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ORIGINAL ARTICLE - RESEARCH

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Description and evaluation of a novel transoral endoscopic arytenopexy in canine cadavers

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Abstract

Objective: To describe the transoral endoscopic arytenopexy (TEA) and evaluate its effects on the rima glottis area (RGA) and laryngeal epiglottic-glottic seal (LEGS). We hypothesize the TEA will be a feasible surgical technique and the TEA will provide a significant increase in RGA with minimal change to the LEGS.

Study design: Canine cadaveric model.

Animals: Fifteen medium- to large-breed canine cadavers.

Methods: Endoscopic photos of the larynx were taken with the epiglottis open for baseline RGA measurement and closed for baseline measurement of exposed RGA and LEGS. A custom endoscopic gag port (EGP) facilitated the TEA, performed by suturing the lateral aspect of the left arytenoid soft tissues to adjacent pharyngeal wall across the piriform recess. Endoscopic photos were repeated to measure changes in RGA and LEGS. A computerized planimetric analysis program was used to calculate baseline RGA and LEGS. The RGA was reported in % change from baseline. The LEGS was reported as intact or altered. A nonparametric Wilcoxon signed-rank test was used to compare baseline to post-TEA RGA.

Results: The mean baseline RGA was 0.52 ± 0.28 cm^3 and mean post-TEA RGA was 0.78 ± 0.37 cm^3 (p-value $< .0001$). The LEGS remained intact post-TEA in all cadavers.

Conclusions: The TEA was technically feasible and resulted in an increase in RGA while maintaining the LEGS.

Clinical significance: The TEA may provide a minimally invasive addition to the established techniques for reducing airway resistance while minimizing the impact on the LEGS.

1 | INTRODUCTION

Laryngeal paralysis (LP) results from failure of the cricoarytenoid dorsalis muscle to abduct one or both arytenoid cartilages during inspiration with clinical signs resulting from the narrowed glottic opening.[1–7]

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Progressive airway narrowing can result in respiratory failure, heatstroke, and death.[5–7] Acquired, idiopathic laryngeal paralysis is the predominant manifestation of this disease and is most commonly seen in middle- to older-aged, large-breed dogs, with Labrador Retrievers overrepresented in the population.[5–8] Surgical intervention is aimed at increasing the rima glottis area (RGA) to decrease laryngeal airflow resistance and improve clinical signs. Since airway resistance is inversely proportional to the airway radius to the fourth power, only a small change in RGA is required to have significant impact on airway resistance and clinical signs.[2,4,7]

Several approaches have been described to increase the RGA in dogs as a treatment for laryngeal paralysis with variable efficacy including unilateral or bilateral ventriculocordectomy, partial arytenoidectomy, modified castellated laryngofissure, and unilateral or bilateral arytenoid lateralization.[10–14] These procedures rely on the resection or modification of regional obstructive tissues, or the static fixation of the arytenoid cartilages in an open position using nonabsorbable suture.[7,9,10,14] When comparing different approaches for increasing the RGA, studies have shown unilateral cricoarytenoid lateralization (UAL) to be superior in its ability to increase the rima glottidis area (RGA) with an open epiglottis; however, the laryngeal epiglottic-glottic seal (LEGS) can be negatively affected based on the technique used.[2,3,5,6] Despite the UAL remaining the preferred procedure for LP due to its consistent resolution of clinical signs,[7] reports have shown up to 33% of patients develop aspiration pneumonia postoperatively.[1,5,6] While there are several contributing factors to the development of aspiration pneumonia postoperatively, such as progressive esophageal dysfunction,[15] a surgical procedure that increases the RGA while preserving the LEGS may decrease the lifelong risk of aspiration pneumonia. Additionally, current techniques require dissection through cervical muscles and complications include possible iatrogenic trauma to surrounding neurovascular structures such as the jugular vein, seroma formation, and incision site infection.[7,9] Furthermore, major complications of the UAL include fracture of the muscular process during or after surgery or failure of the suture, thereby resulting in return of clinical signs.

The translaryngeal percutaneous arytenoid lateralization technique was recently proposed as a minimally invasive technique to temporarily increase the rima glottidis cross-sectional area in dogs with urgent clinical signs from LP, while stabilized[16] This technique involves percutaneous placement of a mattress suture through the right arytenoid cartilage with the suture exiting the skin ventral to the jugular vein, passed through a button and tied to lateralize the arytenoid cartilage. This technique resulted in a 25% increase to the rima glottidis cross-sectional area based on a cadaveric model.[16] However, when this technique was replicated in live animals, loosening of the suture and a subsequent decrease in rima glottidis area was observed within 24 h of placement in all animals.[17] Additionally, there was purulent discharge around the button in several cases, necessitating the need for antibiotic therapy, and it was observed that the sutures had migrated through the corniculate process in varying degrees based on post-mortem examination.

In human pediatric medicine, the most common cause of stridor in pediatric patients is laryngomalacia with secondary posterior displacement of the epiglottis during inspiration.[18] A modified epiglottopexy was developed to prevent the epiglottic posterior displacement by removing the mucosa of the epiglottic lingual surface and corresponding mucosa of the tongue base with a CO2 laser followed by fixing the epiglottis to the tongue base with sutures. Investigators found the procedure to be well tolerated with resolution of clinical signs, and no evidence of postoperative aspiration pneumonia or long term-complications. Additionally, they found that fibrinous adhesions formed at the pexy site, so the epiglottis remained fixed even if the sutures at the pexy site loosened.[18] A similar intraoral technique is described for dogs diagnosed with epiglottic retroversion, with good long-term outcome reported following epiglottopexy.[19]

The goals of this study were to describe and evaluate a novel minimally invasive surgical technique, the transoral endoscopic arytenopexy (TEA), for potential treatment of canine LP, to evaluate the effects of a TEA on the RGA and LEGS, and to develop and evaluate an endoscopic gag port (EGP) to aid in performing transoral, endoscopic surgery. We hypothesize that: the TEA will be a feasible surgical technique that can be completed using the custom EGP; and the TEA will provide a significant increase in RGA with minimal change to the LEGS.

2 | MATERIALS AND METHODS

The study protocol was approved by the Institutional Animal Care and Use Committee (protocol No. 202011076). A power analysis was performed using a significance of 0.05 and a power of 80% with the effect size determined based on previously reported median values for the change in rima glottidis area and laryngeal epiglottic-glottic seal.[16] Fifteen privately donated medium- to large-breed canine cadavers ranging from 18–25 kg (mean 21.5 kg), humanely euthanized for reasons unrelated to airway disease, were collected, stored at 3.3°C, and tested within 48 h. Dogs were positioned in sternal recumbency in a trough with the forelimbs pulled

FIGURE 1 A novel adjustable transoral endoscopic gag port (EGP) was designed using modular external skeletal fixator components and used to maintain an open-jaw position and serve as a mount for endoscopic instrumentation.

forward. Strips of medical tape were secured over the maxillary canines and attached to adjustable IV poles to suspend the head in an open mouth position. Prior to performing the TEA, a stay suture was placed

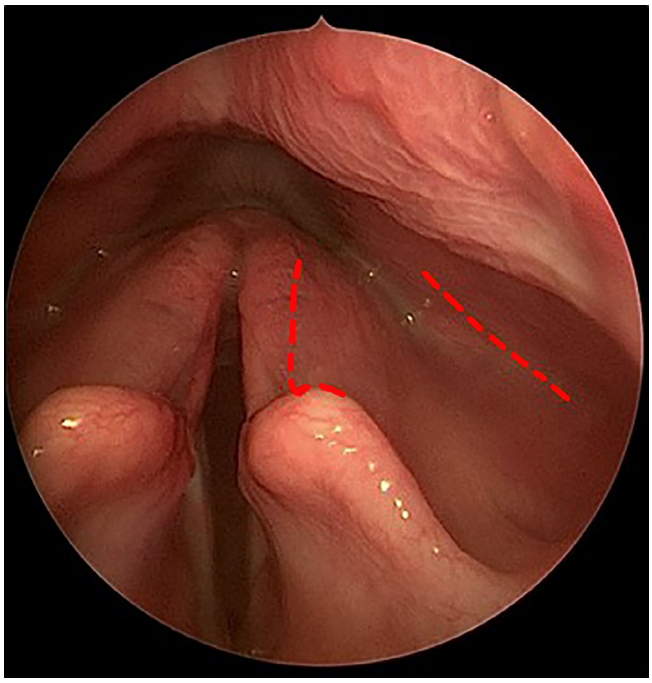

FIGURE 2 Endoscopic image of the transoral endoscopic arytenopexy (TEA) surgical site. Red dotted lines represent the surfaces sutured together to create the arytenopexy.

through the tip of the epiglottis using 3-0 Monocryl (poliglecaprone 25; Ethicon) for rostral retraction. A tracheotomy was performed with a #10 scalpel blade between the fourth and fifth tracheal rings. A second stay suture was placed opposite the first, in a horizontal direction across the tip of the epiglottis and the suture was directed caudally and out the tracheotomy site to facilitate closure of the epiglottis. A novel, adjustable transoral endoscopic gag port (EGP) was designed using IMEX S external skeletal fixator components (IMEX Veterinary Inc.) and used to maintain an open-jaw position while serving as a mount for endoscopic instrumentation (Figure 1). Any loss of open jaw positioning during the procedure due to loosening of the EGP components was documented as EGP failure to maintain positioning.

A 30° 5 mm 29 cm endoscope (Karl Storz, Goleta, CA) was passed through a SK one-hole post mounted on the EGP and advanced to the oropharyngeal region to facilitate visualization of the surgical site. Care was taken to ensure that camera was inserted into the EGP at a 90° angle with the 30° scope facing dorsally in all trials. An endoscopic photo of the larynx was taken from the rostral aspect with the epiglottis in an open position for a baseline measurement of the RGA. The epiglottis was closed via traction on the previously placed transtracheal stay suture and an endoscopic photo of the larynx was taken with the epiglottis in the closed position for baseline

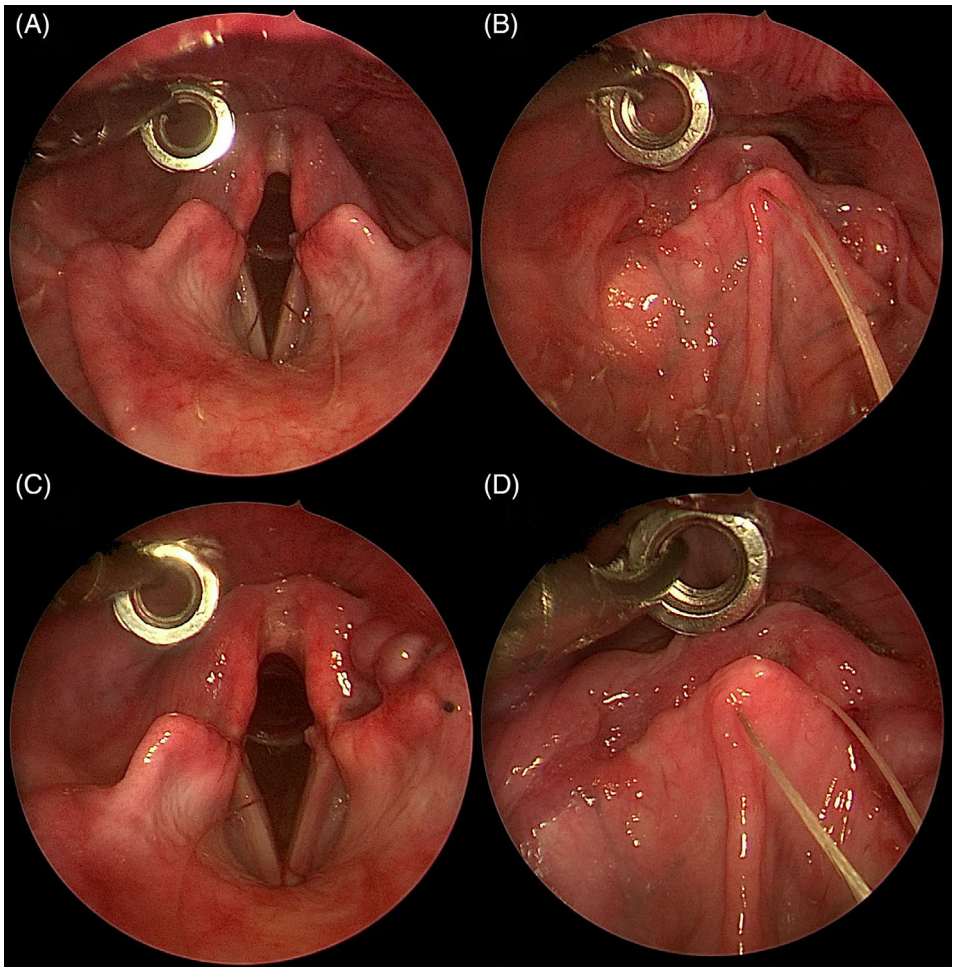

FIGURE 3 Endoscopic photos of the larynx were taken from the rostral aspect with a calibration marker in the upper left corner of every picture. (A) Open epiglottis pre-TEA (transoral endoscopic arytenopexy). (B). Closed epiglottis pre-TEA. (C). Open epiglottis post-TEA. (D). Closed epiglottis post-TEA.

measurement of exposed RGA and evaluation of the LEGS in the frontal plane. A TEA was performed by suturing the lateral aspect of the left arytenoid soft tissues to pharyngeal wall tissues immediately across the piriform recess using endoscopic needle drivers (KOH Macro Needle Holders, Karl Storz) with a self-anchoring barbed suture (2–0 V-Loc, Medtronic, Minneapolis, MN). Instruments were passed through a SK one-hole post mounted on the EGP. The arytenopexy was initiated in the dorsal 1/3 of the corniculate process and continued rostrally for 3–4 bites before ending at the apex of the cuneiform process (Figure 2). Suture bites incorporated adjacent soft tissues and perichondrium; no cartilage was included. Post-TEA images were taken to measure changes in RGA and LEGS in the same manner as the preoperative photos (Figure 3). All photos contained the same 12 mm diameter nut from the IMEX Kirschner–Ehmer (KE) external skeletal fixator components (IMEX Veterinary Inc., Longview, TX) as a calibration marker and were imported into a computerized planimetric analysis program (ImageJ, U. S. National Institutes of Health, Bethesda, Maryland) used to measure RGA and LEGS before and after TEA. The RGA was reported in percent change from baseline. The LEGS was evaluated in the frontal plane and reported as intact or altered. If the TEA was successfully completed in 75% of attempts, we considered the procedure to be clinically feasible.

2.1 | Statistical analysis

R Version 4.1.3 software package meta was used for statistical analysis. A nonparametric Wilcoxon signed-rank test was used to determine if there was a change between baseline RGA to post-procedure RGA. A p-value $< .05$ was statistically significant.

3 | RESULTS

The EGP successfully maintained adequate open-mouth patient positioning and facilitated the use of endoscopic surgical equipment in all dogs. The TEA procedure was technically feasible and completed as described in all dogs. The RGA was increased in all dogs following the TEA with a mean baseline RGA of

FIGURE 4 There was an increase in the RGA cross-sectional area following a TEA with a *p*-value of <.0001.

TABLE 1 The mean percent change in rima glottidis area (RGA) following the trans-oral endoscopy arytenopexy (TEA) was compared to the previously reported percent change in RGA following other surgical interventions in a canine cadaveric model.[20,26]

Procedure	Mean % change of RGA
CAL-AF/SB[26]	192[a], IQR 54
CAL-MP/SB[26]	189[a], IQR 75
CAL-AF[26]	188[a], IQR 30
CTAL + 500 g suture tension[20]	183 ± 36.3
CAL + 500 g suture tension[20]	179.3 ± 30.0
MP/sCT[23]	178 ± 44
CAL-MP/DIS[23]	174[a], IQR 32
CAL-MP[26]	171[a], IQR 39
CTAL + 100 g suture tension[20]	164.2 ± 38.3
MP/iCT[23]	164 ± 38
CAL + 100 g suture tension[20]	159.2 ± 27.5
TEA	157 ± 34

[a]Indicates values reported as median % change of RGA with the interquartile range (IQR). MP/iCT: UAL sutured to the lateral muscular process, intact cricothyroid articulation; MP/sCT: UAL sutured to the lateral muscular process, sectioned; CAL-MP: cricoarytenoid lateralization procedure, suture passed through muscular process; CAL-MP/SB: CAL-MP plus transection of interarytenoid sesamoid band; CAL-MP/DIS: CAL-MP plus cricoarytenoid disarticulation; CAL-AF: cricoarytenoid lateralization procedure, suture passed through articular facet of arytenoid cartilage after cricoarytenoid disarticulation; CAL-AF/SB: CAL-AF plus transection of interarytenoid sesamoid band; Cricoarytenoid lateralization (CAL) + 100 g suture tension; Cricothryoarytenoid lateralization (CTAL) + 100 g suture tension; CAL + 500 g suture tension; CTAL + 500 g suture tension.

0.52 ± 0.28 cm^3 (range 0.13–1.099 cm^3) and mean post-TEA RGA of 0.78 ± 0.37 cm^3 (range 0.184–1.628 cm^3) (Figure 4) (*p*-value < .0001). The mean percent change in RGA after TEA was 157.00% (139.14–174.86). LEGS remained intact in the frontal plane following the TEA in 15/15 dogs.

4 | DISCUSSION

The TEA was a technically feasible procedure, and the EGP successfully maintained an open-mouth patient position while facilitating the use of endoscopic instrumentation. The TEA resulted in a significant increase in RGA while maintaining the protective LEGS in the frontal plane. However, the percent increase in RGA after TEA was less than what has been previously reported following variations of UAL.[20,26] Although our hypotheses were accepted, the cadaveric nature of our investigation precludes conclusion as to the clinical efficacy and safety of the TEA procedure in dogs with laryngeal paralysis, warranting further investigation.

The ideal increase in RGA to treat canine laryngeal paralysis would achieve decreased airway resistance without increasing the risk of subsequent aspiration pneumonia, the most common postoperative complication.[9] Table 1 compares the reported percent change in RGA from several cadaveric studies evaluating variations of unilateral arytenoid lateralization to TEA.[20,26] Across these UAL techniques, there was an average increase in RGA of 180.07% (173.68–186.45), while the TEA yielded an average 157.00% (Table 1). Many studies evaluating surgical treatment for canine laryngeal paralysis have shown that only a small increase in RGA is required to provide relief of clinical signs.[14,21–23,26,27] Over the years, the literature has shifted practice away from procedures which dramatically increase the RGA to those that provide a moderate increase in order to lessen the risk of aspiration through better preservation of the LEGS.[11,14,20,21,23,27] The Hagen-Poiseuille equation describes the impact of airway radius on the physics of laminar gas flow, principally, that airway resistance is inversely proportional to the airway radius to the fourth power. Based on our results, the average increase in RGA following a TEA would equate to an estimated 84% decrease in airway resistance using this calculation. Though significant, it is possible that the increase in RGA following TEA is not adequate to alleviate dyspnea in clinical patients, in which case bilateral TEA may be effective. While bilateral arytenoid lateralization has been shown to increase the risk of aspiration pneumonia,[9] the preservation of the LEGS seen with the TEA may allow for a better outcome following a bilateral procedure; further studies are needed to assess this hypothesis. It is possible that the increase in RGA following a TEA could be temporarily impacted by intraoral swelling post-procedure in a live patient, which could lead to early postoperative complications. Live animal studies would be required to determine if clinically significant intraoral swelling occurs and the immediate and long-term impact it may have on the RGA.

Many described techniques for UAL have been documented to cause an alteration in the LEGS postoperatively.[27] In contrast, the TEA did not alter the LEGS in any cadavers to expose the rima glottidis in the frontal plane with the epiglottis in a closed position. Guillemot, et al. examined the effects of variable suture placement, tension, and joint disarticulation during UAL on LEGS in the sagittal plane and found that all variants of UAL impacted the LEGS, with more aggressive dissections causing greater disruption.[23] The preservation of LEGS after TEA is likely due to the relatively lower magnitude increase in RGA and lack of laryngeal dissection. Since UAL anchors the arytenoid cartilage in abduction to a relatively fixed cricoid cartilage, the change in the LEGS and its contribution to risk of aspiration are static. One idea behind the TEA was to fix the arytenoid cartilages to more dynamic pharyngeal soft tissues to, in theory, increase RGA and resist paradoxical inward motion during inspiration, while allowing for normal laryngeal motion and epiglottic airway protection during swallowing. We hypothesize that in live dogs, pharyngeal constriction during swallowing would cause medial deviation of the arytenopexy site, decreasing the RGA and maintaining the LEGS when aspiration risk is highest. While the LEGS is not the only contributing factor to development of postoperative aspiration pneumonia, it is possible that the overall risk of aspiration pneumonia may be lessened with the TEA compared to the UAL. Clinical investigation of the TEA procedure is necessary to test this hypothesis.

Cadaveric airways have been utilized as models for canine laryngeal paralysis in several studies evaluating surgical effects on RGA and airway resistance.[20–27] The lack of muscle tone in the canine cadaver larynges causes passive adduction of both arytenoid cartilages, emulating a state of bilateral laryngeal paralysis. The epiglottis can be manually opened or closed to simulate inspiration and protection of the airway during swallowing, respectively. However, the effects of swallowing and repeated respiratory motion on the arytenopexy cannot be evaluated in cadavers and represents one major limitation of the present study. It is possible that medial pharyngeal wall movement and reduction of the RGA could occur with increased respiratory pressures. Objective testing of airway resistance with different respiratory pressures following a TEA would be needed to determine the effect of increased respiratory pressures on the RGA. It is also possible that the RGA and LEGS are altered during different phases of swallowing after TEA, or that food material becomes entrapped ventral to the arytenopexy site within the piriform process. Repeated respiratory motion could possibly fatigue the soft tissues involved in the arytenopexy and lead to decreased efficacy over time in clinical patients as well. This may require an alteration in technique to take deeper bites to include underlying cartilage when performing the TEA. Testing in live dogs would be required to determine the likelihood of these scenarios.

Another limitation was the inability to harvest the larynges for direct airway resistance measurements as in prior studies,[20–22,27] as the arytenopexy would be disrupted after the dissection of surrounding tissues. Finally, no endotracheal tube was placed during this study. The authors initially intubated the cadavers, however the lack of elasticity in cadaveric tissue following extubation resulted in an artificial increase in the RGA so the cadavers included in this study were not intubated. However, intubation did provide inherent lateral retraction of the larynx and may be clinically advantageous in improving working space in a live patient.

In the present study, the TEA was found to be technically feasible using the EGP and demonstrated an increase in RGA without a significant change to the LEGS in canine cadavers. This surgical procedure may represent an effective therapy for dogs with laryngeal paralysis, however clinical investigation is necessary to examine the effects of swallowing and respiratory motion on the integrity of the TEA, patient outcome, and risk of complications.

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CONFLICT OF INTEREST

The authors declare no conflict of interest related to this study.

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