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Evaluation of Translaryngeal Percutaneous Arytenoid Lateralization (TPAL) in dogs with experimentally created laryngeal paralysis

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Abstract

The aim of this experimental study was to evaluate the effect of Translaryngeal Percutaneous Arytenoid Lateralization (TPAL) in dogs with experimentally created laryngeal paralysis. All dogs ($n = 5$) underwent bilateral recurrent laryngeal neurectomy before TPAL. Two TPAL suture techniques were evaluated. TPAL-CranialCaudal (TPAL-CC) was performed first, followed 11 to 14 days later by TPAL-DorsalVentral (TPAL-DV). For both techniques, a mattress suture was placed through the arytenoid cartilage via an oral approach. Laryngeal examination was performed before, immediately after, and on days 1, 3 and 7 for both TPAL techniques. Ipsilateral hemiglottic surface area and the degree of laryngeal swelling or reaction to the suture were recorded. Laryngeal tissue was evaluated by histopathology at the end of the study. For both TPAL techniques, hemiglottic surface area was increased immediately after suture placement ($P < 0.05$). At all other times, hemiglottic area was not statistically different from preoperative value ($P > 0.05$). TPAL-DV resulted in less laryngeal swelling compared to TPAL-CC. Histopathology of the arytenoid cartilage surrounding the mattress suture revealed mucosal ulceration and inflammation consistent with the presence of the suture material. Both TPAL techniques were effective at lateralizing the arytenoid cartilage and significantly increasing hemiglottic surface area immediately after suture placement. However, mucosal swelling and loss of tension on the mattress suture lead to a decrease in glottic area within 24 h. Further refinements in suture placement technique are warranted to minimize swelling and improve the duration of arytenoid lateralization prior to clinical application.

Keywords

Canine laryngeal paralysis; Percutaneous arytenoid lateralization; Rima glottidis area; Arytenoid lateralization

1. Introduction

Acquired laryngeal paralysis in the dog is a progressive and potentially life-threatening condition that results in obstruction of the rima glottidis due to loss of normal abduction of

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the arytenoid cartilages and paradoxical motion during inspiration (Bahr et al., 2014; MacPhail, 2014; MacPhail and Monnet, 2001; Monnet, 2016; von Pfeil et al., 2014; Snelling and Edwards, 2003; Weinstein and Weisman, 2010). Obstruction of the rima glottidis can lead to episodes of severe respiratory distress and secondary complications such as hyperthermia, hypoxemia, and non-cardiogenic pulmonary edema (MacPhail and Monnet, 2001; Snelling and Edwards, 2003). Severe episodes of laryngeal obstruction can be challenging to treat and may require emergency endotracheal intubation to relieve the airway obstruction. Temporary endotracheal intubation is effective at breaking the cycle of respiratory distress and stabilizing most dogs; however, not all dogs are able to be safely extubated due to persistent airway obstruction or severe secondary complications as noted above.

Options for relieving airway obstruction in these dogs include: 1) proceeding with a definitive surgical procedure in the emergency setting, which may be undesirable for dogs with significant secondary complications; 2) intubating dogs, which in some cases requires ongoing mechanical ventilation; 3) performing a temporary tracheostomy, which requires relatively intense postoperative management and has been associated with increased morbidity in dogs with laryngeal paralysis (MacPhail and Monnet, 2001).

Recently, three techniques for percutaneous arytenoid lateralization have been described in a canine cadaver model as minimally-invasive options for management of dogs with laryngeal paralysis (Hardie, 2016; Shipov et al., 2015; Stegen et al., 2015). These techniques are intended as a less-invasive alternative to conventional surgical procedures or as an alternative to temporary tracheostomy for dogs at risk of repeated airway obstruction during transportation to a referral center, or for dogs requiring extended stabilization or additional diagnostic procedures prior to definitive surgical treatment. The three techniques involve placing either a mattress suture or suture anchor through the arytenoid cartilage via a percutaneous or oral approach. In two of the techniques, a mattress suture exits the skin on the lateral aspect of the neck. The free ends of the suture are either passed through a button and tied on the surface of the neck or tied on the lateral surface of the thyroid cartilage via a mini surgical approach, lateralizing the arytenoid cartilage. Both techniques are relatively easy to perform and proved effective at enlarging the rima glottidis in a cadaver model (Hardie, 2016; Shipov et al., 2015). However, further investigation in an experimental model is warranted before clinical application.

The purpose of this study was to describe and evaluate two Translaryngeal Percutaneous Arytenoid Lateralization (TPAL) techniques in dogs with experimentally created laryngeal paralysis. Specific objectives included the evaluation of: 1) the change in rima glottidis surface area after TPAL suture placement, 2) the degree of swelling or tissue reaction around the suture, and 3) episodes of coughing or gagging during eating and drinking.

2. Materials and methods

2.1. Animals

Five, 8-month-old, intact male hound dogs (weight 24–29 kg) were studied. A physical examination and bloodwork (packed cell volume, total protein, and blood urea nitrogen)

were performed on all dogs. Body weight was monitored weekly throughout the study period. Dogs were housed individually in a temperature and humidity controlled facility with a 12-hour light/dark cycle. All procedures were performed with approval from the Animal Care and Use Committee of the University of Wisconsin-Madison (V01508-0-11-10).

2.2. Study timeline

The timeline and a brief description of the procedures performed in this study are depicted in Fig. 1.

2.3. Anesthetic protocol

For bilateral recurrent laryngeal neurectomy, dogs were administered carprofen (4.4 mg/kg, orally) 30 min before induction. Dogs were premedicated with acepromazine (0.03 mg/kg intramuscularly [IM]) and hydromorphone (0.05 mg/kg IM), induced with propofol (4–6 mg/kg intravenously [IV] to effect) and maintained with isoflurane in oxygen. Postoperatively, dogs received hydromorphone (0.05 mg/kg IM) every 4–6 h for additional analgesia.

For the TPAL procedures and all subsequent laryngeal examinations, dogs were premedicated with dexmedetomidine (4–5 mcg/kg IV) and hydromorphone (0.05 mg/kg IV), and induced with propofol (4–6 mg/kg IV to effect). Anesthesia was maintained with additional boluses of propofol administered intermittently as needed. Supplemental flow-by oxygen was provided via placement of the circuit tubing at the commissure of the mouth. A single dose of hydromorphone (0.05 mg/kg IM) was administered postoperatively for analgesia and dexamethasone sodium phosphate (0.07–0.25 mg/kg IV) was administered as an anti-inflammatory agent. Dogs were assessed for pain post operatively (continuously for 6 h, at 12 h post-operatively and every 12 h thereafter), and no additional analgesia was indicated.

2.4. Bilateral recurrent laryngeal neurectomy

Bilateral recurrent laryngeal neurectomy was performed with dogs positioned in dorsal recumbency. An 8 cm ventral midline cervical incision was made starting 1 cm caudal to the larynx. The sternohyoideus muscles were separated and the recurrent laryngeal nerves identified on the lateral aspects of the trachea. The nerves were transected at the mid-cervical region and the free ends ligated with absorbable suture material (3-0 Glycomer 631, Covidien, Mundelein, IL). The sternohyoideus muscles, subcutaneous tissues and skin were closed routinely. Dogs were monitored daily for 7 days prior to performing the TPAL procedure.

2.5. Translaryngeal Percutaneous Arytenoid Lateralization (TPAL) techniques

Two TPAL suture placement techniques were evaluated in this study. The techniques were labeled relative to the intraluminal orientation of the lateralizing suture. TPAL-CranialCaudal (TPAL-CC) was performed first on the right side of the larynx. Eleven to 14 days later, TPAL-DorsalVentral (TPAL-DV) was performed on the left side of the larynx. A single mattress suture was used for both techniques.

For the TPAL-CC technique, the mattress suture was oriented in a craniocaudal direction. The first suture pass was placed caudal to the corniculate process, just dorsal to the vocal fold in a caudal, lateral and ventral direction through the thyroid cartilage. The second suture pass was placed through the caudal portion of the cuneiform process and directed caudolaterally through the thyropharyngeal membrane (Fig. 3a).

For the TPAL-DV technique, the mattress suture was oriented in a dorsoventral direction. The first suture pass was placed through the dorsal aspect of the corniculate process 2–3 mm ventral to the apex of the glottis and directed in a caudal, lateral and ventral direction through the thyroid cartilage. The second suture pass was placed through the ventral portion of the corniculate process, dorsal to the vocal fold, and directed caudolaterally through the thyropharyngeal membrane (Fig. 3b).

To perform the techniques, the ventral cervical area was clipped and aseptically prepared. The location of the jugular vein was marked on the skin to facilitate identification during placement of the TPAL suture. Dogs were placed in sternal recumbency with the maxilla supported on a metal rack and the mandible held open with a mouth gag. The larynx and hyoid apparatus were palpated and the exit sites for the suture identified ventral to the jugular vein. A standard laryngoscope with a long blade was used to expose the larynx and needles were placed using a long-handled Mayo-Hegar needle holder. The mattress suture (2-0 nylon, Covidien, Mundelein, IL) was placed through the arytenoid cartilage via an oral approach, exiting the skin approximately 2 cm ventral to the jugular vein (Fig. 2). The first suture pass was made using a 51 mm, swaged, straight, reverse cutting needle. The second suture pass was made by first passing a 22 gauge, 2 ½ inch spinal needle through the arytenoid cartilage, exiting the skin on the lateral aspect of the larynx just cranial and ventral to the first suture. An 18 gauge, 2 ½ inch spinal needle was then placed over the 22 gauge spinal needle and advanced until the tip was positioned just inside the rima glottidis. The free end of the suture was threaded through the tip of the 18 gauge needle and advanced until it exited the hub of the needle on the surface of the skin. Once the suture was exposed, the needle was withdrawn and the suture ends passed through a button and tied on the surface of the skin. The suture was tightened while examining the larynx to assess the degree of lateralization, with the goal of achieving maximum lateralization without excessive tension on the suture. After completion of the procedure, a light bandage was placed around the neck to prevent scratching or irritation of the button.

2.6. Laryngeal examination and rima glottidis surface area measurement

Rima glottidis surface area (mm^2) was evaluated via videoendoscopic laryngeal examination before (baseline) and immediately after the TPAL procedures, as well as on days 1, 3 and 7. Video images were collected using a 10 mm, 0 degree rigid endoscope (Karl Storz GmbH & Co. KG, Germany). Surface area was measured during peak inspiration for all time points. A standardized marker, placed at the level of cuneiform process, was used for image calibration. Surface area was calculated from digital images using Image J software (Image J, NIH). For TPAL-CC and TPAL-DV measurements, the right and left halves of the rima glottidis were evaluated, respectively. The landmarks for determining the midline of the rima glottidis were the junction between the left and right corniculate processes on the dorsal midline and the

junction between the left and right vocal folds on the ventral midline. The percent change in hemiglottic surface area was calculated by comparing with baseline images taken immediately before each technique (Fig. 4).

2.7. Post-TPAL treatment and monitoring

Dogs were examined daily for evidence of swelling or irritation at the button sites. Dogs were administered dexamethasone SP (0.25 mg/kg IV) 24 h after each TPAL procedure, followed by a tapering dose of prednisone (0.5 mg/kg orally) every 12 h for 2 days, and then every 24 h for 2 days. Dogs that developed evidence of abscess formation or cellulitis around the button site were administered amoxicillin/clavulanic acid (18–22 mg/kg orally every 12 h) (Clavamox, Zoetis, Florham Park, NJ) for 5 days.

Respiratory effort and presence of coughing or gagging during drinking and eating were evaluated using a visual analog scale (VAS). Dogs were evaluated by two investigators (SJS, RJH) at 5 time points: 1) at the beginning of the study; 2) 24 h after neurectomy; 3) 48 h after neurectomy; 4) 48 h after TPAL-CC; 5) 48 h after TPAL-DV. For each variable, a scale from 0 to 100 was used to score the respective findings. For respiratory effort, 0 represented “no increase in effort” and 100 represented “severe or continuous respiratory distress.” For coughing and gagging, 0 represented “no coughing or gagging during drinking or eating” and 100 represented “continuous coughing and gagging during drinking and eating.” The distance of the mark from “0” was measured and converted to a score from 0 to 100 (Joyce et al., 1975).

2.8. Gross examination and histopathology

The larynx was examined grossly and structures penetrated by the TPAL suture were evaluated for evidence of tissue reaction immediately after euthanasia. The larynges were removed and placed in 10% neutral buffered formalin. Representative sections from both the left and right arytenoid cartilage and underlying tissues penetrated by the sutures were sampled, embedded in paraffin, and stained with hematoxylin and eosin for histopathological evaluation. The tissue response including inflammation, fibrous reaction, and myocyte degeneration were graded using a 0 to 3 scale (see Appendix A).

2.9. Statistical analysis

For hemiglottic surface area analysis, the Kolmogorov-Smirnov test was used to evaluate normality. Mean hemiglottic surface area before TPAL-CC and TPAL-DV was compared using a paired Student's *t*-test. Each TPAL procedure was analyzed as a separate experiment and hemiglottic surface area was compared over time using one-way repeated-measures ANOVA with the Tukey's post-hoc test. Visual analog scores for respiratory effort and coughing and gagging during eating and drinking were analyzed with the Friedman test. Results were considered significant at $P < 0.05$.

3. Results

3.1. Preoperative assessment and bilateral recurrent laryngeal neurectomy

No significant abnormalities were identified on the preoperative examination or blood work. Bilateral recurrent laryngeal neurectomy procedures were performed without complication and bilateral laryngeal paralysis was confirmed postoperatively in all dogs.

3.2. Hemiglottic surface area measurements

Mean $\pm$ SD hemiglottic surface area before TPAL-CC was $5.02 \pm 1.16 \text{ mm}^2$ (range: 3.4–6.3 mm^2) and before TPAL-DV was $5.3 \pm 1.18 \text{ mm}^2$ (range: 3.7–6.4 mm^2). No significant difference was found in the respective preoperative hemiglottic surface areas ($P = 0.72$).

3.3. TPAL-CC technique

Sutures were placed successfully in all dogs. Right hemiglottic area was significantly increased immediately after surgery ($9.26 \pm 1.18 \text{ mm}^2$; range: 7.1–12.4 mm^2) compared to baseline preoperative area ($5.02 \pm 1.16 \text{ mm}^2$; range: 3.4–6.3 mm^2) ($P < 0.05$), with a mean percentage increase of 189% (Fig. 5). By day 1, edematous swelling was noted around the suture. Right hemiglottic area was significantly decreased on days 1 ($4.38 \pm 1.80 \text{ mm}^2$; range: 2.1–7 mm^2) and 3 ($2.92 \pm 2.10 \text{ mm}^2$; range: 0–4.9 mm^2) compared to postoperative values ($9.26 \pm 1.18 \text{ mm}^2$; range: 7.1–12.4 mm^2) ($P < 0.05$, $P < 0.005$, respectively), but were not significantly decreased from baseline preoperative area (Fig. 6). By day 3, the suture was no longer visible on the surface of the arytenoid cartilage and was buried under the mucosa (Fig. 5). By day 7, right hemiglottic area ($5.80 \pm 2.90 \text{ mm}^2$; range: 0–7.8 mm^2) was not significantly different from baseline or postoperative values (Fig. 6). At this time point, the swelling was nearly resolved, although 1–3 mm of slack was present in the mattress suture resulting in loss of mechanical lateralization of the arytenoid cartilage.

3.4. TPAL-DV technique

Sutures were placed successfully in all dogs. Left hemiglottic area was significantly increased immediately after surgery ($7.62 \pm 1.06 \text{ mm}^2$; range: 6.6–9.2 mm^2) compared to baseline preoperative area ($5.3 \pm 1.18 \text{ mm}^2$; range: 3.7–6.4 mm^2) ($P < 0.05$), with a mean percentage increase of 153% (Fig. 5). Less swelling was noted around the suture compared to the TPAL-CC technique at all time points postoperatively. Left hemiglottic area was slightly greater on days 1 ($5.70 \pm 0.86 \text{ mm}^2$; range: 5–7.2 mm^2) and 3 ($5.76 \pm 1.04 \text{ mm}^2$; range: 4.5–6.7 mm^2) compared to baseline but the difference was not significant (Fig. 6). Similar to the TPAL-CC technique, the suture was no longer visible on the surface of the cartilage and became buried under the mucosa within 3 days (Fig. 5). By day 7, the left hemiglottic area ($4.7 \pm 2.48 \text{ mm}^2$; 0–6.3 mm^2) was not different from baseline values (Fig. 6). At this time there was 1–3 mm of slack present in the mattress suture, similar to the TPAL-CC technique.

3.5. Postoperative monitoring

Thoracic auscultation, mucous membrane color, and respiration rate were within normal limits (VAS scores of 0) for all dogs with the exception of two incidents in two different

dogs. An increase in inspiratory effort was noted in one dog 9 days after TPAL-CC, which was associated with excitement (VAS respiratory effort score 31). Another dog was noted to cough between swallowing kibble 48 h after TPAL-DV (VAS eating score 16). No other episodes of increased respiratory effort ($P = 0.42$) or coughing or gagging during drinking ($P = 1$) or eating ($P = 0.42$) were noted during the study period.

Purulent discharge was noted around the button site in two dogs, 3 and 4 days after TPAL-CC. In another dog, swelling occurred around the button/suture site 7 days after TPAL-CC, but no purulent discharge was noted. These dogs were subsequently treated with amoxicillin/clavulanic acid and the button site was cleaned with dilute chlorhexidine every 12 h for 36–48 h. Discharge and swelling around the button site resolved in all dogs within 3 days.

3.6. Gross and histopathological examination

The suture tracts were dissected in all dogs. The suture track was similar to that described in a previous cadaveric study (Hardie, 2016) and there was no evidence of disturbance to the jugular vein. Additionally, there was no evidence of entrapment of branches of the cranial laryngeal nerve by the suture; however, we cannot definitively rule-out the potential for iatrogenic injury to the nerve due to adjacent tissue swelling as a result of tightening the suture. The sutures penetrated the cartilage of the corniculate process appropriately and there was no evidence of fracture. The sutures had migrated through the corniculae process to various degrees and were no longer visible in the larynx. There was evidence of mild irritation and distortion of the corniculate process from the presence of the sutures but the mucosa over the site had appeared to have re-epithelialized.

On histopathological examination, there was a relatively wide variation in scoring of the tissue response between dogs. Mean scores for inflammation, fibrous tissue formation and myocyte degeneration were 2, 1.6 and 2 for the TPAL-CC suture tracts and 1.8, 1.6 and 1.6 for the TPAL-DV suture tracts, respectively. Examination of the arytenoid cartilage penetrated by the mattress sutures revealed ulceration of the mucosal surface in two TPAL-DV dogs. In all of the other samples, re-epithelialization of the mucosal surface had occurred. In three dogs (2-TPAL-DV and 1-TPAL-CC) microabscesses or pyogranulomatous inflammation was present around the suture tracts deep to the cartilage.

4. Discussion

Based on the results of this study, both TPAL techniques were effective at lateralizing the arytenoid cartilage and significantly increasing hemiglottic surface area immediately after suture placement. However, complications with mucosal swelling and loss of tension on the mattress suture led to a decrease glottic area within 24 h of suture placement.

The swelling seen with the TPAL-CC technique was most likely due to the orientation of the mattress suture. For the TPAL-CC technique, the mattress suture was oriented in a craniocaudal direction and positioned at the base of the corniculate process just dorsal to the vocal fold. This orientation resulted in direct lateral tension on the arytenoid cartilage as the suture was tightened and thus a biomechanical advantage compared to the orientation of the TPAL-DV suture. However, for some dogs, this orientation resulted in the dorsal aspect of

the vocal fold becoming entrapped under the mattress suture causing excessive swelling of the vocal fold within 24 h.

In contrast, the mattress suture for the TPAL-DV technique was oriented in a dorsoventral direction completely within the corniculate process and thus did not involve the vocal fold. This orientation resulted in dorsolateral tension on the arytenoid cartilage as the suture was tightened which was mechanically less effective than the TPAL-CC technique. However, this orientation avoided entrapment of the vocal fold and thus did not result in the same degree of mucosal swelling.

Lateralization with the TPAL technique relies on the mattress suture being well anchored in the arytenoid cartilage as it is tensioned against the skin. With both techniques, a “solid bite” of the corniculate process was taken and the larynx was observed as the suture was slowly tightened to help avoid excessive tension on the suture. Despite these measures, the sutures in both techniques gradually migrated through the corniculate process to various degrees, leading to progressive loss of lateralization and slack in the suture over time. This complication is somewhat different from that described in humans where long-term function of percutaneous lateralization sutures, as well as the ability to adjust the tension periodically, has been reported (Ejnell et al., 1984; Ezzat et al., 2010; Kirchner, 1979; Lichtenberger, 2002; Mathur et al., 2004; Rovó et al., 2000). The reason for this difference in suture migration between humans and this canine study is unknown, but may be due to the age of the dogs used in this study, as well as species differences in structural integrity of the arytenoid cartilage or greater mobility of the arytenoid cartilage in humans and thus the ability to lateralize the cartilage with less tension on the suture. Nevertheless, to potentially reduce the likelihood of the suture migrating through the cartilage in dogs, further investigation into the optimal location of suture placement and the degree of tension applied to the suture is warranted. Furthermore, in the emergency setting, it may be reasonable to consider that simply fixing the arytenoid cartilage in place to prevent paradoxical motion may be all that is necessary to temporarily prevent airway obstruction, rather than attempting to enlarge the rima glottidis similar to that of conventional procedures.

Placement of the TPAL suture was relatively straightforward and is intended to be able to be performed in a matter of minutes, assuming one has thoroughly reviewed the relevant anatomy and practiced the technique appropriately. Depending upon the size of the dog, long-handled instruments may be necessary to enable accurate placement of the needles. In this study, placement of the mattress suture was modified slightly from the previous cadaver study (Hardie, 2016) in that both a swaged-on straight needle and a spinal needle were used rather than double-armed suture with swaged curved needles (2-0 Surgipro, KV-7 tapercut needle, Covidien, Mundelein, IL). The first suture was placed using the swaged-on needle as previously described. The second suture was placed by threading the free end of the suture through the tip of an 18 gauge needle that was placed from lateral to medial over a previously placed 22 gauge spinal needle that had been passed through the larynx from medial to lateral. Placing the 22 gauge spinal needle via an oral approach was technically similar to placing the swaged-on needle using the long-handled needle holders. The rigidity and sharpness of the spinal needle allowed it to penetrate the arytenoid cartilage easily, and

the needle was long enough to be easily located as it exited the skin on the lateral aspect of the larynx.

Based on observations of the dogs while eating and drinking, the TPAL techniques did not appear to result in obvious problems with swallowing. However, this type of evaluation is limited in its ability to detect subtle abnormalities and therefore caution should still be taken to minimize the risk of aspiration with this procedure. Furthermore, although the mechanism for lateralizing the arytenoid cartilage is different from conventional techniques, the immediate increase glottic area was similar to previous reports; therefore, it is presumed that the risk for aspiration due to failure of the epiglottis to fully cover the rima glottidis would likewise be similar with the TPAL techniques (Demetriou and Kirby, 2003; Griffiths et al., 2001; Lussier et al., 1996).

The abscesses that developed around the percutaneous suture site in two dogs underscores the need for prophylactic antibiotics with this technique. Although aerobic cultures of the sites were not performed, the source of contamination was most likely oral or skin bacteria that seeded the percutaneous suture tract. In both dogs, the infection responded quickly to oral antibiotic therapy and did not appear to result in any other systemic complications. As percutaneous techniques continue to evolve, we would recommend starting antimicrobial therapy at the time of the procedure, continuing therapy for at least 5 days post-operatively, and then adjusting the duration based on how long the suture is in place and the condition of the skin and suture track.

The histopathological changes seen in the arytenoid cartilage varied between individual dogs but were similar for both techniques. Although the samples for each technique were collected at different times after initial suture placement (TPAL-DV 7 days post-op and TPAL-CC 18 to 21 days post-op), the inflammatory changes were consistent with the presence of the suture material and did not reveal any unexpected findings.

The TPAL technique described in this study differs slightly from the technique described by Shipov et al. (2015). Firstly, the sutures were placed via an oral approach rather than from the external surface of the neck. We found that placing the sutures via the mouth was relatively straightforward and allowed for accurate placement into the desired location of the arytenoid cartilage. Secondly, the TPAL sutures were placed more cranial in the arytenoid cartilage and engaged more of the corniculate process, as opposed to the suture being placed more caudally in the middle portion of the arytenoid cartilage. In light of the swelling and loss of suture tension seen with both TPAL techniques described in this study, the more caudal location for suture placement would appear to be advantageous. Lastly, the TPAL sutures were tightened over a button on the surface of the dog's neck, rather than directly on the lateral surface of the thyroid cartilage via a small incision in the skin. This difference reflects the different rationales for the two procedures with the TPAL intended as an alternative to temporary tracheostomy in the emergency setting and the other intended as a minimally-invasive alternative to conventional lateralization procedures.

This study had several limitations. The dogs used for this work were young and had experimentally induced laryngeal paralysis, which does not necessarily mimic the

neurologic deficits present in dogs with acquired laryngeal paralysis. Consequently, the effect of TPAL on swallowing function or the risk of aspiration may be different in clinical cases of acquired laryngeal paralysis. Dogs in this study were younger than dogs typically affected with acquired laryngeal paralysis, and it is therefore possible that the TPAL technique may function differently in older dogs due to age and disease-related changes to the laryngeal cartilages. Hemiglottic surface area was used to assess the effect of each TPAL procedure, rather than total glottic surface area, to allow use of both sides of the larynx in a single dog. Ideally, these procedures would have been performed in two different study populations; however, to minimize animal use, the authors felt it reasonable to utilize hemiglottic surface area to enable the use the same dogs for both procedures. A further limitation includes the lack of any mechanical testing of the laryngeal cartilages after the procedure was undertaken, resulting in an inability to determine whether the cartilage, and in particular the corniculate process, was mechanically compromised as a result of these techniques. Lastly, the dose of post-operative dexamethasone was varied slightly in the dogs studied, which was a result of an evolution in the author's assessment of the need for increased anti-inflammatory medication after the first two procedures were performed.

5. Conclusion

The TPAL techniques described in this study appear to have limited clinical application due to the short duration (< 24 h) of rima glottidis enlargement. Further refinements in suture placement technique are warranted to minimize swelling and improve the duration of arytenoid lateralization. Specific recommendations include avoiding excessive tension on the suture to reduce the likelihood of migration through the arytenoid cartilage and avoiding entrapment of the vocal fold to minimize the degree of mucosal swelling caused by the suture.

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Appendix A. Histological grading scale for the arytenoid cartilage penetrated by the mattress suture

Inflammation

0: None

1: Few small aggregates of lymphocytes and plasma cells. Expected post-surgical inflammation.

2: Multiple larger aggregates, potentially coalescing, of lymphocytes, plasma cells and other cells (neutrophils, macrophages). More robust but still acceptable post-surgery.

3: Diffuse sheets of mixed inflammation (neutrophils, macrophages, lymphocytes, plasma cells). Considered excessive – indicates infections, suture reaction or other complication.

Fibrous tissue

0: None

1: Thin band along suture tract. Expected post-surgical healing.

2: Thicker band along suture tract. More robust but still acceptable post-surgery.

3: Extensive bands that extend beyond suture tract. Considered excessive, likely associated with other (inflammatory) complications.

Myocyte degeneration/regeneration

0: None

1: Few disrupted cells along suture tract. Expected post-surgery.

2: Moderate numbers of disrupted cells along suture tract. More robust but still acceptable.

3: Extensive disruption along and beyond suture tract. Considered excessive and likely associated with other complications.

Fig. 1.

Timeline of study. The TPAL-CC was performed 7 days after bilateral recurrent laryngeal neurectomies, and the TPAL-DV was performed 4–7 days after completion of the TPAL-CC study. Laryngeal examinations were performed before and after the TPAL procedures and again on days 1, 3 and 7 after each technique.

Fig. 2. Location of external suture placement. The button was used to secure the suture on the lateral aspect of the neck and was positioned cranial and ventral to the jugular vein over the thyroid cartilage.

Fig. 3.

Needle placement for TPAL techniques. A) The location of needle placement for the mattress suture for the TPAL-CC (right) and TPAL-DV (left) techniques. B) For the TPAL-CC technique, the suture was placed in a craniocaudal orientation. The first needle was placed caudal to the corniculate process, dorsal to the vocal fold and directed through the thyroid cartilage. The second needle was placed through the caudal portion of the cuneiform process of the arytenoid cartilage. C) For the TPAL-DV technique, the suture was placed in a dorsoventral orientation. The first needle was placed through the dorsal aspect of the corniculate process 2–3 mm ventral to the apex of the glottis, and directed through the thyroid cartilage. The second needle was placed through the ventral portion of the corniculate process. R = right side of glottis, L = left side of glottis.

Fig. 4.

Hemiglottic surface area measurement method. A) A 0.25 cm diameter spherical marker was placed at the level of the cuneiform process to allow for image calibration. B) A line was made from the junction between the left and right corniculate processes on the dorsal midline to the junction between the left and right vocal folds on the ventral midline to demarcate the midline of the rima glottidis (vertical line). Hemiglottic surface area was then determined by tracing the outline of the glottic area to the level of midline (dotted line).

Fig. 5.

Glottic surface area changes throughout study period. These representative images show glottic appearance at baseline, immediately after suture placement, and days 1, 3 and 7 for the TPAL-CC and TPAL-DV techniques. White arrows indicate suture location. R = right side of glottis, L = left side of glottis.

Fig. 6. Significant changes in hemiglottic surface throughout the study period. Graphs representing the hemiglottic area immediate before (pre-op) and after (post-op) suture placement, and on days 1, 3 and 7 for TPAL-CC (A) and TPAL-DV (B) techniques. * - $P < 0.05$ vs. immediately before surgery or as indicated. Error bars represent standard deviation.