

Technique for Evaluation of Gravity-Assisted Esophageal Transit Characteristics in Dogs with Megaesophagus

Jillian M. Haines, DVM, MS, Alison Khoo, DVM, Erin Brinkman, DVM, John M. Thomason, DVM, MS, Andrew J. Mackin, DVSc, BVMS

ABSTRACT

Movement of food material in the esophagus during upright feeding in dogs with megaesophagus (ME) is poorly characterized. A standardized contrast videofluoroscopy technique was used to evaluate esophageal transit characteristics in dogs with ME while in an upright position. Twelve dogs with ME (congenital, acquired idiopathic, or secondary to myasthenia gravis) were placed in an upright position using Bailey chairs and given liquid barium, canned food meatballs, and their normal diet consistency if different than meatballs. Passage of ingesta was videofluoroscopically evaluated by direct observation and change in ingesta area as determined by manual tracing or barium column product calculations. Significant individual variation was seen. Complete esophageal clearance of liquid was seen in four dogs, and complete clearance of meatballs in three dogs, with a median time of 5 min for both. Two of seven dogs fed a slurry diet had complete clearance by 10 min. No significant difference was found between area calculated via tracing or barium column product. Based on imaging results, alterations in food consistency, duration upright, or medication were recommended for nine dogs. In dogs with ME accustomed to a Bailey chair, contrast videofluoroscopy was technically straightforward and allowed for more specific physician-guided management recommendations. (*J Am Anim Hosp Assoc* 2019; 55:167–177. DOI 10.5326/JAAHA-MS-6711)

Introduction

Megaesophagus (ME), an esophageal disorder characterized by hypomotility and esophageal dilation, is a common cause of regurgitation in dogs.^{1,2} Megaesophagus is generally classified as either congenital or acquired, with many conditions associated with its development.¹ Prognosis for ME is considered grave, with a median survival time of 1–3 mo after diagnosis.^{3,4} Aspiration pneumonia is a common cause of death or euthanasia.^{3–5} Other causes of death or euthanasia include death due to underlying disease, progressive malnutrition, perceived poor quality of life, or owner frustration and inability to provide appropriate care.^{2,3}

Dogs with ME can benefit from feeding practices designed to maximize food delivery to the stomach while minimizing the risk of aspiration. Affected dogs are typically fed in a cranially elevated or upright position to allow gravity to move ingesta through the non-peristaltic esophagus and into the stomach.¹ A specialized feeding chair, known as the “Bailey” chair, is used to assist in upright feeding. Upright feeding recommendations are primarily based on clinical experience and anecdotal evidence, with typical recommendations consisting of meatball or slurry diets and up to 30 min spent raised at 45° or higher. Owners are currently instructed to use a trial-and-error

From the Department of Clinical Sciences, College of Veterinary Medicine, Washington State University, Pullman, Washington (J.M.H.); Upstate Veterinary Specialties, Latham, New York (A.K.); and Department of Clinical Sciences, College of Veterinary Medicine, Mississippi State University, Starkville, Mississippi (E.B., J.M.T., A.J.M.).

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Correspondence: jmhaines@wsu.edu (J.M.H.)

approach to determine the best food consistency and duration of time spent upright for their individual dog.

Cervical and thoracic radiographs, with and without an oral contrast agent such as barium, are commonly used to diagnose ME but do not provide an accurate assessment of esophageal function^{1,6,7} Videofluoroscopic esophagrams can provide a real-time assessment of esophageal function and transit time in human and veterinary patients and are the gold standard method in humans for evaluating bolus transit time.⁷⁻⁹ Videofluoroscopy can provide insight into esophageal clearance and characteristics of movement of ingesta through the esophagus in dogs with ME. A previous study in healthy dogs detailing the use of videofluoroscopic esophagrams was performed in sternal or lateral positions.⁷ However, dogs with ME who rely on gravity to move ingesta through the esophagus may be better imaged in an upright position to provide clinically relevant transit times.

The purpose of our study was to develop and evaluate a technique using videofluoroscopy to assess transit characteristics of food consistencies commonly used in dogs with ME. We hypothesized that videofluoroscopy could be used to evaluate esophageal clearance of several food consistencies in dogs with ME while in an upright position and to provide information allowing for individual feeding recommendations. We further evaluated several methods for quantitating esophageal clearance through visual observation, area determination, and measurement of liquid column height and width.

Materials and Methods

This study was approved by the Institutional Animal Care and Use Committee at Mississippi State University.

Animals

Twelve client-owned dogs previously diagnosed with ME were used. Dogs were otherwise healthy based on physical examination, owner history, and medical records, with no clinical or radiographic evidence of current aspiration pneumonia. Dogs were previously diagnosed with congenital ME, idiopathic-acquired ME, or ME secondary to myasthenia gravis. Idiopathic-acquired ME was determined by a combination of a lack of clinical signs of an underlying disease and no significant abnormalities on diagnostic tests for myasthenia gravis, hypothyroidism, and hypoadrenocorticism. Additionally, dogs had to be acclimated to a Bailey chair and willing to eat in the hospital setting. Dogs were recruited over an 8 mo period based on a search of the Mississippi State University Animal Health Center medical records, contact with local veterinarians, and advertisement to national ME groups. Dogs were fasted the morning of the study and did not receive any promotility medications within 12 hr of the study imaging.

A sample size calculation was performed to determine the number of dogs who would be needed to establish the esophageal

transit time in dogs with megaesophagus. The assumptions used in the calculations were an alpha level of 0.05, a power of 0.8, and a standard deviation of 4.5 min. The standard deviation was estimated by assuming that the clearance times of dogs with the condition would range from 3 to 30 min. An arbitrary upper limit of 30 min was chosen based on the assumption that many owners are directed to keep their dog upright for this amount of time. Assuming that this interval of 27 min would represent 99% of the population, and then dividing by 6, would give an estimated standard deviation of 4.5 min. With these assumptions, a sample size of nine dogs would allow for estimation of the mean transit time with an allowable error of 3 min. Twelve dogs were used for the study to ensure appropriate power in case of dog attrition.

Equipment

Bailey chairs were constructed out of thin wood, consisting of a base and three vertical sides (two side panels and a back panel), padded with foam, and were adjustable to fit a variety of dog sizes. An adjustable feeding platform at shoulder height allowed the dog to eat comfortably from a bowl. A standard videofluoroscopic C-arm unit¹ was positioned across the Bailey chair to allow for a horizontal cross beam evaluation of the full length of the esophagus.

Ingesta Consistencies

All dogs were administered both liquid barium and meatballs mixed with barium. Dogs normally fed a slurry/gruel diet at home were also fed this diet combined with barium. Slurry diets were thicker than water and more similar to a milkshake or yoghurt consistency. To simulate water consumption, 60% w/v liquid barium sulfate was given orally at a volume standardized to dog weight. Dogs weighing <5 kg received 5 mL, 5–20 kg received 10 mL, and 21–40 kg received 15 mL. Meatballs consisted of barium contrast added to a commercial canned diet² at a volume of 1 mL barium per 5 g canned food. Meatball sizes were based on dog weight, with 3–10 kg dogs receiving 5 g meatballs, 11–20 kg dogs receiving 10 g meatballs, 21–30 kg dogs receiving 15 g meatballs, and 31–40 kg dogs receiving 20 g meatballs. When appropriate, dogs were also fed 25% of the volume of the typical slurry consistency at home meal provided by the owners, with barium added at 1 mL per 5 g of food.

Videofluoroscopic Assessment and Image Capture

Dogs were fasted at least 6 hr prior to fluoroscopy. Thoracic radiographs (ventrodorsal and right and left lateral views) were performed to confirm ME and to evaluate for aspiration pneumonia. The Bailey chair was placed on a height-adjustable hydraulic table. The videofluoroscopic unit was positioned around the chair to create a lateral view of the dog. Videofluoroscopy was performed using an image intensifier and recorded.

An initial videofluoroscopic scan was performed prior to consumption of liquid or food. Dogs were evaluated in two separate

sessions, with a rest period out of the chair between sessions. During the first session, dogs were carefully syringe fed liquid barium sulfate. Fluoroscopic evaluation was initiated immediately after swallowing, and videos were obtained at baseline and every 5 min thereafter for a maximum of 20 min, or until all barium had cleared the esophagus, whichever came first. In two dogs, imaging of the liquid phase was only available for 10 and 15 min, respectively, as a result of technical difficulties relating to the videofluoroscopy unit and image saving/transfer. Within 2–3 min of completion of the liquid phase, dogs were fed the meatballs, and imaging was performed immediately after initiation of swallowing and every 5 min for a maximum of 30 min or until all food had cleared the esophagus. Dogs remained in the Bailey chair for the duration of the first session. If indicated and following a 3–4 hr rest period, the second session to evaluate the at-home slurry diet was performed as previously described for a maximum of 30 min or until full esophageal clearance.

Area Calculations

At each time point, videofluoroscopic imaging was collected of the full length of the esophagus. Using a medical imaging viewer³, the esophagus was separated into the following three regions of interest: (1) oropharynx to thoracic inlet, (2) thoracic inlet to carina, and (3) carina to diaphragm. Quantitative assessments of clearance were made in three ways. First, for each barium/food consistency, subjective visual observation was used to estimate the percent clearance from the esophagus. Second, the two-dimensional area of liquid or food was determined via tracing within each region at each time point. Third, for the liquid, two-dimensional barium column height and width were determined following guidelines for barium esophagrams in people with esophageal achalasia.^{10–12} Clearance of material from the esophagus into the stomach was assessed via visual observation by evaluators (JMH, AK, and JMT) both during the imaging process and on review of the saved video clips (JMH). All measurements were performed by a single observer (JMH) in triplicate and then averaged. The measurements were further reviewed by an outside observer who was blinded to the dog's signalment (SM). Any traces of barium only coating the esophageal mucosa, or faint or thin lines of barium extending down the length of the margin(s) of the esophagus after bolus passage, were not included in area or column measurements. For area calculations, manual regions of interest were drawn using the tracing tool in the medical imaging viewer, and material in the esophagus was traced following the most distinct margins of ingesta (**Figure 1**). To calculate barium column height and width, parallel lines were drawn at the most cranial and caudal margins of the column. The caudal margin for barium at the esophagogastric junction was drawn where the esophagus was seen to taper down (**Figure 2**). Column height was defined as the craniocaudal distance between the two parallel lines. Column

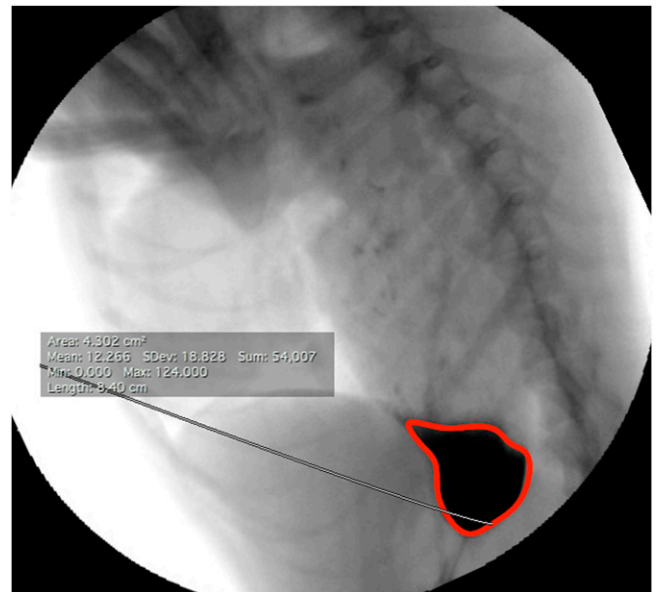


FIGURE 1 Example of area tracing performed on a lateral videofluoroscopic still image from a dog with material retained in the esophagus at the level of the lower esophageal sphincter. Cranial is to the top of the image and ventral is to the left.

width was defined as the mediolateral distance calculated by measuring the barium column at its widest point perpendicular to the long axis of the esophagus.¹¹ Area was estimated by multiplying column height by width. When ingesta was present in multiple regions of interest, the area and barium column parameters were calculated separately and then summed into a single figure.

Establishment of Esophageal Clearance Times

Clearance time was defined as the time from ingestion of material to completion of movement of the material into the stomach. When complete clearance did not occur by 20 min for liquid or 30 min for solid diets, transit time was recorded as either 20 or 30 min, respectively, to prevent excessive censoring of dogs.

Minimal clearance was defined as subjective movement into the stomach of <5% of the total food or liquid volume in the esophagus, as determined by visual observation. Partial clearance of barium/material was defined as up to 95% of material still remaining in the esophagus after 20 min (liquid) or 30 min (meatballs or regular food). Thin lines of barium along the margins of the esophagus were not included in this definition.

Recommendations for Alterations in Management

An alteration in diet consistency was suggested for dogs who were found to have faster or more complete clearance of the esophagus with a diet consistency different from what was being fed at home. A change in time spent upright was advised for dogs who showed

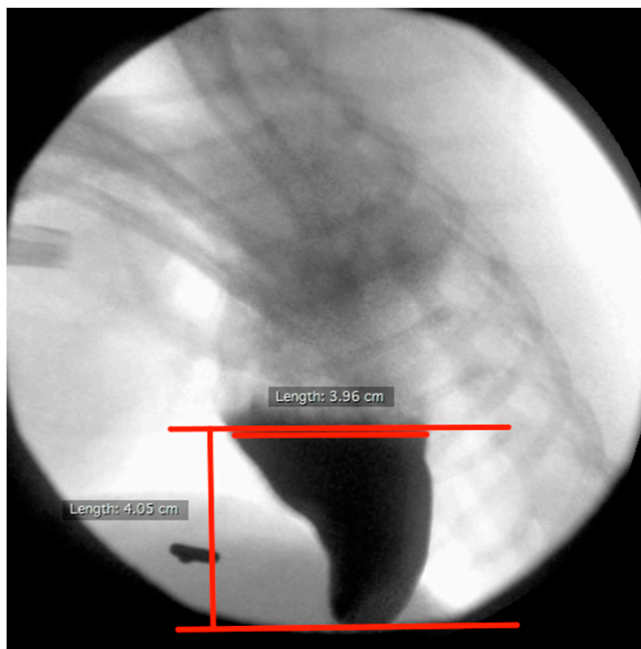


FIGURE 2 Example of barium column measurements performed on a lateral videofluoroscopic still image from a dog with material retained in the esophagus at the level of the lower esophageal sphincter. Two horizontal parallel lines were drawn at the cranial and caudal margins of the barium column. The height was measured as the distance between the two horizontal lines. The width was determined by measuring the barium column at its widest point. Cranial is to the top of the image and ventral is to the left.

clearance of the esophagus in a shorter time span than current at-home practices. A change or addition of medications (i.e., a promotility drug and proton pump inhibitor) was recommended if there was evidence of gastroesophageal reflux.

Statistical Analysis

Descriptive statistics (mean, median, standard deviation, range) were determined using a spreadsheet software program⁴. Statistical software⁵ was used to compare the two area calculation methods. Normality of the data was assessed using the Shapiro-Wilk test, and the Mann-Whitney *U* test was used to compare the median of the areas. A *P* value < .05 was considered statistically significant.

Results

Population

The following 12 dogs were enrolled in the study: 7 spayed females, 3 neutered males, and 2 intact males, with a median age of 1.5 yr (range 3 mo to 12 yr) and a median weight of 16.7 kg (range 3.4–35.6 kg). Breeds included three dachshunds (two miniature and one standard), two mixed-breed dogs, and one each of basset hound, Chinese crested, Great Dane, Rhodesian ridgeback,

Siberian husky, Spanish water dog, and standard poodle. Diagnoses included congenital ME (six dogs), acquired-idiopathic ME (four dogs), and ME secondary to myasthenia gravis (two dogs). Median time from diagnosis until study commencement was 11.4 mo (range 1 mo to 4 yr) for all dogs, 8.4 mo (range 1 mo to 2 yr) for dogs with congenital ME, 2.1 yr (range 3 mo to 4 yr) for dogs with myasthenia gravis, and 1.5 yr (range 3 mo to 3 yr) for dogs with idiopathic-acquired ME. Four dogs were receiving famotidine; two dogs pyridostigmine; one dog omeprazole and maropitant; one dog metoclopramide, cisapride, enrofloxacin, and metronidazole; and one dog amoxicillin/clavulanic acid. Three dogs were on two or more medications, and five dogs were not on any pharmaceuticals. Dogs were reported by their owners to be kept in an upright position after feedings for an average of 25.8 min (range 10–60 min). Nine dogs had a history of aspiration pneumonia on at least one occasion, with one dog having two episodes and another four episodes. Information for all 12 dogs is summarized in **Table 1**. At the time of the study, thoracic radiographs in all dogs showed dilation of the esophagus consistent with ME, with no evidence of pneumonia. At-home diets were a meatball-like diet in four dogs and a slurry/gruel in seven dogs. One dog received either a slurry or meatballs at home.

Clearance Time

Clearance of material from the esophagus into the stomach was assessed via visual observation by evaluators (JMH, AK, and JMT) both during the imaging process and on review of the saved video clips (JMH). Six dogs had no movement of any liquid barium into the stomach by the end of the liquid imaging period (20 min in four dogs, 15 min in one dog, and 10 min in one dog). Two more dogs had minimal or partial clearance of barium. Four dogs had complete clearance of barium, with two dogs having almost immediate movement of all barium into the stomach. Median transit time for dogs with full clearance was 5 min (range 0–15 min). Median transit for the entire group, with the last time that imaging was recorded used for dogs with no or partial clearance of liquid, was 17.5 min (range 0–20 min).

Four dogs had no clearance of meatballs into the stomach by 30 min. Five dogs had minimal-to-partial clearance, including two with almost complete clearance (one meatball retained). Only three dogs had complete clearance by 30 min. Median transit time for dogs with full clearance was 5 min (range 0–15 min). Median transit for the entire group, with 30 min used for dogs with no or partial clearance of meatballs, was 30 min (range 0–30 min).

Eight dogs received a slurry diet at home. One dog was unwilling to eat the slurry diet in the hospital, so only seven dogs were evaluated for this phase. All seven dogs were fed a slurry or gruel-type food consistency consisting of a commercial diet (canned or dry) mixed

TABLE 1**Individual Details for All 12 Dogs**

Dog No.	Breed	Age	ME Type	Duration of ME	Medications	At-Home Food Type	Clearance Liquid, min (Amount)	Clearance Meatballs, min (Amount)	Clearance Slurry, min (Amount)	GER AP	Recommended Changes	Comments
1	Dachshund	7 yr	I	1 yr	None	MB/S	20 (N)	30 (P)	30 (M)	Yes 1	CS, M	GER of pre-existing gastric contents occurred between liquid and meatballs. Four meatballs passed within first 5 min, 1 meatball retained in esophagus for 30 min
2	Golden retriever/poodle mix	2 yr	CG	2 yr	None	S	10 (N)	30 (P)	30 (N)	No 1	CS, T	Four meatballs passed within first 5 min, 1 meatball retained in esophagus for 30 min
3	Mix	1 yr	CG	1 yr	None	S	15 (N)	30 (P)	10 (F)	Yes 1	M	GER witnessed at 15 min following slurry consumption
4	Rhodesian ridgeback	2 mo	CG	1 mo	None	S	20 (M/P)	30 (P)	30 (P)	No 1	—	
5	Miniature dachshund	6 yr	MG	4 yr	Pyridostigmine	MB	20 (N)	30 (MI)	—	No 1	CS	
6	Chinese crested	6 yr	I	3 yr	Famotidine, metoclopramide, cisapride, enrofloxacin, metronidazole	S	20 (N)	30 (N)	30 (P)	No 4	T	
7	Siberian husky	1 yr	MG	3 mo	Pyridostigmine, famotidine	MB	0 (F)	5 (F)	—	No 2	T	Liquid cleared immediately
8	Miniature dachshund	11 mo	CG	6 mo	Omeprazole, maropitant	S	20 (M/P)	30 (N)	30 (P)	Yes 0	CS	GER observed between liquid and meatball consumption
9	Standard poodle	6 yr	I	3 mo	None	MB	15 (F)	15 (F)	—	No 0	CS	Aspirated liquid and some meatball material but coughed up all material; evidence of concurrent swallowing disorder
10	Great Dane	11 mo	CG	11 mo	Famotidine	S	20 (N)	30 (N)	—	No 0	—	
11	Spanish Water Dog	6 mo	CG	3 mo	Clavamox	S	0 (F)	5 (F)	5 (F)	No 1	—	Liquid cleared immediately
12	Basset Hound	12 yr	I	2 yr	Famotidine	MB	10 (F)	30 (N)	—	No 1	CS	

Type of megaesophagus (idiopathic acquired, congenital, myasthenia gravis); food consistency fed at home at time of study (meatballs, slurry); clearance time and amount of clearance (partial, minimal, full, none) in minutes for liquid, meatballs, and slurry; documented gastroesophageal reflux during study imaging; number of known aspiration pneumonia episodes; and recommended changes in management (consistency, time upright, medication).

AP, aspiration pneumonia; CG, congenital; CS, consistency; F, full; GER, gastroesophageal reflux; I, idiopathic acquired; MB, meatballs; M = medication; MI, minimal; ME, megaesophagus; MG, myasthenia gravis; N, none; P, partial; S, slurry; T, time upright.

with oil or other liquids. Only two of seven dogs had complete clearance of their normal slurry consistency diet by 30 min, whereas four had minimal-to-partial clearance and one had no clearance. Both dogs with full clearance had transit times of 10 min. Median transit for the entire group, with 30 min used for dogs with no or partial clearance of slurry diets, was 30 min (range 5–30 min).

In all dogs, ingesta moved to the area of the esophagus just above the lower esophageal sphincter (LES) within the first 5 min after ingestion. In some dogs, the ingesta was also partially retained in focally distended regions (“pockets”) of the thoracic esophagus. Of the eight dogs with no or partial clearance of the liquid barium, six had all retained liquid at the LES and two had liquid at the LES and in one other single region of the thoracic esophagus. In the nine dogs with incomplete clearance of meatballs, six had all retained meatballs at the LES and three had meatballs additionally retained in a single region of the thoracic esophagus. In one dog, the meatballs within the thoracic esophagus moved to the LES by 10 min. Of the five dogs with incomplete clearance of the slurry diet, four retained slurry at the LES only and one also retained slurry in a single pocket of the thoracic esophagus.

During imaging, three dogs were identified as having gastro-esophageal reflux, with reflux of stomach contents into the esophagus noted either during imaging or between sessions. Additionally, one dog was identified as having a swallowing disorder characterized by aspiration of liquid barium and barium-containing food into the larynx and trachea, even during voluntary eating. All aspirated barium material was eliminated from the airways, as assessed by video-fluoroscopy, by the end of the imaging session.

Area Calculations

Barium column height and width products, as well as traced areas, were calculated for the liquid phase for 10 of 12 dogs (**Figure 3**). One dog with myasthenia gravis and one dog with congenital ME had rapid movement of liquid into the stomach, and measurements were therefore not possible. In 10 dogs, the liquid moved rapidly to the LES. In one dog, most of the barium remained in an esophageal outpouching in the upper thorax until completion of the study (20 min), and in another dog, most of the barium moved rapidly to the LES, although a small amount remained in a pocket in the upper thorax for 10 min before moving to the LES. Two dogs with acquired idiopathic ME had complete clearance of liquid by 10–15 min. In dogs with retained barium, values for column height and width for each dog varied between time points. The variation in values often appeared to coincide with positional changes within the Bailey chair, and not with movement of material into the stomach. Differences between disease subtype groups could not be evaluated as group size did not allow sufficient power to determine significance.

Area of the liquid phase was calculated in all dogs who had barium column measurements (10 dogs). The liquid area calculated via tracing was compared with the area determined using the column measurement at each 5 min increment from 0 to 20 min. Results for traced area mostly paralleled barium column area results for all dogs, although the column product measurement was generally found to overestimate the total area. However, no significant difference was found between the two methods at any time point. The median (range) difference between the two methods for all the dogs immediately following ingestion (0 min) was 2.7 cm² (4.0–23.4; $P = .16$), at 5 min was 1.6 cm² (0–14.7; $P = .3$), 10 min was 4.0 cm² (0.7–13.9; $P = .1$), 15 min was 2.4 cm² (0.2–9.8; $P = .25$), and at 20 min was 2.3 cm² (0.5–3.9; $P = .3$).

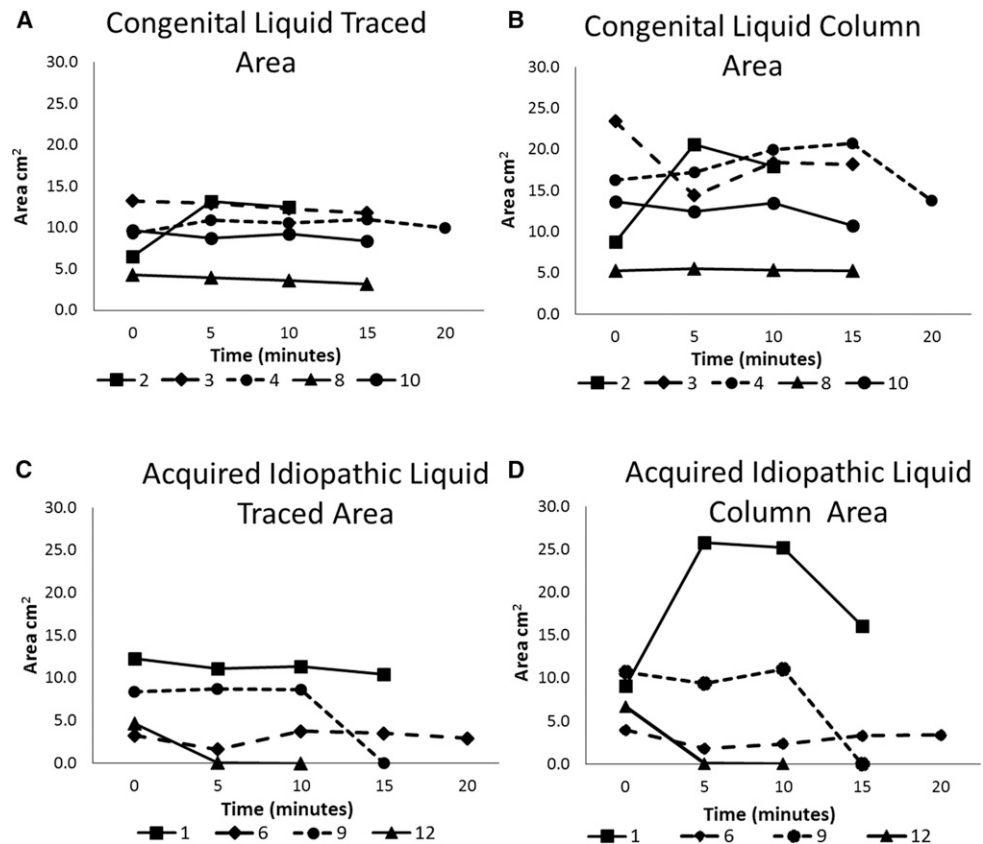
Results for traced area (centimeters squared) for 11 of 12 dogs receiving meatballs are shown in **Figure 4** for congenital, acquired, and myasthenia gravis groups. One dog with congenital ME cleared the esophagus too rapidly to allow area measurement. Downward trends in area were associated with visual assessment of clearance of meatballs into the stomach in the eight dogs with partial or full clearance. The area increased in one and remained stable with some fluctuation in the remaining three of four dogs with no visual clearance of meatball material.

Eight dogs received slurry as their at-home diet; however, one dog (Dog 10) would not eat the slurry diet during the imaging. Therefore, seven dogs received the barium slurry, and the results for traced area (centimeters squared) for six dogs grouped by congenital and acquired causes is shown in **Figure 5**. Six of the dogs still had meatball material retained in the esophagus. In five of the six dogs, the retained meatball material immediately entered the stomach after the slurry was fed. One dog with congenital ME cleared the slurry from the esophagus too quickly to allow area measurement (Dog 11). Downward trends in area were associated with visual assessment of movement into the stomach in three of five dogs with minimal, partial, or full clearance. One dog showed relatively stable but fluctuating area and only minimal visual clearance likely because of the relatively small amount of slurry that cleared from the esophagus (Dog 4). Another dog (Dog 1) with minimal clearance demonstrated a steady increase in area likely due to changes in dog position. The area remained stable in the single dog with no visual clearance of material.

Therapeutic Recommendations

The diet consistency with the best esophageal clearance was different from the current at-home diet in three dogs. Additionally, full esophageal clearance was not achieved in seven dogs using the current at-home diet consistency.

FIGURE 3 Change in area (centimeters squared) of liquid retained in the esophagus over time for (A) traced area in dogs with congenital megaesophagus, (B) column area in the same dogs with congenital megaesophagus, (C) traced area in dogs with acquired idiopathic megaesophagus, and (D) column area in the same dogs with acquired idiopathic megaesophagus. Dog number is listed next to the corresponding line symbol.



Based on fluoroscopic findings, therapeutic changes were recommended for nine dogs, including a change in diet consistency (six), alteration of duration in an upright position (three), and modification of medications (two). Medication changes were recommended for dogs displaying reflux, including addition of proton pump inhibitors, H₂-receptor inhibitors, and promotility agents. Only one dog was already receiving promotility medications at the time of the study (Dog 6) and showed no difference in transit time compared with the other dogs evaluated.

Discussion

This is the first study to describe videofluoroscopic evaluation of dogs with ME during upright feedings. The results of the study supported the hypothesis that this technique allowed for assessment of the clearance of ingesta from the esophagus and provided information that could potentially be used to make feeding recommendations for individual dogs. In dogs who were accustomed to a Bailey chair, contrast videofluoroscopy in an upright position was technically straightforward.

Visual observation of movement of material from the esophagus to the stomach was found to be a reasonable method for determining esophageal clearance. However, additional quantitative methods were also assessed for potential use in situations where

visual estimates may not be reliable. Area tracings are likely to be the most accurate method but are not available without specific imaging software. In our study, calculated column measurements consistently overestimated the true area, by as much as 4 cm², most likely because of the extreme esophageal dilation seen in dogs with ME as well as variability in the degree of distension. Humans undergoing similar imaging studies usually do not have marked esophageal dilation, and on two-dimensional imaging the esophagus remains rectangular in shape.^{10–12} Based on the findings in this study, many dogs with ME, in contrast, have a “funnel” or triangular-shaped esophagus, with a wide cranial border that tapers down sharply to the LES. Therefore, an equation for determining area of a triangle may be more appropriate. In our study, the area tracings and column measurements were not statistically different, although our study was underpowered to detect a significant difference. Sample size calculations performed after completion of data analysis suggest that, to detect a difference of 4 cm² with a power of 0.8, 19 dogs would need to be evaluated⁶. Both calculation methods did allow for monitoring of trends with reduction of area occurring as esophageal contents passed into the stomach. Compared with visual assessment of esophageal emptying, both calculation methods provided similar results, and were not superior to subjective visualization.

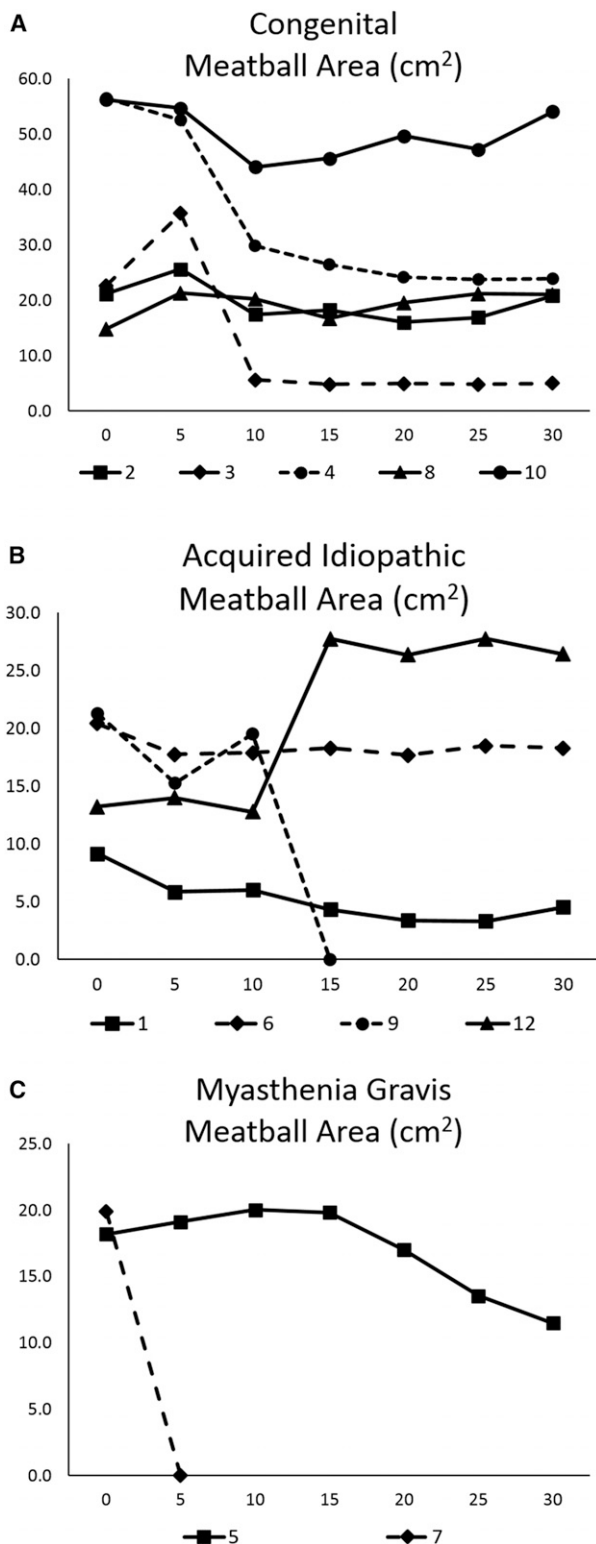


FIGURE 4 Change in traced area (centimeters squared) of meatballs retained in the esophagus over time for (A) dogs with congenital megaesophagus, (B) dogs with acquired idiopathic megaesophagus, and (C) dogs with myasthenia gravis. Dog number is listed next to the corresponding line symbol.

Additional limitations to the calculation methods include that the column measurement method can only be used for liquids, that area tracings may be affected by progressive compression of food material at the LES, and that dogs fed upright frequently readjust position, potentially changing the shape of esophageal content. Ultimately, given the limitations of each technique, visual observation may be a superior method for assessing esophageal emptying.

Based on visual observation, the main reason that esophageal content did not pass into the stomach was because the LES failed to open. The LES has two phases of relaxation during ingestion of solids and liquids. First, sensory afferents in the pharynx are stimulated during swallowing, leading to primary esophageal peristalsis and opening of the LES. Next, following esophageal distention and the generation of luminal bolus pressure, a second period of LES relaxation occurs.^{13–15} Without the ability of the esophagus to sense distention or to contract, the LES may not be stimulated to open or may not open as a coordinated process.¹⁶ In humans with esophageal achalasia, the LES is unable to relax as a result of local loss of myenteric neurons.¹⁷ One case report describing a dog with myasthenia gravis demonstrated, via manometry, a condition similar to esophageal achalasia.¹⁸ A second case report described a dog with videofluoroscopic evidence of esophageal motility, with no relaxation of the LES, who was treated with esophagomyotomy and clinically improved, leading to a presumed diagnosis of achalasia.¹⁹ Neither case report, however, provided histopathologic support for a diagnosis of esophageal achalasia.^{18,19}

Although esophageal achalasia may be a cause of ME in a subset of dogs, all but one dog in our study showed evidence of either full or partial passage of at least one food consistency, suggesting that, if retention of ingesta is caused by failure of the LES to open, it may be because of asynchronous or delayed opening, rather than true achalasia. In some dogs, the LES opened for all food consistencies, but more commonly, one type of food consistency was superior at facilitating LES relaxation. Relaxation of the LES did not always occur immediately after swallowing, and often occurred 10–15 min later, suggesting that, unlike in normal dogs, LES relaxation in some ME dogs was triggered by something other than primary peristalsis. All of the studied dogs were in good body condition, suggesting that all dogs were eventually able to move food into the stomach via opening of the LES.

Three dogs exhibited gastroesophageal reflux during the imaging period. It is uncertain how much reflux contributed to the frequency or severity of regurgitation, or if reflux contributed to the development of ME. For the dogs in our study with gastroesophageal reflux, additional therapies were recommended, including pro-motility agents and proton pump inhibitors. As imaging was only performed every 5 min in order to limit radiation exposure, it is

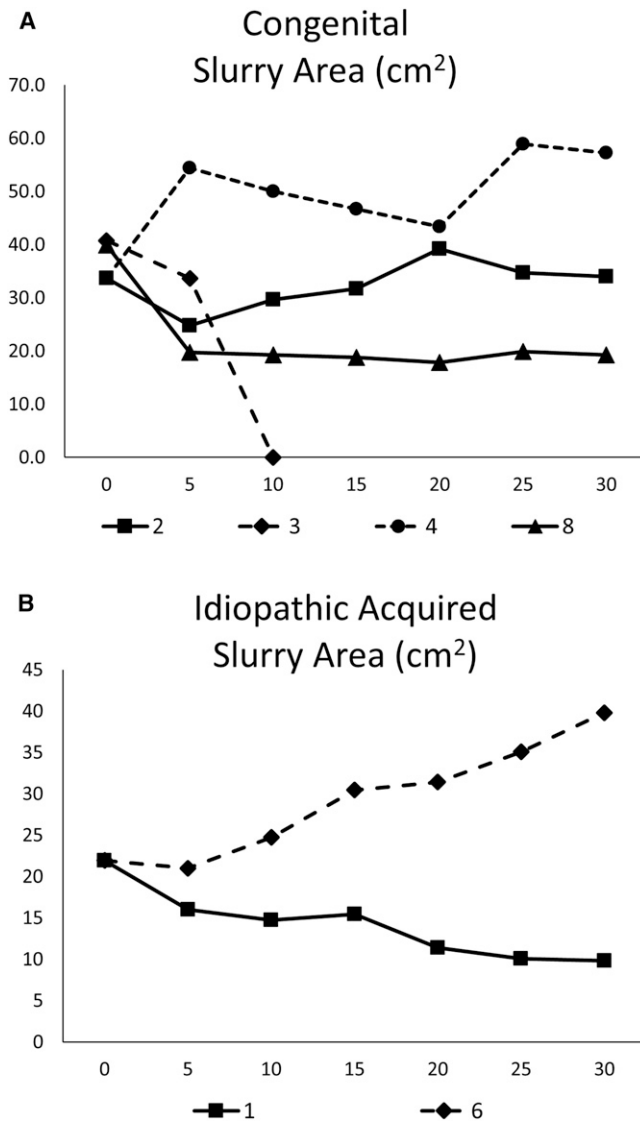


FIGURE 5 Change in traced area (centimeters squared) of slurry retained in the esophagus over time for (A) dogs with congenital megaesophagus and (B) dogs with acquired idiopathic megaesophagus. Dog number is listed next to the corresponding line symbol.

plausible that passage followed by reflux may have occurred without detection and had been misinterpreted as failure of clearance. It is reasonable to suspect that evidence of this would have been seen, such as residual material remaining in the stomach or a change in the distribution of material in the esophagus. When gastroesophageal reflux was noted, it was either visualized or was seen as passage of material into the stomach at one time point followed by an increase in esophageal contents at a later point.

Only one dog was receiving promotility medications (metoclopramide and cisapride) at the time of our study, although this dog did not receive the medications within 12 hr of imaging. This dog, as

with all of the dogs in our study, had no videofluoroscopic evidence of esophageal peristaltic activity. The primary goal of our study was to develop an imaging technique that could facilitate more individualized therapeutic recommendations for dogs with ME. For the majority (75%) of the dogs in our study, imaging results led to recommendations for therapeutic modifications. No specific consistency of ingesta reliably allowed esophageal contents to pass into the stomach, confirming that an imaging study may be needed in order to determine optimal consistency. Many dogs could not pass liquid-consistency ingesta into the stomach, although in individual dogs, liquids moved rapidly through the esophagus. Furthermore, whereas some dogs did well with all food consistencies, typically only one or two of the evaluated consistencies provided the best esophageal transit times. For example, one dog (Dog 3) demonstrated no clearance of liquid barium by 20 min (Figure 3A), partial esophageal emptying over 30 min with meatballs (Figure 4A), and full clearance within 10 min with a slurry (Figure 5A).

The results of our study suggest that the perception of optimal feeding management in dogs with ME does not correspond with videofluoroscopic evidence of esophageal emptying. Most owners are given the primary responsibility for dietary management of their ME-affected dog and are advised to use a trial-and-error technique to determine ideal food consistency, tolerance of water, and duration spent upright. Although this approach was successful in some dogs in this study, five of the seven dogs who were assessed using their at-home slurry diet did not show full esophageal clearance by 30 min. These dogs were, however, perceived to be reasonably well controlled by their owners. This study did not include follow-up information on dogs after recommendations were made. Therefore, further studies would be needed to determine the overall benefit of this imaging technique in dogs with ME.

In most cases evaluated in this study, if at least some material did not pass into the stomach during the first 5 min of the study, none was likely to pass. This was shown by the fact that meatball material was still present in the esophagus several hours later in the dogs fed the slurry consistency. A longer time spent in an upright position may, however, still decrease the likelihood of regurgitation due to compaction of material just cranial to the LES. This material may pass on its own later, or it could be pushed down by subsequent meals, creating a cycle of food retention, but these possibilities were not evaluated in this study.

There were several limitations to this study. Imaging was only performed over 1 day and was considered unlikely to completely mimic the varying at-home conditions for the dogs. However, in our opinion, if a food consistency passes easily into the stomach while in the hospital, it is likely to have a similar action when fed at home. There are many factors that can contribute to the clinical signs seen

in dogs with ME and may impact the imaging results and the applicability of the imaging technique to future management. Changes in tolerance of different food consistencies (either worsening or improving) could develop, and it is therefore possible that the initial assessment provided by this imaging technique may not be applicable for the entire life of the dog. Additional imaging studies may be needed at later time points of the dog's condition or circumstances change. Dogs recruited for this study had to be acclimated to, or at least tolerant of, the use of a Bailey chair. This could have led to some case selection bias toward dogs with more chronic illness and dogs with more controlled or stable disease. However, time since diagnosis was only 1–3 mo in 4 of the 12 dogs in the study, making this less of a concern.

Previous studies report median survival times of 1–3 mo in dogs with ME, but many dogs will live beyond this life expectancy. In fact, many of the dogs in our study had already surpassed this life expectancy at the time of study participation. The dogs in our study may represent a population with mild or stable disease, whereas the previous studies may represent dogs with more severe disease with significant complications, such as aspiration pneumonia.^{3,4}

As these were client-owned dogs, certain accommodations were needed to ensure dog safety. In standard esophagrams, barium liquid and barium-soaked kibble are commonly administered to assess esophageal function. In our study, dogs did not receive a kibble diet because this food consistency is commonly associated with regurgitation. The intent of the study was not to perform standard esophagrams but to evaluate only those diets and food consistencies commonly fed to dogs with ME. The amount of liquid and food material given was a smaller volume than a standard meal because larger volumes of food and contrast, if retained in the esophagus, could increase the risk of significant regurgitation and aspiration pneumonia. It is possible that, with larger meals, the greater volume of esophageal ingesta could push more material into the stomach or stimulate esophageal contraction if the ability to do so is still present. Consistencies were not randomized, and the order was determined again with safety of the dog in mind. When the study was designed, a liquid consistency was thought more likely to clear, and if the liquid did not clear, it was hoped that it would be pushed down by subsequent food material. The diet most consistent with the normal diet was given last, again in the hope that less residual material would remain in the esophagus at the end of the imaging. Finally, because of the nature of ME, in contrast to esophagrams performed in normal dogs, it was impossible to ensure an empty esophagus before administration of contrast. When ingesta was present in the esophagus prior to the addition of contrast, it was generally either pushed into the stomach or retained along with the newly ingested material. Any

of these factors may have affected clearance in some dogs. Furthermore, dogs were only kept upright for a maximum of 30 min after ingestion of liquid or food because of concerns about comfort and animal welfare. Some dogs did not clear the material from their esophagus by 30 min, and to prevent excessive censoring of data, they were assigned a clearance time of 30 min. Therefore, this does not allow for establishment of an actual expected transit time in dogs with ME. The establishment of exact esophageal transit times was not the goal of this study, and additional studies would be required.

Conclusion

In conclusion, the imaging technique described in our study was well tolerated and provided clear information that allowed for individual evaluation of esophageal clearance of liquid and various food consistencies in dogs with ME. Additionally, the technique provided individualized information that resulted in recommendations to change specific feeding practices. Long-term follow-up would be needed to assess the efficacy of these recommendations. This technique has the potential to be a beneficial tool for defining individualized dietary recommendations to improve feeding strategies and overall management in dogs with ME. ■

FOOTNOTES

- ^a OEC 9600 C-Arm Unit; GE Healthcare, Salt Lake City, Utah
- ^b Purina EN; Nestlé Purina PetCare Company, St. Louis, Missouri
- ^c Osirix 7.0; Pixmeo SARL, Bernex, Switzerland
- ^d Microsoft Excel; Microsoft Corporation, Redmond, Washington
- ^e GraphPad Prism software; GraphPad Software, La Jolla, California
- ^f G*Power Version 2, gpower.hhu.de/

REFERENCES

1. Washabau RJ. Gastrointestinal motility disorders and gastrointestinal prokinetic therapy. *Vet Clin North Am Small Anim Pract* 2003;33(5):1007–28.
2. Gaynor AR, Shofer FS, Washabau RJ. Risk factors for acquired megaesophagus in dogs. *J Am Vet Med Assoc* 1997;211(11):1406–12.
3. McBrearty AR, Ramsey IK, Courcier EA, et al. Clinical factors associated with death before discharge and overall survival time in dogs with generalized megaesophagus. *J Am Vet Med Assoc* 2011;238(12):1622–8.
4. Harvey CE, O'Brien JA, Durie VR, et al. Megaesophagus in the dog: a clinical survey of 79 cases. *J Am Vet Med Assoc* 1974;165(5):443–6.
5. Boudrieau R, Rogers W. Megaesophagus in the dog: A review of 50 cases. *J Am Anim Hosp Assoc* 1985;21(1):33–40.
6. Pollard RE. Imaging evaluation of dogs and cats with dysphagia. *ISRN Vet Sci* 2012;2012:238505.
7. Bonadio C, Pollard R, Dayton PA, et al. Effects of body positioning on swallowing and esophageal transit in healthy dogs. *J Vet Intern Med* 2009; 23(4):801–5.
8. Imam H, Shay S, Ali A, et al. Bolus transit patterns in healthy subjects: a study using simultaneous impedance monitoring, videoesophagram, and esophageal manometry. *Am J Physiol Gastrointest Liver Physiol* 2005; 288(5):G1000–6.

9. Stanley BJ, Hauptman JG, Fritz MC, et al. Esophageal dysfunction in dogs with idiopathic laryngeal paralysis: a controlled cohort study. *Vet Surg* 2010;39(2):139–49.
10. Kostic SV, Rice TW, Baker ME, et al. Timed barium esophagogram: A simple physiologic assessment for achalasia. *J Thorac Cardiovasc Surg* 2000;120(5):935–43.
11. Neyaz Z, Gupta M, Ghoshal UC. How to perform and interpret timed barium esophagogram. *J Neurogastroenterol Motil* 2013;19(2):251–6.
12. de Oliveira JM, Birgisson S, Doinoff C, et al. Timed barium swallow: a simple technique for evaluating esophageal emptying in patients with achalasia. *AJR Am J Roentgenol* 1997;169(2):473–9.
13. Boeckxstaens G. The lower oesophageal sphincter. *Neurogastroenterol Motil* 2005;17(Suppl 1):13–21.
14. Hershcovici T, Mashimo H, Fass R. The lower esophageal sphincter. *Neurogastroenterol Motil* 2011;23(9):819–30.
15. Washabau RJ, Day MJ. *Canine and Feline Gastroenterology*. St. Louis: Elsevier Saunders; 2013.
16. Schachtel J, Lattimer J, Grobman M, et al. Videofluoroscopic swallow study (VFSS) protocol identifies a possible link between canine lower esophageal achalasia/dyssynchrony and megaesophagus [abstract]. In: American College of Veterinary Radiology Annual Scientific Conference; October 19–22, 2016; Orlando, FL.
17. O'Neill OM, Johnston BT, Coleman HG. Achalasia: a review of clinical diagnosis, epidemiology, treatment and outcomes. *World J Gastroenterol* 2013;19(35):5806–12.
18. Kempf J, Beckmann K, Kook PH. Achalasia-like disease with esophageal pressurization in a myasthenic dog. *J Vet Intern Med* 2014;28(2):661–5.
19. Boria PA, Webster CR, Berg J. Esophageal achalasia and secondary megaesophagus in a dog. *Can Vet J* 2003;44(3):232–4.