The ability of abdominal ultrasound to identify gastrointestinal foreign body characteristics prior to attempted laparoscopic-assisted gastrointestinal foreign body removal.

by

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Abstract

Objective: To determine the accuracy of abdominal ultrasound (AUS) in determining gastrointestinal foreign body obstruction (GIFB) type, location, size and shape; and to determine the success rate of laparoscopic-assisted GIFB removal (LGFBR) with GIFB of various sizes, shapes, and locations.

Study Design: Prospective clinical study.

Animals: Client-owned dogs (30) that underwent LGFBR (31).

Methods: Dogs with known or suspected GIFB obstruction underwent a preoperative AUS performed by a board-certified radiologist. GIFB type, location within the gastrointestinal tract, size, and shape were recorded, as well as the presence or absence of peritoneal fluid, pneumoperitoneum, or gastrointestinal mural changes. LGFBR was then attempted in all patients. Surgical findings were compared to preoperative ultrasound findings.

Results: AUS was able to determine the type, location, and shape of GIFB with accuracies of 96.8%, 74.2%, and 93.5% respectively. AUS had moderate accuracy (80%), at identifying the presence of adhesions, and was inaccurate at determining GIFB size. LGFBR was successful in 16/30 (53.3%) of cases, including 2/7 (28.6%) of linear, 14/23 (60.9%) non-linear, and 1/1 (100%) gastric foreign bodies, but was not successful for GIFB near the caudal duodenal flexure (0/2, 0%).

Conclusion: Preoperative AUS is a useful diagnostic to aid in determining the suitability of a patient to undergo LGFBR. Linear and gastric foreign bodies were not contraindications to LGFBR, however GIFB located at the caudal duodenal flexure were.

Clinical Significance: Based on our study, AUS would be recommended prior to attempting LGFBR. Further studies are recommended to investigate contraindications to LGFBR.

Table of Contents

List of Figures ... v

List of Abbreviations ... vi

Acknowledgements ... vii

Chapter 1 - Gastrointestinal Foreign Body Obstruction Literature Review ... 1

- Clinical Presentation and Pathophysiology ... 1
- Foreign Body Types ... 3
- Diagnosis, Treatment, and Complications ... 4

Chapter 2 - Minimally Invasive Surgery Literature Review ... 6

- Laparoscopic and Laparoscopic-Assisted Surgery ... 6
- Minimally Invasive Gastrointestinal Surgery ... 8

Chapter 3 - Gastrointestinal Ultrasound Literature Review ... 10

- Establishing Normal Gastrointestinal Sonographic Features ... 10
- Ultrasonography of Gastrointestinal Diseases ... 12
- Contrast-Enhanced Ultrasonography ... 16

Literature Review References ... 17

Chapter 4 - Evaluating the use of abdominal ultrasound to identify gastrointestinal foreign body characteristics prior to attempted laparoscopic-assisted gastrointestinal foreign body removal. ... 31

- Acknowledgements ... 33
- Abstract ... 34
- Introduction ... 36
- Materials and Methods ... 38
- Results ... 42
- Discussion ... 47

References ... 53

List of Figures

Figure 1. Graph depicting the relationship between surgical foreign body measurements on the y-axis and ultrasound foreign body measurements on the x-axis. 58

Figure 2. Box and whisker plot of median foreign body size in laparoscopic-assisted and open laparotomy groups. 59

Figure 3. Images from a patient with a non-linear jejunal foreign body successfully removed with LGFBR. Ultrasound image at the level of the foreign body (A), identification of the jejunal segment with the foreign body during laparoscopic explore (B), exteriorization of the jejunal segment containing the foreign body (C), and foreign body following removal from the jejunum (D)... 60

List of Abbreviations

AUS – Abdominal ultrasound

BCS - Body condition score

CT – Computed tomography

GI – Gastrointestinal

GIFB – Gastrointestinal foreign body

GFBO – Gastrointestinal foreign body obstruction

LAIS – Laparoscopic-assisted intestinal surgery

LFB – Linear foreign body

LGFBR - Laparoscopic-assisted GIFB removal

MIS – Minimally invasive surgery

MODS – Multiorgan dysfunction syndrome

NLFB – Non-linear foreign body

OL - Open laparotomy

SIRS – Systemic inflammatory response syndrome

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Chapter 1 - Gastrointestinal Foreign Body Obstruction Literature Review

Clinical Presentation and Pathophysiology

Gastrointestinal (GI) foreign body obstructions (GFBO) are one of the most common indications for laparotomy in dogs due to their large esophageal size allowing dogs to swallow objects much larger than can be passed safely through the intestines.[1] Dogs with GFBO tend to be young, large breed dogs with a male sex predilection.[2-4] Clinical signs associated with GFBO may vary based on the location of the obstruction within the GI tract, but commonly include vomiting, inappetence, lethargy, and abdominal discomfort.[2] Physical exam findings of dogs with GFBO can range from mild dehydration to signs of shock. In some cases, the foreign body can be detected on abdominal palpation as a firm structure within the small intestines.[5]

GFBO leads to fluid and electrolyte imbalances and disruption in acid-base status. The most common imbalance seen with GFBO is hypochloremic, hypokalemic metabolic alkalosis, and can be seen with both proximal and distal obstructions.[6] The healthy GI tract is responsible for the secretion and absorption of large volumes of water and electrolytes. The proximal small intestines, primarily the duodenum, are responsible for secretion of fluid rich in sodium and bicarbonate to aid in neutralizing hydrochloric acid secreted by the stomach. The mid- to distal small intestines, jejunum and ileum, have a net absorption of fluid, and are responsible for approximately 75% of the total intestinal fluid absorption, with the colon contributing only about 1-4%.[7] In dogs with GFBO, the parasympathetic nervous system is activated by the stretch of the small intestines leading to secretion of electrolytes and water into the intestinal lumen.[8] The obstruction prevents this secreted fluid and ingesta from moving aborally, thus leading to progressive dilation of the intestinal lumen proximally. This sequestration of fluid and electrolytes in the intestinal lumen, coupled with vomiting and reduced oral intake of food and water leads to dehydration and hypovolemic shock. Hypotension and subsequent decrease in cardiac output reduces perfusion to all organs causing activation of the sympathetic nervous system.

The sympathetic nervous system helps to maintain tissue perfusion and may also override the parasympathetic nervous system leading to a decrease in intestinal secretions. While this is beneficial in reducing intestinal dilation and preventing exacerbation of hypovolemia, it is detrimental to maintenance of intestinal mucosal integrity.[8] Decreased secretion of alkaline mucus exposes the mucosa to harmful gastric acid that disrupts mucosal tight junctions that in the healthy intestine are responsible for preventing bacterial penetration. The nutrient rich fluid sequestered in the intestinal lumen serves as the ideal medium for enteric bacterial growth and proliferation. The combination of the disruption of mucosal barriers and bacterial overgrowth increases the risk for bacterial translocation and subsequent systemic inflammation.

GFBO results in supraphysiologic intraluminal pressures orad to the obstruction, and even greater pressure at the level of the foreign body.[9] The increase in intraluminal pressure causes disruption in the microvascular perfusion to the intestinal segment and ischemic injury to the intestinal wall occurs. This injury will progress to full thickness necrosis, and subsequent perforation if not addressed. Leakage of intestinal luminal contents leads to the exposure of the peritoneal cavity to inflammatory mediators, bacteria, and toxins. The resultant septic peritonitis leads to systemic inflammatory response syndrome (SIRS) and ultimately multiorgan dysfunction.[2,9]

Foreign Body Types

There are two types of foreign bodies: non-linear and linear. Linear foreign bodies (LFB) have a component that lodges orad in the GI tract (most commonly in the pyloric outflow tract in dogs) and then a linear component that extends into the small intestines. This aborad component tracks within the small intestines and leads to varying degrees of intestinal plication. In some cases, the linear component of the foreign body can become embedded into the intestinal wall and lead to perforation. LFB are more likely to cause partial obstruction when compared to non-linear foreign bodies (NLFB). NLFB are discrete foreign bodies that are contained within the stomach or lodge within the small intestines. When excluding gastric foreign bodies that are endoscopically removed, the most common location for NLFB is the jejunum, ranging from 48% to 63% of cases.[2,10] A NLFB can cause a partial or complete obstruction depending on the type of material and its shape (i.e. if it has a lumen).

Diagnosis, Treatment, and Complications

Following suspicion of a GFBO due to a dog's clinical signs and physical exam findings, diagnosis is obtained through abdominal imaging. The two imaging modalities most used are radiography and ultrasonography. Radiography can diagnose GFBO through identification of a radiopaque foreign body or through identification of segmental intestinal dilation. The success of abdominal radiography to diagnose GFBO ranges from 56% to 70%.[11-12] Ultrasonographic signs of GFBO include abnormal motility, GI dilation, and identification of a foreign body represented by shadowing luminal material.[12] Compared to radiography, ultrasonography is successful in diagnosis of GFBO in 88.2% to 97% of cases.[12-15] Partial obstructions may be more challenging to diagnose as they tend to result in less severe clinical signs, and there may not be characteristic intestinal dilation on abdominal radiography or ultrasonography.

Once there is a confirmed GFBO diagnosis, treatment involves either conservative management, endoscopic removal, or surgical intervention. Conservative management entails intravenous fluid therapy, GI support, and anti-nausea medications. Conservative management can be successful in up to 47% of cases.[16] The success of conservative management may be significantly affected by the type of foreign body, as LFBs are less likely to resolve without surgical intervention.[16] Endoscopic foreign body removal is feasible for NLFB contained within the esophagus, stomach, or proximal duodenum.[3,17] Endoscopic removal is minimally invasive, faster than surgical removal, has shorter hospitalization times, and avoids an incision into the GI tract.[18] The absence of GI incisions removes the risk for dehiscence and secondary septic peritonitis.

Cases where the foreign body has moved into the small intestines beyond the proximal duodenum and conservative management has failed are addressed with surgical intervention. Traditionally this involves an exploratory laparotomy to identify the GFBO and to remove it through an enterotomy or an enterectomy.[5,19-20] In some cases, the foreign body can be safely milked back into the stomach and removed through a gastrotomy. More recently, laparoscopic-assisted foreign body removal (LGFBR) has been described.[21-22] This is a minimally invasive alternative to exploratory laparotomy that has been shown to reduce overall patient morbidity.[23-24] However, it does not eliminate a GI incision.

The complication rates for the different procedures vary and can significantly affect the overall patient outcome and financial cost to the owner. The dehiscence rate for enterotomies is approximately 2%,[25] which contrasts with hand-sutured enterectomies (13-16%) and stapled enterectomies (5-11%).[26-28] Dehiscence of gastrotomies is uncommon and a recent report showed no documented gastrotomy dehiscence in 302 cases of dogs and cats following gastric foreign body removal, however two cases of post-operative septic peritonitis were euthanized and therefore gastrotomy dehiscence could not be ruled out. Both of these patients also had an intestinal resection and anastomosis performed and this may have been the more likely site of dehiscence.[29] Preoperative risk factors for dehiscence include low serum albumin levels, preoperative septic peritonitis, intraoperative hypotension, American Society of Anesthesiologist status greater than 3, a left shift, and cachexia.[19-20,30-32] The overall survival rate for dogs with GFBO that underwent surgical intervention ranges from 86% to 98%.[2,10,33-34]

Chapter 2 - Minimally Invasive Surgery Literature Review

Laparoscopic and Laparoscopic-Assisted Surgery

Minimally invasive surgery (MIS) in veterinary medicine originated in the late 1980s through research into laparoscopic sterilization in dogs and cats.[35] Several laparoscopic and laparoscopic-assisted techniques have since been developed, including laparoscopic-assisted ovariohysterectomy,[36-38] laparoscopic-assisted intestinal surgery (LAIS),[21-22,39] laparoscopic ovariectomy,[24,38,40-42] cryptorchiectomy,[43] gastropexy,[44-45] cholecystectomy,[46-47] adrenalectomy,[48] ureteronephrectomy,[49] and cystopexy.[50] Additionally, laparoscopy has been used to facilitate organ biopsy.[51-53] The emergence of MIS in veterinary medicine corresponded with the increased use of these techniques in humans.

Investigation into the benefits of MIS has been a point of focus in human medicine and led to animal models for laparoscopic cholecystectomy and colorectal surgery.[46,53-55] These studies showed faster return to GI motility[46,53,55] and reduced adhesion formation.[54] The comparison between open ovariohysterectomy and laparoscopic ovariectomy has shown lower pain scores, decreased cortisol and glucose levels compared to baseline, and a faster return to function in the laparoscopic groups.[24,37] A faster return to function was also demonstrated in comparison between open and laparoscopic gastropexy using intracorporeal suturing.[52] In a retrospective study of 165 MIS procedures and 363 open laparotomies, the incidence of surgical site infection was significantly less in the MIS group (1.8%) when compared to the open group (5.5%).[56] These benefits of MIS have led to further adoption of these techniques throughout veterinary surgery, and research is ongoing into new and improved techniques.

The disadvantages of MIS include the restricted degrees of freedom of surgical instruments, challenges in triangulation, loss of tactile sensation, and a steep learning curve.[24,49,57] These can be overcome with careful practice and further development of articulating instruments.

For MIS, both longer surgical times[24] and no difference in surgical times[52] have been documented. It is difficult to determine the true effect of MIS on surgical times as this is not always reported in veterinary literature and, when it is reported, likely includes a portion of a surgeon's learning curve.

Minimally Invasive Gastrointestinal Surgery

There has been a recent push to investigate minimally invasive GI surgery in dogs as GI disease is common in this species. A study by Schmid et. al. in 2024 reported a prevalence of 30% for GI disease in a population of 43,517 dogs presented over a three-year period.[58] The introduction of LAIS has allowed surgeons to not only perform intestinal biopsies minimally invasively,[38,59] but more recently to remove obstructive intestinal foreign bodies.[21,22] For gastric foreign bodies, a single report of laparoscopic gastric foreign body removal using a specimen bag and linear stapling device for closure has been reported.[60] However, further investigation into fully laparoscopic GI surgery in dogs has not occurred. LGFBR has been reported in a study by Gibson et. al.[61] in 2020 where successful removal was performed in four dogs.

A study by Gower et. al. [39] in 2010 demonstrated that successful extracorporeal evaluation of the small intestines is feasible, and can facilitate intestinal biopsy and mass removal. Further, Case et. al. [21] in 2013 successfully removed three intestinal foreign bodies using LGFBR. Following this study, there was concern that a laparoscopic-assisted exploratory may be insufficient to diagnose all GFBO, especially regarding gastric foreign bodies. Therefore in 2017, Barry et. al.[62] compared the exploratory findings between LGFBR and open exploratory laparotomies for GFBO and found that there was no difference in identification of foreign bodies within the GI tract between the two methods. This increased the confidence that LAIS is a viable option for GFBO. A larger study was performed by Otomo et. al.[22] in 2018 investigating 28 dogs with intestinal foreign body obstruction. Thirteen of these cases underwent LGFBR and were successful in 77% of cases. In both the Case[21] and Otomo[22] studies, all the foreign body obstructions successfully removed minimally invasively were mostly located within the jejunum.

There are no established criteria for patient selection of LGFBR. Potential contraindications have been suggested; including preoperative septic peritonitis, foreign body size greater than 5 cm, foreign bodies located at the caudal duodenal flexure near the duodenocolic ligament, foreign bodies located near the ileocecocolic junction, or the presence of a gastric or linear foreign body.[21-22,39,62] Additionally, there are limited reports of attempted LGFBR located within the duodenum or ileum, only in one report, all requiring conversion to open laparotomy.[22]

Chapter 3 - Gastrointestinal Ultrasound Literature Review

Establishing Normal Gastrointestinal Sonographic Features

Prior to the use of ultrasonography, the GI tract was predominantly evaluated using a combination of plain and contrast radiography. While many radiographic techniques had been developed to better evaluate the GI tract, significant limitations persisted. These techniques could be time-consuming, requiring multiple exposures, and the images could be difficult to interpret. The intestinal wall could also be challenging to assess.[63] Ultrasonography allows for evaluation of parenchymal changes in solid organs, the intestinal wall, and assessment of the hepatobiliary system.

Early investigation into the normal GI tract began in the late 1980s and early 1990s through descriptions of features such as identification of the intestinal wall layers, thickness of the walls, and determining the degree of peristalsis.[64-65] Ultrasonographic identification of five GI layers was established: the luminal mucosal interface, mucosa, submucosa, muscularis propria, and serosa.[64-65] The normal canine duodenal wall is reported to range from 5-6 mm thick[66-67] and the jejunal wall is 2-4.7 mm thick.[64,67] There is a positive correlation between intestinal wall thickness and body weight of the dog.[67] Further, mucosal thickness of the duodenum and jejunum has been measured and ranges from 2.4-2.8 mm and 1.8-2.2 mm respectively, again correlating with the body weight of the dog.[68] Peristalsis can be evaluated in real-time, and in a normal canine occurs at a rate of 4 to 5 contractions per minute.[64] Upon systematic evaluation of the GI tract, specific regions can be identified and evaluated due to their consistent anatomic locations including the stomach, pyloric outflow tract,[69] descending duodenum, ileocecocolic junction,[70] and colon.[63] The jejunum can be more challenging to systematically evaluate due to its mobility within the abdomen.

The effect of fasting on ultrasonographic evaluation of the abdomen has been investigated and it was determined that fasting is not necessary prior to abdominal ultrasound (AUS) as it did not affect the ability to evaluate specific organs, including the GI tract.[71] While fasting did not influence the ability to evaluate the abdominal organs, it can decrease GI contraction rates and therefore may affect the ability to accurately evaluate the rate of peristaltic contractions.[72]

Ultrasonography of Gastrointestinal Diseases

In addition to the establishment of normal ultrasonographic features of the canine GI tract, the ultrasonographic features of several diseases were subsequently described, including gastric ulceration,[73] intestinal intussusception,[74-75] GI perforation,[76-77] inflammatory diseases,[78-80] intestinal neoplasia,[79] pancreatitis,[81] intestinal lipogranulomatous lymphangitis,[82] and GI pneumatosis.[83]

Along with descriptions of various GI diseases, ultrasound has been used for the assessment of adhesions following gastropexy. It was demonstrated that ultrasound was an efficient and reliable diagnostic to identify and evaluate gastropexy adhesions at different time points following surgery.[84-85]

AUS has become a more commonly used modality, in addition to abdominal radiography, for the evaluation of GI obstructions secondary to foreign body ingestion. In 1992, Tidwell and Pennick described non-linear gastrointestinal foreign bodies in 14 dogs that were evaluated using ultrasound when radiographs were inconclusive.[86] This included a description of the anatomic location of the foreign body, as well as variable acoustic patterns at the level of the foreign body dependent on the individual foreign body characteristics. The first ultrasonographic description of gastroduodenal linear foreign bodies was in 2003 by Hoffman et. al.,[87] describing a tortuous path to the descending duodenum, “hair-pin turns” of the jejunum, and a hyperechoic linear structure within the duodenal lumen traced orad to the pylorus.[87]

A 2011 study by Garcia et. al.[13] reported that when performed and evaluated in real-time by a radiologist or radiology resident, AUS has a reported sensitivity and specificity for identifying GFBO of 100% and 95.8%, respectively, and a positive predictive value and negative predictive value of 87.5% and 100%, respectively.[13] In a cohort of 38 dogs and cats, of which 17 had confirmed GFBO, AUS was effective in differentiating obstructed from non-obstructed cases 88.2% of the time.[14] AUS can also be useful in a tele-ultrasound setting where accuracy of GFBO diagnosis ranged from 78.9% to 87.8% depending on the experience level of the image interpreter (ranging from first-year radiology resident to boarded radiologist with 22 years' experience).[15]

Intestinal segmental dilation is a primary feature used for the diagnosis of GFBO for both abdominal radiography and ultrasonography. A commonly used metric from radiography is the ratio of intestinal lumen diameter to the body of L5, in which dogs with a ratio less than 1.3 are unlikely to be mechanically obstructed, and those with a ratio greater than 1.9 are very likely to be mechanically obstructed.[88] This is refuted by a study in 2013 by Ciasca et. al.[89] that showed no increased accuracy using this ratio. While no such ratio exists for abdominal ultrasonography, segmental intestinal dilation is a significant factor in diagnosis of GFBO.

When compared to radiography, ultrasonography is more successful at identifying the GFBO and can identify additional important patient information such as intestinal mural changes, adhesions, and extra-GI characteristics (i.e. lymphadenopathy).[11-12] In comparison to abdominal computed tomography (CT), ultrasound's success at identifying GFBO was slightly lower than CT, however this was not statistically significant.[90-91] Additionally, ultrasound can provide improved detail on intestinal mural changes when compared to CT, and therefore in some cases may be preferred. In cases of septic peritonitis, where 70.2% were GI in origin, AUS was able to correctly identify the causative lesion in 67% of cases, including the correct anatomic location within the GI tract in 76% of cases.[92] In a study with 19 dogs presenting for an acute abdomen, ultrasound's diagnostic accuracy was 94%.[93] Despite being a useful tool in identifying GFBO, ultrasound can reveal misleading results and has been reported to both diagnose functional ileus as a GFBO[92,94-95] and fail to identify a confirmed GFBO.[14,91] In addition to misdiagnosis, ultrasound may miss important preoperative lesions such as GI perforation or rupture, even up to 25% of cases.[96] Even with these limitations to ultrasonography, it remains a critical component in diagnosis of GI diseases.

Following any surgical incision into the GI tract, either an enterotomy or enterectomy, there is a concern for dehiscence and subsequent septic peritonitis. AUShas been investigated as a potential imaging modality for evaluating these postoperative sites. In a study in 2008 by Matthews et. al.,[97] twenty dogs with twenty-five GI incision sites were evaluated. Ultrasound was successful in identifying and evaluating 57% of the enterotomy sites and 100% of the enterectomy sites. Specifically, the intestinal wall layering was evaluated, and revealed absent wall layering in 96% of cases after 1 day, and this wall layering remained altered or absent for 20 days postoperatively. In addition to intestinal wall layering, peritoneal effusion and pneumoperitoneum were reported to resolve in 80% of cases by day 10.[97] A few years later in 2010, Mareschal and colleagues[98] sonographically evaluated twenty-eight dogs with postoperative enterectomy sites at least six months after surgery, and up to seven years postoperatively. The authors successfully identified 78.6% of these sites. Altered or absent wall layering was present in all cases with hyperechoic foci proposed to be fibrosis or suture material was noted in 63.6% of sites. Intraluminal gas was a common finding in 81.8% of cases, and in approximately half of the cases a focal deviation of the intestinal course was noted.[98]

A more recent study in 2024 by Rafael and colleagues[99] evaluated early postoperative enterotomies and enterectomies in 114 cases to detect postoperative dehiscence. Ultrasound was found to be a sensitive diagnostic for detecting dehiscence with a success rate of 100% for confirmed dehiscence. The specificity could not be calculated as one case of sonographically suspected dehiscence did not undergo a second surgery and the patient subsequently recovered without incident. Further, no cases of sonographically absent dehiscence had clinical evidence of dehiscence during the postoperative period.[99] These studies show that ultrasound can be an important diagnostic tool for evaluating postoperative GI incisions, and for the early detection of postoperative dehiscence.

Contrast-Enhanced Ultrasonography

More recent literature has focused on contrast-enhanced ultrasonography for improved visualization of the intestinal lumen as well as intestinal perfusion. A technique for the evaluation of jejunal perfusion was developed by Jiménez and colleagues[100] in 2011 through a midline celiotomy and injection of an ultrasound contrast medium intravenously in nine healthy dogs. Several studies have documented the use of non-invasive contrast-enhanced ultrasonography with injections of microbubble contrast medium to successfully evaluate duodenal perfusion.[101-103] Mucosal perfusion to assess intestinal inflammation was successfully evaluated in 2020 by Salavati and colleagues also through the use of microbubble contrast medium.[104] For improved colonic visualization, both agitated saline[105] and water[106] have been used as contrast agents and have improved evaluation of the colonic lumen and wall layers.

A study performed in 2020 by Kang and colleagues[107] evaluated a modified contrast medium (carboxymethycellulose combined with iohexol) for the assessment of the small intestine radiographically and sonographically. The contrast medium did not interfere with sonographic evaluation of the small intestine and subjectively may have improved visualization of the far-field wall.

Overall, the use of AUS for GI evaluation, both pre- and postoperatively, has greatly increased over the last 30 years, and it is now a part of routine diagnostic assessments for a variety of GI diseases ranging from inflammatory bowel syndrome to GFBO.

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Chapter 4 - Evaluating the use of abdominal ultrasound to identify gastrointestinal foreign body characteristics prior to attempted laparoscopic-assisted gastrointestinal foreign body removal.

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"Evaluating the use of abdominal ultrasound to identify gastrointestinal foreign body characteristics prior to attempted laparoscopic-assisted gastrointestinal foreign body removal."

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Abstract

Objective: To determine the accuracy of abdominal ultrasound (AUS) in determining gastrointestinal foreign body (GIFB) type, location, size and shape; and to determine the success rate of laparoscopic-assisted GIFB removal (LGFBR) with GIFB of various sizes, shapes, and locations.

Study Design: Prospective clinical study.

Animals: Client-owned dogs (30) that underwent LGFBR (31).

Methods: Dogs with known or suspected GIFB obstruction underwent a preoperative AUS performed by a board-certified radiologist. GIFB type, location within the gastrointestinal tract, size, and shape were recorded, as well as the presence or absence of peritoneal fluid, pneumoperitoneum, or gastrointestinal mural changes. LGFBR was then attempted in all patients. Surgical findings were compared to preoperative ultrasound findings.

Results: AUS was able to determine the type, location, and shape of GIFB with accuracies of 96.8%, 74.2%, and 93.5% respectively. AUS had moderate accuracy (80%), at identifying the presence of adhesions, and underestimated GIFB size. LGFBR was successful in 16/30 (53.3%) of cases, including 2/7 (28.6%) of linear, 14/23 (60.9%) non-linear, and 1/1 (100%) gastric foreign bodies, but was not successful for GIFB near the caudal duodenal flexure (0/2, 0%).

Conclusion: Preoperative AUS is a useful diagnostic to aid in determining the suitability of a patient to undergo LGFBR. Linear and gastric foreign bodies were not contraindications to LGFBR. GIFB located at the caudal duodenal flexure were not able to be successfully removed by LGFBR.

Clinical Significance: Based on our study, AUS was able to identify several characteristics which may predict the success of LGFBR, and AUS would be recommended prior to attempting LGFBR. Further studies are recommended to investigate contraindications to LGFBR.

Introduction

Small intestinal obstructive foreign bodies are one of the most common indications for laparotomy in dogs due to their large esophageal size allowing dogs to swallow objects much larger than can be passed safely through the intestines.[1] Minimally invasive techniques for foreign body retrieval have significant benefits to the dog, as the smaller incisions lead to reduced post-operative morbidity and a faster return to function.[2-4] Additionally, several experimental animal studies have documented a faster return to gastrointestinal motility[5-10] and reduced adhesion formation[11-12] following laparoscopic gastrointestinal and hepatobiliary surgery.

Several studies in dogs have described the use of laparoscopic-assisted GIFB removal (LGFBR) [13-15], as well as laparoscopic[16] or laparoscopic-assisted gastrointestinal exploratory surgery.[17] Many of these reports have suggested contraindications to laparoscopic-assisted intestinal surgery (LAIS): preoperative septic peritonitis, foreign bodies located at the caudal duodenal flexure near the duodenocolic ligament, foreign bodies located near the ileocecocolic junction, or the presence of a gastric or linear foreign body; however, there are no studies investigating whether these contraindications actually lead to lower surgical success if LGFBR is performed. Additionally, there is no published data in veterinary medicine for a cut-off of maximum lesion size for LAIS. Case et. al. in 2013[14] suggested a potential cutoff of less than 5 cm based on guidelines set within the human literature suggesting LAIS for small intestinal resections should be limited to lesion diameters less than 5 cm.[18]

During LAIS, there is the potential need to convert to an open laparotomy. This need can be reduced through careful patient selection. Both abdominal radiography and ultrasonography have been demonstrated to be accurate for diagnosing small intestinal obstruction in dogs; however, ultrasound had greater accuracy and provides greater diagnostic confidence.[19-20] Ultrasonography has the potential to provide greater detail on foreign body and gastrointestinal characteristics within individual dogs, such as evaluation of gastrointestinal wall layers[21-22], extra-gastrointestinal organ evaluation[23], and determination of the anatomic location of the foreign body.[24] There have been no studies in veterinary medicine demonstrating how accurate abdominal ultrasonography is at determining the location, type, shape, and size of a GIFB. This information could prove invaluable in patient selection for LGFBR, reducing the incidence of conversion to open laparotomy.

The objectives of this study were to assess the accuracy of abdominal ultrasonography in describing foreign body characteristics, as well as to determine the success rate of LGFBR for removing gastrointestinal foreign bodies of various sizes, shapes, and in various locations.

Materials and Methods

Study Design

In this prospective clinical study, thirty sequential client-owned dogs weighing greater than 15 kilograms with a confirmed or suspected diagnosis of an intestinal foreign body obstruction were enrolled. Dogs with confirmed or suspected preoperative abdominal sepsis were excluded. All dogs underwent an AUS followed by attempted LGFBR.

Data collected for each dog included sex, age, breed, weight (kg), body condition score (BCS), clinical signs and duration.

Ultrasound Image Acquisition and Interpretation

Abdominal ultrasonography was performed immediately pre-operatively by one of four board certified radiologists, including two American College of Veterinary Radiology diplomats and two European College of Veterinary Diagnostic Imaging diplomats.

Ultrasonography was performed using two different ultrasound machines (Aplio i500 or Aplio i800, Canon Medical Systems USA, Tustin, CA). A 7-10 MHz small curvilinear transducer was most commonly used, with a large curvilinear (3-8 MHz) and linear (10-14 MHz) transducers used when deemed necessary by the radiologist. Images were optimized at the radiologist's discretion, and all measurements were made in millimeters, using the ultrasound machine.

The imaging radiologist recorded the foreign body type (linear versus non-linear), shape (ovoid, fusiform or rectangular), length (measurement of the foreign body parallel to the intestinal lumen at its longest point), width (measurement of the foreign body perpendicular to the intestinal lumen at its widest point), and location within the gastrointestinal tract. The presence or absence of adhesions, peritoneal fluid, and pneumoperitoneum were recorded. Additionally, small intestinal mural changes were described if present.

Laparoscopic-assisted foreign body removal

Anesthetized dogs were placed in dorsal recumbency with the ventral abdomen aseptically prepared. An approximately 10 mm incision was made on midline just cranial to the umbilicus. Dissection continued down to the linea alba, and a single stay suture was placed as the caudal aspect of the incision through the linea alba. A stab incision was made through the linea alba into the peritoneal cavity. A 5.5 mm laparoscopic cannula with a blunt trocar (Stryker, Kalamazoo, MI) was inserted into the abdomen. The peritoneal cavity was insufflated to a pressure of 8-10 mmHg using CO_2 gas (Stryker, Kalamazoo, MI). A 5 mm, 30-degree laparoscope (Stryker, Kalamazoo, MI) was inserted for visualization. An instrument port was placed with a 5.5 mm cannula and sharp trocar on midline cranial to the first port under direct visualization. This port was placed within 50 mm of the first. A blunt palpation probe (Stryker, Kalamazoo, MI) and laparoscopic Babcock forceps (Stryker, Kalamazoo, MI) were used to facilitate visualization of abdominal organs and used to palpate the stomach. The dog was rotated 45^o to the left to facilitate visualization of the entirety of the descending duodenum to the level of the caudal duodenal flexure in all dogs. Following the laparoscopic exploratory, a portion of grossly healthy small intestine was grasped with the laparoscopic Babcock forceps and held within the abdomen. The laparoscope and first laparoscopic cannula were removed, and abdominal insufflation was lost. The incision was then extended to connect the two ports, while simultaneously removing the instrument cannula, laparoscopic Babcock forceps, and grasped intestinal segment. An Alexis wound retractor (Applied Medical, Rancho Santa Margarita, CA) was placed into the incision, and the intestinal segment was passed through the retractor. Moistened laparotomy sponges were placed surrounding the incision. The small intestine was traced extracorporeally orad and aborad. Following extracorporeal evaluation, the affected intestinal segment was exteriorized. An enterotomy or resection and anastomosis was performed as clinically indicated. The intestinal segment was returned to the abdomen. The length (mm), width (mm), and location of the foreign body was recorded. The shape and type of foreign body were recorded with the same descriptions used during the AUS examination. Additionally, the presence or absence of adhesions and peritoneal effusion was recorded. After the first case, the ability to successfully exteriorize the ileocecocolic junction was recorded. The Alexis wound retractor was removed, and the incision was closed in routine fashion. The surgery was converted to an open laparotomy if the foreign body was unable to be exteriorized, if there was concern for intestinal plication to lead to perforation, if adhesions impeded the ability to perform a complete laparoscopic abdominal exploratory, or if there was an equipment malfunction. At that time, the reason for conversion and time of conversion was recorded.

Post-Operative Outcomes

Short-term (up to 14 days postoperatively) and long-term (after 14 days postoperatively) follow-up data were collected from owners or the primary care veterinarian via telephone interview by the primary surgeon and recorded, and the follow-up time was reported (days). Data on incisional healing was recorded as healed appropriately, seroma formation, or surgical site infection. Surgical site infection was defined as the presence of one or more of the following: incisional dehiscence, purulent incisional discharge, erythema with associated swelling of the incision site, or a documented positive culture. Long-term follow up determined whether the dog was deceased and if the cause of death was related or unrelated to the foreign body ingestion and surgery.

Statistical Analysis

All statistics were performed using Microsoft Excel or with the aid of Julius AI. A chi squared test for the binomial variables (foreign body type, location, and shape, adhesions and peritoneal fluid, and BCS), a Mann-Whitney U test for categorical variables (duration of clinical signs and incision length), and a t-test for the continuous variables (size) were performed. The length and width measurements were combined into a size category for statistical analysis.

Results

Cases

Thirty dogs with 31 foreign bodies were included in the study. Dog breeds included were mixed breed dog (7), Labrador retriever (4), golden retriever (4), Bernese Mountain dog (2), German shepherd dog (2), Siberian husky (2), and 1 of each Belgian Malinois, Brittany spaniel, Chesapeake Bay retriever, English bulldog, English springer spaniel, Kangal, bullmastiff, Saint Bernard, and Visla. The median age was 3 years (range: 0.6-12 years), and the median weight was 29.8 kg (range: 15.7-57.9 kg). There were 22 males (6 intact, 16 neutered) and 8 females (1 intact, 7 spayed). The median body condition score (BCS) was 5 (range: 3-9). The most common clinical sign was vomiting (27/30; 90%), followed by inappetence (19/30; 63%), lethargy (9/30; 30%), diarrhea (5/30; 17%), abdominal discomfort (4/30; 13%), and regurgitation (2/30; 7%). The median duration of clinical signs was 2 days (range: 0.5-28 days).

Abdominal Ultrasound

AUS identified 30/31 (96.8%) foreign bodies confirmed via surgery. In the one patient where the AUS did not identify the foreign body, surgery revealed a non-linear jejunal foreign body as well as a severely gas-distended stomach with an intact incisional gastropexy, as well as multiple mesenteric adhesions to the small intestine secondary to an intestinal enterotomy and serosal patch performed one year prior. Additionally, this patient weighed 47.8 kg and was a BCS of 9/9. In another patient, ultrasound identified two non-linear foreign bodies which were found to be a single non-linear foreign body at the time of surgery. Overall accuracy of ultrasound identification of gastrointestinal foreign bodies was 93.8%.

For the 31 foreign bodies that were identified at the time of surgery, there was a significant relationship between ultrasound foreign body type (linear vs. non-linear) and surgery foreign body type, X^2 (2, N = 31) = 31, $p < 0.0001$, and the accuracy was 96.8%. There was a significant relationship between ultrasound foreign body location and surgery foreign body location, X^2 (49, N = 31) = 155.0, $p < 0.0001$, and the accuracy was 74.19%. Of the seven linear foreign bodies, ultrasound was able to accurately identify the aborad extent of the foreign body in all cases (100%).

There was a significant relationship between ultrasound foreign body shape and surgery foreign body shape, X^2 (25, N = 31) = 118.08, $p < 0.0001$. There was not a significant relationship between ultrasound foreign body size and surgery foreign body size, t(39) = -0.6679, p = 0.5082. On average, ultrasound measurements were about 9.93 mm smaller than surgical measurements (Figure 1).

For the 30 dogs in the study, there was a significant relationship between the presence of adhesions on ultrasound and the presence of adhesions during surgery, X^2 (1, N = 30) = 5.926, p = 0.0149. The sensitivity, specificity, and accuracy for ultrasonographic detection of adhesions was 66.7%, 85.7%, and 80% respectively. There was not a significant relationship between the presence of peritoneal fluid on ultrasound and the presence of peritoneal fluid during surgery, X^2 (1, N = 30) = 1.35, p = 0.2453. The sensitivity, specificity, and accuracy for ultrasonographic detection of peritoneal fluid was 60%, 70%, and 63.3% respectively.

Small intestinal mural changes were described in 9/30 (30%) of dogs. Partial loss of wall layering was described in 4/30 (13%), thickening was described in 4/30 (13%), complete loss of wall layering was described in 3/30 (10%), and foreign bodies embedded in the intestinal wall layers were described in 2/30 (7%). The small intestinal mural changes, aside from noting the presence or absence of gastrointestinal perforation, were not evaluated at the time of surgery, therefore precluding the ability to perform a statistical comparison.

Surgery Outcomes

LGFBR was successful in 16/30 (53.3%) cases and conversion to open laparotomy (OL) was needed in 14/30 cases. The median conversion time was 30 minutes (range: 24-50 minutes). Most conversions (7/14; 50%) occurred within 30 minutes or less. There was no significant association between foreign body type and surgery outcome, X^2 (1, N = 31) = 1.3353, p = 0.2479. Though it did not reach statistical significance, of the 31 foreign bodies included in this study, non-linear foreign bodies were more likely to result in successful LGFBR (15/24; 62.5%), while linear foreign bodies were more likely to result in OL (5/7; 71.4%). Excluding linear foreign bodies, there was no significant association between foreign body location and surgery outcome, X^2 (3, N = 24) = 6.08, p = 0.1078. The most common location was the jejunum (20/24; 83.3%), followed by caudal duodenal flexure (2/24; 8.3%), gastric (1/24; 4.2%), and ileum (1/24; 4.2%). LGFBR was successful in 14/20 (70%) cases with a jejunal foreign body, 1/1 (100%) cases with a gastric foreign body, 0/1 (0%) cases with an ileal foreign body, and 0/2 (0%) cases with a foreign body at the caudal duodenal flexure. Excluding gastric and linear foreign bodies, there was no difference in foreign body size and surgery outcome, t(11) = 1.0104; p = 0.3340. The median foreign body size in dogs with successful LGFBR was 51.0 mm (range: 25.4-240 mm) and in dogs requiring OL was 50.0 mm (range: 14.5-300 mm). There was a significant overlap between foreign body sizes between the LGFBR and OL groups as depicted in Figure 2.

There were three dogs (3/30; 10%) that had undergone previous gastrointestinal surgery, and all three had adhesions at the time of surgery. Six additional dogs without a history of previous gastrointestinal surgery had adhesions for a total of nine dogs (9/30; 30%). Of these nine dogs, four had successful LGFBR. There was no significant association between the presence of adhesions and surgery outcome, X^2 (1, N = 30) = 0.1199, p = 0.7292. There was no significant association between BCS and surgery outcome, X^2 (6, N = 30) = 4.6909, p = 0.5840. There was no significant difference in the duration of clinical signs between the LGFBR and OL groups, U = 106.0000, p = 0.8123. The median incision length for the LGFBR was 46 mm (range: 40-50 mm), and the median incision length for OL was 134 mm (range: 83-163 mm).

The reason for conversion to OL was due to adhesions (4/14; 28.6%), moderate-severe intestinal plication (4/14; 28.6%), tethering by the duodenocolic ligament preventing exteriorization (3/14; 21.4%), and inability to exteriorize the foreign body due to intestinal dilatation (3/14; 21.4%). The ileocecocolic junction was able to be exteriorized in 20/29 (69.0%) cases (in the first case exteriorization was not attempted).

There were three dogs with small intestinal perforation at the time of surgery. Of these dogs, 2/3 (66%) had small intestinal mural changes described as having complete loss of wall layering on AUS. Three of the four dogs with small intestinal mural changes described as having partial loss of wall layering had regions of small intestine with questionable viability during surgery that were leak tested and ultimately deemed viable. Representative images of a single patient’s ultrasound, laparoscopic exploratory, and surgery are shown in Figure 3.

Post-operative Outcome

Follow-up was available for 28/30 (93.3%) of dogs. Two dogs were lost to follow up immediately following surgery, and both were in the LGFBR group. One dog died postoperatively secondary to intractable regurgitation and subsequent severe aspiration pneumonia. This was deemed unrelated to the surgical procedure as there was no gastrointestinal incision and the GI tract, aside from the colon, was empty prior to surgical closure. Another dog experienced dehiscence of the enterectomy site 3-days postoperatively and underwent a second surgery. This dog was in the OL group and had a duodenal perforation that required an enterectomy at the initial surgery. The dog recovered well from the second surgery and survived to discharge.

Of the remaining 26 dogs, the median follow-up time was 223.5 days (range: 12-439 days). All were doing well at the time of last follow up. Only three dogs experienced incisional complications. Two dogs (one in the LGFBR group and one in the OL group) had an incision site infection treated with systemic antibiotics. A culture was performed in both cases. The first dog's culture grew *Streptococcus canis, Pseudomonas oryzihabitans*, and *Kosakonia cowanii* and, and the second dog's culture grew *Klebsiella pneumoniae*, *enterococcus faecalis,* and *Salmonella sp.* One dog in the OL group had seroma formation that was treated without medication. Overall, 1/13 (7.7%) dogs in the LGFBR group and 2/13 (15.4%) dogs in the OL group had incisional complications.

Discussion

Abdominal ultrasound was accurate at identifying most foreign bodies, and was useful in determining foreign body type, location, and shape. AUS, however, was consistently underestimating foreign body size. AUS had moderate accuracy at identifying adhesions, with a sensitivity and specificity of 66.7% and 85.7% respectively. This information provided could be used to provide guidance to the surgeon prior to performing LGFBR, as adhesions were one of the most common reasons for conversion to OL.

In our study, AUS identified 96.8% of foreign bodies, which is similar to previous reports ranging from 81.2% to 97%.[19-20,25-26] There was only one case where AUS was unable to identify the non-linear foreign body. This may have been due to the size of the dog (47.8 kg), BCS (9/9), and previous intestinal surgery leading to several adhesions. Ultrasound successfully identified all cases of linear foreign bodies using characteristics that have been previously described[19,27], such as plication of the small intestine and a persistent hyperechoic linear structure within the center of the intestinal lumen. In all seven cases of linear foreign bodies in this study, AUS was able to correctly identify the aborad extent of the linear foreign body (100% accuracy).

In cases of non-linear foreign bodies, AUS was able to accurately identify the foreign body location in 74.19% of cases. This is similar to a prior study,[24] in which AUS was able to identify the correct anatomic location of lesions in the gastrointestinal tract in 76% of cases of septic peritonitis. The most common location of the foreign body in our study was the jejunum (83.3%), which is more than previous studies (48% to 63%),[28-29] and significantly more than a study by Di Palma et. al. in 2022[30] that reported jejunal foreign bodies in only 28% of cases. The latter study included non-obstructive foreign bodies that were removed endoscopically from the stomach or duodenum, which likely explains the discrepancy in location.

AUS was accurate at determining the foreign body shape, however not accurate at determining their size. Ultrasound foreign body measurements were on average about 9.93 mm smaller than true foreign body size. Though ultrasound was not able to accurately provide this information, we question the usefulness of knowing the exact foreign body dimensions preoperatively. The difference between the median foreign body size between LGFBR and OL groups was 1.0 mm, which was clinically insignificant. Additionally, foreign bodies up to 240 mm were successfully removed with LGFBR. This is likely because many foreign bodies consumed by dogs, such as textiles and toys, have a great degree of malleability. This type of foreign material can be manipulated out of small incisions. In some cases, foreign bodies are not as easily deformed, such as corncobs and plastic toys. In our study, the few examples of the latter type of foreign bodies were small enough to be removed from the smaller incision, however, it is reasonable to assume that a larger non-deformable foreign body would not be successfully exteriorized.

AUS had a sensitivity of 66.7% with an 80% accuracy for identifying adhesions. AUS has been a useful tool for evaluating the adhesions formed following laparoscopic or laparoscopic-assisted gastropexy.[31-32] No studies have reported the ability of ultrasound to identify intestinal adhesions. In our study, ultrasound was able to accurately detect adhesions in 80% of cases. In several cases with adhesions (4/14; 28.6%), the ability to exteriorize the intestinal segment was limited due to the adhesions and led to OL. Adhesions, along with plication of the small intestines leading to concern for perforation, were the most common reasons for conversion. Although 33% of adhesions were not identified by the AUS in our study, this diagnostic may still be useful in this regard.

In addition to providing information regarding the foreign body and adhesions, AUS was able to identify mural changes in nine cases. Of these nine cases, three were described as having complete loss of wall layering, two of which had confirmed small intestinal perforation at the time of surgery. The use of AUS to identify gastrointestinal perforation, including secondary to foreign bodies, has been reported in the veterinary literature with many studies reporting successful identification of suspected perforation preoperatively[22,33-34], while another study demonstrated more cases where the perforation was missed.[35] This information would be beneficial for the surgeon preoperatively, and more studies looking at ultrasound's ability to identify suspected intestinal perforation are needed.

AUS was not accurate at determining the presence or absence of free peritoneal fluid. This may have been due to the exclusion of patients with concern for septic peritonitis, and therefore there were less likely to be cases with significant amounts of fluid, and therefore more easily detected on ultrasound. Additionally, the abdominal ultrasounds were most often performed on awake dogs prior to complete intravenous fluid resuscitation, and therefore this may have affected the presence of fluid. Another factor may have been that the population consisted of many young dogs where a small amount of free fluid can be considered appropriate for the patient age and may be more easily identified at the time of surgery.

The success of LGFBR in our study was 53.3%, including 28.6% of linear foreign bodies and 62.5% of non-linear foreign bodies. It is difficult to compare this success rate to previous studies[14-15] as we attempted LGFBR in all cases regardless of pre-operative radiographic and ultrasonographic findings, apart from patients with confirmed or suspected sepsis. Case and Ellison in 2013[14] reported on single-incision laparoscopic-assisted intestinal surgery in 7 dogs and 1 cat. Of these cases, 4 were dogs with a foreign body obstruction, and they were successful in 3/4 (75%). The one failure was due to adhesions from a prior abdominal surgery, similar to findings in our study. Otomo et. al. in 2018[15] reported on single-incision laparoscopic-assisted intestinal surgery in 13 dogs with foreign body obstructions. All foreign bodies were in the jejunum, and they were successful in 10/13 (76.9%) of cases, similar to our success rate of 14/20 (70%) of jejunal foreign bodies.

LGFBR was successful in 2/7 (28.6%) cases with linear foreign bodies, and in both cases the foreign material did not extend to or beyond the caudal duodenal flexure. The remaining 5 cases did extend beyond the flexure. This demonstrates that the removal of linear foreign bodies may not be an absolute contraindication to LGFBR, however, the aborad extent of the foreign material may be a factor in determining success. Though a small number of cases, our study demonstrated both that LGFBR for linear foreign bodies is possible, and that AUS can provide the location of the aborad extent of the foreign material.

There were two cases in the current study which a non-linear foreign body was located near the caudal duodenal flexure. In both cases, the tethering effect of the duodenocolic ligament prevented exteriorization of the foreign body and led to OL. Although only two cases, we believe this would hold true for a larger number of foreign bodies at this location due to the anatomic constraints. Therefore, foreign bodies located at or near the caudal duodenal flexure may be a true absolute contraindication for LGFBR.

There was only one case of a gastric foreign body, excluding the pyloric anchor of linear foreign bodies. In this case, the gastrotomy was successfully performed using LGFBR, demonstrating that this technique is feasible to remove gastric foreign bodies if endoscopy is unavailable or unsuccessful. Additionally, there was only one case with a foreign body located near the ileocecocolic junction, and this was converted to OL due to an inability to exteriorize the foreign body. The reasons for conversion recorded by the surgeon included significant orad dilation of the intestinal segments and excess mesenteric fat occluding the small incision within the wound retractor device. This patient was one of two patients with a BCS 9/9, and both patients were converted to OL. In our study, the association between BCS and surgery outcome did not reach clinical significance. However, this may be a type II statistical error and we suspect that in a larger cohort with greater distribution of BCS scores, statistical significance may be reached. Further, in 20/29 cases, the ileocecocolic junction was able to be exteriorized, and therefore this location may not be an absolute contraindication to LGFBR.

Limitations of this study include its limited patient numbers, reducing the number of different types of foreign bodies and locations. This led to only a single case each with a gastric or ileocecocolic foreign body, and only seven cases of linear foreign bodies. There was also no control comparison of cases without foreign body obstruction for AUS examination. Our objective was to determine the ability of AUS to describe foreign body characteristics rather than diagnose obstruction. Another limitation was that there were multiple ultrasonographers, however, each was a board-certified radiologist. Additionally, the surgeon attempting LGFBR was not blinded to all the ultrasound information and therefore may have been biased to convert based on this knowledge.

Based on the current study, we confirm that foreign bodies at the level of the caudal duodenal flexure are not amenable to LGFBR. Adhesions were a common reason for conversion, however several cases with adhesions or prior intestinal surgery were removed successfully via LGFBR. Therefore, the presence of adhesions or prior intestinal surgery is not an absolute contraindication for LGFBR, however, it does appear to increase the need for OL. Though linear foreign bodies were previously considered an absolute contraindication, we demonstrated that if these do not extend beyond the caudal duodenal flexure, they may be amenable to LGFBR. Additionally, the degree of intestinal plication and dilation should be taken into consideration. Gastric foreign bodies and foreign bodies located at or near the ileocecocolic junction may also be amenable to LGFBR. More studies evaluating the success of LGFBR for foreign bodies in locations other than the jejunum are warranted. Finally, the results of this study show that AUS can provide vital information regarding foreign body (type, location, shape) and patient (adhesions, mural changes) characteristics allowing for improved patient selection for LGFBR.

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Figures

Figure 1. Graph depicting the relationship between surgical foreign body measurements on the y-axis and ultrasound foreign body measurements on the x-axis.

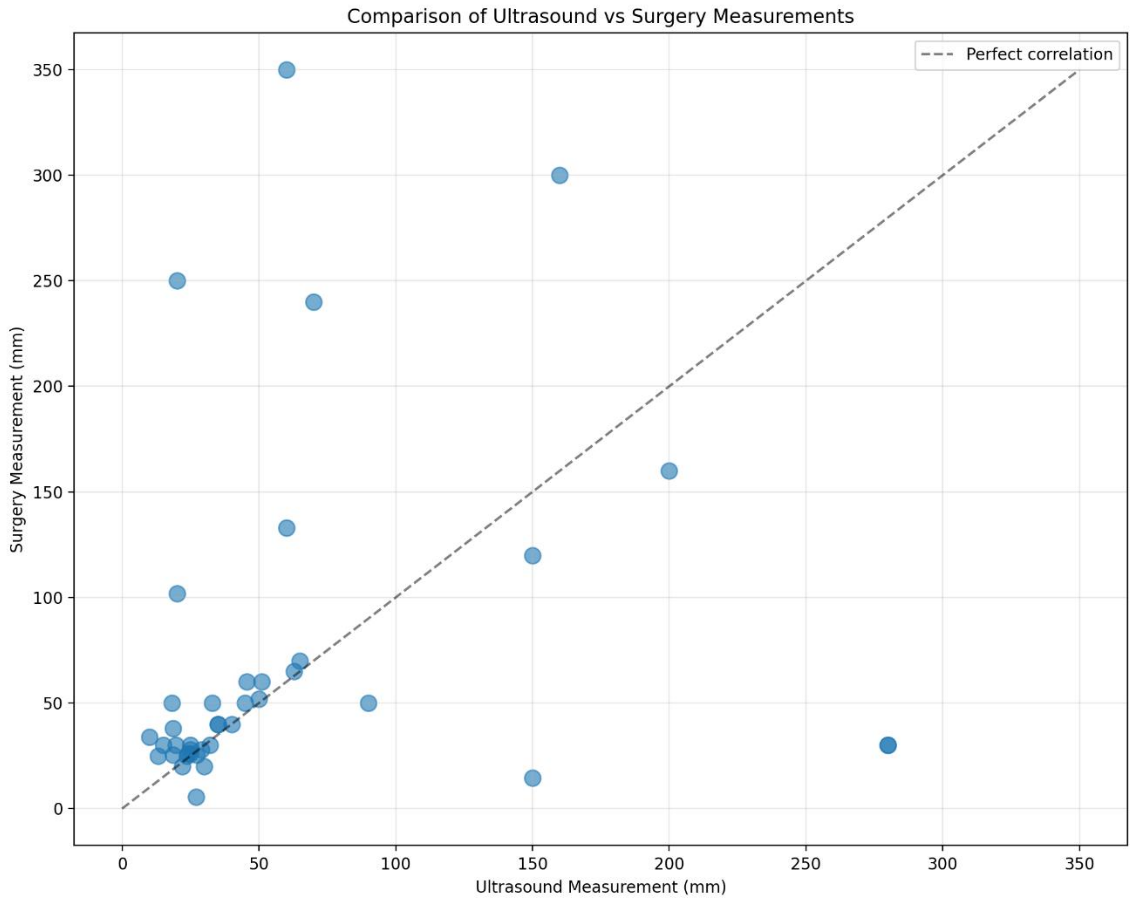

Figure 2. Box and whisker plot of median foreign body size in laparoscopic-assisted and open laparotomy groups.

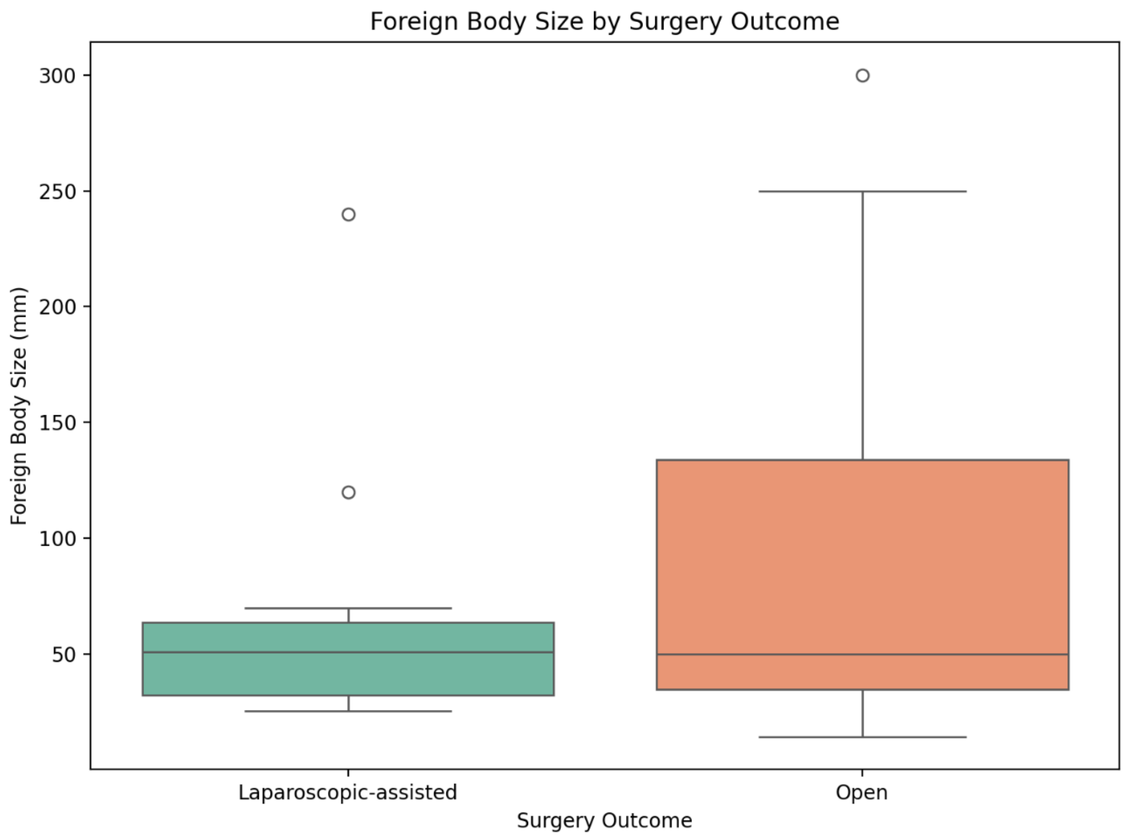

Figure 3. Images from a patient with a non-linear jejunal foreign body successfully removed with LGFBR. Ultrasound image at the level of the foreign body (A), identification of the jejunal segment with the foreign body during laparoscopic explore (B), exteriorization of the jejunal segment containing the foreign body (C), and foreign body following removal from the jejunum (D).