In vitro evaluation of anatomic landmarks for the placement of suture to achieve effective arytenoid cartilage abduction by means of unilateral cricoarytenoid lateralization in dogs

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Objective—To evaluate anatomic landmarks to define the ideal suture placement location to achieve appropriate and consistent arytenoid cartilage abduction via unilateral cricoarytenoid lateralization (UCL) in dogs.

Sample—6 cadaveric canine larynges.

Procedures—Laryngeal airway resistance (LAR) was determined for each specimen before (baseline) and after suture placements with the epiglottis open and closed. To achieve UCL, suture was placed through the cricoid cartilage just caudal to the cricoarytenoid articulation (suture placement position [SPP] 1), one-fourth of the distance caudally between the cricoarytenoid and cricothyroid articulations (SPP 2), and three-fourths of the distance caudally between the cricoarytenoid and cricothyroid articulations (SPP 3). The LAR was again calculated after tensioning of each suture separately.

Results—With a closed epiglottis, median LAR was 30.0, 20.4, 11.4, and 3.3 cm H_2O/L/s at baseline and SPPs 1, 2, and 3, respectively. After UCL at SPP 1, LAR with the epiglottis closed was not significantly different from that at baseline. With an open epiglottis, median LAR was 2.0, 0.4, 0.2, and 0.0 cm H_2O/L/s at baseline and SPPs 1, 2, and 3, respectively. After UCL at SPPs 1, 2, or 3, LAR with an open epiglottis was significantly lower than that at baseline.

Conclusions and Clinical Relevance—Results indicated that placement of suture through the cricoid cartilage at the caudal border of the cricoarytenoid articulation was appropriate to sufficiently reduce LAR without increasing the risk of aspiration pneumonia through overabduction of the arytenoid cartilage. (*Am J Vet Res* 2014;75:602–606)

Laryngeal paralysis is a commonly diagnosed condition in dogs that is characterized by an inability to abduct 1 or both arytenoid cartilages.[1,2] This condition can be congenital or acquired, with the acquired form being more common.[2–4] Surgical treatment of laryngeal paralysis focuses on increasing the laryngeal lumen size to decrease upper airway resistance. Several surgical techniques have been described, including unilateral arytenoid cartilage lateralization, bilateral arytenoid cartilage lateralization, partial arytenoidectomy, ventriculocordectomy, castellated laryngofissure, and permanent tracheostomy.[5–9] Unilateral cricoarytenoid lateralization involves affixing one of the arytenoid cartilages in an abducted position and is currently regarded as the treatment of choice for dogs with this condition.[5,7,10] Although the procedure is successful in decreasing upper airway resistance, it has been associated with an increased risk of aspiration pneumonia.[5–7,10] This is thought to be due to the inability of the epiglottis to completely cover the rima glottidis as a result of overabduction of the arytenoid cartilage.[11,12] This leaves affected patients at higher risk of inhaling ingesta and water during feeding or aspirating fluid during episodes of vomiting or regurgitation.

Abbreviations

LAR	Laryngeal airway resistance
SPP	Suture placement position
UCL	Unilateral cricoarytenoid lateralization

Ideally, during unilateral arytenoid cartilage lateralization, a surgeon would abduct the arytenoid cartilage to such an extent that upper airway resistance during breathing would be markedly reduced, yet the proportion of the rima glottidis uncovered by the epiglottis during swallowing would not be substantially increased. Greenberg et al[12] reported that performing this procedure with low suture tension results in a significant decrease in LAR with the epiglottis open but no significant decrease in LAR with the epiglottis closed. A tensiometer has been used during this procedure in an effort to objectively determine the tension placed on the cricoarytenoid suture.[13] However, intraoperative measurement of suture tension is not clinically feasible

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because of the difficultly of obtaining this measurement while tying a knot and the need to use a tensiometer during surgery.

The purpose of the study reported here was to evaluate anatomic landmarks in vitro to define the ideal suture placement location to achieve appropriate and consistent arytenoid cartilage abduction by means of UCL in dogs. A UCL procedure involves placement of a suture through the arytenoid and cricoid cartilages, which is tensioned and tied, resulting in abduction of the arytenoid cartilage and an increase in functional airway diameter. We hypothesized that the distance between the caudal border of the cricoarytenoid articulation and the site of suture placement through the cricoid cartilage would have an effect on LAR with the epiglottis open or closed.

Materials and Methods

Laryngeal specimen preparation—Larynges were harvested from cadavers of large-breed dogs that were euthanatized by IV infusion of pentobarbital-phenytoin sodium solution for purposes unrelated to the study. All larynges were visually inspected to determine that the anatomic features appeared normal. All extrinsic soft tissues were removed from each larynx, leaving only the laryngeal cartilages, intrinsic laryngeal musculature, and the first 4 tracheal rings.

The left cricoarytenoid articulation of each specimen was identified by palpation of the muscular process of the arytenoid cartilage. The left cricoarytenoideus dorsalis muscle was transected at the midbody position. The joint capsule of the left cricoarytenoid articulation was sharply incised with a No. 15 scalpel blade; care was taken to fully transect the joint capsule and disarticulate the joint.

Three sutures of 3-0 polyglyconate suture material were passed around the caudal border of the left cricoid cartilage, then passed through the cricoid cartilage in a medial to lateral direction. Each suture was placed through the cricoid cartilage in a different location correlating with 3 treatment positions. The sutures were passed through the cricoid cartilage just caudal to the cricoarytenoid articulation (SPP 1), one-fourth of the distance caudally between the cricoarytenoid and cricothyroid articulations (SPP 2), and three-fourths of the distance caudally between the cricoarytenoid and cricothyroid articulations (SPP 3; **Figure 1**). Positions of the suture were determined from measurements obtained with Vernier calipers, and the 3 SPPs were aligned on a straight line between the cricoarytenoid and cricothyroid articulations. A stay suture of 2-0 polydioxanone suture material was placed through the tip of the epiglottis. The suture ends were bound together and passed down the trachea to serve as a handle with which to close the epiglottis. The specimens were wrapped in laparotomy sponges moistened with saline (0.9% NaCl) solution and were stored at 2°C until testing.

LAR testing—After suture placement, LAR was calculated for each specimen before application of any treatment (baseline) and after tensioning of each of the 3 cricoarytenoid sutures separately. Only 1 treatment was applied at a time; on each occasion, the tension at the evaluated SPP was released prior to application of tension to another suture. The order in which the 6 specimens were tested and the order in which each treatment was applied and evaluated in each larynx were randomized by means of a random-number generator. Larynges were periodically moistened with saline solution throughout testing.

Laryngeal airway resistance was determined according to the technique described by Greenberg et al.[12] The pressure in the chamber was measured by use of a manometer, extension tubing, and a 3-way stopcock. The extension tubing was attached to the testing cylinder at the inflow end of the chamber, 2 cm from the air inflow stream. The manometer was mounted in a vertical position and was zeroed at the level of the center of the laryngeal lumen for each specimen before each test. The outflow pressure was atmospheric pressure. Airflow was controlled with a precalibrated flowmeter[a] and was set at 1.00 L/s when the epiglottis was open and 0.17 L/s when the epiglottis was closed.

For each test, a larynx was secured into the testing chamber and the epiglottis was either opened or closed. The manometer was filled with saline solution, and the 3-way stopcock access to the testing chamber was turned off. The flowmeter was then set to the desired air flow level. The 3-way stopcock access to the testing chamber was then opened, and the manometer was allowed to equilibrate to the pressure within the chamber. The testing chamber pressure value was recorded once the manometer pressure reading remained at a constant value for a period of 10 seconds. Each test was repeated 3 times to ensure repeatability. The values were only accepted if the 3 pressure measurements obtained with the epiglottis open or with the epiglottis closed did not differ by more than 2 cm H_2O. The median of these 3 values was then recorded. Then the overall median values were calculated for all 6 larynges.

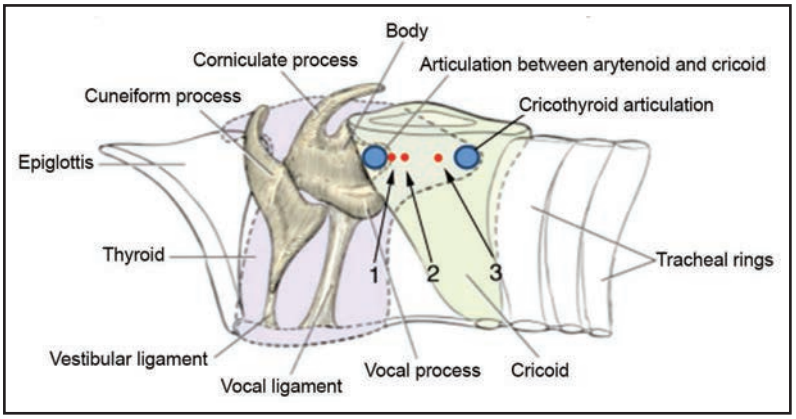

Figure 1—Illustration of the evaluated SPPs used for UCL in cadaveric canine larynges. The cranial and caudal blue dots represent the cricoarytenoid and cricothyroid articulations, respectively. In the cranial to caudal direction, the red dots represent SPPs 1, 2, and 3. (Adapted from Monnet E, Tobias KM. Larynx. In: Tobias KM, Johnston SA, eds. *Veterinary surgery: small animal*. St Louis: Elsevier, 2012;1718–1733; and from Grandage J, Richardson K. Functional anatomy. In: Slatter DH, ed. *Textbook of small animal surgery*. Philadelphia: Saunders/Elsevier, 1985;902–918. Reprinted with permission.)

Table 1—Median (range) laryngeal resistance and chamber pressure in 6 cadaveric canine larynges determined with the epiglottis open and closed before alteration of the arytenoid cartilage position (baseline) and after UCL performed with suture material placed through the cricoid cartilage in each of 3 treatment positions (placement just caudal to the cricoarytenoid articulation [SPP 1], one-fourth of the distance caudally between the cricoarytenoid and cricothyroid articulations [SPP 2], and three-fourths of the distance caudally between the cricoarytenoid and cricothyroid articulations [SPP 3]).

	Baseline		SPP 1		SPP 2		SPP 3	
Variable	Epiglottis open	Epiglottis closed	Epiglottis open	Epiglottis closed	Epiglottis open	Epiglottis closed	Epiglottis open	Epiglottis closed
Chamber pressure (cm H_2O)	2.0[a] (1.3–3.2)	5.0[d] (2.0–5.7)	0.4[b] (0.3–0.6)	3.4[d] (1.5–5.4)	0.2[c] (0.0–0.3)	1.9[e] (0.4–2.9)	0.0[c] (0.0–0.1)	0.6[f] (0.2–1.2)
LAR (cm H_2O/L/s)	2.0[g] (1.3–3.2)	30.0[i] (12.0–34.2)	0.4[h] (0.3–0.6)	20.4[j] (9.0–32.4)	0.2[i] (0.0–0.3)	11.4[k] (2.4–17.4)	0.0[i] (0.0–0.1)	3.3[l] (0.6–7.2)

Only 1 treatment was applied at a time; on each occasion, the tension at the evaluated SPP was released prior to application of tension to another suture. The order in which the 6 specimens were tested and the order in which each treatment was applied and evaluated in each larynx were randomized by means of a random-number generator. Laryngeal airway resistance was determined by means of a pressure chamber according to the technique described by Greenberg et al.[12] Airflow was controlled with a precalibrated flowmeter and was set at 1.00 L/s when the epiglottis was open and 0.17 L/s when the epiglottis was closed. Each test was repeated 3 times to ensure repeatability. The values were only accepted if the 3 pressure measurements obtained with the epiglottis open or with the epiglottis closed did not differ by more than 2 cm H_2O. The median of these 3 values was then recorded, and the overall median values were calculated for all 6 larynges.

[a–l]Within a variable, median values with different superscript letters differ significantly ($P < 0.05$).

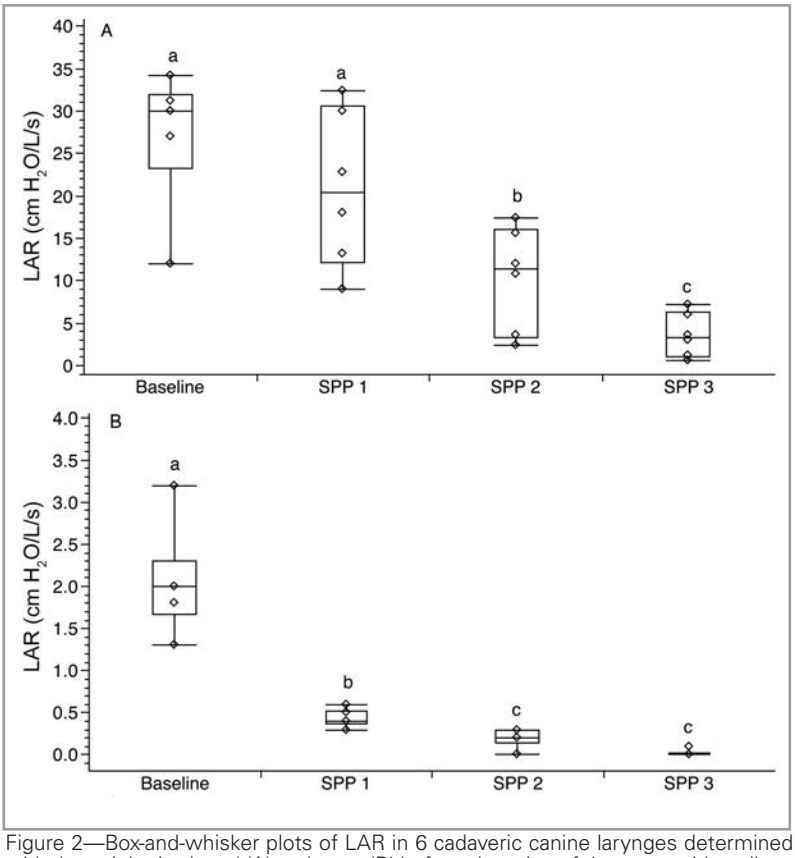

Figure 2—Box-and-whisker plots of LAR in 6 cadaveric canine larynges determined with the epiglottis closed (A) and open (B) before alteration of the arytenoid cartilage position (baseline) and after UCL performed with suture material placed through the cricoid cartilage in each of 3 treatment positions (placement just caudal to the cricoarytenoid articulation [SPP 1], one-fourth of the distance caudally between the cricoarytenoid and cricothyroid articulations [SPP 2], and three-fourths of the distance caudally between the cricoarytenoid and cricothyroid articulations [SPP 3]). Only 1 treatment was applied at a time; on each occasion, the tension at the evaluated SPP was released prior to application of tension to another suture. The order in which the 6 specimens were tested and the order in which each treatment was applied and evaluated in each larynx were randomized by means of a random-number generator. For each box, the horizontal line represents the median value, and the upper and lower boundaries represent the 25th to 75th percentile range, respectively. Whiskers represent the full range of the data; diamonds represent each data point. Median values with different letters differ significantly ($P < 0.05$).

Baseline resistance measurement—Laryngeal airway resistance was first measured for each larynx with the epiglottis open and closed before any treatments at the 3 SPPs were performed. These values were considered the baseline LARs. To obtain the baseline LARs, each larynx was secured into the testing chamber with the epiglottis open. The flow was set at 60 L/min, and the testing chamber pressure was measured. The flow was then reduced to 10 L/min, and the epiglottis was closed by pulling the epiglottic suture. The chamber pressure was again measured. Laryngeal airway resistance with the epiglottis open or with the epiglottis closed was calculated for each specimen by use of the following equation:

$$LAR = \Delta P/V$$

where V was the airflow and ΔP was the pressure gradient. This pressure gradient was the difference between the pressure in front of the larynx (the measured pressure in the testing chamber) and the pressure beyond the larynx (atmospheric pressure). Because the transducer was zeroed at the level of the larynx, the pressure recorded by the transducer during the experiment was ΔP.

UCL and evaluation of LAR after treatments—Each laryngeal specimen was then removed from the testing chamber, and a left cricoarytenoid lateralization procedure was performed by use of 1 of the 3 preplaced sutures. For each larynx, the suture at the SPP evaluated first (the order of treatments having been randomly assigned by means of a random-number generator) was passed through the center of the articular surface of the muscular process of the arytenoid cartilage. A slipknot was tightened until the arytenoid cartilage was visually confirmed to overlie the site of suture placement in the cricoid cartilage. A square knot was then added on top of the first knot. Arytenoid cartilage abduction and rima glottidis opening were visually confirmed during suture tightening. After arytenoid cartilage abduction, the larynx was remounted in

the testing chamber, and chamber pressure was again measured in the previously described manner with the epiglottis in open and closed positions. The LARs with the epiglottis open and closed were calculated for that SPP. The larynx was then removed from the chamber, and the suture under evaluation was cut and removed. The suture at the SPP evaluated second was then passed through the existing hole in the muscular process of the arytenoid cartilage. This suture was tightened and the specimen was tested again, as for the first evaluated suture treatment. The LARs with the epiglottis open and closed were calculated for that second SPP. The larynx was then removed from the chamber, and the suture under evaluation was cut and removed. This entire procedure was then repeated for the remaining suture, and the LARs with the epiglottis open and closed were calculated for that remaining SPP.

Statistical analysis—Laryngeal airway resistance data were not normally distributed according to the Shapiro-Wilk test for normality. The effect of suture position on LAR was analyzed by means of a Wilcoxon signed rank test with statistical software.[b] The LAR data are reported as median and range (cm H_2O/L/s). Values of $P < 0.05$ were considered significant.

Results

Six canine larynges from adult coonhounds of similar size and age were used for testing. All larynges appeared grossly normal and were obtained from dogs that had no clinical signs or history associated with upper or lower airway disease or dysfunction.

LAR with the epiglottis closed—For all larynges with the epiglottis closed, median LAR was 30.0 cm H_2O/L/s (range, 12.0 to 34.2 cm H_2O/L/s), 20.4 cm H_2O/L/s (range, 9.0 to 32.4 cm H_2O/L/s), 11.4 cm H_2O/L/s (range, 2.4 to 17.4 cm H_2O/L/s), and 3.3 cm H_2O/L/s (range, 0.6 to 7.2 cm H_2O/L/s) at baseline and SPPs 1, 2, and 3, respectively (**Table 1**; **Figure 2**). The median LAR after UCL at SPP 1 was not significantly ($P < 0.13$; power = 0.47) different from baseline. The median LARs after UCL at SPPs 2 and 3 were significantly (both $P < 0.03$) lower than baseline. The median LAR after UCL at SPP 3 was significantly ($P < 0.03$) lower than that at SPP 2.

LAR with the epiglottis open—For all larynges with the epiglottis open, median LAR was 2.0 cm H_2O/L/s (1.3 to 3.2 cm H_2O/L/s), 0.4 cm H_2O/L/s (0.3 to 0.6 cm H_2O/L/s), 0.2 cm H_2O/L/s (0.0 to 0.3 cm H_2O/L/s), and 0.0 cm H_2O/L/s (0.0 to 0.1 cm H_2O/L/s) at baseline and SPPs 1, 2, and 3, respectively (Table 1; Figure 2). The median LARs after UCL at SPPs 1, 2, and 3 were significantly (all $P < 0.03$) lower than baseline. The median LAR after UCL at SPP 2 was significantly ($P < 0.03$) lower than that at SPP 1. The median LAR after UCL at SPP 3 was not significantly ($P < 0.06$) lower than that at SPP 2.

Discussion

In the present study involving cadaveric larynges from dogs, we found that anatomic landmarks could be used to identify an ideal suture placement location for UCL that provided sufficient abduction of the arytenoid cartilage to reduce LAR with an open epiglottis without affecting LAR with a closed epiglottis. The cricoarytenoid and cricothyroid articulations were used as anatomic landmarks and were easily identifiable in the cadaveric specimens. During the UCL procedure in vivo, these 2 articulations are readily identified in the surgical field. The cricoarytenoid articulation is exposed and opened during dissection for placement of the suture; the cricothyroid joint is easily palpable after lateral retraction of the thyroid cartilage and is sometimes disarticulated during the surgical approach.

Dogs with laryngeal paralysis have a higher incidence of regurgitation and also have an increased incidence of aspiration pneumonia after undergoing UCL.[2,3,5] This is thought to be a result of overzealous abduction of the arytenoid cartilage or distortion of the laryngeal lumen during the procedure.[11,12] As shown by Bureau and Monnet,[11] performing this procedure with a suture under high tension can significantly increase the area of rima glottidis that is not protected by the epiglottis during swallowing. In the present study, performing this procedure with the suture passed through the cricoid cartilage just caudal to the cricoarytenoid articulation did not significantly reduce LAR, compared with pretreatment baseline findings, when the epiglottis was closed. Greenberg et al[12] suggest that changes in closed-epiglottis LAR can be used as a marker of the amount of rima glottidis that is no longer protected by the closed epiglottis. Therefore, decreased LAR when the epiglottis is closed would imply an increase in the proportion of unprotected rima glottidis and, in turn, a higher risk of aspiration. This suggests that performing this procedure with the suture placed just caudal to the cricoarytenoid articulation would not increase the risk of aspiration and associated aspiration pneumonia.

Dogs with laryngeal paralysis have increased upper airway resistance because of a lack of abduction of the arytenoid cartilages when the epiglottis is open during inspiration.[1,12] According to the Hagen-Poiseuille equation,[14] with other variables held constant, a decrease in laryngeal radius of 50% can result in a 16-fold increase in airway resistance. Similarly, increasing the radius of the functional laryngeal lumen by even a small amount can lead to a marked decrease in upper airway resistance. Therefore, mild arytenoid cartilage abduction can have a substantial impact on resistance, as demonstrated after UCL at SPP 1 in the larynges used in the present study for which LAR was decreased by 80%. This magnitude of change in LAR should decrease upper airway resistance sufficiently to eliminate clinical signs in dogs with laryngeal paralysis.

In the present study, the capsule of the cricoarytenoid articulation was fully transected to allow full mobility of the arytenoid cartilage. This ensured that the postoperative position of the arytenoid cartilage was determined by the site at which the suture was passed through the cricoid cartilage and not by how much capsule remained intact or the tension of the suture. When the sutures were tightened with the capsule fully transected, the arytenoid cartilages transposed to the suture placement site in the cricoid cartilage in each larynx.

We do not recommend full transection of the capsule in a clinical case.

Cadaveric canine larynges have been previously used in experimental investigations of laryngeal paralysis.[11–13,15] In the present study, the LAR measurements obtained prior to application of any treatments (baseline) were very similar to those found in other studies.[11–13] Dogs with bilateral laryngeal paralysis cannot abduct either arytenoid cartilage; this anatomic abnormality is very similar to a characteristic of cadaveric specimens, in that those specimens do not have tone in the cricoarytenoideus dorsalis muscle, thereby causing passive adduction of both arytenoid cartilages. Assuming that this passive adduction in vitro is the same as that in a dog with laryngeal paralysis in vivo, a similar level of LAR should be created at airflows similar to those generated by a live animal. In the present study, airflows (0.16 to 1.0 L/s) that were similar to findings in spontaneously breathing dogs[16,17] were used.

In the present study, procedures were performed on specimens from multiple dogs that were of the same breed and of similar size. It is possible that this technique would provide different results when applied to larynges obtained from dogs of different sizes or breeds or in animals of other species. If that were to be the case, different cricoarytenoid SPPs may be recommended for patients with different signalments in clinical settings.

By use of anatomic landmarks, an ideal SPP to achieve a consistent abduction of the arytenoid cartilage and reduction in LAR in dogs undergoing UCL was identified in the present study. Performing a UCL with a suture placed through the cricoid cartilage at the caudal border of the cricoarytenoid articulation and through the center of the articular surface of the arytenoid cartilage appeared to provide sufficient reduction in LAR without increasing the risk of aspiration pneumonia as a result of overabduction of the arytenoid cartilage. A prospective, randomized clinical trial would be needed to determine whether this technique alleviates clinical signs without increasing the risk of aspiration pneumonia in dogs in vivo.

a. Riteflow 150-mm mounted flowmeter, Bel-Art Products, Pequannock, NJ.
b. JMP, version 10.0.2, SAS Institute Inc, Cary, NC.

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