have a significantly different percent tracheal coverage from dogs who died from other causes (74 and 80%, respectively; $P = .204$). Additionally, the specific position of the tracheal stent in relation to the larynx and carina was not associated with survival ($P = .946$ and $P = .730$, respectively).

In measuring changes in stent dimensions over time, 14/27 patients had follow-up radiographs for comparison. Mean time to follow-up radiographic study was 265 days. It was found that stent shortening occurred in 38.5% of dogs, lengthening occurred in 19.2% of dogs, and no significant change in length was found in 42.3% of dogs. It was found that dogs who had lengthening of the stent had a median survival time of 502 days, dogs who had stent shortening had a median survival time of 429 days, and dogs that had no change in stent length had a median survival time of 454 days. There was no statistical significance between groups ($P = .310$).

Multivariate Tests

Multivariate tests were used primarily to test for possible confounding because only one variable was significant in the univariate tests at the $P = .05$ level, and all other variables were not significant even at the .3 level. Tests of all, as well as all pairs of variables, indicated no confounding was present. This analysis also confirmed the univariate analysis: only the occurrence of a serious complication had a statistically significant ability to predict survival time ($P = .039$).

Complications

Complications associated with the stent placement procedure itself were recorded in only one dog. In this case, the stent was found to

cause laryngeal impingement after complete deployment. Subsequently, the stent was withdrawn orally using hemostats without incident, and a shorter stent was placed. On fluoroscopic and radiographic assessment, the second stent had ideal placement. In another dog, the placement procedure was uneventful, and fluoroscopy confirmed appropriate stent placement. However, the following morning, radiographs obtained revealed stent migration into the mainstem bronchus, and the patient was re-anesthetized for stent repositioning. The stent was accessed orally using a small wire hook and was retracted cranially to its correct position. A lateral cervicothoracic radiograph obtained after the procedure confirmed appropriate stent positioning, and stent migration was not a recurrent problem during the patient's 7 mo survival period.

Two patients exhibited stent-related complications that did not result in specific treatment. One patient developed a clinically silent pneumothorax after stent placement that self-resolved. Follow-up radiographs obtained in another dog showed multiple fractures at the caudal aspect of the stent 205 days after initial stent placement, diagnosed via follow-up radiography. These fractures did not cause obstruction of airflow, and this patient exhibited a cough that responded well to cough suppressant therapy.

Ten patients experienced serious complications related to the stent that resulted in either hospitalization, a second procedure (surgery or additional stent placement), or death. Two of these patients experienced more than one complication. The most frequent complication was a granuloma formation at the cranial aspect of the stent, occurring in five patients (18.5%). This was diagnosed by either radiography (three patients) or tracheoscopy (two patients). One patient developed a granuloma 3 mo after initial stent placement, and a tracheal resection and anastomosis was performed to remove the affected tracheal segment. This patient died 2 days later due to associated complications. Another patient developed marked respiratory distress 18 mo after initial stent placement, and a second sent was placed. Ten mo after the second stent placement, the patient developed recurrent respiratory distress, and a granuloma with concurrent pneumonia was diagnosed based on radiography. At this time, a third stent was placed and the patient lived for an additional 12 mo without complications, dying at home due to unrelated causes. A third patient developed a suspected granuloma diagnosed with radiographs 10.5 mo after initial stent placement, at which point a second stent was placed. This patient lived an additional 18 mo before being euthanized for recurrent and refractory respiratory signs, suspected to be secondary to another granuloma based on radiography. A fourth patient exhibited a persistent cough after the initial stent placement and presented 12.5 mo later in respiratory distress, at which time a granuloma was diagnosed via tracheobronchoscopy (no radiographs were performed at that time). A second stent was placed during this hospital stay, and this patient lived an additional 8.5 mo. Lastly, one other patient presented 2 mo after initial stent placement for respiratory distress. At this time a granuloma was diagnosed via tracheobronchoscopy, and an additional stent was placed. One month later, this patient re-presented for similar signs, and repeated tracheobronchoscopy revealed in-growth of the previous granuloma into the second stent. This patient continued medical management before being euthanized due to respiratory signs 5.5 mo later.

For all patients who developed a granuloma cranial to the stent, the average time to granuloma formation after initial stent placement was 9.5 mo (range 69–561 days). For patients who received a second stent (four patients), average survival following additional stent placement was 13.3 mo.

Material failure was another source of stent-related complications. One patient experienced stent fracture 26 days after placement and was euthanized the following day. Another patient presented 15 days after initial stent placement for respiratory distress. Stent deformation was noted on radiography, and this patient was anesthetized for ballooning of this segment, as was offered in a previous case report of material fracture.[15] Under the same anesthetic event, an extraluminal prosthetic tracheal ring was surgically placed in this region for added support. The patient recovered from anesthesia well, and was discharged from the hospital 2 days later. This patient died suddenly at home 2 days after that, with causes presumably attributable to complications.

The remaining four serious complications comprised cases of pneumonia, all diagnosed via radiography. One patient developed aspiration pneumonia in the first few hours after stent placement, ultimately dying before being discharged from the hospital. Another patient developed pneumonia that was documented radiographically immediately poststent placement. This patient responded well to supportive care and empiric antibiotic therapy and was discharged from the hospital 3 days later. The remaining two patients developed pneumonia 8 days and 2 years after stent placement, respectively, and both responded to empiric antibiotic therapy.

Discussion

The purpose of this paper was to examine cases of tracheal stent placement and to determine whether the amount of trachea supported by the stent makes a difference in long-term outcome. It was hypothesized that patients who had larger percentages of their trachea supported by a stent would live longer and be less likely to experience complications than patients who had less of their trachea supported, leaving larger portions subject to collapse.

Additionally, we wanted to investigate the incidence of changes in stent diameter over time and determine if this phenomenon affected outcome.

Overall median survival for our patients was 502 days, with 78% of patients surviving at least 6 mo, 60% of patients surviving at least 1 yr, and 26% of patients surviving at least 2 yr. This is comparable to previous reports, in which one study showed a 25% mortality rate within the first 6 mo, and another showed an 11% mortality rate within the first 60 days.[18,5] Compared with surgical treatment for tracheal collapse using extraluminal prostheses alone, wherein long-term survival ranges have reportedly been between 70–85%, our results show similar longevity, with 60–78% living 6 mo to a yr or more.[9,10] Most recently, one study on long-term outcome for patients with extraluminal ring placement showed a median survival of 50.5 mo for patients treated for their cervical tracheal collapse. While this is a definitively favorable outcome, it should be noted that 17% of these cases overall developed laryngeal paralysis postoperatively.[11]

In looking at factors that might affect survival time, none of the variables examined exhibited a statistically significant correlation to a shorter survival. However, patients exhibiting serious complications did have a shorter median survival time at 208 days, as compared to 543 days for those who did not experience complications, with a *P* value approaching significance at .072, suggesting that survival times may not be as favorable in these cases. Explanation for this finding is likely related to the nature of serious complications, as they are defined as those resulting in hospitalization, a second procedure, or death. Because these complications require in-patient therapy to which patients are sometimes refractory, it is not surprising that survival time may not be as favorable in these cases.

Percent of the trachea that the stent occupied at initial placement was not found to significantly affect survival; that is to say, a longer percent tracheal coverage did not correlate to a longer survival as we had expected. In addition, those who experienced serious complications did not have a significantly different percent tracheal coverage than those who did not experience complications. This was interesting to note, as we expected that a larger proportion of unsupported trachea would correlate to increased severity of signs reflective of tracheal disease. In light of these findings, it is possible that strategic placement of the stent should have more to do with location of support than the absolute magnitude of support. For example, for patients that exhibit signs attributable to collapse primarily at the thoracic inlet, it is possible that stenting the trachea at this location exclusively will ameliorate signs just as effectively as placing a stent that supports the entire working length of the trachea. In the same vein, patients who experience chondromalacia and collapse of their lower airways are likely to continue exhibiting some degree of respiratory signs due to small airway obstruction even if upper airway resistance is completely eliminated with tracheal stenting. In one report of 58 cases of respiratory disease examined with bronchoscopy, 47% of dogs exhibited bronchomalacia.[20] This underscores the idea that localization of airway collapse and subsequent obstruction should be a key component in planning surgical or minimally invasive management of these cases. However, another study showed no difference in survival between dogs with cervical tracheal collapse alone as compared to those with intrathoracic airway collapse, suggesting that lower airway collapse should not be an exclusion criterion for addressing cervical tracheal collapse surgically or minimally invasively.[6] However, further research is warranted to investigate the impact of concurrent bronchomalacia on patients treated for tracheal collapse with endoluminal stenting.

Alternatively, it is possible that there is a minimum threshold for tracheal support, and any coverage beyond this threshold has negligible impact on outcome. The patient in this study with the smallest percent of the trachea initially covered by the stent had 41% coverage. Twenty-three out of 27 (85%) of our patients had greater than 70% of the trachea covered on initial placement. It may be true that there is a minimum percent of the trachea for which stent support can impact outcome, but this potential minimum was not determined in this study.

Interestingly, 19% of our patient population appeared to exhibit lengthening of the tracheal stent over time. It should be noted, however, that 13 patients did not have follow-up measurements available, making it difficult to draw a conclusion based on this finding. To the author's knowledge, lengthening has not been previously documented, and an explanation for it is not clear. It is possible that lengthening may reflect weakening of the stent material over time, making it subject to external compression from the softened tracheal cartilage, resulting in a narrowed diameter and corresponding increase in length. This speculation, however, has not been verified, and further research is indicated to investigate potential causes for stent lengthening.

In measuring the percent of the trachea covered by the stent, measurements were taken of the trachea prior to stent placement on a lateral radiographic projection to evaluate the overall length. A recent study showed no significant difference between computed tomography and radiographic measurements regarding tracheal length on lateral projections, making radiography an appropriate method to assess this parameter.[21]

Previous reports highlight stent fracture as the most frequent complication associated with tracheal stenting, occurring in 42% of patients in one study and 22% of dogs in another report.[5,18] This is

in contrast to our findings, in which stent fracture occurred in 1/27 (4%) patients. Reasons for this difference are unclear though may be related to the frequency of coughing or differences in relative stent motion.

The most frequent serious complication encountered in this population of patients was granuloma formation at the cranial aspect of the stent, documented to have occurred in 18.5% of our cases. Interestingly, all of the cases treated for this complication had manifestations at the cranial aspect of the stent, visible either radiographically or via tracheoscopy. Etiology for the formation of excessive granulation tissue adjacent to the stent has not been specifically defined. In humans, it is thought to occur in patients with pre-existing tracheal inflammation at the time of stent placement.[22] One study showed an incidence of bacterial tracheitis in 42% of dogs after tracheal stent placement.[5] It is possible that granuloma formation may be either a result or a cause of bacterial tracheitis, and it is the authors' opinion that antibiotic use should be strongly considered for these cases. In the same study, another 42% of dogs were diagnosed with inflammatory tracheitis after stent placement, as confirmed via cytologic analysis paired with a negative bacterial culture.[5] Causes for this inflammatory tracheitis may include direct irritation of the trachea by the stent, small movements of the stent interstices during coughing, or tracheal irritation from continued bronchial collapse with associated coughing.[5] Presence of pre-existing tracheitis may predispose to granuloma formation in dogs, which can further impair expulsion of respiratory secretions as well as causing direct airway obstruction and respiratory distress. In the absence of tracheitis, it is possible that mechanical irritation from small movements of the stent during coughing or other changes in tracheal dimensions could incite a focal deposition of granulation tissue. Medical treatment of a stent-related granuloma resulting in resolution has been documented in a dog using colchicine therapy.[22] However, treatment with oral doxycycline was instituted concurrently in that case report, making it difficult to attribute resolution of the granuloma to the colchicine therapy alone. Colchicine therapy was instituted in two of our patients with documented granulomas, and no clinical improvement was noted.

For four of our patients that developed a granuloma, an additional stent was placed with the intent to cover the area of granulation tissue, aiming to increase lumen diameter and decrease airway resistance. To the author's knowledge, this treatment has not been specifically described to address granuloma formation. While the sample of patients with this treatment was small, our impression is that this technique results in a significant extension in survival time, with an average subsequent survival of 399 days in our patients after placement of an additional stent. Further investigation should be performed regarding this option as a treatment for granuloma formation.

There were several limitations to this study, including its retrospective design and small sample size. Because treatment and follow-up protocol were tailored to each patient's relative health and degree of clinical signs, follow-up visits and intervals of radiographic studies were not standardized across the patient population. Therefore, follow-up measurements regarding tracheal dimensions were not obtained at regular or consistent intervals, making interpretation of changes in stent dimension difficult. Similarly, because follow-up radiographic studies only represent snapshots in time of tracheal and stent dimensions, it is possible that small variations could occur on a day-to-day basis that would not be accounted for in the radiographic measurements. Additionally, medications for all patients were not standardized, and corticosteroid, antibiotic, antitussive, and bronchodilator administration was variable. For this reason, it is difficult to determine the degree of impact on outcome or complications any given medication may contribute. Lastly, radiographs obtained prior to stent placement were obtained using positive pressure ventilation. Once the patient was anesthetized, positive pressure ventilation was performed to evaluate tracheal diameter for stent selection, but for the purposes of length measurement and comparison, positive pressure ventilation could not be achieved once patients were extubated or in awake patients during initial or follow-up exams. For the purposes of appropriate stent selection, however, 10–20% of the diameter was added to the measurements, and this has been shown to be an adequate correction in a recent study comparing radiographic and computed tomography measurements of tracheal dimensions.[21]

Conclusion

In summary, for patients that have become recalcitrant to conservative management of tracheal collapse, endoluminal stenting can prolong survival significantly. Relative positioning of the stent within the tracheal lumen and proportion of the tracheal length it occupies does not appear to affect incidence of complications or long-term survival. Based on the data herein, complications occurred in 37% of patients, for whom a median survival time of 208 days was found. For patients who did not experience a complication, a median survival of 543 days was noted; these survival times were not found to be significantly different. For cases of granuloma formation adjacent to the stent, placing an additional stent was successful at affording additional survival time.

FOOTNOTES

[a] Vet Stent—Trachea; Infiniti Medical, LLC , Malibu, California

[b] DexStent-TN; Dextronix Inc., Pheonix, Arizona
[c] SPSS-PASW, version 17; SPSS: An IBM Company, Somers, New York

REFERENCES

1. Payne JD, Mehler SJ, Weisse C. Tracheal Collapse. *Compend Contin Educ Pract Vet*. 2006;28:373–82.
2. Sun f, Uson J, Ezquerra J, et al. Endotracheal stenting therapy in dogs with tracheal collapse. *The Vet J*. 2008;175:186–93.
3. Hedlund CS. Surgery of the Upper Respiratory Tract. In: Fossum TW, ed. *Small Animal Surgery*. 3rd ed. St. Louis: Elsevier; 2007:847–51.
4. Sura PA, Durant, AM. Trachea and bronchi. In: Tobias KM, Johnston SA, eds. *Veterinary Surgery Small Animal*. Vol 2. St Louis: Elsevier; 2007: 1735–51.
5. Durant AM, Sura P, Rohrbach B, et al. Use of Nitinol Stents for End-Stage Tracheal Collapse in Dogs. *Vet Surg*. 2012;41:807–17.
6. Becker W, Beal M, Stanley B, et al. Survival after Surgery for Tracheal Collapse and the Effect of Intrathoracic Collapse on Survival. *Vet Surg*. 2012;41:501–6.
7. Macready DM, Johnson LR, Pollard RE. Fluoroscopic and radiographic evaluation of tracheal collapse in dogs: 62 cases (2001–2006). *J Am Vet Med Assoc*. 2007;230:1870–6.
8. White RAS, Williams JM. Tracheal collapse in the dog- is there really a role for surgery? A survey of 100 cases. *J Small Anim Pract*. 1994;35: 191–6.
9. Tangner CH, Hobson HP: A retrospective Study of 20 Surgically Managed Cases of Collapsed Trachea. *Vet Surg*. 1982;11:146–9.
10. Buback JL, Booth HW, Hobson, HP. Surgical treatment of tracheal collapse in dogs: 90 cases (1983–1993). *J Am Vet Med Assoc*. 1996;208: 380–4.
11. Chisnell HK, Pardo AD. Long-Term Outcome, Complications, and Disease Progression in 23 Dogs After Placement of Tracheal Ring Prostheses for Treatment of Extrathoracic Tracheal Collapse. *Vet Surg*. 2015;44:103–13
12. Hobson HP. Total Ring Prosthesis for the Surgical Correction of Collapsed Trachea. *J Am Anim Hosp Assoc* 1976;12:822–8.
13. Gellasch KL, Da Costa Gomez T, McAnulty JF, et al. Use of intraluminal nitinol stents in the treatment of tracheal collapse in a dog. *J Am Vet Med Assoc*. 2002;212:1719–23.
14. Moser JE, Geels JJ. Migration of extraluminal tracheal ring prostheses after tracheoplasty for treatment of tracheal collapse in a dog. *J Am Vet Med Assoc*. 2013;243:102–4.
15. Mittleman E, Weisse C, Mehler SJ, et al: Fracture of an endoluminal nitinol stent used in the treatment of tracheal collapse in a dog. *J Am Vet Med Assoc*. 2004;225:1217–21.
16. Moritz A, Schneider M, Bauer N. Management of Advanced Tracheal Collapse in Dogs Using Intraluminal Self Expanding Biliary Wallstents. *J Vet Intern Med*. 2004;18:31–42.
17. Kim JY, Han HJ, Yun HY, et al: The safety and efficacy of a new self expandable intratracheal nitinol stent for the tracheal collapse in dogs. *J Vet Sci*. 2008;9:91–3.
18. Sura PA, Krahwinkel DJ. Self-expanding nitinol stents for the treatment of tracheal collapse in dogs: 12 cases (2001–2004). *Journal J Am Vet Med Assoc*. 2008;232:228–36.
19. Hosmer DW, Lemeshow S, May S. *Applied Survival Analysis: Regression Modeling of Time to Event Data*. 2nd ed. Hoboken, NJ: Wiley; 2008.
20. Johnson LR, Pollard RE. Tracheal Collapse and Bronchomalacia in Dogs; 58 Cases (7/2001-1/2008). *J Vet Intern Med*. 2010;24:298–305.
21. Montomery JE, Mathews KG, Marcellin-Little DJ, et al. Comparison of Radiography and Computed Tomography for Determining Tracheal Diameter and Length in Dogs. *Vet Surg*. 2014;43:1–5.
22. Brown SA, Williams JE, Saylor DK. Endotracheal Stent Granulation Stenosis Resolution after Colchicine Therapy in a Dog. *J Vet Intern Med*. 2008;22:1052–5.