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Effects of Body Positioning on Swallowing and Esophageal Transit in Healthy Dogs

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Background: Contrast videofluoroscopy is the imaging technique of choice for evaluating dysphagic dogs. In people, body position alters the outcome of videofluoroscopic assessment of swallowing.

Hypothesis/Objective: That esophageal transit in dogs, as measured by a barium esophagram, is not affected by body position.

Animals: Healthy dogs ($n = 15$).

Methods: Interventional, experimental study. A restraint device was built to facilitate imaging of dogs in sternal recumbancy. Each dog underwent videofluoroscopy during swallowing of liquid barium and barium-soaked kibble in sternal and lateral recumbancy. Timing of swallowing, pharyngeal constriction ratio, esophageal transit time, and number of esophageal peristaltic waves were compared among body positions.

Results: Transit time in the cervical esophagus (cm/s) was significantly delayed when dogs were in lateral recumbency for both liquid (2.58 ± 1.98 versus 7.23 ± 3.11; $P = .001$) and kibble (4.44 ± 2.02 versus 8.92 ± 4.80; $P = .002$). In lateral recumbency, 52 ± 22% of liquid and 73 ± 23% of kibble swallows stimulated primary esophageal peristalsis. In sternal recumbency, 77 ± 24% of liquid ($P = .01$ versus lateral) and 89 ± 16% of kibble ($P = .01$ versus lateral) swallows stimulated primary esophageal peristalsis. Other variables were not significantly different.

Conclusions and Clinical Importance: Lateral body positioning significantly increases cervical esophageal transit time and affects the type of peristaltic wave generated by a swallow.

Key words: Contrast radiography; Gastroenterology; Gastrointestinal tract; Physiology; Radiology and diagnostic imaging.

Dysphagia is defined as difficulty in swallowing. Both anatomical and functional disorders of the oropharynx, cricopharynx, and esophagus can lead to dysphagia.[1,2] Currently there are several diagnostic methods available to veterinarians to evaluate the causes of dysphagia, including esophagoscopy, survey radiography, and contrast videofluoroscopy.[3] In people, esophageal manometry, pH testing, and impedance testing are commonly used to further characterize the cause of dysphagia, although the latter studies are rarely performed in veterinary medicine.[4] Although esophagoscopy and survey radiography provide anatomic information about the structures involved with the swallowing reflex,[5] neither provides information about esophageal function. This is an important limitation of these diagnostic techniques, particularly in animals that are dysphagic secondary to dynamic disorders such as cricopharyngeal disease or esophageal dysmotility. Contrast videofluoroscopy involves real-time image capture of the dog as it is swallowing liquid barium or barium-soaked kibble. This method has an advantage over standard radiographs and esophagoscopy because it allows the clinician to evaluate the function of the pharynx and esophagus, allowing for better and more accurate diagnosis of the cause for dysphagia.

Abbreviations:

LES	lower esophageal sphincter
PES	proximal esophageal sphincter
ROI	region of interest

One problem with videofluoroscopy is that animal positioning is not standardized. Videofluoroscopic studies can be done with the dog restrained in lateral recumbency or with the dog in a sternal or standing position. Presumably, sternal positioning bears more resemblance to the posture in which a dog would normally eat and drink, and videofluoroscopy done in this body position might be more representative of true swallowing. However, at our institution, sternal and standing studies have been technically difficult to perform because the dog's head cannot be adequately restrained without substantial radiation exposure to the personnel performing the study. More specifically, the head of a laterally recumbent dog can be controlled by holding the ear and pressing the head against the table. The head of a standing dog cannot be pressed against the table because the body is free to squirm and move about. Studies done in people have shown that the outcome of contrast videofluoroscopy of swallowing differs depending on the positioning of the patient.[6] Nevertheless, to the authors' knowledge, the influence of alterations in body positioning, specifically the effect of sternal versus lateral recumbency, upon the outcome of videofluoroscopy, has not been assessed in dogs.

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The purpose of this study was to develop a restraint device for imaging dogs in sternal recumbency and then to determine the effects of body position on the timing of the swallow reflex, the pharyngeal constriction ratio, esophageal peristalsis, and esophageal bolus transit speed. We hypothesized that measurement of these parameters would not be affected by body position.

Materials and Methods

Restraint Device Design

The restraint system was constructed out of 1/2 "and 3/8" transparent polycarbonate.[a] Polycarbonate sheets were cut and milled in a machine shop, and glued together using cement.[b] Polycarbonate was chosen because it is radiolucent and nonmagnetic so it can be used for both X-ray and, if need be, magnetic resonance systems. Additionally, polycarbonate is highly durable and resistant to ethanol and other disinfectants. The restraint device is a 3-dimensional rectangular frame. The only face of the cube that is fixed to the frame is 1 long side. When in use, this is the side placed closest to the X-ray detector. The 2 short sides of the cube and the bottom of the cube are open, and the opposite long side of the cube has a freely movable piece that sits in grooves carved into the frame. These grooves allow the restraint device to accommodate dogs of different widths. The open short sides of the restraint device allow the dog to walk through it and then assume sternal recumbency. The movable long side panel is aligned closer so that the dog is effectively "squeezed" between the 2 long side panels within the restraint device. The open short sides of the box allow the handlers access to the dog's muzzle in order to administer barium contrast material.

Inclusion Criteria

Healthy dogs owned by staff members and students of the University of California, Davis, School of Veterinary Medicine, with no history of esophageal or gastrointestinal disease were included. Dogs must not have had a history of oral or oropharyngeal dysphagia. Dogs could not be on medications that would alter swallowing or esophageal function.

General Protocol

All procedures were approved by the institutional animal care and used committee. Survey radiographs of the thorax were performed along with a complete blood count and serum biochemistry panel before videofluoroscopy in all dogs. All dogs were videofluoroscopically imaged both sternally and laterally without sedation using a standard fluoroscopy unit.[c] Dogs were randomized to determine which body position was studied first. A radiodense imaging ruler was placed next to the dog's head to allow for correction of magnification. Sixty percent w/v liquid barium sulfate[d] was administered PO in 2 different forms: as a liquid and soaked into kibble, as is consistent with University protocol for a contrast esophagram study. All dogs imaged in lateral recumbency were restrained in right lateral recumbency, also consistent with University protocol. For sternal studies, the dogs were placed into the restraint device and allowed to relax in sternal recumbency. For either body position, liquid boluses were administered in 5–10 mL doses with a 30 mL catheter tip syringe, and 3–5 swallows were observed, with at least 1 bolus followed to the stomach. The barium soaked in kibble was given to determine abnormalities in swallowing of solid food. Dogs that would not willingly eat the kibble were offered smaller boluses consisting of 5–10 kibble pieces each, that were gently pushed into the mouth and the mouth held in the closed position until a swallow occurred. Three to 5 swallows were observed, and at least 1 bolus of solid material was followed to the stomach.

Image Analysis

All survey radiographs and contrast videofluoroscopic esophagrams were reviewed by a board-certified veterinary radiologist. Videos were recorded onto a DVD and viewed by commercially available software.[e] Still images were captured and analyzed by commercially available software.[f] It was not possible for the reviewer to be blinded to the body position of the dogs in the study because of the presence or absence of the restraint device in the image.

Pharyngeal Constriction Ratio

The pharyngeal constriction ratio was measured as described previously.[7] From the digitized videofluoroscopic studies, a hold frame and a maximum contraction frame were selected. The hold frame was identified as a frame in which the larynx appeared at rest without rostral or caudal motion. The maximum contraction frame was identified as a frame in which the dorsal pharyngeal wall had reached its most ventral and caudal position. For the hold frame, a region of interest (ROI) was drawn around the air space beginning dorsal to the soft palate then rostrally to the hyoid apparatus and tympanic bulla, dorsally to the dorsal aspect of the pharyngeal wall, caudally along the dorsal aspect of the pharyngeal wall to the proximal esophageal sphincter (PES), and ventrally around the corniculate process of the arytenoid cartilage to include the vallecula, finally connecting the epiglottis to the starting point. The PES was specifically defined as the region in the cranial esophagus that remained the narrowest through the study.[8] For the maximum contraction frame, an ROI was drawn around any residual barium or airspace identified within the pharyngeal area. The ROIs were expressed in pixel numbers and the pharyngeal constriction ratio was calculated by dividing the number of pixels in the maximum contraction frame by the number of pixels in the hold frame.

Timing of Swallow

Timing was measured as described previously.[9] The videos were viewed frame by frame where each frame represented 1/30th of a second. The frame in which the epiglottis was observed to close over the larynx was considered as the starting point for all time measurements. From this point, frames were counted until the observation of maximal contraction of the pharynx, opening of the PES and closing of the PES. The swallow was considered completed when the epiglottis was observed to re-open. Once the number of frames to each point in the swallow were calculated, that number was divided by 30 to obtain the number of seconds from the initiation of the swallow to each particular event within that swallow (each frame represents 1/30th of a second in the NTSC system, the analog television system used in the United States).

Esophageal Peristalsis

The type of esophageal peristaltic wave that moved each bolus from the cervical esophagus to the stomach was recorded.[10] A primary peristaltic wave was defined as a wave that would move a bolus of food or liquid from the PES all the way to the lower esophageal sphincter (LES) immediately after the transition from the pharynx through the PES into the cervical esophagus.[6] A secondary peristaltic wave was defined as 1 that was not associated with a swallow but moved a stationary bolus of food or liquid to the LES.[1] Secondary peristaltic waves are necessary when a primary peristaltic wave is absent or insufficient to propel the bolus the entire distance of the esophagus.[1] If a peristaltic wave was not triggered and the bolus was propelled to the stomach with the next swallowed bolus (and its accompanying primary peristaltic wave), then the original swallow was recorded to have had no associated peristaltic wave. The percent of swallows resulting in each type of peristaltic wave was calculated for each dog for liquid and kibble swallows in both body positions.

Bolus Transit Speed

Boluses of liquid and kibble that were followed to the stomach were tracked so that the length of the esophagus and the speed of the bolus as it traveled through the different portions of the esophagus could be measured. Images of the cervical, cranial thoracic, and caudal thoracic esophagus were captured and the esophageal length calculated after correcting for magnification with the imaging ruler. The cervical esophagus was defined as the length of esophagus from the caudal aspect of the PES to the thoracic inlet. The cranial thoracic esophagus was the length of esophagus from the thoracic inlet to the middle of the base of the heart. The caudal thoracic esophagus was measured from the middle of the base of the heart to the LES. The number of frames (each frame being 1/30th of a second, in the NTSC system) it took for each bolus to travel the length of each section of the esophagus was tabulated and this number was divided by 30 in order to obtain the number of seconds that it took for a bolus to travel the length of each section of the esophagus. Once the length of the esophagus and speed of the bolus was calculated, the bolus transit speed could be calculated for the cervical, cranial thoracic, caudal thoracic, and entire esophagus.

Statistics

A nonparametric Wilcoxon's Signed-Rank test[g] was used to assess for statistical differences among the time to maximal pharyngeal contraction, time to PES opening, time to PES closing, time to epiglottic re-opening, pharyngeal constriction ratio, percent of swallows with no peristaltic wave, percent of swallows with a primary peristaltic wave, percent of swallows with a secondary peristaltic wave, and esophageal transit times for sternal liquid versus lateral liquid and sternal kibble versus lateral kibble studies. A P value $\leq .05$ was considered significant.

Results

Of the 15 dogs recruited for the study, 9 dogs were castrated males and 6 dogs were spayed females. The dogs ranged in age from 7 months to 10 years with a mean age (±SD) of 5.4 (±3.6) years. Breeds represented included 3 Labrador Retrievers, 2 Springer Spaniels, and 1 each of the following breeds: Border Collie Cross, Pointer Cross, Australian Shepard, Cavalier King Charles Spaniel, Anatolian Shepard Cross, Jack Russell Terrier, German Shepard Cross, Cairn Terrier, Golden Retriever, and Coon Hound. Survey thoracic radiographs, CBC, and serum biochemistry panels were unremarkable in all dogs. Fourteen of the 15 dogs tolerated positioning in right lateral recumbency, the final dog was not willing to be restrained in lateral recumbency and the study was discontinued. This dog's numerical data were not included in mean values. All 15 dogs tolerated positioning in the restraint device.

The values that were obtained regarding pharyngeal constriction ratio were similar to the values reported previously in the literature (Table 1).[7] There were no significant differences among body positions. The time to maximum pharyngeal contraction, PES opening, and epiglottis reopening were not significantly different among body positions (Table 1) and were similar to the values reported previously.[9,11] The time to PES opening was significantly shorter in dogs in sternal recumbency (as compared with lateral recumbency) when being fed kibble but not liquid.

With regards to esophageal peristalsis (Table 1), when dogs were placed in lateral recumbency, liquid barium elicited a primary peristaltic wave 52 ± 22% of the time versus 77 ± 24% of the time when the dogs were in sternal recumbency. In addition, when dogs were placed in sternal recumbency, both liquid and kibble were far more likely to trigger a primary wave than any other type of wave. Only a small number of boluses were propelled to the LES in either body position for both kibble and liquid. The number of secondary waves was not significantly different between body positions.

Bolus transit speed was significantly faster for dogs in sternal versus lateral recumbency for both liquid and kibble (Table 2). This was primarily because of faster transit time through the cervical esophagus but not the

Table 1. Values for swallowing parameters in 14 dogs are given for liquid and kibble in both sternal and lateral recumbency.

	Liquid Studies			Kibble Studies		
	Lateral	Sternal	*P* Value	Lateral	Sternal	*P* Value
PCR	0.11 ± 0.35	0.14 ± 0.04	.20	0.11 ± 0.04	0.11 ± 0.21	.93
Time to maximum pharyngeal contraction (second)	0.11 ± 0.04	0.10 ± 0.03	.89	0.13 ± 0.06	0.14 ± 0.04	.97
Time to PES opening (second)	0.10 ± 0.02	0.11 ± 0.02	.37	0.14 ± 0.06	0.15 ± 0.05	.70
Time to PES closure (second)	0.25 ± 0.04	0.27 ± 0.04	.24	0.33 ± 0.07	0.28 ± 0.05	.02
Time to epiglottis reopening (second)	0.24 ± 0.04	0.25 ± 0.05	.56	0.29 ± 0.06	0.26 ± 0.04	.28
Number peristalsis[a]	48 ± 22%	23 ± 24%	.01	27 ± 23%	11 ± 16%	.01
Primary peristalsis[b]	52 ± 22%	77 ± 24%	.01	73 ± 23%	89 ± 16%	.01
Secondary peristalsis[c]	8 ± 10%	10 ± 13%	.70	16 ± 22%	6 ± 11%	.19

Mean ± standard deviation.
[a]No peristalsis, proportion of swallows that did not generate a primary peristaltic wave.
[b]Primary peristalsis, proportion of swallows that generated a primary peristaltic wave.
[c]Secondary peristalsis, proportion of swallows needing additional peristaltic wave(s) to propel bolus to LES.
PCR, pharyngeal constriction ratio; PES, proximal esophageal sphincter

Table 2. Esophageal transit speeds (cm/s) for the cervical, cranial thoracic, and caudal thoracic regions for liquid and kibble swallowing studies in 14 healthy dogs imaged in both sternal and lateral recumbency.

	Liquid Studies			Kibble Studies		
	Lateral	Sternal	*P* Value	Lateral	Sternal	*P* Value
Cervical esophagus	2.58 ± 1.98	7.23 ± 3.11	.001	4.44 ± 2.02	8.92 ± 4.80	.002
Cranial thoracic	6.48 ± 3.14	6.89 ± 2.23	.56	5.30 ± 1.88	6.40 ± 3.54	.11
Caudal thoracic	4.91 ± 0.91	5.60 ± 1.79	.28	4.81 ± 1.15	5.37 ± 1.69	.56
Total bolus transit speed	13.97 ± 1.12	19.72 ± 2.13	.001	14.55 ± 1.06	20.69 ± 2.48	.008

cranial or caudal thoracic esophagus when dogs were in sternal recumbency.

Discussion

There were multiple parameters assessed in this study of which several were found to be significantly different between body positions and others parameters were not. Cervical esophageal transit time was significantly shorter for dogs in sternal recumbency and the frequency of the type of peristaltic wave triggered by a swallow was different between body positions. Those parameters that were not different included pharyngeal constriction ratio, time to maximum contraction, time to PES opening, time to epiglottis reopening, and the percentage of secondary peristaltic waves. The fact that 4/5 parameters (pharyngeal constriction ratio and timing of the swallow) were not significantly different is not surprising because both pharyngeal contraction and bolus propulsion are reflexive and consequently are conserved despite positioning. We believe that the significant delay in timing of PES closure in lateral kibble studies compared with sternal kibble studies is because of our inability to standardize bolus size, and not a truly significant physiological difference. Therefore, it is our opinion that in a clinical setting, values for these parameters can be measured in either body position and compared directly without concern of body positioning having a confounding effect.

The percentage of primary waves was significantly greater in sternal liquid and kibble studies when compared with lateral liquid and kibble studies, and the percentage of swallows that had no associated primary peristaltic waves was higher for lateral studies. In addition, bolus transit speed, particularly in the cervical esophagus, was significantly different between body positions. This is clinically important when imaging a dog in lateral recumbency as one might interpret retention of barium in the cervical esophagus as indicating poor motility when it is actually a feature of body position. Moreover, one cannot compare quantitative values from studies performed in sternal to those performed in lateral recumbency directly because body position has an effect on the measured outcome. There was no significant difference in the percentages of secondary waves seen between the 2 body positions. It has been previously shown that bolus size and consistency are directly responsible for triggering esophageal peristalsis.[12,13] Therefore, it might be expected that the smaller liquid boluses would be less likely than a kibble bolus to trigger a peristaltic wave. However, the cause for a difference in esophageal peristalsis between body positions seen in this study is less clear. One factor contributing to the presence or absence of peristaltic wave production is the motion of the pharynx.[14] If repeated swallowing attempts are being made at the pharyngeal level, esophageal peristalsis will decrease in frequency or stop.[14] Although difficult to assess, it is possible that dogs in lateral recumbency may swallow smaller boluses, which are less likely to trigger a peristaltic wave. This would decrease the number of primary peristaltic waves and result in retention of liquid and kibble in the cervical esophagus. This can also lead to an increase in the number of secondary peristaltic waves seen to help strip the esophagus of food or liquid retained in the cervical esophagus.

In people it has been shown that body position (sitting versus supine) dramatically alters esophageal transit times.[6,15] One possible explanation for this is that in people, gravity would speed bolus transit in the sitting position where the esophageal path is vertically oriented in comparison to the supine position where the esophageal path is horizontally oriented. In dogs, however, the esophagus has a horizontal path in both sternal and lateral recumbency thereby negating the effect of gravity. Even though the dog's esophagus is technically horizontal in both body positions, we still saw a significant difference in transit speed between the sternal and lateral recumbency. This could be related to the dog struggling to swallow while in lateral recumbency, leading to a decrease in esophageal peristalsis, an increase in retention of bolus material in the cervical esophagus, and an increase in overall transit time.

This study had several limitations. The most significant limitation was the lack of standardization in liquid and kibble bolus size. Variable bolus size has been shown to substantially alter quantitative measures of swallowing in people.[12] Although we attempted to give 5–10 mL liquid boluses and 5–10 pieces of solid kibble food boluses, many dogs would either let the liquid dribble from their mouths or spit the kibble out. This is not just a limitation for this study but for all esophagrams performed in veterinary patients.

Another important outcome determinant is that all of the dogs in this study were clinically healthy. It is unclear whether dysphagic dogs might not struggle more, be unwilling to eat or that quantitative measures might not be altered more significantly by body positioning. Presumably, dysphagic dogs would struggle more in both positions but because they are physically restrained in lateral recumbency and not in the restraint device, the detrimental effect of motion on image quality might be more severe in the sternal position. Additional studies involving dysphagic dogs are warranted to determine the importance of this factor.

Footnotes

[a] McMaster Carr, Santa Fe Springs, CA
[b] IPS Weld-On cement, McMaster Carr
[c] EasyDiagnost Eleva, Philips Medical Systems, N.A., Bothell, WA
[d] Novopaque, LPI Diagnostics, Yorba Linda, CA
[e] QuicktimePro, Apple Inc, Cupertino, CA
[f] NIH ImageJ, National Institute of Health, Bethesda, MA
[g] VassarStats, Vassar College, Poughkeepsie, NY

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