

Incidence, clinical signs, and videofluoroscopic swallow study abnormalities associated with airway penetration and aspiration in 100 dogs

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Abstract

Background: Videofluoroscopic swallow studies (VFSS) utilizing penetration-aspiration (P-A) scoring assesses airway protection in people. On VFSS, penetration (ingesta or secretions immediately cranial to the vocal folds) and aspiration (material caudal to the vocal folds) are associated with increased risk of lung injury in people. Penetration-aspiration (P-A) scoring has been validated in animal models, but the incidence of P-A, clinical signs (CS), and dysphagic disorders associated with P-A in dogs are unknown.

Objectives: Using VFSS, identify the incidence of P-A, compare CS between dogs with and without P-A, and identify predisposing dysphagic abnormalities for P-A.

Animals: One hundred client-owned dogs.

Methods: Sequential VFSS and associated medical records from dogs presenting to the veterinary teaching hospitals at Auburn University (n = 53) and the University of Missouri (n = 47) were retrospectively reviewed. Statistical comparisons were made using Mann-Whitney tests, one-way analysis of variance (ANOVA) on ranks, multiple linear regression, and Spearman rank order correlation ($P < .05$).

Results: On VFSS, the incidence of pathologic P-A was 39%. No significant differences in CS were found between dogs with or without P-A ($P > .05$), with 14/39 dogs with P-A presenting without respiratory CS. Pharyngeal ($P < .001$) and esophageal ($P = .009$), but not oral-preparatory ($P = .2$) dysphagia was more common with P-A. Pharyngeal weakness ($P < .001$) and esophago-oropharyngeal reflux (EOR; $P = .05$) were independent predictors of P-A and were moderately and weakly positively correlated with P-A score respectively ($P < .001$, $r = 0.489$; $P = .04$, $r = 0.201$).

Abbreviations: AARS, aspiration associated respiratory syndromes; AP, aspiration pneumonia; AU-VTH, Auburn University Veterinary Teaching Hospital; BALF, bronchoalveolar lavage fluid; COPD, chronic obstructive pulmonary disease; CP, conscious proprioceptive; CS, clinical sign; CT, computed tomography; DC, discharge; EER, extraesophageal reflux; EER, extraesophageal reflux disease; EOR, esophago-oropharyngeal reflux; EP, esophageal phase; ESP, elongated soft palate; GER, gastroesophageal reflux; GI, gastrointestinal; HT, hypoplastic trachea; LES-AS, lower esophageal sphincter achalasia-like syndrome; ME, megaesophagus; MSBC, mainstem bronchial collapse; MU-VHC, Missouri Veterinary Health Center; NPR, nasopharyngeal reflux; OP, oral-preparatory; P-A, penetration-aspiration; PP, pharyngeal phase; sHH, sliding hiatal hernia; TC, tracheal collapse; UES, upper esophageal sphincter; VFSS, videofluoroscopic swallow study.

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Conclusions: Penetration-aspiration occurs in dogs in the absence of respiratory CS (i.e., occult P-A). Dogs with pharyngeal weakness and EOR should be considered at risk for P-A.

KEYWORDS

aerodigestive, dysphagia, pharyngeal, pneumonia, reflux

1 | INTRODUCTION

Accidental invasion of liquids or food into the respiratory tract is a potentially clinically relevant consequence of dysphagia in people and dogs.^{1,2} Both macro- and microaspiration events are known contributors to respiratory disease in people including aspiration pneumonia, asthma, chronic obstructive pulmonary disease, bronchiolitis, and pulmonary fibrosis.³⁻⁵ Similar relationships among dysphagia, aspiration, and respiratory disease have been identified in dogs.^{2,6} Detection of aspiration events in dogs however represents a diagnostic challenge because many affected dogs present without respiratory clinical signs (CS) such as cough, with normal thoracic radiographs, or both.² Additionally, episodic (intermittent) or microscopic aspiration events make detection difficult despite advances in diagnostic strategies.⁷

Videofluoroscopic swallow studies (VFSS) represent the criterion standard for evaluation of dysphagia, both for detecting pathology and for evaluating response to clinical intervention.⁸ In people, VFSS utilizing a penetration-aspiration (P-A) scoring system have been used to objectively assess airway protection. This 8-point multidimensional scale is used to score the severity of invasion into the respiratory tract by evaluating the volume, location, and clinical response to invasion events.⁹ Penetration is described as ingesta immediately cranial to the vocal folds, and aspiration, as material caudal to the vocal folds. Penetration-aspiration scores of ≥ 3 are considered pathologic and uncommon in people without dysphagia.^{10,11} Pathologic P-A scores are associated with increased risk of lung injury, and laryngeal penetration without aspiration has been shown to be a predictor of aspiration-related respiratory syndromes in children and adults.^{9,12-14}

In veterinary medicine, aspiration of liquid and food into the airways is largely described in descriptive terms with little attention paid to material that does not pass caudal to the vocal folds (ie, laryngeal penetration). A 7-point P-A scoring system has been validated in animal models but is infrequently used in clinical patients.¹⁵ Therefore, the incidence of P-A as well as the CS and dysphagic disorders associated with P-A in dogs are unknown.

Our objectives were 3-fold. The first was to identify the incidence of P-A in dogs by evaluating 100 sequential free-feeding VFSS at 2 tertiary veterinary hospitals. The second was to compare CS, physical examination variables, and demographic features between dogs with and without pathologic P-A (score ≥ 3). The third objective was to identify predisposing dysphagic disorders for P-A using free-feeding VFSS. We hypothesized that dogs undergoing VFSS would commonly be

presented with occult P-A (i.e., no respiratory CS) and occult P-A would be associated with pharyngeal phase swallowing defects.

2 | MATERIALS AND METHODS

2.1 | Case selection

Sequential VFSS and the associated medical records from dogs presented to 2 tertiary veterinary hospitals, Auburn University (AU-CVM) and the University of Missouri (MU-VHC), between 8/1/2019 and 1/30/2020 were retrospectively reviewed. Dogs were enrolled sequentially from the start of the collection period if they had a VFSS for any reason, inclusive of respiratory, gastrointestinal (GI), or neurologic CS, and a complete medical record until 100 dogs were enrolled

TABLE 1 Mammalian penetration-aspiration scale^{2,15} describing entrance of food or liquid into the respiratory tract

Classification	Score	Description
Normal	1	No material enters the supraglottic space during swallow
Penetration	2	Material enters the supraglottic space during swallow but is ejected before swallow completion
	3	A small amount of material enters the supraglottic space during swallow and remains after swallow completion, or large amounts of material remain in the pharynx after swallow completion without entrance in to the supraglottic space ^a
	4	A large amount of material enters the supraglottic space during a swallow and remains after swallow completion
Aspiration	5	Material falls caudal to the vocal folds but is actively ejected (ie, cough)
	6	Material falls caudal to the vocal folds and is not ejected despite effort (ie, cough)
	7	Material falls caudal to the vocal folds and no effort is made to eject the material (ie, occult aspiration)

Note: A score of ≥ 3 is considered clinically significant (ie, pathologic P-A).^{10,11} Swallow completion refers to the epiglottis returning to the rest position following the end of pharyngeal swallowing (Figure 1).

^aThis modification to the P-A scale was made because of the increased aspiration risk associated with pharyngeal retention in people.¹⁹

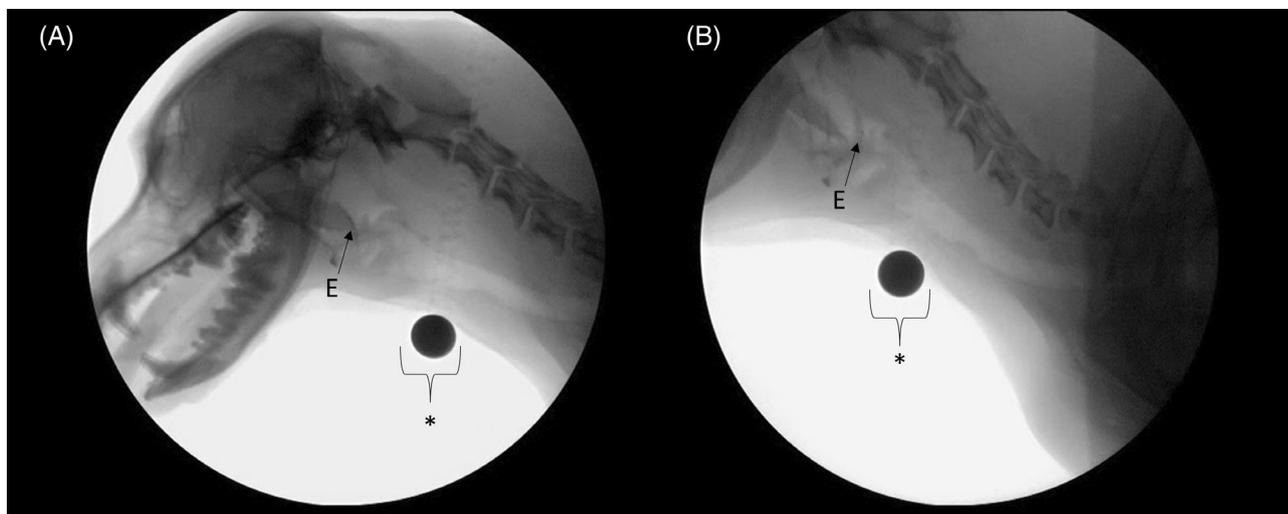


FIGURE 1 Still images from VFSS of the same dog showing the epiglottis (E) in a resting position (A) and elevated protect the larynx (B). A 1 cm size marker is denoted by *. The head is oriented to the left and the tail to the right

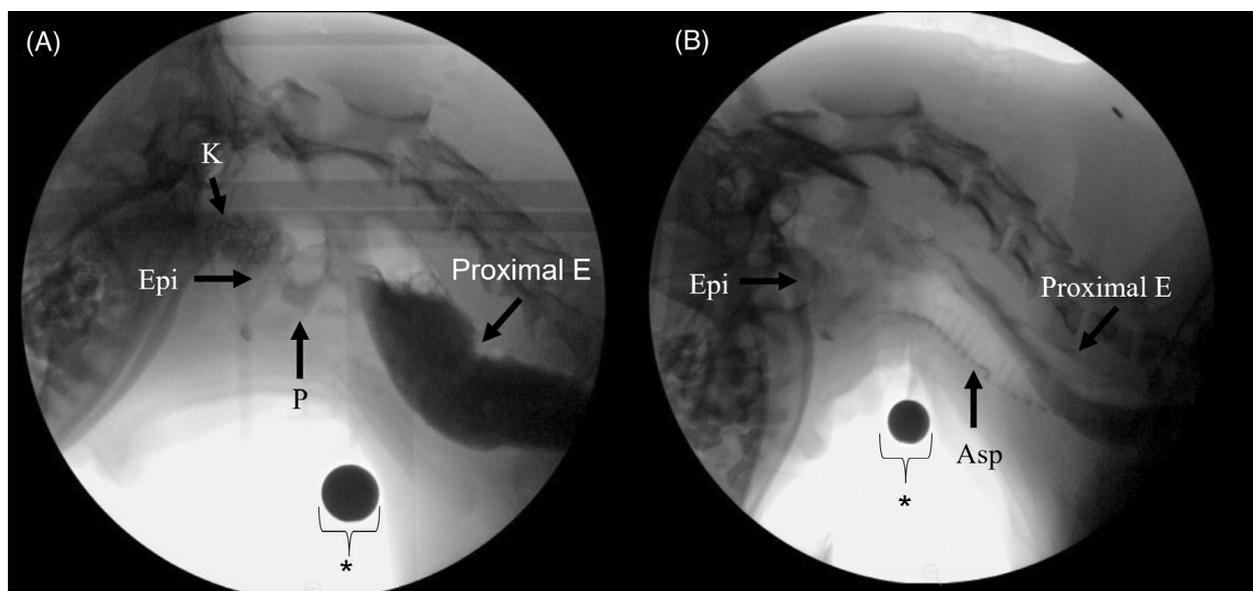


FIGURE 2 Still images from videofluoroscopic swallow studies (VFSS) showing penetration (P) and aspiration (Asp). The head is oriented to the left and the tail to the right. A 1 cm size marker is denoted by *. A food bolus is present in the proximal esophagus (proximal E). In the left image (A), a large volume of liquid containing iohexol is found within the supraglottic space (cranial to the vocal folds) following an episode of extraesophageal reflux (EER). The contrast remains in the supraglottic space after the end of pharyngeal swallow (P-A score: 4) and a new bolus (kibble) begins accumulating in the valleculae (K). In the right image (B), liquid containing iohexol is shown in the ventral aspect of the trachea (caudal to the vocal folds). No effort is made to eject the material (not shown in still image; P-A score: 7). The bolus in the proximal esophagus in image B reflects multiple rapid swallow inhibition and is considered a normal variant.¹⁶ Epi, epiglottis

between both institutions. In all cases, VFSS were standing and free-feeding as previously described.¹⁶ Demographic data (age [years], breed, sex, body weight [kg], body condition score [BCS; 9-point scale], head conformation [brachycephalic, mesocephalic, or dolichocephalic]), CS at presentation (including respiratory and GI CS), and duration of CS were recorded. Clinical signs associated with head conformation (eg, stertor in brachycephalic dogs) were only counted if they were the reason for the evaluation by a veterinarian. Dogs were considered to be in respiratory distress if they required

emergency intervention (eg, oxygen support) at the time of presentation. Clinical signs inclusive of the degree of respiratory effort, dysphonia, cough, vomiting, regurgitation, gagging, abdominal pain, or dysphagia were retrieved from the medical record. All thoracic radiographs were reviewed by a board-certified radiologist. Radiographic metrics inclusive of esophageal fluid (present or absent), aerophagia (present or absent), bronchiectasis, aspiration pneumonia (alveolar or interstitial pattern localized to the cranioventral lung fields) were obtained from the radiographic reports. After

TABLE 2 Standardized criteria for evaluating videofluoroscopic swallow studies (VFSS) and respiratory fluoroscopy

Criteria	Definition
VFSS	
Oral-preparatory phase (O-P) ²	Dogs were evaluated for appropriate jaw excursions, prehension, and accumulation and containment of a food bolus within the valleculae (ie, between soft palate, epiglottis, and base of the tongue) Leakage of contrast material outside the valleculae during bolus accumulation prior to initiation of a pharyngeal swallow was considered abnormal
Pharyngeal phase (PP) ^{1,2}	Dogs were evaluated for complete pharyngeal constriction (ie, absence of residual pharyngeal air during swallow), propulsion and clearance of all material from the pharynx at the end of the swallow, and appropriate opening of the UES relative to initiation of a pharyngeal swallow and closure of the UES after bolus passage into the esophagus Multiple swallow attempts to clear most food boluses, residual material in the pharynx at the end of the swallow (ie, epiglottis returned to rest/flat position), and visible air in the pharynx with maximal pharyngeal constriction were considered consistent with pharyngeal weakness Spontaneous UES opening ^a not associated with a pharyngeal swallow or eructation or incomplete or uncoordinated opening of the UES with pharyngeal swallow (achalasia and dyssynchrony respectively) with multiple swallow attempts to clear most food boluses were considered abnormal
Esophageal phase (EP) ²	Dogs were evaluated for appropriate peristaltic contractions (either 1° or 2°). Dogs with absent or ineffective peristaltic waves, or with retrograde movement of contrast through the UES (esophago-oropharyngeal reflux (EOR)) were considered to have esophageal hypomotility
Megaesophagus ²	Subjective assessment of esophageal dilation with concurrent dysmotility
Lower esophageal sphincter achalasia-like syndrome ²⁰	Failure of the LES to relax in response to pharyngeal swallow
Gastroesophageal reflux (GER) ¹⁶	Orad movement of contrast from the stomach into the esophagus. Refluxate extending beyond the distal 1/3 of the esophagus was considered pathologic
Esophago-oropharyngeal reflux (EOR) ²	Orad movement of esophageal contents through the UES into the oropharynx
Extraesophageal reflux (EER) ²	Orad movement of gastric contents through the esophagus and through the UES into the oropharynx or nasopharynx
Nasopharyngeal reflux (NPR) ²	Movement of contrast from the oropharynx to the nasopharynx with O-P or PP swallowing or EOR and EER
Sliding hiatal hernia (sHH) ²	Herniation of the stomach into the thorax through the esophageal hiatus (hernia type 1). Dogs were assessed for sHH passively and with abdominal compression
Aerophagia ²	>1/3 of the bolus volume contains air and/or results in gastric distention (>1/3 of end gastric volume)
Respiratory fluoroscopy	
Upper airway obstruction	
Pharyngeal collapse ²¹	Naso-, oro-, and laryngopharynx were evaluated for static or dynamic collapse of ≥50% during quiet breathing
Elongated soft palate ²²	Palate was evaluated for marked overlap of the epiglottis during quiet breathing
Epiglottic retroversion ²³	Epiglottis was evaluated for normal movement during breathing (flat/rest position) and swallow (elevated position) (Figure 1) Dogs with elevation of the epiglottis during inspiration were diagnosed with epiglottic retroversion
Other laryngeal defects ^{2,24}	Dogs were evaluated for other laryngeal defects thought to contribute to P-A (eg, masses) or associated with laryngeal dysfunction (eg, air in laryngeal ventricles)
Airway collapse ²⁵	Extra- and intrathoracic trachea and mainstem bronchi were evaluated for collapse during quiet breathing

^aAn example of spontaneous UES opening not associated with pharyngeal swallow or eructation is shown in Figure 3.

enrollment, all VFSS were reviewed by a single investigator (MG) with experience in interpreting VFSS using the metrics described below.^{2,16-18}

On VFSS, P-A scoring was performed as previously described with minor variations.^{2,15} Briefly, dogs were given a score of 1 to 7 using a 7-point scoring system based on the depth, volume, and response to material entering the respiratory tract (Table 1; Figure 2). Maximum scores for each dog were recorded. Extrapolating from the human

medical literature, dogs with scores ≥3 were considered to have pathologic P-A.^{10,11} Dogs with a P-A score of 2 were considered to have nonpathologic P-A and included with P-A scores of 1 (ie, normal) for the calculation of incidence and statistical evaluation.⁹ Additional parameters evaluated on VFSS and respiratory fluoroscopy are provided in Table 2 and Figure 1. Other diagnostic tests including bronchoscopy, bronchoalveolar lavage fluid (BALF) cytology, BALF culture, and laryngeal function examinations (with doxapram) were evaluated where available.



FIGURE 3 Still image from a videofluoroscopic swallow study (VFSS) showing spontaneous opening of the upper esophageal sphincter (UES) denoted by the bracket and asterisk (*). The opening is not associated with either pharyngeal swallow or eructation. A bolus of kibble is being formed within the valleculae (arrowhead). A residual bolus in the proximal esophagus (arrow) abuts the open UES

2.2 | Statistical analysis

Statistical analysis was performed using commercial statistical analysis software (SigmaPlot 12.0). Descriptive statistics were performed where appropriate. Data for categorical variables were presented as (n) ± percentage. The normality assumption was evaluated using the Kolmogorov-Smirnov test. All variables were nonnormally distributed. Data for quantitative variables were presented as median and interquartile range (IQR). Between group comparisons (pathologic P-A [scores 3-7] and without pathologic P-A [scores 1-2]) were made using Mann-Whitney rank sum tests and one-way analysis of variance (ANOVA) on ranks. Multiple linear regression was performed to identify independent predictors of pathologic P-A. Correlations between demographic and clinical data, diagnostic test results, and P-A scores were performed using Spearman rank order correlation. To minimize type 2 error, statistical comparisons were limited to clinical, demographic, or diagnostic variables exhibited by >12 dogs. Variables exhibited by ≤12 dogs were provided descriptively. A $P < .05$ significance level was assigned in all cases.

3 | RESULTS

3.1 | Animals

One hundred client-owned companion dogs were enrolled: AU-VTH (n = 53), MU-VHC (n = 47). Thirty-seven breeds were represented (Table 3). Overall median (IQR) age at presentation was 6 years (2-9 years; range, 1 month-15 years). Sixty-eight of 100 dogs were

TABLE 3 Number (n) of dogs of various breeds undergoing sequential VFSS

Dogs (n)	Breed
17	Mixed breed dog, Labrador retriever
5	German shepherd
4	Miniature dachshund
3	American bulldog, miniature schnauzer, French bulldog, pomeranian, Yorkshire terrier, boxer, beagle, goldendoodle, Shetland sheepdog
2	Great Dane, chihuahua, Italian greyhound, American Staffordshire terrier, Boston terrier, English bulldog
1	Pug, Brussels griffon, dalmatian, standard poodle, bichon frise, Jack Russel terrier, Welsh corgi, soft-coated wheaten terrier, Weimaraner, bull terrier, Maltese, miniature poodle, golden retriever, Vizsla, papillon, Australian shepherd

mesocephalic, 17/100 were brachycephalic, and 15/100 were dolichocephalic. Forty-nine dogs were male (11 intact [MI]; 38 castrated [MC]) and 51 were female (13 intact [FI]; 38 spayed [FS]). Median (IQR) weight was 15.5 kg (7.5-26.9 kg; range, 1.7-48.6 kg). Body condition scores were available for 97/100 dogs. The median (IQR) BCS was 5/9 (4-6; range, 1-9). Dogs were presented exclusively for GI CS (n = 41), respiratory CS (n = 30), a combination of respiratory and GI CS (n = 27), and for pelvic limb weakness (n = 2). Reported respiratory and GI CS are presented in Table 4. Median (IQR) duration of CS was 4 months (1-12 months; range, 1 month-12 years). Ten dogs were presented with a history of aspiration pneumonia (AP). Conscious proprioceptive (CP) deficits were found in the pelvic limbs of 7 dogs with physical examination findings consistent with diffuse polyneuropathy in 2 dogs.

3.2 | Diagnostic imaging

Videofluoroscopic swallow studies and respiratory fluoroscopy were performed in all dogs (n = 100). Twenty-five dogs had normal VFSS. Swallowing abnormalities were identified in 75/100 dogs: oral-reparatory phase (OP; n = 21), pharyngeal phase (PP; n = 30), and esophageal phase (EP; n = 39). Pathologic P-A (ie, P-A score ≥3) was identified in 39/100 dogs for an incidence of 39%. All P-A scores are presented in Table 5. Pathologic penetration was identified in 28/39 dogs and aspiration in 11/39. Dogs with pathologic P-A were presented exclusively for GI CS (14/39), exclusively respiratory CS (14/39), or mixed GI and respiratory CS (11/39). Median (IQR) P-A score for all dogs (n = 100) was 2/7 (1-3; range, 1-7). Median (IQR) P-A scores for dogs with pathologic P-A (n = 39) was 4/7 (4-6; range, 3-7).

Dogs with pathologic P-A had defects across all phases of swallowing. The numbers of dogs with pathologic P-A are provided compared to the total number of dogs with swallowing defects across each phase: OP (10/21; 48%), PP (26/30; 87%), EP (20/39; 51%). A

TABLE 4 Summary of clinical signs (CS) in dogs with and without pathologic P-A

Clinical signs	Pathologic P-A (n)	Nonpathologic P-A (n)	Total (n)
GI			
Regurgitation	16	30	46
Vomiting	8	9	17
Gagging	6	4	10
Repetitive “dry” swallowing ^a	4	3	7
Ptyalism	2	4	6
Abdominal pain	1	3	4
Eructation	2	1	3
Lip licking	2	1	3
Fly biting	0	1	1
Respiratory			
Cough	18	24	42
Stridor	1	5	6
Respiratory distress ^b	2	3	5
Panting	3	2	5
Nasal discharge	2	2	4
Stertor	1	3	4
Dysphonia	2	1	3
Sneezing	3	0	3
Snoring	1	1	2
Exercise intolerance	1	1	2
Restlessness	1	1	2
Labored breathing ^b	0	1	1
Reverse sneezing	1	0	1
Syncope	1	0	1
Other			
Pelvic limb weakness	0	2	2

Note: Clinical signs were included in the study when they were the reason for veterinary evaluation. Dogs may have had >1 CS. No significant differences were detected between groups ($P > .05$).

^aA “dry” swallow refers to spontaneous, reflexive swallowing that occurs without eating or drinking.

^bDogs requiring emergency intervention at the time of presentation were considered to be in respiratory distress whereas labored breathing referred to dogs that increased respiratory effort but did not require emergency stabilization.

TABLE 5 Penetration-aspiration scores for 100 dogs (n) undergoing videofluoroscopic swallow studies (VFSS)

Penetration-aspiration score	Dogs (n)
1	48
2	13
3	17
4	11
5	0
6	1
7	10

video clip from a dog demonstrating multiple swallowing abnormalities and aspiration (P-A score: 7) is available in supplementary materials. Thoracic radiographs were available for review in 99/100 dogs.

Abnormalities on thoracic radiographs, VFSS, and respiratory fluoroscopy are presented in Table 6.

On VFSS, reflux was identified in 43/100 dogs. Nasopharyngeal reflux was identified in 3 dogs, 1 of which also had gastroesophageal reflux. Gastroesophageal reflux (41 dogs total) had margination involving the distal third ($n = 8$), middle third ($n = 8$), and proximal third ($n = 10$) of the esophagus, or it was extraesophageal ($n = 15$). Pathologic reflux was identified in 36/43 dogs, including 14 dogs with pathologic P-A Table 7.

Thirty-nine dogs had normal thoracic radiographs and 20 (51%) had either exclusively respiratory or mixed respiratory and GI CS. Pathologic P-A was noted in 11/39 (28%) dogs with normal thoracic radiographs. Twelve dogs had radiographic evidence of AP at the time of enrollment. Five of 12 dogs (41.6%) with radiographs consistent with AP had exclusively GI CS. Three of the dogs with only GI signs and AP had pathologic P-A on VFSS Table 7.

TABLE 6 Summary of results from laryngeal function examinations (with doxapram), bronchoscopy, and BALF cytology and culture

Diagnostic imaging findings	Pathologic P-A (n)	Nonpathologic P-A (n)	Total (n)
Laryngeal function exam			
Laryngeal paralysis	3	3	6
Laryngeal erythema	1	4	5
Unremarkable	2	2	4
Bronchoscopy			
Airway hyperemia	5	6	11
Airway mucous	4	4	8
Bronchiectasis	1	3	4
Bronchial collapse (static or dynamic)	2	0	2
Tracheal collapse	0	1	1
BALF cytology			
Nonseptic suppurative	3	3	6
Unremarkable	1	2	3
Septic suppurative	0	2	2
Eosinophilic	1	0	1

Note: Dogs may have had >1 abnormality.

Other diagnostic tests included functional laryngeal examinations (with doxapram; $n = 15$), bronchoscopy ($n = 12$), bronchoalveolar lavage fluid (BALF) cytology ($n = 12$), and BALF culture ($n = 12$). Results are presented in Table 6. Three of 6 dogs (50%) with laryngeal paralysis had pathologic P-A, CP deficits or signs consistent with diffuse polyneuropathy, as well as pharyngeal and/or esophageal dysmotility. Bronchoscopy and BALF cytology and culture were performed in 12 dogs. Nonseptic suppurative inflammation, unremarkable findings, septic suppurative inflammation, and eosinophilic inflammation on cytologic examination of BALF were identified in 6/12, 3/12, 2/12, and 1/12 dogs, respectively. The BALF cultures were positive (ie, moderate-heavy bacterial growth) in 2/12 dogs. Isolated bacteria included *Pseudomonas aeruginosa* ($n = 1$) and *Acinetobacter dijkschoorniae* and *Stenotrophomonas maltophilia* ($n = 1$).

3.3 | Between group comparisons: Dogs with and without pathologic P-A

No significant differences were detected for dogs with and without pathologic P-A based on age ($P = .76$), weight ($P = .54$), head conformation ($P = .33$), duration ($P = .06$) or type of CS (ie, exclusively GI [$P = .56$], exclusively respiratory [$P = .38$], or mixed respiratory and GI CS [$P = .93$]). No significant differences were detected between groups for cough ($P = .62$), regurgitation ($P = .57$), vomiting ($P = .52$), presence of pathologic reflux ($P = .8$), reflux margination ($P = .55$), leakage from valliculae ($P = .28$), esophageal fluid on radiographs ($P = .74$), unremarkable radiographs ($P = .11$), or the presence of megaesophagus (ME; $P = .63$). No single consistency (liquid, puree, or kibble) was significantly associated with detection of pathologic P-A ($P > .05$). Intact male dogs were overrepresented in the pathologic P-A group compared to FS and MC but not FI dogs ($P < .05$). Pharyngeal phase (PP) swallowing abnormalities ($P < .001$), esophageal phase

(EP) swallowing abnormalities ($P = .01$), esophago-oro-pharyngeal reflux (EOR) ($P = .05$), esophageal dysmotility ($P = .02$), and pharyngeal weakness ($P < .001$) on VFSS were significantly more common in dogs with pathologic P-A scores compared to dogs without pathologic P-A. Multiple linear regression identified pharyngeal weakness ($P < .001$) and EOR ($P = .01$) as independent predictors of pathologic P-A. Penetration-aspiration score was moderately and weakly positively correlated with pharyngeal weakness ($P < .001$; $r = 0.489$) and EOR ($P = .04$; $r = 0.201$), respectively.

4 | DISCUSSION

In our study, the incidence of pathologic P-A was 39% in dogs undergoing VFSS regardless of clinical indication at 2 tertiary referral centers. With P-A, it would be expected that dogs should have a robust cough reflex, however, although respiratory CS were common, 36% of dogs with pathologic P-A were presented with exclusively GI CS (i.e., occult P-A). Of those presented with exclusively GI signs, 28% had normal thoracic radiographs emphasizing how easy it is for clinicians to miss P-A. Pharyngeal weakness, EOR, or both, caused by failure to effectively clear an esophageal bolus were associated with pathologic P-A and positively correlated with P-A score. Patients with either pharyngeal or esophageal phase swallowing abnormalities should be considered at high risk for pathologic P-A. Evaluation for P-A in dogs by performing VFSS is warranted to evaluate dogs for failures in airway protection, particularly those with evidence of pharyngeal and esophageal swallowing dysfunction even in the absence of respiratory CS or radiographic evidence of AP.

Penetration and aspiration require that multiple airway protective mechanisms be overcome, including normal swallowing and cough.²⁶ In addition to AP, chronic macro- and microaspiration have been implicated in refractory asthma,²⁷ idiopathic pulmonary fibrosis,²⁸

TABLE 7 Summary of imaging findings in dogs with and without pathologic P-A

Diagnostic imaging findings	Pathologic P-A (n)	Nonpathologic P-A (n)	Total (n)
Radiographs (n = 99)			
Unremarkable	11	28	39
Esophageal fluid	7	9	16
ME (general)	6	7	13
Aspiration pneumonia	7	5	12
Bronchial pattern	5	6	11
Bronchiectasis	4	4	8
Tracheal collapse	1	4	5
Interstitial pattern	2	3	5
Aerophagia	2	2	4
Pulmonary artery enlargement	1	1	2
ME (focal)	0	1	1
Tracheal mineralization	0	1	1
Laryngeal mineralization	0	1	1
Lung mass	0	1	1
sHH	0	1	1
Hypoplastic trachea	1	0	1
Laryngeal mass effect	1	0	1
Venous enlargement	1	0	1
VFSS (n = 100)			
O-P defects			
Vallecular leakage	10	8	18
Nasopharyngeal reflux	1	2	3
Abnormal prehension	0	1	1
PP defects			
Pharyngeal weakness ^a	17	2	19
Abnormal UES opening	5	2	7
Cricopharyngeal dyssynchrony	2	0	2
Cricopharyngeal achalasia	1	0	1
EP defects			
Diffuse esophageal hypomotility	12	10	22
ME	6	7	13
EOR ^a	13	0	13
Proximal esophageal hypomotility	7	4	11
LES-AS	2	6	8
sHH	2	5	7

TABLE 7 (Continued)

Diagnostic imaging findings	Pathologic P-A (n)	Nonpathologic P-A (n)	Total (n)
Stricture	2	1	3
Foreign body	0	1	1
Focal ME	0	1	1
Respiratory fluoroscopy (n = 100)			
Elongated soft palate	7	7	14
Tracheal collapse	4	8	12
Pharyngeal collapse	3	6	9
Mainstem bronchial collapse	3	5	8
Epiglottic retroversion	2	2	4
Air in laryngeal ventricles	2	1	3
Laryngeal mass effect	1	0	1

Note: Dogs may have had abnormalities in >1 area. Dogs had radiographic evidence of aspiration pneumonia based on the presence of a cranioventral interstitial or alveolar pattern observed on thoracic radiographs.

Abbreviations: EOR, esophago-oropharyngeal reflux; EP, esophageal phase; LES-AS, lower esophageal sphincter achalasia-like syndrome; ME, megaesophagus; O-P, oral-preparatory phase; P-A, penetration-aspiration; PP, pharyngeal phase; sHH, sliding hiatal hernia; UES, upper esophageal sphincter.

^aStatistically significant differences ($p < .05$).

chronic obstructive pulmonary disease (COPD), chronic cough, and bronchiolitis in people.²⁹ Similar relationships among dysphagia, aspiration, and aspiration-associated respiratory syndromes (AARS) exist in dogs.^{6,30} Importantly, treatment of the underlying alimentary disease can improve respiratory CS, making identification of affected patients critically important.^{31,32} The criterion standard for evaluation of dysphagia in people and dogs is VFSS.^{1,16} Videofluoroscopic swallow studies using objective metrics, including P-A scores, have been used to assess airway protection and response to targeted intervention in dysphagic people.^{8,33,34} Penetration-aspiration scoring allows concurrent assessment of volume, distance traveled, and clinical response to aspirated material (i.e., cough). Its widespread use in human clinical patients and in dysphagia research reflects its value as a clinical outcome measure.^{9,11} although a 7-point P-A scale has been validated in dogs,^{15,16} it is uncommonly used in veterinary patients.²

In our study, 39% of dogs presented for VFSS had pathologic P-A (P-A score ≥ 3). Of these, 14/39 dogs presented with occult pathologic P-A (i.e., exclusively GI CS without induction of a protective cough reflex). These included 7 dogs with normal thoracic radiographs. In 3 dogs with normal radiographs and occult P-A, scores were ≥ 5 (ie, aspiration). These findings suggest that neither the absence of respiratory CS nor unremarkable thoracic radiographs are sufficient to rule out pathologic P-A. Additionally, 3/14 dogs with occult

pathologic P-A had radiographs consistent with AP. Ten dogs in our study had a P-A score of 7, which is characterized by aspiration below the vocal folds without an attempt to clear the aspirated material (i.e., cough). These findings indicate that the absence of respiratory CS does not preclude the presence of active pulmonary pathology. This lack of clinical response to aspiration may increase the risk of developing aspiration-related respiratory syndromes because clients, veterinarians and nursing staff are likely to be unaware that repetitive micro- or macroaspiration events are occurring. Additionally, in the case of dogs with radiographic evidence of AP, lack of clinical or radiographic response to treatment may lead to the unnecessary escalation of treatments (including antibiotics) because additional aspiration events remain undetected. Dynamic imaging modalities such as VFSS are necessary complements to conventional diagnostic tests (e.g., thoracic radiographs, thoracic computed tomography (CT), and functional upper airway examination) to detect dogs with P-A, localize the cause of failed airway protection (e.g., dysphagia), and initiate targeted patient-specific intervention.²

In our study, pharyngeal weakness was identified as an independent risk factor for pathologic P-A. This conclusion is supported by studies in people with pharyngeal weakness who were found to be at high risk for laryngeal penetration and aspiration, with 57% of aspiration events occurring during PP swallowing.^{35,36} Additionally, incomplete bolus clearance was considered predictive of pathologic P-A in elderly people.³⁷ A combination of muscular and neurosensory mechanisms is thought to contribute to the strength of pharyngeal closure in people and animal models.^{35,38} Common innervations result in combined laryngopharyngeal swallowing defects in dysphagic people, increasing the risk of P-A.^{39,40} In our study, 3/6 dogs with laryngeal paralysis had pathologic P-A. In each dog, either CP deficits to pelvic limbs or evidence of diffuse polyneuropathy, and either pharyngeal or esophageal dysmotility, were identified consistent with geriatric onset laryngeal paralysis polyneuropathy complex.⁴¹ Conditions involving cranial nerve X, including laryngeal paralysis, are of clinical importance because the dual roles in both bolus propulsion and cough.⁴² Further investigation of the neurosensory contribution to pharyngeal constriction and airway protection in dogs is warranted.

In addition to pharyngeal weakness, EOR also was identified as an independent predictor for pathologic P-A. Esophago-oropharyngeal reflux may occur because of poor upper esophageal sphincter (UES) tone or failed esophageal peristalsis resulting in bolus accumulation in the proximal esophagus. The UES opens to accommodate an antero- grade food bolus during swallowing or retrograde bolus flow during eructation, vomiting, or regurgitation and remains tonically closed when not actively involved in swallowing (i.e., breathing) or during nonpharyngeal phases of swallowing.⁴³ After normal swallowing, a postdeglutitive increase in UES pressure occurs which, combined with normal esophageal peristalsis, acts as an airway protective mechanism to prevent backflow of esophageal contents into the pharynx.⁴⁴ Manometric studies in human patients have identified alterations in UES tone and esophageal motility in patients with both respiratory and GI disease.^{29,45} For example, upregulation of spontaneous

esophago-UES relaxations have been documented in patients with regurgitation episodes occurring in the supine position⁴⁶ and decreased basal UES pressures have been identified in people with idiopathic pulmonary fibrosis and gastroesophageal reflux disease.⁴⁷ Another study evaluating people with COPD found an inverse correlation between basal UES pressures and lung function.⁴⁸ Esophageal hypomotility is commonly reported in human patients with several pulmonary diseases, including asthma and idiopathic pulmonary fibrosis.^{47,49} In cases where food boluses accumulate in the proximal esophagus, even normal UES relaxations may result in EOR.

Our study had several limitations, many related to its retrospective nature. These include nonuniform diagnostic testing and small numbers of dogs presented with specific diagnostic and clinical endpoints. As such, not all findings of interest could be evaluated statistically. Additionally, our study had no control population and thus the incidence of pathologic P-A in normal healthy dogs could not be determined or compared to the results in our patients.

5 | CONCLUSIONS

The use of VFSS is necessary to effectively evaluate patients for failures in airway protection during and after eating and drinking. Neither CS nor thoracic radiographic findings are sufficient to effectively screen for P-A in this patient population because many of them presented without respiratory CS (i.e., occult P-A), had normal thoracic radiographs, or both. Detection of affected dogs is critically important because correction of GI disease has been shown to improve respiratory clinical signs.^{31,32} Pharyngeal weakness and EOR were associated with pathologic P-A in dogs suggesting that these dogs may be at increased risk for aspiration and its associated respiratory syndromes.

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CONFLICT OF INTEREST DECLARATION

Authors declare no conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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