Effects of successive tracheal resection and anastomosis on tracheal diameter and position of lobar bronchi in dogs

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OBJECTIVE
To evaluate the effects of successive large-segment tracheal resection and anastomosis on tracheal diameter and position of lobar bronchi in dogs.

ANIMALS
5 adult Beagles.

PROCEDURES
Right lateral radiographs were obtained for all dogs and used to measure tracheal length. Dogs were then euthanized, and successive segmental tracheal resections (intervals of 10% from 20% to 50% of the tracheal length), each of which was followed by anastomosis, were performed in each cadaver. Tracheobronchoscopy was performed before the first tracheal resection and after each of the anastomoses to evaluate tracheal diameter and changes in position of lobar bronchi.

RESULTS
Tracheal diameter was minimally affected by resections up to 50% of the tracheal length. Diameter of the trachea and position of bronchi were not affected by resection of 20% of the tracheal length. Changes in the position of various lobar bronchi were detected after resection of 30% of the tracheal length.

CONCLUSIONS AND CLINCIAL RELEVANCE
In this study, tracheal resections of 20% of the tracheal length were accommodated, possibly as a result of stretching of the annular ligament. Resections of ≥ 30% of the tracheal length altered the position of lobar bronchi. Clinical effects, if any, attributable to these changes in bronchial position remain to be elucidated. (*Am J Vet Res* 2016;77:658–663)

Segmental tracheal resection and anastomosis is not commonly performed in dogs, but it may be the only viable option for the treatment of tumors, strictures, and necrotic conditions.[1–3] Extensive resections predispose patients to partial or complete dehiscence and postanastomotic tracheal stenosis as a result of scar formation.[4–6] The maximum extent of STR associated with an acceptable clinical outcome is unknown for humans or dogs. In humans, a significant increase in complication rates is observed with resections ≥ 4 cm in length.[7] In only a few studies have investigators attempted to address the limits of STR in dogs. It has been suggested that as much as 60% of the tracheal length can be resected in adult dogs.[4] Results of tension induced by anastomosis, short-term postoperative clinical outcome, and histologic abnormalities after extensive STR and anastomosis in 42 research dogs have been reported.[4] In that study,[4] 6 dogs died during surgery or within 48 hours after surgery. Partial to complete dehiscence of the anastomotic site was detected in 15 dogs (46% to 63% of the trachea removed). Only 21 dogs (20% to 58% of the trachea removed) had primary healing of the anastomotic site.

ABBREVIATIONS

STR	Segmental tracheal resection

In a later study,[5] 15 to 17 tracheal cartilages from 7 medium-sized dogs were resected (approx 37% to 42% of the tracheal length). One dog was euthanized for exercise intolerance; all the remaining dogs developed immediate postoperative complications that included coughing, wheezing, and hoarseness.[5] Evaluation of long-term postsurgical clinical performance was not reported in the aforementioned studies,[4,5] and all dogs were euthanized at study conclusion.

The objective of the study reported here was to evaluate changes in the anatomic structure of the trachea and lobar bronchi caused by increases in tracheal resection (from 20% to 60% of the tracheal length) and anastomosis. We thought that an STR of 60% of the tracheal length would not be achievable in most dogs and that tension resulting from resections > 20% of the tracheal length followed by anastomosis would decrease tracheal diameter and alter position of lobar bronchi.

Materials and Methods

Animals

Five adult sexually intact (3 males and 2 females) Beagles were used in the study. The dogs had participated in a pharmacological study prior to inclusion

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in this study. Dogs were cared for in accordance with established principles,[8] and all procedures were approved by the University of Missouri Animal Care and use Committee.

Measurement of tracheal length

Right lateral radiographs were obtained for all dogs and used to measure tracheal length. Radiographic magnification was corrected by the use of a standard measuring bar.

Tracheobronchoscopy

After radiographs were obtained, dogs were euthanized by administration of an overdose of pentobarbital sodium[a] (120 mg/kg, IV). Immediately after dogs were euthanized, they were placed in dorsal recumbency. The neck of each cadaver was extended for the tracheobronchoscopy procedure, which was initiated within minutes after the dogs were euthanized.

Tracheobronchoscopy was performed with a flexible endoscope[b] prior to the first tracheal resection and serially after each anastomosis. During the interval between resections and during tracheobronchoscopy, the external surgical field was covered with surgical sponges soaked in warm (37°C) saline (0.9% NaCl) solution to minimize tissue dehydration. Tracheoscopy was performed first, and it included both video recordings of the entire length of the trachea and photographs of each of 3 locations (surgical site [indicated by pushing the tip of a 22-gauge needle through the tracheal wall into the lumen at the intended surgical site], 2 cm cranial to the surgical site, and 2 cm caudal to the surgical site). Bronchoscopy also included both video recordings and photographs of the carina (allowing for visual examination of lobar bronchi); photographs were centered over the right main stem bronchi and left main stem bronchi. One investigator (CRR) performed all tracheobronchoscopic examinations and reviewed all video recordings and photographs to score alterations in structural anatomy. Bronchial anatomy was as described in another study[9] **(Figure 1)**. Changes in tracheal diameter were graded in accordance with the system described in another study.[10] Briefly, decreases in tracheal diameter were classified as grade I (25%), grade II (50%), grade III (75%), or grade IV (100%).

After each STR and anastomosis was performed, positions of the lobar bronchi were photographed for use in comparing positions of the same bronchi when the trachea was intact. In anatomically normal dogs, the circular opening of the lobar bronchus to the right cranial lung lobe (ie, RB1) lies approximately parallel to the long axis of the trachea (which is the reason that RB1 is not easily visible when an endoscope is centered at the carina), with its associated bronchus perpendicular to the long

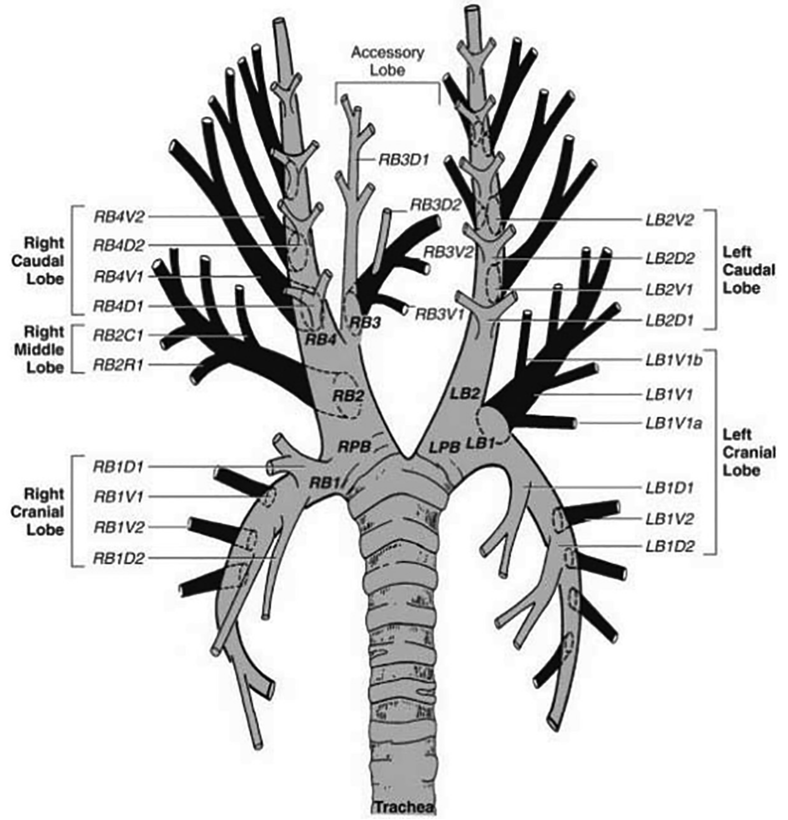

Figure 1—Diagram of the canine bronchial tree and identification of the principal, lobar, segmental, and subsegmental bronchi. LB1 = Left cranial lung lobe bronchus. LB1D1 = First dorsal segment to the left cranial lung lobe. LB1D2 = Second dorsal segment. LB1V1 = First ventral segment to the left cranial lung lobe. LB1V1a = First ventral segment to the left cranial lung lobe; subsegment a. LB1V1b = First ventral segment to the left cranial lung lobe; subsegment b. LB1V2 = Second ventral segment to the left cranial lung lobe. LB2 = Left caudal lung lobe bronchus. LB2D1 = First dorsal segment to the left caudal lung lobe. LB2D2 = Second dorsal segment to the left caudal lung lobe. LB2V1 = First ventral segment to the left caudal lung lobe. LB2V2 = Second ventral segment to the left caudal lung lobe. LPB = Left principal bronchus. RB1 = Right cranial lung lobe bronchus. RB1D1 = First dorsal segment to the right cranial lung lobe. RB1D2 = Second dorsal segment to the right cranial lung lobe. RB1V1 = First ventral segment to the right cranial lung lobe. RB1V2 = Second ventral segment to the right cranial lung lobe. RB2 = Right middle lung lobe bronchus. RB2C1 = First segment to the right middle lung lobe. RB2R1 = Second segment to the right middle lung lobe. RB3 = Right accessory lung lobe bronchus. RB3D1 = First dorsal segment to the accessory lung lobe. RB3D2 = Second dorsal segment to the accessory lung lobe. RB3V1 = First ventral segment to the accessory lung lobe. RB3V2 = Second ventral segment to the accessory lung lobe. RB4 = Right caudal lung lobe bronchus. RB4D1 = First dorsal segment to the right caudal lung lobe. RB4D2 = Second dorsal segment to the right caudal lung lobe. RB4V1 = First ventral segment to the right caudal lung lobe. RB4V2 = Second ventral segment to the right caudal lung lobe. (Adapted from Amis TC, McKiernan BC. Systematic identification of endobronchial anatomy during bronchoscopy in the dog. *Am J Vet Res* 1986;47:2649–2657. Reprinted with permission.)

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axis of the trachea **(Figure 2)**. An abnormal position was recorded at the percentage of tracheal resection that corresponded to when RB1 first became visible from the carina and the circular opening was more perpendicular to the long axis of the trachea. The bronchus leading to the right middle lung lobe (ie, RB2) is ventrally dependent in anatomically normal dogs, with its opening lying on the floor of the right primary bronchus just past that bronchus entrance. An abnormal position was recorded at the percentage of tracheal resection that corresponded to when RB2 was first noted to be no longer lying flat on the floor of the right primary bronchus. The typical position for the bronchial entry to the accessory lung lobe (ie, RB3) is an oval opening only partially visible from the carina. An abnormal position was recorded at the percentage of tracheal resection that corresponded to when RB3 was more perpendicular to the long axis of the trachea and had a more circular appearance. The bronchus leading to the left cranial lung lobe (ie, LB1) is visible from the carina as a slit, with the circular opening parallel to the long axis of the trachea; it splits into 2 branches (a bronchus leading to the cranial portion of the left cranial lung lobe and a bronchus leading to the caudal portion of the left cranial lung lobe). The split into the 2 branches typically is not visible from the carina; an abnormal position was recorded at the percentage of tracheal resection that corresponded to when both branches of LB1 were visible from the carina.[9]

Surgery

A skin incision was made on the ventral cervical midline extending from the cricoarytenoid cartilage to the manubrium. Subcutaneous fat was incised to expose the sternohyoideus muscles, which were bluntly separated to expose the trachea. Connective tissue surrounding the trachea was gently dissected to free the tracheal segments for resection and to isolate the recurrent laryngeal nerves from the surgical site.[11] After the trachea was exposed, the lengths for tracheal cartilages 6 through 9 were measured with calipers at the most ventral aspect of the cartilages (ie, 6-o'clock position). On the basis of the length of the trachea (measured radiographically) and the length of those 4 cervical tracheal cartilages, the percentage of resection was calculated. Resection in all canine cadavers began caudal to the fifth tracheal cartilage. Eight tracheal cartilages were initially resected (resection of approx 20% of the tracheal length). Anastomosis was performed by use of 4-0 polypropylene with 6 simple interrupted sutures that encircled 2 of the tracheal cartilages (sutures at the 2-, 4-, 10-, and 12-o'clock positions) and the trachealis muscle (sutures at the 6- and 8-o'clock positions) immediately adjacent to the resection. Four successive resection and anastomosis procedures were performed. At each successive resection, 1 tracheal cartilage cranial to and 3 tracheal cartilages caudal to the previous anastomotic site were removed, which resulted in removal of approximately 10% of the tracheal length/resection.

Results

Feasibility of incremental STR and anastomosis

Length of STR was based on total tracheal length measured by use of radiography. Total length of the trachea measured radiographically ranged from 16.1 to 18.8 cm (mean, 17.5 cm). Mean length of cartilages 6 through 9 before STR and anastomosis was 1.5 cm (range, 1.4 to 1.6 cm), which was equal to 10% (range, 9.8% to 10.3%) of the tracheal length; thus, initial resection of 8 tracheal cartilages resulted in removal of 20% of the total tracheal length. Successful STR and anastomosis was readily accomplished in all 5 cadavers at 20%, 30%, and 40% of the tracheal length and in 4 cadavers at 50% of the tracheal length. This was confirmed by anatomic apposition of the tracheal cartilages and minimal overlap for STR at 50% of the tracheal length. Tearing of the tracheal cartilages or inability to appose the tracheal segments as a result of excessive tension prevented anastomosis after STR at 60% of the tracheal length in 4 cadavers. In the fifth cadaver, marked cervical ventroflexion was required to achieve anastomosis after STR at 60% of the tracheal length, and apposition was poor.

Alterations in tracheal diameter

Preoperative tracheal diameter was maintained in 4 of 5 cadavers for all tracheal positions evaluated (ie, viewed from the larynx, site of STR and anastomosis, 2 cm cranial to the surgical site, and 2 cm caudal to the surgical site). In the fifth cadaver, tracheal diameter was considered grade I (approx 25% decrease in

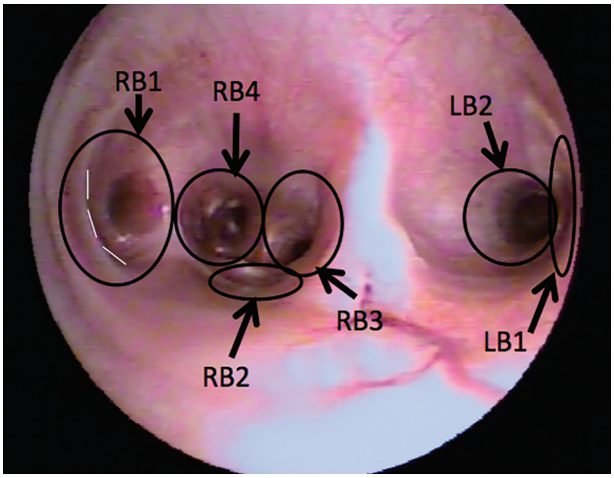

Figure 2—Endoscopic view obtained from a canine cadaver with anatomically normal airways with the endoscope placed cranial to the carina. Airways leading to the right lung lobes are on the left, and airways leading to the left lung lobe are on the right. Notice that portions of RB1 and LB1 are perpendicular to the long axis of the trachea and have a slit-like appearance. The opening to RB1D1 is indicated (dashed line). ***See*** Figure 1 for remainder of key.

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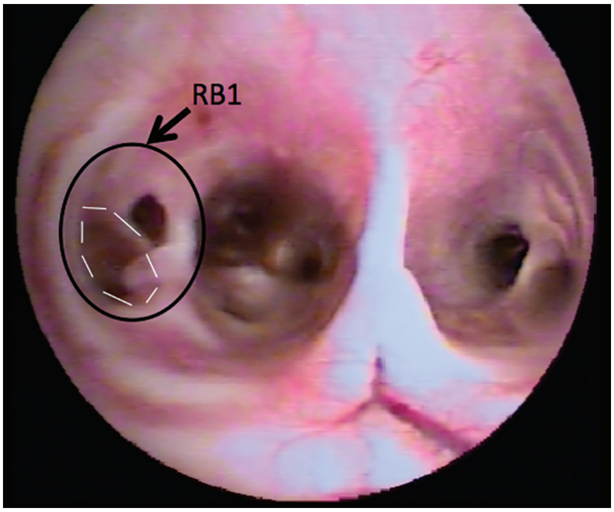

Figure 3—Endoscopic view obtained from a canine cadaver after STR at 30% of the tracheal length. Notice that the position of RB1 changed so that the opening is readily visible from the carina. Additionally, the slit-like appearance has changed to a more oval appearance (dashed line). ***See*** Figure 1 for remainder of key.

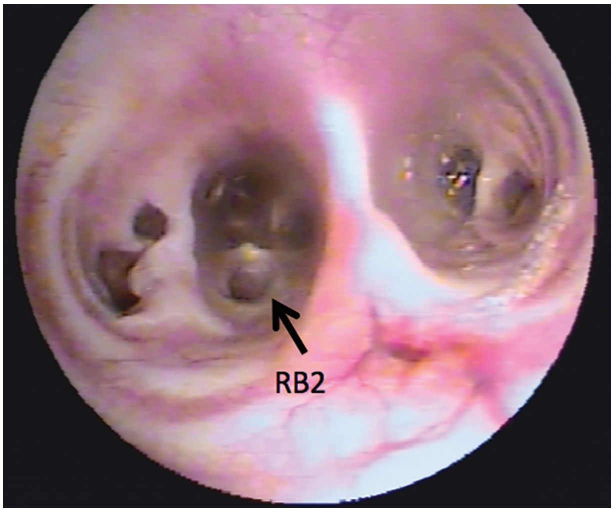

Figure 4—Endoscopic view obtained from a canine cadaver after STR at 50% of the tracheal length. Notice that the ventrally dependent RB2 was lifted from the floor of the right principal bronchus and has a more easily identified circular appearance during endoscopy with the endoscope placed cranial to the carina. ***See*** Figure 1 for remainder of key.

luminal diameter) at 2 cm caudal to the surgical site, which was detected starting at resection of 30% of the tracheal length. In that cadaver, there was no decrease in tracheal diameter as viewed from the larynx, site of STR and anastomosis, or 2 cm cranial to the surgical site.

Alterations in position of lobar bronchi

The most consistent endoscopic changes were evident for the position of the lobar bronchi as viewed from the carina. Compared with the anatomically normal position of each lobar bronchus, STR and anastomosis caused marked changes in the position of

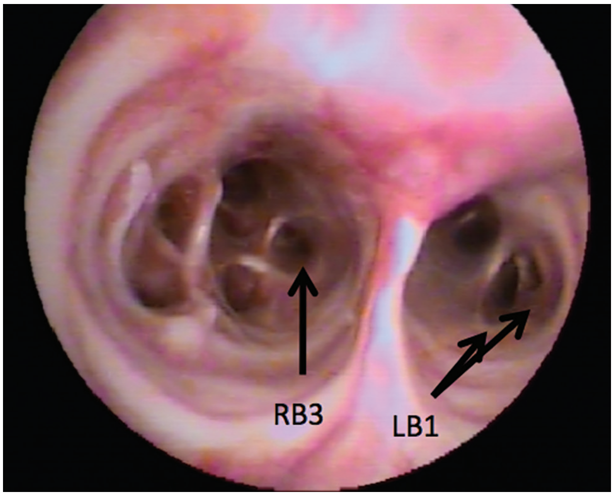

Figure 5—Endoscopic view obtained from another canine cadaver after STR at 50% of the tracheal length. Notice that RB3 is more perpendicular to the long axis of the trachea and has a more circular appearance. Both branches of LB1 are now easily visible during endoscopy with the endoscope placed cranial to the carina. ***See*** Figure 1 for remainder of key.

the lobar bronchi that were detected after resection of 30% of the tracheal length (ie, removal of 12 tracheal cartilages). Traction exerted by the STR did not affect the same bronchus and in the same manner for each cadaver, although the magnitude of those positional changes increased with successive resections **(Figures 3–5)**. The percentage of resection at which changes in the position of the lobar bronchi were first detected was as follows: RB1, 2 cadavers at 30% of the tracheal length, 2 cadavers at 40% of the tracheal length, and 1 cadaver at 50% of the tracheal length; RB2, 3 cadavers at 30% of the tracheal length and 2 cadavers at 40% of the tracheal length; RB3, 3 cadavers at 30% of the tracheal length and 2 cadavers at 40% of the tracheal length; and LB1, 1 cadaver at 30% of the tracheal length, 3 cadavers at 40% of the tracheal length, and 1 cadaver at 50% of the tracheal length.

Discussion

Results of the present study suggested that STR at 60% of the tracheal length was unlikely to be successfully performed in dogs. The study was performed on a small number of fresh canine cadavers. One should expect that tissues of live patients will be more elastic than will cadaver tissues. Despite this, large tracheal resections (> 50% of the tracheal length) in live patients may result in tearing of tracheal cartilage, inability to appose tracheal segments, or the need for extreme neck ventroflexion to achieve tracheal anastomosis. In live patients, extensive tension could disrupt the segmental blood supply to the trachea, thus decreasing healing and predisposing patients to necrosis and dehiscence.[4,5] Investigators of 1 study[4] found that STR of up to 58% of the tracheal length achieved primary healing of the anastomosis, provided tension measured by use of a tensiometer at the anastomotic site was < 1,700 g. In another study,[5] in which 15 to 17 tracheal cartilages were removed, excessive manip-

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ulation of the trachea (which was necessary for use of the tensiometer) caused additional trauma and resulted in poor mucosal healing and an increase in the amount of collagen, size and number of blood vessels, and number of inflammatory cells at the anastomotic site. The authors concluded that use of the tensiometer in a clinical setting might not be feasible.[5] Furthermore, all dogs in that study[5] developed a cough, and one of them had to be euthanized because of severe respiratory distress. The study reported here revealed secondary bronchial conformational changes that were evident after STR of > 20% of the tracheal length. These bronchial changes may have been responsible for the respiratory signs reported in other studies[5,6] that involved extensive STR. In contrast, no clinical signs were observed for up to 150 days after STR (8 tracheal cartilages) and anastomosis in 12 Beagles.[4–6,12]

It was unexpected that extensive STR and anastomosis would result in a minimal effect on the luminal diameter of the trachea. Tension exerted as a result of STR and anastomosis appeared to predominantly pull the lobar bronchi cranially and did not narrow the tracheal diameter. Only in 1 cadaver was the tracheal lumen decreased, and that decrease (approx 25%) was relatively minimal. We believe that the space between the rings (annular ligament) stretched under tension, which resulted in elongation. Eventually, this tension was distributed over all segments of the respiratory tract, which resulted in changes in bronchial anatomy. Resection and anastomosis of 20% of the tracheal length was easily performed and did not result in any changes in position of the lobar bronchi. With less extensive STRs, stretching of the annular ligaments and consequent cartilage separation prevented conformational changes in lobar bronchi. It may not be easy to compensate for additional tension (at least acutely), which could lead to changes in position of the lobar bronchi. Tension-relieving techniques have been described that can be used to decrease dehiscence and scar-related tracheal stenosis after STR and anastomosis.[1,5,6] Investigators of 1 study[6] performed STR and anastomosis (0 to 13 tracheal cartilages) with sling sutures in 68 dogs and found that anastomosis at < 750 g of tension typically healed well. Furthermore, that same study[6] found that anastomotic tension as high as 2,550 g was effectively alleviated by the use of sling sutures. We chose to not perform a tension-relieving technique to allow full evaluation of changes caused by the STR and anastomosis. Although tension-relieving techniques may be successful for decreasing tension at an anastomotic site, they may result in even more dramatic stretching of the remaining airways.

Techniques for controlled cervical flexion have been described. Postoperative cervical flexion can be achieved by suturing the intermandibular skin to the sternum followed by application of a sling.[13–15] Cervical flexion, even if temporary, may not be tolerated well by most patients or by the owners of patients undergoing those procedures.

The inconsistency in bronchial changes among dogs was likely attributable to intercadaver variability in the distribution of mechanical forces. Despite that, longer resections always led to more severe bronchial changes in every cadaver, even though the percentage STR at which these changes occurred differed among cadavers. It is important to mention that there was a percentage of STR at which the appearance of a specific bronchus was altered in all cadavers (ie, magnitude of the STR was such that airways of all cadavers were affected; for example, RB1 and LB1 of all cadavers were affected at STR of 50% of the tracheal length, and RB2 and RB3 of all cadavers were affected at STR of 40% of the tracheal length).

In humans, predisposing factors for complications after STR and anastomosis have been described and include the need for another surgery, STR ≥ 4 cm in length, diabetes mellitus, laryngotracheal resections, surgery performed in patients ≤ 17 years old, and the need for preoperative tracheostomy.[7] In dogs, complications associated with STR and anastomosis reportedly include suboptimal tissue apposition and leakage, dehiscence, and stricture. Poor tissue apposition and dehiscence may lead to subcutaneous emphysema, pneumomediastinum, and, potentially, pneumothorax of various degrees.[1,3,5] Postoperative stricture formation is thought to be secondary to excessive tension at an anastomotic site. This is the complication reported most commonly and may lead to severe respiratory distress.[4–6]

Limitations of the present study included that it was performed in cadavers and thus dynamic changes in airflow and pressure-exerting conformational changes in airway structures could not be assessed. All dogs were Beagles; therefore, they may not have reflected the various conformations of other breeds. Finally, the number of tracheal cartilages can differ among dogs. In 1 study,[4] investigators reported that there were typically 40 tracheal cartilages (range, 34 to 44 tracheal cartilages) in mixed-breed dogs of various sizes.

In the study reported here, tracheal resections of 20% of the tracheal length were readily achievable in canine cadavers and did not appear to grossly affect tracheal diameter or position of lobar bronchi, which we believe was the result of postanastomotic stretching of the annular ligament. Resections ≥ 30% of the tracheal length altered conformation of the lobar bronchi, probably as a result of increased tension. These bronchial changes may be associated with clinical signs and should be considered before extensive tracheal resections are performed in canine patients.

Acknowledgments

The authors declare that there were no conflicts of interest.

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Footnotes

a. Fatal Plus, Vortech Pharmaceuticals Ltd, Dearborn, Mich.
b. Fujinon FB-120T, Fujinon Inc, Wayne, NJ.

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