Tracheal collapse, or tracheal chondromalacia, is a progressive, degenerative condition of the hyaline cartilage rings that support the tracheal lumen. Weakening of the trachealis muscle contributes to the loss of tracheal lumen during different phases of respiration. The resulting clinical syndrome typically manifests as a “goose honk” cough with varying degrees of dyspnea and is most commonly identified in toy breed dogs. Conservative management techniques and medical management can be useful to palliate clinical signs for years, however more aggressive treatment is often required for those animals that eventually fail these more conventional treatments.

Candidates for surgical or interventional therapy are those that have failed aggressive conservative medical management. Various surgical techniques have been described, however the currently recommended surgical therapy is extraluminal polypropylene prosthesis. This technique involves placing extraluminal support rings around the trachea during an open cervical approach and has a reported 75%-85% overall success rate in 90 dogs for reducing clinical signs.¹ This procedure is now without complications however. The same study reported that 5% of animals died peri-operatively, 11% developed laryngeal paralysis from the surgery, 19% required permanent tracheostomies, and ~23% die of respiratory problems with a median survival of 25 months. More importantly, only 11% of the dogs in this study had intra-thoracic tracheal collapse (all dogs had extrathoracic tracheal collapse). The authors advised against this technique in animals with intra-thoracic tracheal collapse as the associated morbidity was unacceptably high.

Humans can develop tracheal collapse as children (chondromalacia) or can have tracheal stenosis (following lung transplantation) or tracheal compression from malignancies. The current therapy in humans is intraluminal stenting with a number of FDA-approved tracheobronchial stents available. The advantages of intraluminal tracheal stenting include minimal invasiveness, shorter anesthesia times, and access to the entire intrathoracic trachea. Disadvantages include tracheal irritation and possibly cycling of the metallic stent when crossing a high-motion area such as the thoracic inlet. Two studies report clinical improvement rates in 75%-90% of animals treated with intraluminal SEMS have been reported.² ³ Immediate complications were typically minor although there was a reported peri-operative mortality rate of approximately 10%, a rather high figure compared to the author’s experience. Late complications included stent shortening, excessive granulation tissue, progressive tracheal collapse, and stent fracture.

**FIGURE 1:** Nitinol mesh, Stainless steel mesh, and braided nitinol stents
Self-Expanding Metallic Stents (SEMS)

Stainless Steel (Elgiloy): The first description of clinical use of self-expanding metallic stents (SEMS) in veterinary patients was in abstract form in 2000. Stainless Steel (or more appropriately, Elgiloy) SEMS such as the Wallstent (Boston Scientific) (Figure 1B) have many advantages over the BEMS, particularly in the trachea. These stents are very flexible with sufficient recoil, they are reconstrainable and repositionable if they have not been fully deployed, and they come in appropriate lengths to treat collapse of the entire trachea. These stents are on relatively narrow delivery systems permitting deployment through the endotracheal tube as well. Wallstents were placed in 17 dogs with approximately 75% fair to excellent results. As expected with a self-expanding stent slightly over-sized and appropriately measured in the anesthetized patient, migration was not noted in any case. Complications included procedure-associated death (2/17; 12%), granulation tissue formation (2/17; 12%) and appeared to be more common in elderly patients, those with longer stents, and those dogs with concurrent heart disease. Three dogs (3/17; 18%) required additional surgeries to correct complications. Although the follow-up was relatively short (1-23 months), results were encouraging for patients that had failed medical management and were not good surgical candidates. More recently, a report on 24 Wallstents placed for tracheal collapse indicated improvement in clinical signs in 90% of dogs with the exception of 2 dogs that died due to complications of the procedure. With a median follow-up time of 2 months, approximately 25% stent shortening occurred in 15 dogs (15/18; 83%) which was associated with clinical signs in 2 dogs. Five dogs (5/18; 28%) developed a steroid-responsive granuloma which was severe in three dogs. While the Wallstents results were encouraging, the granuloma formation was not always responsive to steroids in this author’s experience. In addition, these granulomas typically occurred at the ends of the stents which created concern about the sharp ends of the loose wires in this stent’s design.

Nitinol (Nickel Titanium Alloy): In the 1960’s, a novel metallic equiatomic alloy of Nickel and Titanium was developed at the Naval Ordinance Laboratory (Ni-Ti-NOL). This metal has revolutionized the field of shape-memory metals in that this simple material has properties very different from traditional metals used for stent design. Unlike stainless steel, nitinol exhibits “biased stiffness” meaning it does not have a fixed modulus of elasticity. The modulus of elasticity (Figure 2) changes because nitinol can exist in two separate phases (austenitic and martensitic phases) that can vary due to temperature changes or stress changes. In addition, the temperature at which these changes take place can be programmed (to some degree) such that the stent designer can take advantages of the different characteristics of the phases. Nitinol is extremely elastic as well. Conventional metals have some inherent elasticity based upon stretching of the atomic bonds. Stainless steel can stretch 0.3% and still return to its initial shape (elastic deformation). Nitinol is able to stretch over 10% and still return to its original shape and dimensions due the phase changes that take place. Nitinol also exhibits excellent biocompatibility, resistance to corrosion and has a similar
galvanic potential to stainless steel so the metals could (technically) be near one another if necessary. The use of nitinol for medical stent manufacturing began in the 1990’s and has largely displaced other metals for this purpose. Tubes of nitinol are laser-cut into stent designs and then super-cooled to be collapsed into low-profile delivery systems. Upon warming to room or body temperature, the nitinol phase change occurs and the stent wants to resume its pre-programmed shape and size. These stents are self-expanding but do not exhibit the foreshortening problem of the stainless steel stent predecessors whose design necessitates foreshortening in order to fit within the delivery system.

We placed between 10 and 15 laser-cut nitinol stents within canine collapsing tracheas and were disappointed with the relatively high rate of stent fracture that occurred. Interestingly, the majority of fractures occurred at the level of the thoracic inlet suggesting perhaps a higher rate of motion or instability at this location. In one case, a tracheal resection and anastomosis was performed at the thoracic inlet with acceptable results afterwards in which basically two separate stent fragments were present in the cervical and thoracic tracheas. As such, we began placing two separate stents— one in the cervical trachea and one in the intra-thoracic trachea – to allow cycling to occur inbetween the individual stents. Unfortunately, these resulted in an unacceptable failure (fracture) rate as well.

Nitinol – Wire-wound (mesh) (Figure 1A) or Braided (Figure 1C): Following the high fracture rate encountered with the laser-cut nitinol stents, we decided to return to the wire mesh design in which the fracture rate was not excessive but to substitute the stainless steel for the more fatigue-resistant nitinol. In addition, a design was chosen in which the stent was made from a single wire wound upon itself resulting in rounded rather than sharp edges in order to reduce the potential for granuloma/inflammation at the stent ends. Subjectively, this stent resulted in reduced granuloma formation but the stent fracture rate (although reduced) was still unacceptable for routine use. Using a combination of mathematical equations and V-block compression testing, a modified nitinol wire wound stent was developed using increased wire diameter. This resulted in >200% the radial resistive force of a comparable-sized wallstent but only about 40% higher chronic outward force (due to the inherent biased stiffness of the nitinol metal). Although no randomized controlled studies have yet been performed, this stent modification has resulted in subjectively fewer stent fractures in this author’s experience. In addition, periodic increases in the wire gauge has further increased the stent’s resistance to fatigue and fracture.

Stent Fracture

Stent fracture remains a serious consequence following tracheal stent placement in dogs with end-stage tracheal collapse. While there remains insufficient knowledge of the causes and risk factors for the development of tracheal stent fracture, the author feels stent fractures are more common in those patients with continued severe coughing; therefore one might expect a higher rate of stent fracture in those patients with concurrent bronchial collapse, other lower airway disease, concurrent heart disease, or those not receiving adequate medical management (anti-tussives and anti-inflammatories). In a recent retrospective study (currently unpublished data), approximately 24% of a variety of tracheal stents resulted in fracture. Those treated with restenting responded better than those treated medically with MST of 1.3 yrs and 4 mos, respectively. From the time of restenting, those dogs lived a median of 1.3 years longer. Ultimate survival time in the stent fracture patients from initial stenting was 2.2 years including
all treatment groups which is not dissimilar from other reports of tracheal stenting in dogs NOT have a stent fracture.

*Discerning between various forms of “Tracheal Collapse”*

The term “tracheal collapse” is used commonly and includes numerous different forms of tracheal lumen narrowing varying from those patients with severe but focal floppy, redundant dorsal tracheal membranes, to those patients with diffuse chondromalacia of the trachea and bronchi. Abnormal tracheal ring conformation is also included. These dogs also have various clinical presentations and manifestations of their diseases including one or more of the following: coughing, dyspnea, honking, raspy breathing, or any combination of the above. Encompassing a number of different disease manifestations under the same heading has complicated the clinical picture in these patients. This has also resulted in difficulty in providing our clients with a clear prognosis following tracheal stent placement. The author is currently attempting to further classify the different types of tracheal collapse into separate categories in order to better provide prognostic information for our clients. Currently, it is the author’s belief that those patients with honking and dyspnea but WITHOUT coughing seem to respond more favorably to tracheal stenting. Those dog with bronchial collapse and other comorbidities seem to have worse prognoses but can still respond favorably to tracheal stenting for an unknown length of time.

*Tracheal Malformations*

Tracheal malformations in which the tracheal cartilage is firm but abnormally developed (“W”-shaped rather than “C” shaped) have become more apparent recently. Tracheal stenting in these patients is more complicated as the expanded stent often leaves a “gutter” or incompletely filled area where there is no contact between the stent and tracheal wall. This can lead to mucus, fluid or tissue accumulation and subsequent chronic coughing and other problems. These can often been identified on pre-stent radiographs if the operator is aware. Concurrent tracheoscopy is recommended in these patients and possible balloon dilation of the stent to ensure adequate trachea-stent contact when possible. The author has had to use two stents in one patient to provide sufficient outward force to restore tracheal lumen patency.

*The Future Tracheal Stent ?*

As for suture material for instance, the search for the “perfect” tracheal stent continues. It is this author’s opinion that our current tracheal stents are adequate for salvage treatment of intractable symptoms associated with tracheal collapse that have failed medical and conservative management. In addition, the current stents are acceptable for use in most cases of malignant tracheal obstructions and even many cases of benign tracheal narrowing. The ideal tracheal stent will need to satisfy many criteria and there will be trade-offs required. Investigation into the next generation of tracheal stents will need to simultaneously consider the stent design, wire analysis, and tracheal environment as all these factors play an important role in stent failure. Current evaluation of segmented stents and tapering stents to more closely approximate the natural environment of the trachea are occurring. It is the author’s opinion that the following criteria will be important in development of the next generation of veterinary tracheal stent:

- Increased RRF without excessive COF – favors nitinol
✓ Increased Stiffness (more similar to normal trachea)
✓ Segmented Design for reduced metal fatigue
✓ Precision Deployment: Non-foreshortening
✓ Endoscopically-placed in the future?
✓ Anatomical Apposition so tapered and ovoid design
✓ Reduced Wire Rubbing

References: