Bronchial abnormalities found in a consecutive series of forty brachycephalic dogs

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Objective—To detect abnormalities of the lower respiratory tract (trachea, principal bronchi, and lobar bronchi) in brachycephalic dogs by use of endoscopy, evaluate the correlation between laryngeal collapse and bronchial abnormalities, and determine whether dogs with bronchial abnormalities have a less favorable postsurgical long-term outcome following correction of brachycephalic syndrome.

Design—Prospective study.

Animals—40 client-owned brachycephalic dogs with stertorous breathing and clinical signs of respiratory distress.

Procedures—Brachycephalic dogs anesthetized for pharyngoscopy and laryngoscopy between January 2007 and June 2008 underwent flexible bronchoscopy for systematic evaluation of the principal and lobar bronchi. For dogs that underwent surgical correction of any component of brachycephalic syndrome, owners rated surgical outcome during a follow-up telephone survey. Correlation between laryngeal collapse and bronchial abnormalities and association between bronchial abnormalities and long-term outcome were assessed.

Results—Pugs (n = 20), English Bulldogs (13), and French Bulldogs (7) were affected. A fixed bronchial collapse was recognized in 35 of 40 dogs with a total of 94 bronchial stenoses. Abnormalities were irregularly distributed between hemithoraces; 15 of 94 bronchial abnormalities were detected in the right bronchial system, and 79 of 94 were detected in the left. The left cranial bronchus was the most frequently affected structure, and Pugs were the most severely affected breed. Laryngeal collapse was significantly correlated with severe bronchial collapse; no significant correlation was found between severity of bronchial abnormalities and postsurgical outcome.

Conclusions and Clinical Relevance—Bronchial collapse was a common finding in brachycephalic dogs, and long-term postsurgical outcome was not affected by bronchial stenosis.

tory distress and noisy breathing were included in this study. All dogs underwent a complete endoscopic examination including pharyngoscopy, laryngoscopy, and tracheobronchoscopy. All endoscopic procedures were performed by the same investigator (DDL). The study protocol was performed in compliance with institutional guidelines for research on animals, the owners of all dogs in our study were informed about all the procedures, and we obtained signed informed consent from every owner.

Procedures—Information obtained for each dog during the preanesthetic evaluation included signalment, clinical signs at the time of admission, physical examination findings, hematologic analysis results, and findings on thoracic radiography (data not analyzed). For the endoscopic procedures, dogs were sedated with medetomidine (30 µg/kg [13.6 µg/lb], IM) and methadone (0.2 to 0.4 mg/kg [0.09 to 0.18 mg/lb], IM), while anesthesia was induced with propofol (4 mg/kg [1.8 mg/lb], IV) and maintained with sevoflurane in oxygen.

Laryngoscopy, pharyngoscopy, and cervical tracheoscopy were performed by use of a 2.7-mm rigid telescope with a halogen light source with dogs under light sedation following IV administration an anesthetic; bronchoscopy was performed under a consistent depth of inhalation anesthesia by passing a 2.7-mm X 100-cm fiber-optic endoscope through a T-adapter inserted between the tracheal tube and the tubing of the anesthesia machine. All endoscopic examinations were performed with dogs in sternal recumbency and were digitally recorded by a camera connected to the endoscopes.

Grading systems—Laryngeal collapse was graded as proposed by Leonard. Stage 1 was characterized by eversion of the laryngeal saccules, stage 2 by a medial displacement of the cuneiform processes of the arytenoid cartilages, and stage 3 by a collapse of the corniculate processes of the arytenoid cartilages with loss of the dorsal arch of the rima glottis.

We adopted a standard bronchoscopic examination with the tracheobronchial anatomy nomenclature proposed by Amis and McKiernan. Once the tip of the bronchoscope approached the carina, each lobar bronchus was examined in the following order: left principal bronchus, left caudal lobe bronchus, left cranial ventral subsegmental bronchus, left cranial dorsal subsegmental bronchus, right principal bronchus, right cranial bronchus, right middle bronchus, right accessory bronchus, and right caudal bronchus.

Tracheal collapse was graded as proposed by Tagner and Hobson. Grade 1 represented a reduction of tracheal diameter up to 25%, grade 2 represented a reduction of diameter up to 50%, grade 3 represented a reduction of diameter up to 75%, and grade 4 represented total tracheal collapse with the lumen completely obliterated.

The grade of bronchial collapse was based on the diameter reduction, considering that normal bronchi have a round or slightly oval, smooth appearance. Grade 1 represented a diameter reduction up to 30%, grade 2 represented a diameter reduction up to 60%, and grade 3 represented a diameter reduction > 60% up to a complete bronchial collapse (100%; Figure 1). A score from 1 (grade 1 stenosis) to 3 (grade 3 stenosis) was assigned to each collapsed bronchus.

Digital files with images from all the procedures were independently reviewed in a blind, separate fashion. Two scorers gave an independent score for laryngeal and tracheobronchial abnormalities, and a discussion, to reach a consensus opinion, was done only in cases of divergent opinion.

Surgical outcome—Surgery included stenotic nares correction by horizontal wedge resection and resection of elongated soft palate and laryngeal saccules. For dogs that underwent surgical correction of any component of brachycephalic syndrome, telephone interviews with the owners of dogs were conducted ≥ 6 months after surgery. Owners were asked to rate the surgical outcome of their dogs as follows: poor (when the clinical situation worsened or did not improve after surgery), moderate (good improvement of the clinical situation with some limitations of physical activity after surgery), and adequate (excellent improvement in both of the clinical situation and physical activity after surgery).

Statistical analysis—Analyses were performed with a commercially available software program. Data analyses were performed to evaluate the correlation between laryngeal collapse, bronchial abnormalities (computed as the sum of the single bronchial scores), and long-term outcome, with Spearman’s rank correlation coefficient. Mann-Whitney and Kruskall-Wallis nonparametric tests were used to compare laryngeal collapse and bronchial abnormalities between sexes and among breeds, respectively. A value of P < 0.05 was considered significant.

Results

The 40 brachycephalic dogs examined with noisy breathing and clinical signs of respiratory distress in the Figure 1—Endoscopic image of the left cranial ventral subsegmental bronchus (black arrow) and left cranial dorsal subsegmental bronchus (white arrow) of a dog; the left cranial ventral subsegmental bronchus has a grade 1 collapse, while the left cranial dorsal subsegmental bronchus has a grade 3 collapse.
period of January 2007 to June 2008 comprised Pugs (n = 20 [50%]), English Bulldogs (13 [33%]), and French Bulldogs (7 [18%]). The study population included 25 male (1 castrated) and 15 female (2 neutered) dogs. Dogs ranged in age from 4 months to 10 years (mean age, 8.7 years; median age, 3 years). Twenty-four of the 40 (60%) dogs were ≤ 3 years old.

All examined dogs had an elongated soft palate and some degrees of stenotic nares. The grade of laryngeal collapse, number of affected dogs, and percentage distribution within each breed and within the total number of dogs were determined (Table 1). Only 1 French Bulldog had a larynx without any degree of collapse (14.3% [1/7] of all French Bulldogs and 2.5% [1/40] of all examined dogs). Only 1 dog, a 10-year-old neutered female Pug, had complete tracheal collapse (grade 4 thoracic collapse).

Endoscopically detectable bronchial abnormalities were recognized in 35 of 40 (87.5%) dogs. Various combinations of both grade and distribution of bronchial collapse were identified. Dogs with grade 1 collapse (score 1) had bronchi with a slightly oval shape with several regularly spaced folds in the mucosa; dogs with grade 2 collapse (score 2) had bronchi with the oval shape changed into a more flattened profile, and in some instances, deeper mucosal folds were visible; and dogs with grade 3 collapse (score 3) had bronchi in which the lumen appeared flattened along a single plane and mucosal folding was not prominent. Closure of the bronchial lumen appeared to occur first at a point within the lumen, while the lumen on both sides of this point was narrowed but still patent (Figure 2). In all affected dogs, the bronchial diameter did not have substantial variations during the different respiratory phases (nondynamic, fixed collapse). In general, the segmental and subsegmental bronchi examined beyond the collapsed bronchus had a normal shape and appearance.

The localization, grade, and breed distribution of bronchial stenoses were summarized (Table 2). Results of data analysis did not reveal any significant differences for laryngeal collapse and bronchial abnormalities with respect to sex of dogs.

A total of 94 bronchial stenoses (31 [32.9%] grade 1, 32 [34.0%] grade 2, and 31 [32.9%] grade 3) were detected in the 40 dogs. Abnormalities were irregularly distributed among the 2 hemithoraces with 15 of 94 (15.9%) bronchial abnormalities in the right bronchial system (5 grade 1, 6 grade 2, and 4 grade 3; right total score, 29), while 79 of 94 (84.0%) bronchial stenoses were detected in the left bronchial system (26 grade 1, 26 grade 2, and 27 grade 3; left total score, 159).

The left cranial dorsal subsegmental bronchus was the most frequently affected bronchus, with 26 of 94 (27.7%); 5 grade 1, 8 grade 2, and 13 grade 3; total score, 60) having abnormalities, while the left cranial ventral subsegmental bronchus was the second most affected bronchus with 23 of 94 (24.5%); 9 grade 1, 6 grade 2, and 8 grade 3; total score, 45) having abnormalities. In general, the left cranial bronchi (ventral and dorsal subsegmental bronchi) were the most affected structures with abnormalities detected in 49 of 94 (52.1%).

Pugs were the most severely affected breed, both for laryngeal collapse ($\chi^2 = 7.3$) and bronchial abnormalities ($\chi^2 = 19.4$), followed by English Bulldogs and French Bulldogs. Laryngeal collapse significantly correlated with more severe bronchial collapse, as determined by the sum of the scores (Spearman’s $\rho = 0.45$).

Of the 36 dogs that underwent surgery and for which follow-up information was available, 21 (58.3%) had an adequate outcome, 11 (30.6%) had a moderate outcome, and 4 (11.1%) had a poor outcome. The severity of bronchial collapse (indicated by the sum of the scores) and outcome were not correlated (Spearman’s $\rho = -0.02; P = 0.8$).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Percentage of all dogs (n = 39)*</th>
<th>Percentage of all dogs (n = 39)*</th>
<th>Percentage of all dogs (n = 39)*</th>
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</thead>
<tbody>
<tr>
<td>Pug (n = 20)</td>
<td>3</td>
<td>7.7</td>
<td>6</td>
</tr>
<tr>
<td>English Bulldog (n = 13)</td>
<td>5</td>
<td>12.8</td>
<td>11</td>
</tr>
<tr>
<td>French Bulldog (n = 6)*</td>
<td>4</td>
<td>10.2</td>
<td>2</td>
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*One of the 7 French Bulldogs of this study is not represented in the table because it had no laryngeal abnormalities.
Discussion

To our knowledge, this is the first study in which endoscopically detectable bronchial abnormalities are described in a series of brachycephalic dogs. While tracheal collapse was detected in only 1 dog in our study, bronchial collapse seemed to be a common finding in dogs of our study. Although the series of brachycephalic dogs in our study may have been too small to provide clinically relevant information and was biased toward dogs with clinical signs of upper airway obstruction, we found that Pugs were at particular risk of bronchial collapse. Moreover, in our study population, the left-side bronchi, particularly the cranial subsegmental branches, were significantly more often affected by this abnormality than the right-side bronchi.

We hypothesized that bronchial collapse can be caused by resistance resulting from obstruction of the upper respiratory tract, a typical feature of these breeds. Brachycephalic breeds are particularly prone to dynamic obstruction of the upper respiratory tract as a result of having narrow nares and redundant tissue folds in the pharynx; these obstruct the air passages so that brachycephalic dogs must generate, from birth, large pressure changes during inhalation and exhalation. During both respiratory phases, pressure gradients develop across the walls of the airways; these gradients change the diameter of the collapsible portions of the airways, thereby changing the airway resistance. Whereas dynamic airway collapse usually occurs during inhalation in the extrathoracic portion of the respiratory tract, it occurs during forced exhalation in the intrathoracic portion.15,16

In healthy dolichocephalic dogs, respiratory muscles relax during exhalation, lungs compress gas in the alveoli, and air flows out; pleural pressure during exhalation is slightly negative (subatmospheric). In brachycephalic breeds, upper airway obstruction causes resistance to air flow and a remarkable increase in the pressures in the upper respiratory tract during exhalation as a result of the use of the accessory muscles of exhalation17; as a consequence, as brachycephalic dogs make a greater effort to exhale, the pleural pressure increases well above atmospheric pressure, causing a dramatic increase in the transmural pressure across the wall of the intrathoracic portion of the respiratory tract, which then collapses.

As the airway becomes compressed, air must accelerate through the collapsed portion; according to the Bernoulli effect, the increased velocity through the narrowed bronchi leads to a further decrease in pressure within the collapsed airways and further narrowing. When brachycephalic dogs try harder to exhale, the pressures decrease more and the airway collapse increases.

If this vicious cycle of events happens in young puppies with more pliable and soft cartilages, it could go on until the bronchi have a complete, fixed collapse (Figure 2); because immature airways are highly compliant, in comparison with those of adults, the bronchi from young animals may be easily compressed and definitively deformed during continuous forced exhalation, as happens in brachycephalic puppies that already have stertorous breathing and snoring during their first weeks of life. The bronchi from human infants are also closed by relatively small transmural pressures, suggesting that infant airways could be more vulnerable to collapse. This may be because the cartilage plates are more pliable and bend easily under lower pressures; compression of infant airways could occur during forced exhalation, such as continuous crying or coughing, or during repeated attempts to clear an obstruction.18

In the dogs of our study, the left-side bronchi were generally more affected by bronchial collapse than were the right-side bronchi. The same distribution is described in infants and children with bronchial collapse.19,20 While, in our dogs, the left cranial dorsal subsegmental bronchi was the most frequently affected bronchus, with 26 (13 grade 3) stenoses detected, in infants and children, the left principal bronchus is the more common site of bronchial collapse because the left mainstem bronchus extends further without branch points than does the right mainstem bronchus, causing it to experience lower resistance to transmural pressures.19

Factors contributing to this particular distribution of bronchial collapse in our group of brachycephalic dogs are not known, though we postulate that thoracic
conformation, comprising the anatomic features of individual bronchi and lung lobes, may be responsible for the predominant left-side involvement. Other likely contributing variables could be heart size in conjunction with the shape of the thoracic cavity and concurrent bronchial diseases.

Bronchial collapse could explain the predisposition of Pugs to cranial left lung lobe torsion. Lung lobe torsion is an uncommon life-threatening condition defined as the rotation of a lung lobe along its long axis with twisting of the bronchovascular pedicle at the hilus. Factors contributing to torsion of the left cranial lung lobe in Pugs are not known. We suppose that lung lobe atelectasis resulting from bronchial collapse may alter the spatial association among the lung lobes and may increase their mobility relative to one another, leading to lobe torsion and thus explaining the particular frequency of left cranial lung lobe torsion in this breed.

Laryngeal collapse is a common secondary change occurring in brachycephalic breeds of dogs, occurring as a result of the chronic increase in negative pressures during inhalation. Results of our study indicate that laryngeal collapse is a more common complication than has previously been reported; overall, 39 of 40 (97.5%) dogs in our study had some degree of laryngeal collapse according to the Leonard grade system. Our findings are in good concordance with data reported by Torrez and Hunt. In their study, 13 Pugs of 46 (28.3%) brachycephalic dogs had laryngeal collapse, while in our study, Pugs with laryngeal collapse comprised 20 of 40 (50%) dogs.

In our study, we found a significant correlation between the severity of laryngeal collapse and the severity of bronchial collapse; we explain this result as a consequence of congenital abnormalities involving the nose and pharynx, causing brachycephalic puppies to require exaggerated respiratory efforts both during inhalation and exhalation, from their birth. In 1 report, the presence of severe secondary laryngeal collapse in a series of 7 brachycephalic puppies aged < 6 months is described; these findings indicate that severe secondary changes caused by respiratory efforts can already be present in young animals. We hypothesize that the same cause (exaggerated respiratory efforts in young animals with more pliable cartilages) is responsible both for laryngeal collapse and bronchial abnormalities, thus explaining the significant correlation between the severity of laryngeal and bronchial collapse.

Despite many reports regarding brachycephalic obstructive syndrome, information about the long-term prognosis after surgery is sparse. In our study, follow-up information was available for all dogs (36/40) that underwent surgical correction of brachycephalic airway obstruction syndrome. The long-term outcome for these dogs was better than previously reported and is similar to that in a more recent study by Riecks et al. Surprisingly, among our dogs, outcomes were not significantly affected by the severity of the bronchial collapse. Some recent publications regarding brachycephalic syndrome in dogs focused on the postoperative outcome in dogs with tracheal hypoplasia and laryngeal collapse. According to findings in a previous study, dogs with a hypoplastic trachea may have a less favorable prognosis than those without; Riecks et al demonstrated that there is no significant difference in the long-term outcome between dogs with a hypoplastic trachea and dogs with a normal tracheal diameter. The same findings were found for our dogs, in which no significant differences were found among dogs according to their bronchial defects.

The results of our study suggest that bronchial collapse is a common finding in brachycephalic breeds and that laryngeal collapse is significantly correlated with more severe bronchial collapse, which may be the result of exaggerated respiratory efforts in young puppies with more pliable cartilages. We found no significant correlations between the severity of bronchial abnormalities and postsurgical outcomes, but we think that bronchial collapse might explain the predisposition of Pugs to cranial left lung lobe torsion. Further characterization of bronchial abnormalities in these breeds is required, and the authors recommend more anatomic, histologic, and eventually ultrastructural studies. Wider-prospective studies evaluating the contribution of collapsed bronchi to increased airway resistance as well as the real incidence and breed prevalence of these abnormalities are warranted.

References

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