Idiopathic laryngeal paralysis is a common disorder in large-breed dogs that can result in life-threatening airway obstruction. This disorder is often treated by unilateral surgical fixation (laryngoplasty) of the left arytenoid cartilage in an abducted (open) position via a lateral approach (a "tie-back procedure"). In retrospective case series, 1–7 0% to 32% of surgically treated dogs have developed aspiration pneumonia after this procedure. Although permanently opening the glottis is likely the largest contributor to the development of potentially fatal aspiration pneumonia after undergoing a tie-back procedure, surgical access to the larynx may contribute to this complication. The standard surgical approach involves transecting muscles that contribute to the upper esophageal sphincter, and thus play a critical role in the act of swallowing and in preventing esophageal reflux.1–4,8,9 This approach also involves transecting the cricoarytenoideus dorsalis muscle, which may increase the risk of damaging local innervation (Figure 1) to ipsilateral laryngeal and pharyngeal muscles as well as the mucosa of the larynx and pharynx. A muscle-sparing laryngoplasty technique thus has the potential to decrease the risk of aspiration in the postoperative period.7,8

We have performed the muscle-sparing technique in canine cadavers and found that, in some cases, transection of the thyropharyngeus muscle and the cricoarytenoideus dorsalis muscle was not required to gain access to the cricoarytenoid joint or to perform arytenoid lateralization, and that the exposure gained can be similar to that when using.
standard technique. This technique is similar to the abductor muscle prosthesis technique reported by Payne, except that the cricoarytenoid joint is opened. Also, in the cases reported by Payne et al., the thyropharyngeus muscle was transected in an unspecified number of dogs.

Our study evaluated fluoroscopically swallowing function and potential aspiration of liquid barium and canned food containing barium into the upper airway before and after a lateral surgical approach to the larynx. This is the first study that we are aware of to determine whether the standard surgical approach for treating canine laryngeal paralysis alters swallowing function in the immediate postoperative period. The goal of this study was to determine whether muscle-sparing laryngoplasty results in fewer changes in swallowing function compared to standard surgical treatment for laryngeal paralysis.

We hypothesized that a muscle-sparing laryngoplasty would result in less severe changes in swallowing function when compared to a standard laryngoplasty technique.

Materials and Methods

Animals

Twelve sexually intact male Beagles were used in this study. Sex and neuter status were inclusion criteria to decrease potential variability. The study was approved by North Carolina State University’s Institutional Animal Care and Use Committee.

Experimental protocol

Dogs in the 2 treatment groups (groups A and B, n = 4 each) were assigned randomly by drawing of sealed envelopes. Control group dogs (group C,
n = 4) were added to the study after data collection from treatment group dogs. All dogs underwent a 2-week acclimation period with twice-daily feeding and training sessions to get them accustomed gradually to being placed in lateral recumbency after a 12-hour fast. Preoperative swallowing studies were performed with the dogs initially in sternal recumbency. Dogs were fed barium liquid (Liquid Polibar, barium sulfate suspension; E-Z-EM Canada Inc) while we recorded swallowing and esophageal motility fluoroscopically. Three swallows that resulted in an esophageal bolus were recorded at 30 frames/second for each dog (Neurostar Plus Polytron T.O.P. 2.5 Biplanar Fluoroscopy, Siemens). Each bolus was followed until it entered the stomach. Barium liquid mixed with canned dog food (Science Diet Maintenance, Hill's Pet Nutrition, Inc) formed into 1-inch meatballs was then fed while still in sternal recumbency. Three swallows were recorded as with the liquid-swallowing study. This process of recording swallowing of liquid followed by meatballs was then repeated with the dog in right lateral recumbency for dogs in groups A and B. Group C dogs did not tolerate feeding in lateral recumbency.

The day after the preoperative swallowing studies, the dogs were anesthetized as follows. Dogs were premedicated with acepromazine (0.025 mg/kg, IV) and hydromorphone (0.05 mg/kg, IV). A cephalic venous catheter was placed. General anesthesia was induced with propofol (6 mg/kg, IV to effect) and the dogs were intubated with auffed endotracheal tube. Anesthesia was maintained with isoflurane (1% to 3% to effect) in oxygen. Lactated Ringer solution (6 to 10 mL/kg/h, IV) was administered throughout the procedure.

All surgical procedures were performed by a single, boarded veterinary surgeon (KGM). After induction, the left side of the neck was clipped and scrubbed with chlorhexidine and alcohol. The dog was then moved into the operating room and placed in right lateral recumbency. A second sterile scrub of the neck was performed. The surgical site was draped and a 6- to 8-cm longitudinal skin incision was made directly over the lateral aspect of the larynx. Dissection was continued through the platysma muscle and the underlying adipose tissue to expose the thyropharyngeus muscle.3 In group A dogs (standard laryngoplasty), the thyropharyngeus muscle was incised at its attachment to the dorsolateral thyroid cartilage perpendicular to muscle fiber orientation. Visible branches of the cranial and caudal laryngeal nerves (Figure 1) were spared and retracted gently if needed throughout the procedure. The cricothyroid articulation was not disrupted. The intact cricopharyngeus muscle was retracted caudally so that the caudal margin of the cricoid cartilage was visible. The cricoarytenoideus dorsalis muscle was transected just caudal to the muscular process of the arytenoid cartilage, the cricoarytenoid joint opened, and the arytenoid cartilage lateralized with two 0-polybutester (Novafil, Coviden) cricoarytenoid sutures. When tying these sutures, a spring scale was attached to the caudal arm of the suture and the suture ends were pulled until 1 kg of force was applied (deemed to be similar to the tension applied in clinical cases). An assistant then grasped the suture at the level of the knot with a needle holder while the second overhand throw was placed, allowing completion of the first square knot without loss of suture tension. The same amount of force was applied to the second (dorsal) suture. In group B dogs (muscle-sparing laryngoplasty), the dorsoventrally oriented muscle fibers of the thyropharyngeus muscle were bluntly separated parallel to fiber orientation (ie, vertically) just caudal to the muscular process. Visible nerves were spared and retracted if needed throughout the procedure. The cricoarytenoideus dorsalis muscle was also spared by bluntly dissecting ventral to the muscle to enter the cricoarytenoid joint. The intact muscle was grasped just caudal to its insertion on the muscular process to allow opening of the joint. The left arytenoid cartilage was lateralized with the same amount of tension applied to the sutures in group A. Group C dogs had an identical surgical approach that ended just lateral to the thyropharyngeus muscle. The muscle was not transected and arytenoid lateralization was not performed in this group. Group A and B dogs had the thyropharyngeus muscle closed, and all dogs had the subcutaneous tissues closed in a routine manner while taking care to avoid incorporation of visible nerves in the sutures. Prior to recovery, the skin incision was infiltrated with 2 mg/kg 0.5% bupivacaine, and each dog received carprofen (4 mg/kg, SC). Each dog was given buprenorphine (0.05 mg/kg, SC) at recovery, and again 8 and 16 hours postoperatively. Each dog was fed after recovery from anesthesia and then held off food for 12 hours prior to the postoperative swallowing studies.

Twenty-four hours after surgery, fluoroscopic swallowing studies were performed in an identical manner to those done preoperatively. Group A and B dogs were euthanized with pentobarbital (430 mg/5 kg, IV) after completion of the postoperative fluoroscopic studies. The larynges were harvested and photographed with a calibration marker in the field. Control dogs were not euthanized.

Outcome measures

Each video was graded for upper airway aspiration and given a score of 0 to 3 (where 0 = none, 1 = mild, 2 = moderate, and 3 = severe) by a boarded radiologist (JB) who was unaware of treatment group. Videos were graded similarly for abnormalities in oral bolus formation (0 = clinically normal, 1 = delayed or difficult, or 2 = unable to form bolus), pharyngeal contraction (0 = clinically normal, 1 = weak with complete passage of bolus, 2 = weak with incomplete passage, or 3 = absent), cricopharyngeal function (0 = clinically normal, 1 = inconsistent or delayed without aspiration, 2 = inconsistent or delayed with aspiration, or 3 = achalasia or lack of opening), and for abnormalities in esophageal motility (0 = bolus completely or almost cleared with primary contractile wave and completely cleared with secondary wave, 1 = bolus not cleared with primary
Laryngeal morphometry

Glottic area was calculated from the photographs using morphometric software (Adobe Photoshop CS6, Adobe Systems Inc; Apple Mac OS X v. 10.6.8 and Apple iMac, Apple Inc).

Statistical analysis

A generalized linear model was used to analyze the relationship between swallowing scores and surgical treatment. The response variable was the number of the 4 feeding combinations (sternal vs lateral position while being fed liquid vs canned food) that dogs had motility impairment (defined as a swallowing score $\geq 2$). The Fisher exact test was performed on 2-way contingency tables to test for a difference in the distribution of esophageal scores between surgery types, to test for a difference between esophageal scores before and after surgery (separated by type of surgery), and to test for a difference in esophageal scores between types of surgery separated by type of food (SAS, version 9.3; SAS Institute Inc). Mean glottic area was compared between groups A and B using a Student $t$ test. Values of $P \leq .05$ were considered statistically significant.

Results

Study dogs were 2 to 7 years old with a median weight of 10.4 kg (range, 7.3 to 17.8 kg). All preoperative fluoroscopic studies were clinically normal (score 0) in regard to oral, pharyngeal, and cricopharyngeal function. There was no evidence of aspiration in any study. Preoperative esophageal motility was also considered clinically normal (score 0/4) except for scores of 1 assigned to 1 sternal liquid study in a group A dog, 1 sternal canned food study and 1 lateral liquid study in a second group A dog, 1 lateral liquid study in a third group A dog, and 3 sternal liquid studies in group C dogs. Presurgical swallowing scores were not included in the model because none of the dogs had scores of 2 or higher prior to surgery.

Postoperative fluoroscopic studies in regard to oral, pharyngeal, and cricopharyngeal function were clinically normal (score 0) with the exception of 1 group B dog that received a pharyngeal score of 2 for 1 lateral canned study, and 1 group A and 1 group B dog that each received a cricopharyngeal score of 2 for 1 sternal liquid study. Aspiration of contrast into the trachea was noted in 2 group A dogs that each received a score of 1 for 1 sternal liquid study, 1 group B dog that received an aspiration score of 1 for a lateral liquid study, and a second group B dog that received a score of 1 for a sternal liquid study.

There were 2 dogs in group A and 2 dogs in group B that had postoperative esophageal motility scores $\geq 2$, indicative of moderate to severe postoperative cervical esophageal paresis (Figure 2, Supplementary Video S1). Postoperative esophageal motility scores of 2 and 3 for canned food were assigned in both recumbencies for the 2 affected dogs in group A. For postoperative group A liquid studies, scores of 2 and 3 were assigned to 1 dog in sternal recumbency and 1 dog in lateral recumbency, respectfully. Postoperative esophageal motility scores of 2 and 4 for canned food were assigned in both recumbencies for the 2 affected dogs in group B. For postoperative group B liquid studies, scores of 2 and 4 were assigned to the 2 affected dog in lateral recumbency, whereas 1 dog had a score of 4 in sternal recumbency. Although no dog had clinical evidence of aspiration pneumonia postoperatively, 1 group A dog regurgitated immediately after the postoperative fluoroscopic study. Thoracic esophageal motility was unaffected. There was no statistically significant ($P = .72$) difference between surgical groups with regard to the distribution of postoperative esophageal motility scores in the generalized linear model. Results of the Fisher exact tests showed no difference in postoperative esophageal motility scores between the 3 groups for liquid barium ($P = .47$) or for canned food ($P = .39$). The difference in the distribution of esophageal motility scores before and after surgery for group A (standard arytenoid...
lateralization) approached statistical significance (Fisher exact test, $P = .054$). There was a significant (Fisher exact test, $P < .001$) difference in the distribution of esophageal motility scores before versus after surgery for group B (muscle-sparing laryngoplasty). Control group dogs had no change in any score between pre- and postoperative studies.

**Laryngeal morphometry**

Gross findings at necropsy failed to identify any differences between groups A and B. All larynges were deemed to be lateralized adequately and equally. There was no difference between these groups with regard to glottic luminal area ($P = .25$).

**Discussion**

Postoperative cervical esophageal paresis in 2/4 dogs in each treatment group was both unexpected and moderate to marked in its severity. This change was statistically significant in group B, and approached significance in group A. Esophageal dysfunction of this severity could increase the risk of postoperative aspiration pneumonia in canine patients treated for laryngeal paralysis via a lateral approach to the larynx. To our knowledge, marked dysfunction of the cervical esophagus in the immediate postoperative period solely as a result of the surgical procedure (arytenoid lateralization) has not been reported previously in dogs. Further study to determine the frequency, specific cause, and duration of esophageal dysfunction in dogs clinically affected by idiopathic laryngeal paralysis is warranted.

The results of preoperative swallowing studies have been reported previously for dogs with laryngeal paralysis, and a subset were documented to have decreased esophageal motility. Twenty-seven of 40 dogs had some degree of esophageal motility impairment and 23/40 dogs had evidence of gastroesophageal reflux preoperatively in these studies. Follow-up swallowing studies in these dogs was either not performed, or occurred 1 month postoperatively. In a study of dogs, 2/8 dogs with clinically normal preoperative studies had cervical esophageal dysmotility at the 1-month postoperative recheck examination. Immediate postoperative swallowing studies were not reported. The immediate postoperative cervical esophageal motility impairment seen in our study in clinically normal dogs may be even more pronounced in dogs with preexisting esophageal dysfunction, but further study is required.

Interestingly, 2/4 dogs in each treatment group in our study were moderately to markedly affected by cervical esophageal paresis. There was no change in esophageal motility in control dogs (lateral studies not performed in this group). It has been proposed that a muscle-sparing technique may decrease the risk of aspiration pneumonia because there would be less surgical trauma to the muscles of the upper esophageal sphincter, especially the thyropharyngeus muscle. Upper esophageal sphincter function in our study appeared unaffected radiographically by the surgical approach, but whether a muscle-sparing approach would benefit clinical patients needs further study, including manometric evaluation of sphincter and esophageal pressures, because both pharyngoesophageal nerve transection and cricopharyngeal myotomy have been shown to decrease pharyngoesophageal pressure in clinically normal dogs. One retrospective study evaluated 22 dogs in which the cricopharyngeal muscle and 75% of the thyropharyngeal muscle was spared from transection, but swallowing studies were not performed. The striking changes in cervical esophageal function in both groups in our study seem to indicate there is at least temporary injury to either the afferent or efferent nerves of the cervical esophagus in some dogs following arytenoid lateralization regardless of whether a muscle-sparing approach is used.

Sensory fibers innervating the cervical esophagus have been shown to run within the cranial laryngeal nerve, whereas motor function is supplied primarily via the pharyngoesophageal nerve. Both nerves are branches of the vagus nerve, which arise at different locations along the vagus. The thoracic esophagus is innervated by the recurrent (caudal) and para-recurrent laryngeal nerves—also branches of the vagus. They may also contribute in part to the innervation of the caudal cervical esophagus. Thoracic esophageal function appeared to be unaltered in the dogs in our study with postoperative cervical esophageal paresis.

The cranial laryngeal nerve runs dorsoventrally cranial to the thyropharyngeal muscle before splitting into external and internal branches. The external branch runs in a craniocaudal direction along the lateral surface of the thyropharyngeal muscle (Figure 1). Thyropharyngeal muscle transection when performed just dorsal to the thyroid cartilage, as is common practice during laryngoplasty, is close to—and parallel to—this nerve branch. The pharyngoesophageal nerve also runs in a craniocaudal direction and lays lateral to the dorsal aspect of the thyroid cartilage. This nerve can be very fine, and can have variations, making it difficult to locate without the assistance of electrical stimulation, which results in cervical esophageal contraction. Both the external branch of the cranial laryngeal nerve and the pharyngoesophageal nerve could be at risk of damage during either vertical separation of thyropharyngeal muscle fibers during a muscle-sparing laryngoplasty or during retraction of the thyropharyngeal muscle during standard laryngoplasty.

The internal branch of the cranial laryngeal nerve lays cranial to the cricoarytenoideus dorsalis muscle (Figure 1). The terminal end of the recurrent laryngeal nerve, also called the caudal laryngeal nerve, runs deep to the cricopharyngeal muscle after passing the cranial pole of the thyroid gland. It then runs just ventral to the cricoarytenoideus dorsalis muscle, and gives off branches to this muscle prior to innervating all other laryngeal muscles except for the cricothyroideus muscle. A communicating branch between the internal branch of the cranial laryngeal nerve, and the caudal laryngeal nerve, is located at

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the dorsal aspect of the cricoarytenoideus dorsalis muscle. It is possible that these branches of the cranial or caudal laryngeal nerves may be damaged during either retraction or transection of the cricoarytenoideus dorsalis muscle, or possibly during tying of the lateralization sutures if the nerves become entrapped or compressed by these sutures. Damage to the recurrent laryngeal nerve should not affect cervical esophageal function, as shown in dogs with either bilateral vagal transection at the level of the larynx or bilateral recurrent laryngeal nerve transection at the base of the neck.12,13 In one study,12 there was no recovery of cervical esophageal motility 8 weeks after bilateral pharyngoesophageal nerve transection in 6 dogs. In another,15 bilateral transection of the pharyngoesophageal nerve at the level of the larynx resulted in cervical esophageal paralysis with barium retention and regurgitation in 2 dogs and 3 cats. As in our study, the thoracic esophagus remained unaffected. Three to 5 weeks later, 4/5 animals were normal radiographically, whereas 1 dog still had slight retention of food in the cervical esophagus 10 weeks postoperatively. Recovery was hypothesized to be a result of input from the recurrent laryngeal nerves.13 If this were true, and if pharyngoesophageal nerve injury during arytenoid lateralization were to occur in clinical cases with preexisting recurrent laryngeal nerve atrophy, then recovery from cervical esophageal dysfunction may be less likely to occur. In our study, unilateral nerve injury, if it occurred, may have been sufficient to result in the postoperative cervical esophageal changes noted.

Last, it has been shown that lateral recumbency during swallowing studies can increase cervical esophageal transit time compared to sternal recumbency.15 It has been common practice to perform swallowing studies with canine patients in lateral recumbency,13,18 even though sternal recumbency more closely reproduces body position during eating; therefore, we recorded data with Group A and B dogs in both positions. There did not appear to be any difference in results based on body position in our study, but the small sample size precludes further comparison. Control dogs would not tolerate feeding in lateral recumbency. Feeding in sternal recumbency is less stressful to the patient and resulted in adequate documentation of swallowing function.

Limitations of this study include the small sample size, lack of lateral swallowing studies in control dogs, and use of Beagles, which are smaller than breeds typically treated for laryngeal paralysis. Although suture tension was standardized between the 2 treatment groups, it cannot be compared to previous studies17,18 because different scales were used. Using the spring scale in our study, 1 kg of force was deemed similar to the tension that would be applied during arytenoid lateralization in a clinical case. There were several scores of 1 for esophageal motility even preoperatively. We were strict in that if there was a delay in any one of the swallows, but clinically normal on subsequent swallows, the esophageal motility was given a score of 1. In the case of liquid swallows, this—in some cases—may have been the result of a smaller bolus volume. In addition, increased cricopharyngeal scores were seen postoperatively in 3 treated dogs. A larger sample size will be needed to determine whether this is an issue in a prospective clinical study.

It will be important to determine whether immediate postoperative esophageal motility changes occur in clinical patients. If present, the underlying mechanism for postoperative esophageal dysmotility needs to be investigated, as well as the duration of impairment in those dogs in which it occurs. The cervical esophageal paresis identified in both study groups could increase the risk of postoperative aspiration pneumonia in canine patients treated for laryngeal paralysis via a lateral approach to the larynx. We found no evidence to support our hypothesis that muscle-sparing laryngoplasty results in less severe changes in swallowing function when compared to a standard laryngoplasty technique. Further study to determine the frequency, specific cause, and duration of esophageal dysfunction is warranted.

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Supplementary Materials
Supplementary materials are posted online at the journal website: avmajournals.avma.org