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ORIGINAL ARTICLE

Prevalence of gastroesophageal reflux in dogs undergoing MRI for a thoracolumbar vertebral column pathology

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Objectives: **The aims of the study were to investigate the prevalence and extent of gastroesophageal reflux, and the prevalence of regurgitation in dogs undergoing thoracolumbar spine magnetic resonance imaging, and to explore possible associations of reflux and regurgitation with signalment (breed, age, sex, neuter status), bodyweight, body condition score and drugs used in the anaesthetic protocol.**

Materials and Methods: **The thoracic part of the oesophagus was retrospectively assessed for presence and quantification of fluid on two T2 weighted sequences. Patient breed, age, sex, neuter status, weight and body condition score were recorded. Anaesthetic records were reviewed for the presence of regurgitation and detailed anaesthetic protocols.**

Results: **Fifty percent (95% confidence interval: 45 to 57%) of included dogs had evidence of gastroesophageal reflux. Reflux was not associated with the individual breed, age, sex, neuter status or body weight. Brachycephalic dogs did not demonstrate significantly higher rates of reflux compared to non-brachycephalic dogs. A larger volume of reflux was associated with a higher chance of regurgitation.**

Clinical Significance: **Gastroesophageal reflux is a common finding in dogs undergoing thoracolumbar spine magnetic resonance imaging. Dogs which regurgitated had higher volumes of reflux. Early detection and quantification of the volume of reflux is helpful as it may allow the anaesthetist to take measures which may reduce the risk of associated complications.**

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INTRODUCTION

The incidence of gastroesophageal reflux in dogs under general anaesthesia (GA) is reported to vary widely from 5% (Savvas *et al.* 2016) to 87.5% (Lambertini *et al.* 2020). After an episode of reflux, dogs can potentially suffer from oesophageal stricture, oesophagitis (Melendez *et al.* 1998, Leib *et al.* 2001, Wilson & Walshaw 2004) and/or aspiration pneumonia (Melendez *et al.* 1998, Wilson & Walshaw 2004, Flouraki *et al.* 2020) with a reported mortality rate for oesophageal stricture ranging from 12% to 23% (Melendez *et al.* 1998, Leib *et al.* 2001, Wilson & Walshaw 2004).

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Gastroesophageal reflux is defined as the retrograde, passive passage of material from the stomach into the oesophagus due to relaxation of the lower oesophageal sphincter. It is not easy to detect clinically unless oesophageal pH is measured. Deviations from normal pH indicates gastric (acidic, pH <4) or biliary (alkaline, pH >7.5) reflux. A number of techniques have been developed and these have recently been reviewed (Alasia *et al.* 2021). The most commonly utilised technique in veterinary medicine is the positioning of a pH probe in the distal oesophagus which can detect strongly acidic reflux. The use of dual multichannel intraluminal impedance monitoring allows detection of reflux of all pH (Zacuto *et al.* 2012, Lotti *et al.* 2021). However, neither pH probe nor combined pH/impedance probe give information on the volume of refluxate.

Devices monitoring pH or combined pH/impedance monitors cannot be used during magnetic resonance imaging (MRI) as the pH probe and impedance catheter are made of ferromagnetic elements which would create local susceptibility artefacts on the images obscuring the surrounding structures (most relevantly the adjacent vertebral column). This may lead to non-diagnostic images for patients undergoing MRI for a thoracolumbar pathology. Additionally, there is a risk of thermal injury due to inductive heating leading to oesophageal burn.

In human medicine, real-time swallowing MRI can be used to diagnose gastroesophageal reflux disease (Kulinna-Consentini *et al.* 2019). Real-time MRI is not feasible with small animals, however oesophageal fluid can be easily detected on T2 weighted (T2w) MR images as it shows a hyperintense signal (Murphy 2020). The incidence of gastroesophageal reflux in dogs undergoing MRI has not been described.

A possible consequence of gastroesophageal reflux is regurgitation, which corresponds to the presence of fluid from the stomach/oesophagus within the mouth or nose and is easier to detect clinically. The incidence of regurgitation in dogs under GA is reported to be between 0.004% and 0.96% and (Galatos & Raptopoulos 1995a, Wilson *et al.* 2005, Lamata *et al.* 2012).

The primary objective of this study is to report the incidence of gastroesophageal reflux in dogs undergoing MRI for a disease not related to gastrointestinal pathologies. The secondary objectives are (1) to explore associations between (a) reflux and (b) regurgitation with signalment (breed, age, sex, neuter status), bodyweight, body condition score (BCS), and the drugs used in the anaesthesia protocol and (2) to report the frequency with which MRI evidence of reflux was documented in the contemporaneous imaging report.

MATERIALS AND METHODS

Study design and inclusion criteria

For this retrospective descriptive study, the database of our institution was searched for dogs that underwent MRI of their thoracolumbar vertebral column between February 1, 2021 and January 31, 2022. Dogs that had parts of their oesophagus included in the field of view on sagittal and/or 3D T2w sequence were included in the study.

Patient breed, age, sex, neuter status, weight and BCS were recorded. The BCS was standardised using a ratio calculated from either commonly used grading system (/5 or /9), resulting in a 0 to 1 number. For example, a BCS of 3/5 would be 0.6, and a BCS of 5/9 would be 0.56. French bulldogs, English bulldogs, bulldogs, Cavalier King Charles spaniels, boxers, Staffordshire bull terriers, mastiffs, Chihuahuas, pugs, shih tzus, Dogues de Bordeaux and mix dogs from these breeds were considered brachycephalic dogs.

Outcomes

The primary outcome was the identification of evidence of gastroesophageal reflux in MRI (see detailed description below). The secondary outcome was the identification of regurgitation by the attending anaesthetist during GA for acquisition of the MRI study, subsequent procedures and recovery.

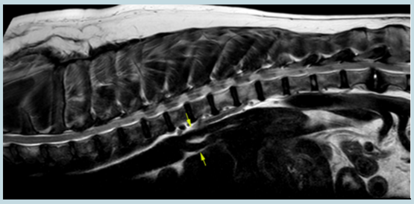
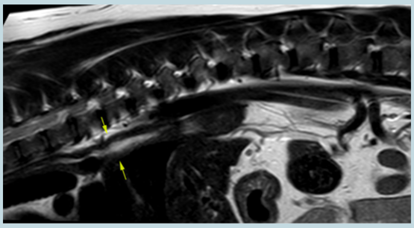
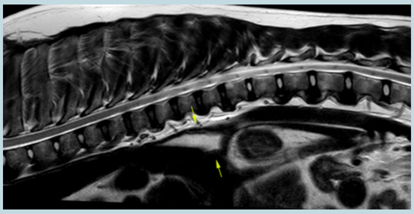
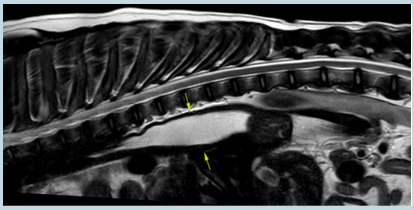
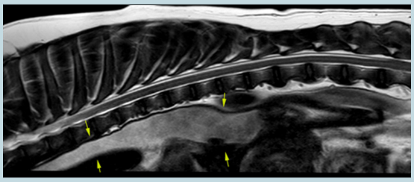
Diagnostic tests performed

All dogs were under GA and positioned in dorsal recumbency for MRI. The images were acquired with a 1.5 T MRI scanner (Philips Ingenia CX 1.5T, Philips Medical Services, Eindhoven, Netherlands). T2w sagittal and/or volumetric (3D) T2w sequences were selected to assess the presence of fluid in the oesophagus. At our institution, turbo spin echo (TSE) T2w and T1w sagittal sequences of the thoracolumbar vertebral column are generally the first performed with the oesophagus typically included in the field of view. The MRI protocol thereafter is not strictly standardised. Instead, sequences are requested by the supervising neurologist or radiologist based on the findings. A 3D T2w sequence, of the thoracolumbar spine (and including the dorsal thoracic and abdominal structures), is acquired on some dogs if requested by the attending clinician.

The included portion of the oesophagus was assessed by a third-year European college of veterinary diagnostic imaging (ECVDI) resident for presence of oesophageal fluid on the available T2w sequences. The volume of oesophageal fluid was subjectively classified with a 5-grade system by the same author. Grade 1 corresponds to a thin T2 hyperintense signal coating the luminal lining of the oesophagus, extending from the heart base to the cardia. In grade 2, there is a small volume of fluid in the caudal part of the thoracic oesophagus, extending from the heart base to the cardia, without clear oesophageal dilation. Grade 3 has a moderate volume of fluid dilating the caudal part of the thoracic oesophagus, extending from the heart base to the cardia. In grade 4, the large volume of oesophageal fluid extends just cranial to the heart base while in grade 5, there is a very large volume of oesophageal fluid extending markedly cranially to the heart base and associated with further dilation of the oesophagus. An example of each grade is depicted in Table 1. In equivocal cases, typically when the presence of very small volumes of oesophageal fluid was questionable, two ECVDI specialists reviewed the images to reach a consensus for the presence or absence of fluid, and its extent.

The original imaging reports were retrospectively reviewed by a third year ECVDI resident. References to the presence of gastroesophageal reflux were documented.

Table 1. Subjective five-grade system to classify the volume of gastroesophageal reflux and examples

Grade	Volume of fluid in the oesophagus	Subjective definition	Examples on T2w sagittal images
1	Very small	T2 hyperintense signal coating the luminal lining of the oesophagus (from the heart base to the cardia)	
2	Small	small volume of fluid in the caudal oesophagus (from the heart base to the cardia), without clear oesophageal dilation	
3	Moderate	moderate volume of fluid which dilates the caudal oesophagus (from the heart base to the cardia), with extension up to the level of the heart base	
4	Large	large volume of fluid extending just cranial to the heart base	
5	Very large	very large volume of fluid extending markedly cranial to the heart base and further dilation of the oesophagus compared to 4	

The yellow arrows indicate the oesophagus

Anaesthetic records were reviewed by an European college of veterinary anaesthesia and analgesia (ECVAA) specialist. Evidence of regurgitation witnessed by the attending anaesthetist was recorded. Anaesthetic protocols and duration of GA were also recorded.

Statistical analysis

All variables were recorded in a spreadsheet in a commercial software calculator package (Microsoft Excel) and imported into an open-source statistical software package (R and RStudio, version 1.3.1093). Descriptive statistics were performed using Excel. The remainder of the statistical analyses were performed using R. Normality for age and bodyweight was tested using a Shapiro-Wilk's test. Data are presented as mean ±sd if normally distributed, and median associated with minimum and maximum values if not. Univariable logistic regression was used to assess associations between the presence of (1) gastroesophageal reflux and (2) regurgitation and several variables (brachycephalic breed, age, sex, neuter status, bodyweight, BCS, use of methadone, butorphanol, alfaxalone, isoflurane). Volume of oesophageal fluid, determined using the grading system described above, was also included as an ordinal variable in analysis (2). Odds ratios and their 95% confidence intervals (CI) are reported. Variables with a P-value<0.2 would then be entered in separate backward stepwise multivariable logistic regression models for analyses (1) and (2). A p-value less than 0.05 was considered statistically significant. A post hoc power analysis was performed with α=0.05, and power=0.08, using the Dartmouth College online sample size calculator for logistic regression for binary covariates.

This observational, retrospective study was approved by our local Ethical Body (VIN/22/018).

RESULTS

Demographic information

Two hundred and seventy-five dogs met the inclusion criteria. French bulldog was the most commonly included breed [21.5%, 95% CI (16.64, 26.36)], followed by dachshund [7.3%, 95% CI (4.23, 10.37)], Labrador retriever [5.5%, 95% CI (2.81, 8.19)], pug [5.1%, 95% CI (2.5, 7.7)] and cross breeds of a non-brachycephalic breed [8.4%, 95% CI (5.12, 11.68)]. The breakdown of other breeds is given in the Appendix. One hundred and twelve dogs were brachycephalic [40.7%, 95% CI (34.89, 46.51)]. There were 42 entire male, 119 neutered male, 29 entire female and 85 neutered female. The median weight was 12.5 kg (4.3 kg; 70 kg). The median age was 70 months (3 months; 172 months). The BCS was recorded for 176 dogs. The median BCS was 0.60 (0.33; 1.00).

Anaesthetic protocol

The GA duration was available in 249 out of the 275 anaesthesia records. The median GA duration was 130 minutes (40; 360). No dogs received anti-emetic, prokinetic or anti-acid drugs before GA or as part of pre-medication. A combination of up to four of the following drugs were used for premedication (number of occurrences): dexmedetomidine (221), methadone (194), butorphanol (58), acepromazine (32), buprenorphine (16), ketamine (five), alfaxalone (four), fentanyl (four) and midazolam (four). Dexmedetomidine was most commonly used in combination with methadone (160) or butorphanol (47) and less commonly with other drugs (13) or as the sole premedication drug (one). Therefore, only the use of butorphanol and methadone were included in the statistical analysis. Considering the smaller number of cases with acepromazine, buprenorphine, ketamine, alfaxalone, fentanyl and midazolam, those premedicants were not included in the statistical analysis. Propofol (191) or alfaxalone (84) were used for induction, occasionally combined with another agent [ketamine (five), midazolam (nine), fentanyl (one), lidocaine (one)]. Only the use of propofol or alfaxalone was included in the statistical analysis. Sevoflurane (209) or isoflurane (64) were used for maintenance of anaesthesia. Some dogs received omeprazole (five), maropitant (one) or both (three) or metoclopramide (one) during GA. These were given after induction of GA following an episode of regurgitation (five) or for a reason not reported on the anaesthesia record (four). One dog received maropitant and omeprazole before the start of MRI study. The detailed anaesthetic record of one dog was missing in our database.

Presence of gastroesophageal reflux

T2W sagittal series and 3D T2w series including the oesophagus were available in 273 dogs and 130 dogs respectively. In total, 140 dogs out of 275 [50.9%, 95% CI (44.99,56.81)] had evidence of fluid within the oesophagus in one or both of these sequences. The oesophageal fluid was visible in 121 dogs on T2w sagittal images and in 74 dogs on 3D T2w images. In 17 dogs out of 128 with both series available, oesophageal fluid was not identified on the initial T2w sagittal images and was present on the subsequent 3D T2w images. Of those 17 dogs, 16 had grade 1 reflux and one had grade 2 reflux. Grade 1 [68/140, 48.6%, 95% CI (42.69, 54.51)] and grade 2 [38/140, 27.1%, 95% CI (21.85, 32.35)] gastroesophageal reflux were most frequently encountered (Fig 1). Two dogs out of 10 with a grade 4 reflux had a prior diagnosis of megaoesophagus.

Sixty-four brachycephalic dogs [64/140, 45.7% of total population with reflux, 95% CI (39.81, 51.59); 64/112, 57.1% of brachycephalic dogs, 95% CI (51.25, 62.95)] and 76 non-brachycephalic dogs [76/140, 54.3% of total population with reflux, 95% CI (48.41, 60.19); 76/163, 46.6% of non-brachycephalic dogs, 95% CI (40.7, 52.5)] had gastroesophageal reflux detected on MRI (Fig 2).

Univariable associations between clinical variables and presence of reflux are presented in Table 2. The use of propofol and

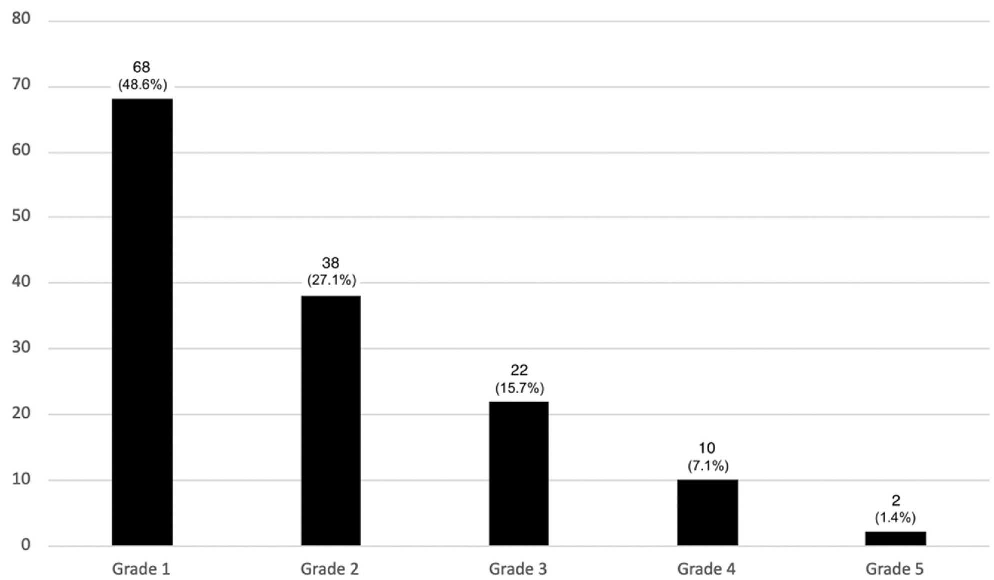


FIG 1. Distribution of dogs with gastroesophageal reflux using the five-grade classification system

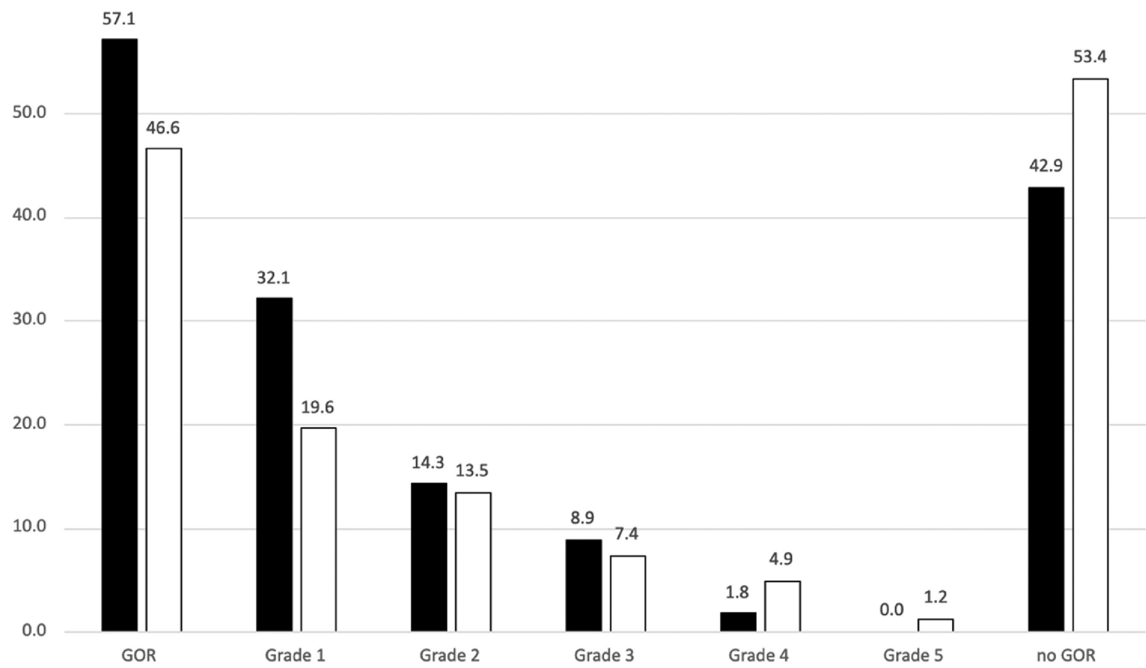


FIG 2. Percentage of gastroesophageal reflux in brachycephalic and non-brachycephalic dogs depending on the volume of oesophageal fluid (brachycephalic dogs in black; non-brachycephalic dogs in white)

sevoflurane showed a perfect linear relationship with the use of alfaxalone and isoflurane respectively as only two drugs were used for induction (propofol or alfaxalone) and maintenance (isoflurane or sevoflurane). Therefore, the variables propofol and sevoflurane were removed from the univariable logistic regressions. There was no significant association between the presence of reflux and any variable explored, including brachycephalic breed, age, sex, neuter status, bodyweight or BCS. As only one variable (brachycephalic breed) had a P-value<0.2, multivariable logistic regression analysis was not performed.

Based on these results, a post hoc power analysis suggested that a sample size of 294 dogs would be required to demonstrate a significant association between brachycephalic breed and the presence of gastroesophageal reflux, assuming a statistical power of 0.8, α=0.05, and odds ratio=1.92.

Presence of regurgitation

Eleven dogs [4.0%, 95% CI (1.68, 6.32)] presented at least one episode of regurgitation while anaesthetised. These dogs had a grade 2 (two), grade 3 (two), grade 4 (four) or grade 5 (one) gastroesophageal reflux at the time of MRI. No dogs with grade 1 reflux had regurgitation. Two dogs had no evidence of oesophageal fluid on MRI and presented regurgitation. Anaesthetic records show that both dogs regurgitated during recovery after their subsequent surgery (hemilaminectomy). These dogs had no reported megaoesophagus; one was a French bulldog and the other a Labrador retriever cross. Of the two dogs with known megaoesophagus both had a grade 4 gastroesophageal reflux, while only one had an episode of regurgitation. Ten of the 11 dogs who regurgitated received dexmedetomidine with one (nine) or two (one) additional drugs (methadone, fentanyl, buprenorphine or ketamine). One dog received acepromazine and buprenorphine. Univariable associations between clinical variables and the presence of regurgitation are presented in Table 3. No dogs with regurgitation received butorphanol; associations

Table 2. Univariable logistic regression to explore associations with gastroesophageal reflux in a cohort of 275 dogs

Variables	Odds ratios	Confidence interval 2.5%	97.5%	P value
Brachycephalic breed	1.92	0.99	3.82	0.057
Age	1.00	1.00	1.01	0.328
Sex	1.05	0.55	2.01	0.879
Neuter status	1.43	0.70	2.98	0.328
Bodyweight	1.02	0.99	1.05	0.271
Body condition score	0.56	0.06	5.50	0.620
Methadone as premedication	0.67	0.21	2.04	0.493
Butorphanol as premedication	0.71	0.20	2.45	0.593
Alfaxalone at induction	1.03	0.51	2.06	0.943
Isoflurane	0.99	0.46	2.15	0.984

Table 3. Univariable logistic regression to determine association with regurgitation in a cohort of 275 dogs

Variables	Odds ratios	Confidence interval 2.5%	97.5%	P value
Brachycephalic breed	1.21	0.23	6.18	0.816
Age	1.0	0.97	1.02	0.860
Sex	2.92	0.56	23.10	0.238
Neuter status	1.55	2.76	13.42	0.647
Bodyweight	1.04	0.97	1.10	0.216
Methadone as premedication	1.77	0.32	11.83	0.525
Alfaxalone at induction	0.58	0.07	3.02	0.546
Isoflurane	1.80	0.09	4.86	0.815
Grade of reflux	2.86	1.76	5.16	<0.001

with regurgitation were therefore not explored. Associations between BCS and the presence of regurgitation could not be assessed due to missing data. The grade of gastroesophageal reflux was significantly associated with the presence of regurgitation. No significant associations were detected between any other clinical variable and the presence of regurgitation. As only one variable (grade of gastroesophageal reflux) had a P-value <0.2, multivariable logistic regression analysis was not performed.

MRI report retrospective review

For the 140 dogs in which MRI evidence of gastroesophageal reflux was identified, this finding was documented in the contemporaneous imaging report in 19 cases (13.6%), 95% CI (9.55, 17.65). Relative frequency of contemporaneous reporting of reflux increased with grade; grade 1, 0/68 [0%, 95% CI (0, 0)]; grade 2, 3/38 [7.8%, 95% CI (4.63, 10.97)]; grade 3, 6/22 [27.3%, 95% CI (22.03, 32.57)]; grade 4, 8/10 [80.0%, 95% CI (75.27, 84.73)]; grade 5, 2/2 [100%, 95% CI (100, 100)]. The presence of gastroesophageal reflux was not documented in the contemporaneous report of any dog without MRI evidence of reflux.

DISCUSSION

The prevalence of gastroesophageal reflux in this cohort of anaesthetised dogs undergoing MRI of the thoracolumbar vertebral column was 50.9% [95% CI (44.99, 56.81)], which is within the range of previous reports (Zacuto *et al*. 2012, Savvas *et al*. 2016, Lambertini *et al*. 2020, Lotti *et al*. 2021). The prevalence of regurgitation in the present study was 4% [95% CI (1.68, 6.32)] which is also consistent with published literature (Galatos & Raptopoulos 1995a, Wilson *et al*. 2005, Lamata *et al*. 2012).

In a recent study including non-brachycephalic dogs undergoing CT and CT myelography for a thoracolumbar pathology (Benzimra *et al*. 2020) 19% of dogs had gastroesophageal reflux based on the presence of oesophageal fluid on the CT images. This is a much lower incidence than was identified in our study population. One explanation for the difference may be that our study comprised brachycephalic as well as non-brachycephalic dogs. Eivers *et al*. (2019) reported that conscious brachycephalic dogs more often show reflux than non-brachycephalic dogs when evaluated with videofluoroscopic swallowing studies. However, our data showed no significant association between the presence of reflux and brachycephalic conformation. This agrees with Shaver *et al*. (2017) who did not find any significant difference between the incidence of reflux in anaesthetised dogs affected by brachycephalic obstructive airway syndrome (BOAS) or not. Shaver *et al*. (2017) acknowledged that their population was probably too small (20 BOAS dogs and 20 control dogs) to show a significant difference. Based on a post hoc power analysis, they recommended to use at least 100 brachycephalic dogs and 100 control dogs. In the present study, 112 brachycephalic and 163 non-brachycephalic dogs were included, and there was not a significant association between the presence of gastroesophageal reflux and brachycephalic breed. A post hoc sample size calculation suggested that approximately 300 dogs would be needed to show a significant association. Further studies should be performed to evaluate whether brachycephalic dogs have a higher likelihood of developing gastroesophageal reflux under GA.

Several diagnostic imaging modalities have been used to detect gastroesophageal reflux in dogs. In conscious dogs, use of nuclear scintigraphy (Grobman *et al*. 2020) and videofluoroscopic swallowing studies (Eivers *et al*. 2019) have been described, with scintigraphy able to detect silent oesophageal and pharyngeal episodes of reflux in 100% of 12 clinically healthy dogs. As mentioned previously, CT has also been used in anaesthetised non-brachycephalic dogs (Benzimra *et al*. 2020) and allowed description of gas, fluid, or alimentary content within the caudal portion of the thoracic oesophagus. MRI provides greater contrast resolution compared to CT (Muller 2002). It is likely that our grade 1 reflux with only a narrow T2 hyperintense layer along the oesophageal lumen would have been overlooked on CT images. This may be another explanation to the difference in incidence of reflux in the present study compared to Benzimra *et al*. (2020).

In the present study, TSE T2w sequences were performed as the initial part of a protocol to assess the vertebral column, as is standard at our institution. With high-field MRI it is also feasible to perform heavily T2w sequences which give a "T2w-myelogram" appearance (Dennis 2011). These are referred to as Half-Fourier Acquisition Single-shot TSE (HASTE), Single-Shot Fast Spin Echo (SS-FSE) or Single-Shot TSE (SS-TSE) depending on the MRI manufacturer. Materials with a long T2 relaxation time show high signal intensity whereas all other materials have low signal intensity. HASTE sequence has been successfully used in the diagnosis of spinal arachnoid diverticulum (Seiler *et al*. 2012) and intervertebral disc disease in dogs (Mankin *et al*. 2012). In human medicine, HASTE has also been used in the investigation of the abdominal cavity (Semelka *et al*. 1995). Heavily T2w sequences of this type typically take only 20 to 30 seconds to complete compared with the 3 to 5 minutes needed for TSE T2w sequences. While it is unlikely that a heavily T2w sequence would entirely replace a standard TSE T2w sagittal sequence as part of a diagnostic protocol for thoracolumbar disease, this sequence could be valuable if a standard sagittal T2w sequence is not to be performed. Alternatively, it could be added at the end of a standard protocol to detect gastroesophageal reflux that may have occurred during the scan, before moving the patient.

The use of MRI will have detected any type of oesophageal fluid as it would appear T2 hyperintense regardless of the pH. This is different from the use of oesophageal pH monitoring, where the pH probe would record episodes of change of the pH in the oesophagus. Only the presence of acidic fluid ($\mathrm{pH} < 4$) is detectable with pH probe while mildly acidic ($4 < \mathrm{pH} < 7.5$) or basic ($\mathrm{pH} > 7.5$) fluid in the oesophagus is detectable with a multichannel intraluminal impedance monitoring (Zacuto *et al*. 2012, Lotti *et al*. 2021).

Our data indicates that MRI is able to demonstrate gastroesophageal reflux ranging from very small volumes of focal fluid accumulation to very large volumes of reflux causing marked dilation of the oesophagus. Again, this is different from the use of oesophageal pH monitoring systems. Information on the magnitude of gastroesophageal reflux can be recorded using a dual oesophageal pH meter where two sensors are present: one in the cervical part of the oesophagus (distal to the upper oesophageal sphincter) and one in the distal part of the oesophagus (proximal to the lower oesophageal sphincter) (Tarvin *et al.* 2016). While this can document the degree of cranial spread of refluxed material it is still not able to give a precise indication of the volume of oesophageal fluid. It is unknown if having only a T2 hyperintense oesophageal mucosal lining (grade 1) must truly reflect small volume reflux or indeed if such small volume has clinical relevance. It could be supposed that even small volumes of true reflux, if highly acidic, has the potential to cause damage to the oesophageal wall. Alternative explanations could be the presence of neutral mucin secreted by mucous and serous glands present in the submucosa and lamina propria mucosae of the canine oesophageal wall (Mahmood *et al.* 2017), presence of saliva or recent liquid ingestion before anaesthesia. The fact that this finding was not ever included in the original MRI report may indicate that it is presumed to be clinically incidental. In the present study, larger volume of reflux is associated with an increased risk of regurgitation. Therefore, early detection and quantification of the volume of reflux is helpful as it may allow the anaesthetist to take measures which may reduce patient risk (Wilson & Evans 2007, Allison *et al.* 2020). Future larger studies could use cohort of dogs suffering from thoracolumbar myelopathy and undergoing an MRI to further explore gastroesophageal reflux and associated risk factors (*e.g.* anaesthetic drugs).

No significant association was found between the presence of gastroesophageal reflux and the dogs' signalment (age, sex, neuter status), bodyweight or BCS. Conflicting evidence exists. The present findings agree with previous publications regarding the absence of correlation with age (Wilson *et al.* 2005, Benzimra *et al.* 2020), sex, reproductive status (Benzimra *et al.* 2020) and weight (Wilson *et al.* 2005). Conversely some authors indicated a significant association between the presence of reflux and heavier bodyweight (Shaver *et al.* 2017, Benzimra *et al.* 2020) or conformation, with large, deep-chested dogs being most frequently affected (Anagnostou *et al.* 2017). Our study did not include assessment of thoracic conformation, and this may form a basis for future research. In another study, geriatric dogs more frequently demonstrated reflux (Galatos & Raptopoulos 1995b).

In the present study, association between the presence of gastroesophageal reflux and several premedication drugs (acepromazine, buprenorphine, ketamine, alfaxalone, fentanyl and midazolam) could not be investigated due to the small number of occurrences. Our data did not reveal a significant association between the presence of gastroesophageal reflux and the use of common opioids (methadone or butorphanol), induction agents (alfaxalone or propofol) or maintenance anaesthetic gas (isoflurane or sevoflurane). This agrees with previously published literature about those two opioids (Lambertini *et al.* 2020) and inhalant agents (Wilson *et al.* 2006). However, dogs induced with propofol have been found to show higher incidence of reflux compared to dogs induced with thiopentone, presumably due to greater relaxation of the lower oesophageal sphincter with propofol (Raptopoulos & Galatos 1997). To the authors knowledge, no prior studies reporting the incidence of gastroesophageal reflux in dogs induced with alfaxalone have been published. No dogs in this study received medication before the anaesthetic that was intended to reduce the incidence of reflux. A small number of dogs received drugs of this nature during the anaesthetic but too few to draw any conclusions about their efficacy. The intravenous administration of a gastroprokinetic (cisapride 1 mg/kg) associated with an anti-acid (esomeprazole 1 mg/kg) is reported to minimise the risk of gastroesophageal reflux and regurgitation during anaesthesia (Zacuto *et al.* 2012). However, reflux and regurgitation can occur even with these drugs and oral anti-acid (omeprazole 1 mg/kg, in the evening prior and morning of GA) is recommended to neutralised reflux pH in patients considered at-risk (Grubb *et al.* 2020).

In the present study, time of gastroesophageal reflux in relation to time of induction was not precisely determined. At our institution, dogs are induced in the induction area and then transferred to the MRI room usually within the first 15 minutes of GA. Most of the included dogs [121/140, 86.4%, 95% CI (82.35, 90.45)] had oesophageal fluid detected on the T2w sagittal sequence, which is typically the first sequence performed in cases of thoracolumbar disease. Therefore, in this cohort of dogs, gastroesophageal reflux can be assumed to have occurred most frequently within the first 15 to 30 minutes of GA. Seventeen dogs without reflux identified in the initial sequence went on to have oesophageal fluid detected on the T2w 3D sequence which was performed later during the same MRI study (<1 hour), implying that reflux occurred between these two time points. Alternatively, given the majority of these dogs had only grade 1 reflux it may be that this small fluid volume could not be visualised on the T2w sagittal images suggesting a reduced sensitivity. Studies using pHmetry can record the precise timing of reflux (Anagnostou *et al.* 2017, Shaver *et al.* 2017, Lambertini *et al.* 2020), however the time of reflux is not always described in these manuscripts. Previous reports have shown that dogs commonly have an episode of reflux in the first 10 minutes post induction of anaesthesia (Shaver *et al.* 2017). However, dogs can also develop gastroesophageal reflux later with reported timing between 5- and 125-minutes post induction (Anagnostou *et al.* 2017, Shaver *et al.* 2017). As such, in the case of the 17 dogs with reflux only identified on the later sequence either of the suggested explanations remain possible. Additionally, dogs presenting an episode of reflux after the T2w/3D T2w sequence or during post-imaging procedures and recovery is possible and would have been missed in this study. This likely explains why two dogs without reflux on MR images subsequently developed regurgitation at the end of anaesthesia, as they could have had an episode of reflux later during their MRI (during other sequences) or during their surgery.

The consequences of gastroesophageal reflux can be severe (Wilson & Walshaw 2004). However, as we and others report the incidence of reflux is high. It is not clear how many patients who experience reflux go on to develop significant side effects (oesophageal stricture, oesophagitis and/or aspiration pneumonia) and as such it is difficult to make treatment recommendations. Our data suggests that higher volumes of reflux are more likely to be associated with regurgitation, which intuitively appears more likely to lead to aspiration. Observation of large volumes of fluid in the oesophagus should prompt the anaesthetist to check the oropharynx for debris and consider suctioning the oesophagus, followed by lavage with saline or tap water, and managing the patient with the risk of aspiration in mind (Grubb *et al*. 2020). Additionally, it is not obvious if the volume of refluxate has a bearing on the occurrence of oesophagitis and it is not clear if patients identified with a small volume of reflux should have any treatment.

Conversely to the point made above, this may explain the more frequent occurrence of large volume reflux mentioned in the MRI report in comparison with smaller volumes. A large volume of reflux would be subjectively considered as more clinically significant by the reporting radiologist. For future retrospective studies based on detection of gastroesophageal reflux during MRI, the authors recommend reviewing all MR images as most of reflux were not mentioned in the original imaging report.

The present study has several limitations. First, as mentioned previously, the presence of gastroesophageal reflux was only evaluated using MR images and no pH monitoring was used after MRI to detect reflux. Therefore, dogs with gastroesophageal reflux occurring after the MRI would have been missed in this study. Second, the pH of oesophageal fluid detected on MR images is unknown. It is also unknown if the consequences of gastroesophageal reflux of various pH are different. Third, although larger than previously published, the sample size of the present study was underpowered for some outcomes, and there was limited variability in anaesthetic protocols which made evaluating the effects of several drugs on reflux impossible. Fourth, retrospective assessment of presence or severity of BOAS in our patient population was beyond the scope of this study. Our results showed absence of significant difference in the prevalence of gastroesophageal reflux between brachycephalic and non-brachycephalic breeds, but we could not assess the difference in prevalence between individuals with or without clinical signs associated with BOAS. Future studies are needed to further assess the potential association of brachycephalic conformation and risk of regurgitation under anaesthesia. Finally, the retrospective nature of the study leads to some data loss and inconsistencies in how data was recorded.

The present study is purely descriptive and reports all the available data. All dogs undergoing MRI for a thoracolumbar pathology and for which T2w images were available for assessment of the oesophagus, were included. Within this data, dogs with known condition (megaoesophagus) or potentially high or low risk of gastroesophageal reflux were also included, giving a fair representation of the chance of gastroesophageal reflux in the population of dogs undergoing this imaging investigation at our institution, thereby reflecting a clinical scenario.

Dogs undergoing anaesthesia and MRI for a thoracolumbar pathology are at relatively high risk of having an episode of gastroesophageal reflux. The presence of reflux was not correlated with the breed, age, sex, neuter status, weight, or anaesthetic protocols. Although brachycephalic dogs did not have a significantly higher instance of reflux, it is likely that the present study was underpowered to demonstrate this, and larger studies should be performed to investigate this relationship further. Only the volume of gastroesophageal reflux was associated with the presence of regurgitation. Therefore, a T2 sagittal sequence or quicker single shot fast spin-echo (*e.g.* SS-FSE in Philips or HASTE in Siemens MRI scanner) could be run first in dogs undergoing an MRI, to inform the attending anaesthetist about presence and volume of reflux. This will allow them to manage the patient with due regard to the presence of this material and potentially reduce patient risk.

Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

Author contributions

Emilie Paran: Conceptualization (equal); data curation (lead); formal analysis (equal); methodology (equal); resources (lead); writing – original draft (equal); writing – review and editing (equal). **Alison Major:** Conceptualization (equal); formal analysis (equal); supervision (equal); validation (equal); writing – original draft (equal). **Christopher Warren-Smith:** Conceptualization (equal); formal analysis (equal); supervision (equal); writing – original draft (equal). **Melanie Jane Hezzell:** Formal analysis (equal); supervision (equal); writing – original draft (equal). **P.D MacFarlane:** Conceptualization (equal); formal analysis (equal); supervision (equal); writing – original draft (equal).

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APPENDIX

Distribution of the dogs within 47 different breeds

Breed	Number of dogs
French Bulldog	59
Crossbreed (known non brachycephalic breed)	42
Dachshund	20
Labrador retriever	15
Pug	14
Crossbreed (known brachycephalic breed)	10
cocker spaniel	8
Jack Russell terrier	8
Miniature dachshund	8
Shih Tzu	7
Staffordshire bull terrier	7
Border collie	6
Cavalier King Charles spaniel	6
Crossbreed (unknown if brachycephalic or not)	6
Golden retriever	6
German shepherd	5
Miniature poodle	4
Boxer	3
Whippet	3
Basset hound	2
Beagle	2
Border terrier	2
Chihuahua	2
Dalmatian	2
Patterdale terrier	2
Yorkshire terrier	2
Alaskan Malamute	1
American Cocker spaniel	1
Bernese Mountain Dog	1
British Bulldog	1
Bulldog	1
Coton De Tulear	1
Dogue De Bordeaux	1
English bull terrier	1
Flat-coated retriever	1
German wire-haired pointer	1
Hungarian Puli	1
Irish setter	1
Lakeland terrier	1
Lurcher	1
Miniature schnauzer	1
Papillon	1
Plummer terrier	1
Rottweiler	1
Sealyham terrier	1
Spanish water dog	1
Springer spaniel	1
St. Bernard	1
Terrier	1
Toy poodle	1