

# Infrared thermography is a novel tool to assess small intestinal surface temperature in dogs undergoing laparotomy for foreign body obstruction

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## OBJECTIVE

To evaluate local temperature differences directly over and adjacent to small intestinal foreign body obstruction (FBO) using infrared thermography (IRT) in dogs.

## ANIMALS

49 client-owned dogs were initially enrolled.

## METHODS

In a prospective, clinical observational study, IRT was utilized to compare median small intestinal (SI) surface temperature differences at the site of FBO and segments oral and aboral before and after surgical resolution from April 24, 2019, to July 19, 2020. These differences were evaluated for correlation with canine acute patient physiologic and laboratory evaluation fast (APPLE<sub>fast</sub>) scoring, lactate, foreign body material (hard vs soft), and blood pressure.

## RESULTS

There was not a significant surface temperature difference between SI segments at the site of FBO, oral or aboral. After resolution of obstruction, there was a significant decrease in median temperature directly over the FBO (2.4 °C; IQR, -2.55 to 10.6 °C;  $P = .0043$ ). A decrease in surface temperature of the oral SI segment was appreciated with FBO due to hard material (-1.7 °C; IQR, -5.2 to 3.4 °C), whereas soft material had an increase in SI surface temperature oral to the FBO (+1.1 °C; IQR, 0.3 to 3.2 °C). This difference did not achieve significance ( $P = .08$ ;  $Z = 1.75$ ). No correlation was found between APPLE<sub>fast</sub>, lactate, or blood pressure and SI segment temperatures.

## CLINICAL RELEVANCE

IRT may be useful diagnostic modality to identify changes in small intestinal surface temperature relating to FBO. Further evaluation is warranted to determine if IRT may be a clinically useful to evaluate intestinal perfusion.

**Keywords:** thermal imaging, infrared thermography, foreign body obstruction, laparotomy, dogs

**F**oreign body obstruction (FBO) is a common cause of small intestinal (SI) mechanical obstruction, with 78% to 100% caused by foreign material versus neoplasia, stricture, or torsion.<sup>1,2</sup> Items associated with FBO can be linear (eg, string, rope), soft (eg, cloth material), or hard (eg, corn cob, rock, rubber toys).<sup>1,2</sup> The foreign material can exert pressure on the SI mucosa, submucosa, and serosa as the obstruction progresses and intraluminal pressure increases.<sup>3</sup> This can result in a local ischemic injury and inflammation and even potential for perforation

if the tissue becomes devitalized.<sup>3,4</sup> The FBO must be resolved surgically via digital manipulation of foreign material aboral through the pylorus and performing a gastrotomy, by making an enterotomy adjacent to the object, or with a resection and anastomosis (R&A) of the affected region of the bowel if the SI is deemed compromised or if a perforation has occurred. Surgeons must make the intraoperative decision of whether bowel resection is needed and how much to remove based on limited proven criteria. Dehiscence rates for FBO with either enterotomy

or R&A have been reported to range from 2 to 28%, with higher rates of dehiscence in R&A patients.<sup>5-7</sup> An increased risk of dehiscence has been associated with preexisting conditions, preoperative peritonitis, and hypoalbuminemia.<sup>5,7</sup>

The current standard of practice in both veterinary and human medicine for evaluating intestinal viability has not changed in over 4 decades and remains subjective visual assessment of the tissue intraoperatively.<sup>8-10</sup> The hallmark for devitalized SI segments includes a change in color, hypomotility, and decreased wall thickness of the associated SI segments, although unfortunately visual assessment is rarely this straightforward especially when considering the factors of surgeon experience in visual assessment and training level.<sup>9,10</sup> Even the most highly skilled surgeons do not have perfect accuracy for detecting devitalized SI, which leads to increased risk of SI surgical site dehiscence and thus increased morbidity and mortality in these patients.<sup>5,6,9</sup> Studies<sup>10,11</sup> in human medicine have shown surgeon assessment of intraoperative SI viability to have a low sensitivity (62% to 78%), varied specificity (52% to 91%), and low predictive values (64%). More objective methods of evaluating intestinal perfusion include fluorescein dye,<sup>9,11</sup> angiography,<sup>9</sup> near-infrared fluorescence,<sup>12,13</sup> pulse oximetry,<sup>14</sup> pulse wave Doppler,<sup>11</sup> and side-stream dark field videomicroscopy.<sup>15,16</sup> Due to cost, invasiveness, difficulty in technique, and insufficient evidence to suggest superiority, clinical application of these has been limited.<sup>9,10,17</sup> Given the limitations of these different modalities, infrared thermography (IRT), also called radiometric thermal imaging, has been explored for its potential as a more clinically applicable tool and has been utilized to assess bowel perfusion in a porcine model<sup>18</sup> and in mesenteric ischemia in human medicine.<sup>8</sup>

Radiometric thermal imaging is a noninvasive and contactless diagnostic tool that has been utilized in clinical practice and research settings.<sup>19,20</sup> This technology uses surface heat emission to create a unique color map that can detect temperature changes as small as 0.01 °C.<sup>20,21</sup> These changes in surface tissue occur due to external environmental factors including ambient temperature, solar radiation, and internal factors including tissue metabolism and local perfusion.<sup>20,21</sup> As long as external environmental factors are controlled and tissue metabolism is fairly constant, changes in surface temperature can be used to approximate local tissue perfusion.<sup>22</sup> The local tissue perfusion is dependent on microcirculation and blood flow, which is regulated by both system factors (eg, the sympathetic nervous system) and local factors (eg, nitric oxide) inducing either vasoconstriction or a relative vasodilation of the tissue surface vessels.<sup>21,23</sup> Vasoconstriction results in a decreased blood flow and therefore temperature, with the opposite being true for vasodilation. In small animal veterinary medicine, IRT has been demonstrated to be a useful diagnostic tool in evaluating regional circulation and blood flow in various clinical applications including feline aortic thromboembolism,<sup>19</sup> efficacy of local analgesia,<sup>24,25</sup>

feline hyperthyroidism,<sup>26</sup> tumor margins,<sup>27</sup> and identifying pain and inflammation.<sup>20,28</sup> Radiometric thermal imaging is an appealing diagnostic tool for evaluating tissue perfusion as it is noninvasive, easy to use, and cost effective.

After an extensive review of the available literature, there is not yet any evidence for the intraoperative use of IRT in the assessment of SI temperature changes associated with FBO in dogs. Therefore, the overall objective of this study was to determine the feasibility of employing IRT in the intraoperative setting in dogs with FBO. Additional objectives were to evaluate for local temperature differences associated with SI FBO before and after resolution of obstruction and to assess for correlation between SI temperature changes and systemic health parameters. Our first hypothesis was that there would be a significant difference in temperature between the FBO-centered intestinal segment and the adjacent regions, as well as after foreign body removal and resolution of mechanical obstruction. Our second hypothesis was that the SI temperature would not correlate with disease severity and thereby reflect local rather than systemic changes.

## Methods

This prospective, clinical observational study's protocol was reviewed and approved by the IACUC and Clinical Trials Office of the authors' research facility and found to be in compliance with the Animal Welfare Act and the guidelines of the Public Health Service as issued in the *Guide for the Care and Use of Laboratory Animals*. Written, informed consent was obtained at the time of enrollment into the study. The study took place from April 24, 2019, to July 19, 2020.

## Study population

Sample size calculation was performed for the primary outcome measured (ie, difference between FBO temperature and oral or aboral temperature) with the assumption that a paired *t* test would be used. Preliminary data (nonpublished) suggested a difference of 2 °C temperature between FBP-affected and -nonaffected intestinal loop. Based on this, 10 paired samples should be enough to detect that difference with an alpha significance set at 0.05 and a power set at 80% (MedCalc Statistical Software version 18.5; MedCalc Software Ltd).

Client-owned dogs at an academic teaching hospital; were enrolled in the study from April 24, 2019, to July 19, 2020. Inclusion criteria included dogs diagnosed with a SI FBO based on radiographs, ultrasound, or CT scan and underwent exploratory laparotomy. All images were reviewed by a board-certified radiologist and/or radiology residents. Dogs were included regardless of acute or chronic onset of clinical signs, presence/absence of peritonitis, or surgical procedure performed (ie, enterotomy vs R&A). Dogs were excluded from the study population if the foreign body was not located in the SI at the time of abdominal explore, if dogs had

concurrent major surgical emergencies (ie, Gastric-Dilation and Volvulus), if incomplete data was collected, if FBO was linear due to poor imaging ability, or if images obtained were subsequently determined to be of insufficient quality for analysis.

### Control population

Dogs who were initially enrolled as part of the study group but who were found to have a gastric foreign body rather than SI, had a negative explore (foreign body not found), or where FBO was resolved without the need for enterotomy or R&A (ie, they were digitally manipulated oral to the stomach or aboral to the colon) were considered controls as a nonmanipulated loop of bowel was utilized.

### Preoperative care

At time of admission, a physical examination was performed by the admitting veterinarian, and the following diagnostic tests were performed: noninvasive blood pressure (oscillometry or doppler), venipuncture, and collection of 3 mL of venous blood. Blood collection was performed in routine technique at the discretion of the technical support team at time of presentation to the emergency room. Samples were divided into blood collection tubes without anticoagulant, an EDTA anticoagulant blood tube, and a heparinized blood gas syringe. The blood collection tube without anticoagulant was allowed to clot for 20 minutes, and serum was separated using a standard blood centrifuge. If samples were collected after hours, they were placed in a refrigerator at 4.40°C to be performed by laboratory personnel during business hours. A point-of-care analyzer (Stat Profile Prime Plus Critical Care) was utilized to obtain BUN, creatinine, lactate, and electrolytes at the time of admission. During business hours, a hematology analyzer (Advia 120) was used to perform complete blood counts (leukocyte count, platelet count, hematocrit), and chemistry analyzer (Cobas C 501) was used to obtain a complete biochemistry panel including liver function testing. As an assessment of systemic health, an acute patient physiologic and laboratory evaluation fast (APPLE<sub>fast</sub>) score was calculated for every patient using blood glucose, albumin, lactate, platelet count, and mentation score. Lactate was converted from mmol/L to mg/dL for use in APPLE<sub>fast</sub> scoring (**Supplementary Figure S1**).<sup>29</sup> Initial stabilization and supportive care were provided by the admitting clinician, at their discretion, before the patient was transferred to the anesthesia and surgery teams including fluid resuscitation.

### Anesthetic care

Anesthetic protocols were developed at the discretion of the attending anesthesiologist to include analgesics and tranquilizers. A specific premedication or induction protocol was not dictated by the study protocol to ensure individual needs were met. Premedication pharmaceuticals included methadone, hydromorphone, ketamine, dexmedetomidine, and midazolam. All dogs were induced with propofol

and intubated, and general anesthesia was maintained using isoflurane or sevoflurane. If indicated, based on the depth of anesthesia, dogs were provided continuous rate infusions of fentanyl, ketamine, or lidocaine. Dogs were provided with heat support to ensure normal body temperature throughout the surgical procedure. All the dogs had body temperature (via rectal or esophageal thermometer), heart rate and rhythm (via electrocardiography), respiratory rate and Pco<sub>2</sub> (via capnography), noninvasive blood pressure (via Doppler or oscillometry), and Spo<sub>2</sub> (via pulse oximetry) monitored and recorded every 5 minutes throughout anesthesia.

### Operative care

All dogs had the ventral abdomen shaved from mid sternum to pubis. A rough preparation of the skin was provided using chlorhexidine scrub followed by ethyl alcohol before entering the operating room. A second sterile preparation of the abdomen was performed using chlorhexidine scrub and ethyl alcohol. Surgeons donned surgical masks and caps. After surgical scrub of hands and forearms using a surgical and healthcare personnel hand antiseptic with moisturizer, surgeons applied a sterile gown and gloves. Dogs were sterilely draped leaving the ventral midline open from the xiphoid to the pubis. In the male, the prepuce was maintained under the drape using a towel clamp. A ventral midline skin and subcutaneous incision were made extending from the xiphoid to the cranial preputial region (male) or pubis (female) using a No. 10 and No. 15 blade, respectively. Local hemostasis was achieved with monopolar electrocautery. A stab incision was made on the ventral midline through the linea alba, and circumferential digital exploration through the incision was performed. The incision was continued in a caudal and cranial direction to the same length as the initial skin and subcutaneous incisions using curved Mayo scissors. The falciform ligament and fat were bilaterally removed with monopolar electrocautery. A routine abdominal exploratory was performed to identify the location of the FBO. SI segments were maintained in the body cavity. If enterotomy or R&A was performed, the area surrounding the planned surgical site was packed with moistened laparotomy sponges to prevent contamination. Enterotomy sites were closed using a 4-0 polydioxanone (PDS) suture in a simple continuous suture pattern, and R&As were performed either hand sewn with a combination of interrupted and simple continuous appositional sutures using 4-0 PDS or stapled with a GIA stapling device. The area underwent copious lavage. The surgical site was digitally occluded oral and aboral, and sterile fluorescence stain was injected into the lumen of the intestine to ensure adequate closure without leakage. The remainder of the SI was leak tested similarly. Before the closure of the abdomen, a sponge count was completed. The body wall was closed using 0 PDS suture in a simple continuous pattern. The subcutaneous tissue was closed using 3-0 Monocryl on a taper needle in a continuous pattern. The skin was closed using 3-0 Monocryl in an



intra-dermal pattern. The surgical procedure was performed either by a surgical resident or a diplomate of the American College of Veterinary Surgeons. Operating rooms were maintained at 68 °F (20 °C) according to standard operating procedures. All surgical lights used were LED and produced negligible heat radiation given the distance to the surgical field.

## Study group

Using a radiometric thermal imaging camera (FLIR E6 Wifi Camera), digital thermal images were obtained once the FBO was identified and isolated (T1). The camera was held approximately 1 m from the exposed SI loop and at an approximately 90° angle to the site of interest. Surgeons pointed to the SI segment oral to the site of FBO as a reference point. The data were saved on the device's memory card for later thermal analysis to be performed. The following data were also obtained at T1: patient temperature, heart rate, respiratory rate, blood pressure, and ambient room temperature. Intestinal FBO location, surgical procedure performed (enterotomy, R&A, gastrotomy), and the nature of the foreign body material were recorded. Foreign body materials were then classified as either hard or soft based on physical characteristics. Digital thermal images were also obtained after enterotomy, or R&As were completed and before "leak test" of the surgical site or lavage of the abdomen (T2). Again, surgeons pointed to the SI segment oral the incision as a reference point. The following data were also obtained at T2: patient temperature, heart rate, respiratory rate, blood pressure,

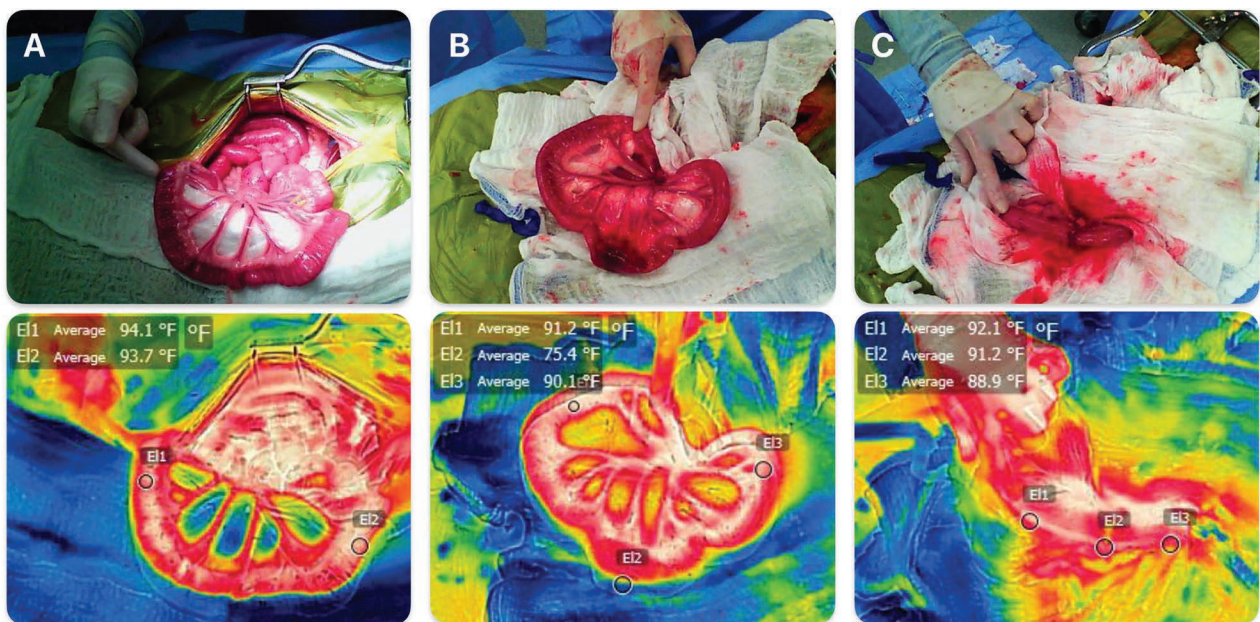
and ambient room temperature (°F). After completion of the surgery, the dogs were then recovered, and supportive care was provided by the clinician at their discretion. No additional data were obtained.

## Control group

In patients that met criteria for inclusion in the control group, the surgeon identified a loop of jejunum remote from any other intestinal manipulation and that appeared grossly normal. The chosen loop of the intestine was exposed and displayed similarly to the study group. Digital thermal images were obtained in the same manner as study dogs at 1 time point only (T1).

## Image analysis

A commercially available radiometric thermal imaging software kit (FLIR Tools) was utilized to analyze the saved images. For the study group T1 images, the ellipsoid measuring tool was placed on an area of SI segment centered on the FBO, 3 to 6 cm oral and 3 to 6 cm aboral to the FBO (**Figure 1**). The program used the selected areas to calculate the average, minimal, and maximal temperatures, generating a final report for each subject. The same process was performed for T2 Images. In the control group, for the T1 images, the ellipsoid measuring tool was placed on an area of normal bowel on the oral side of the segment and the aboral side of the segment. The program used the selected areas to calculate the average, minimal, and maximal temperatures, generating a final report for each subject.



**Figure 1**—A to C—Digital images created from the commercially available radiometric thermal imaging software kit demonstrating control group (A), before resolution of mechanical obstruction (T1) study group (B), and after surgical correction of mechanical obstruction (T2) study group (C). The surgeon points to the oral side of the foreign body obstruction (FBO) in each panel using a finger. An ellipse measuring tool has been placed on the segment of interest and labeled accordingly with E1 (oral), E2 (FBO or aboral in control), or E3 (aboral). The average temperature within each ellipse is calculated by the software. B—T1 digital image report for study patient 37 before resolution of hard textured (rubber ball) FBO. C—T2 digital image for the same patient after resolution of FBO with resection and anastomosis.

## Statistical analysis

The continuous data were evaluated for normality using the Shapiro-Wilk statistic. A signed rank test was used to analyze differences in temperature at each time point when data were nonparametric. Correlations to APPLE<sub>fast</sub>, lactate, and blood pressure at time of admission and image acquisition were calculated using Spearman's rank order correlation coefficient. The data were converted to log scale to perform a simple linear mixed model with the patient enrollment number as a random effect variable to compare the T1 and T2 time points. A multivariable linear mixed model was used to correlate APPLE<sub>fast</sub>, lactate, and blood pressure at time of admission and image acquisition, at the 2 time points. The differences between foreign body texture, study, and control groups were analyzed using a Wilcoxon 2 sample test. Adjusted *P* values were derived using Tukey's adjustment with criteria for significance set at *P* < .05. A commercially available software package (SAS v9.4; SAS Institute Inc) was used for all statistical analyses.

## Results

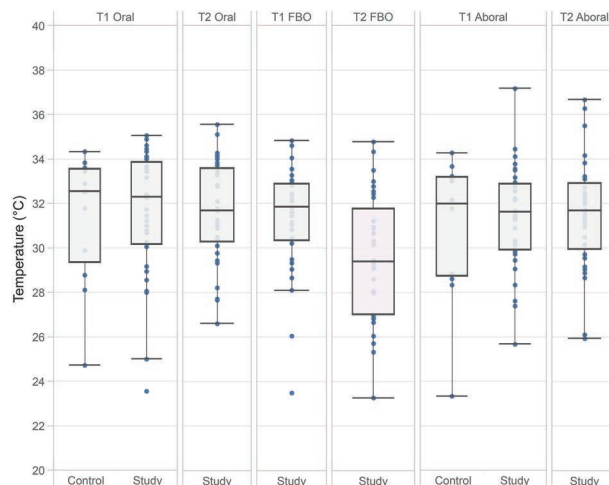
A total of 49 dogs were enrolled in the study. Six were excluded due to missing data (2 dogs), inability to obtain adequate images due to the linear nature of mechanical obstruction (3 dogs), or images of insufficient quality for analysis (1 dog). There were 31 dogs in the study group including 14 mixed breed dogs, 17 pure breed dogs (3 Labrador Retrievers, 2 Australian Shepherds, and 1 each of Bernese Mountain Dog, Boxer, Cane Corso, Cavalier King Charles Spaniel, Chihuahua, Doberman Pinscher, German Shepherd Dog, Mastiff, Newfoundland, Schnauzer, Vizsla, and Weimaraner). There were 6 males, 11 altered males, 1 female, and 13 altered females. The median age for the study group was 3 years old (0.38 to 10 years old) with a median weight of 22.1 kg. FBO was resolved with enterotomy in 26 dogs and R&A in 5 dogs.

There were 12 dogs in the control group including 5 mixed breed dogs and 7 pure breed dogs (1 each of Australian Shepherd, Doberman Pinscher, English Bulldog, Golden Retriever, Maltese, Rottweiler, and Siberian Husky). There were 3 males, 6 altered males, and 3 altered females. The median age for the control group was 5 years old (0.3 to 12 years old) with a median body weight of 26.2 kg. There were 7 gastrotomies, 1 negative explore, and 4 in which the foreign material was manipulated into the colon for natural expulsion.

The data for average temperatures (°C) of SI segments was nonparametric. The data were log transformed to facilitate analysis.

### Comparing study group to control group

There was not a significant difference when comparing the median T1 oral and T1 aboral SI segment temperatures between the study group and the control group (**Figure 2**). The T1 oral median temperature for the control group was 32.6 °C (IQR,



**Figure 2**—Box and whisker plot demonstrating the average small intestinal (SI) surface temperatures from dogs (*n* = 43) with foreign body obstruction undergoing laparotomy from April 24, 2019, to July 19, 2020. Dogs who did not require enterotomy or resection and anastomosis were in the control group (*n* = 12) and the study group (31) included dogs requiring enterotomy or resection and anastomosis. SI surface temperatures were obtained at time points T1 and T2. The center horizontal line inside the box represents the median surface temperatures with upper and lower quartiles designated by the upper and lower margins of the box. Each individual dot represents the average ellipsoid temperature and whiskers represent 1.5 times the IQR. The pink color indicates a significant difference. There was a significant decrease in temperature after resolution of foreign body obstruction, 2.4 °F with IQR, -2.55 to 10.6 °C.

29.6 to 33.5 °C) and the T1 oral median temperature for the study group was 32.3 °C (IQR, 30.2 to 33.8 °C). The difference between these, 0.30 °C (IQR, -0.97 to -0.9) was not significant (*P* = .7173). The T1 aboral median temperature for the control group was 32.0 °C (IQR, 28.8 to 33.2 °C) and the T1 aboral median temperature for the study group was 31.6 °C (IQR, 29.9 to 32.9 °C). The difference of 0.60 °C (IQR, -2.00 to 0.50) was not significant (*P* = .8454). The differences between the study and control group SI segment median temperatures had no correlation with the APPLE<sub>fast</sub> score, lactate, or blood pressure at time of admission or image acquisition (**Table 1**).

### Comparing within the study group

There was not a significant difference when comparing the median T1 oral, FBO, and aboral SI segments within the study group. The T1 FBO median temperature was 31.8 °C (IQR, 30.3 to 32.9 °C), which did not show significant difference to the adjacent oral and aboral SI segments (Figure 2; Table 1). The differences in T1 SI segment median temperatures were not correlated with the APPLE<sub>fast</sub> score, lactate, or blood pressure a time of admission or image acquisition.

There was not a significant difference when comparing the T1 oral and T2 oral SI segments (**Table 2**). The median temperature for T2 oral was

**Table 1**—Table representing median differences in small intestinal (SI) surface temperatures from dogs (n = 43) with foreign body obstruction (FBO) undergoing laparotomy from April 24, 2019, to July 19, 2020.

SI segment	Group	Median difference (°C)	Significance of temperature difference [signed rank (P value)]	Correlation w/APPLE <sub>fast</sub> [Spearman ρ (P value)]	Correlation w/BP at T1/T2 [Spearman ρ (P value)]	Correlation w/lactate [Spearman ρ (P value)]
T1 oral to T1 aboral	Control	+0.5 (IQR, 0.6 to 1.5)	17 (.204)	-0.160 (.682)	0.700 (.188)	0.333 (.289)
T1 oral to T1 aboral	Study	+0.7 (IQR, 0.5 to 1.7)	34.5 (.629)	0.212 (.300)	0.342 (.195)	0.095 (.637)
T1 oral to T1 FBO	Study	+0.6 (IQR, -0.3 to 1.7)	56.5 (.252)	0.313 (.119)	0.259 (.333)	0.049 (.810)
T1 aboral to T1 FBO	Study	-0.2 (IQR, -0.8 to 0)	-11 (.807)	-0.027 (.895)	-0.007 (.978)	0.029 (.887)

Dogs who did not require enterotomy or resection and anastomosis were in the control group (n = 12) and the study group (31) included dogs requiring enterotomy or resection and anastomosis. Differences in surface temperature between site of FBO and adjacent oral and aboral SI segments before (T1) and after (T2) resolution of mechanical obstruction. Temperature differences were not correlated to disease severity using canine acute patient physiologic and laboratory evaluation fast (APPLE<sub>fast</sub>) scoring, noninvasive blood pressure (BP), or lactate.

**Table 2**—Table representing median differences in SI surface temperatures from dogs (n = 43) with FBO undergoing laparotomy from April 24, 2019, to July 19, 2020.

SI segment	Group	Median difference (°C)	Significance of temperature difference [P value using linear mixed model with T1, T2 variable (CI)]	Correlation with APPLE <sub>fast</sub> [adjusted P value using linear mixed model with T1, T2 variable (CI)]	Correlation with BP at T1/T2 [adjusted P value using linear mixed model with T1, T2 variable (CI)]	Correlation with lactate [adjusted P value using linear mixed model with T1, T2 variable (CI)]
T1 oral to T2 oral	Study	+0.6 (IQR, -0.2 to 0.4)	.982 (-0.02 to 0.02)	.783 (-0.019 to 0.025) .180 (-0.002 to 0.008)	.982 (-0.020 to 0.021) .306 (-0.000 to 0.001)	.642 (-0.016 to 0.029) .371 (-0.011 to 0.029)
T1 FBO to T2 FBO	Study	+2.4 (IQR, -2.55 to 10.6)	.004 (-0.07 to -0.14)	.001 (-0.07 to -0.02) .22 (-0.002 to 0.007)	.005 (-0.08 to -0.02)* .77 (-0.0009 to 0.0007)	.0087 (-0.07 to -0.02) .27 (-0.008 to 0.03)
T1 aboral to T2 aboral	Study	-0.1 (IQR, -0.1 to -0.05)	.9002 (-2.12 to 2.4)	.887 (-2.77 to 2.40) .235 (-0.136 to 0.530)	.394 (-2.01 to 4.82) .228 (-0.032 to 0.124)	.547 (-1.587 to 2.927) .633 (-1.77 to 1.10)

Median differences in surface temperature between site of FBO and adjacent oral and aboral SI segments at T1 and T2 of surgical resolution of mechanical obstruction were compared. Temperature differences were not correlated to disease severity using canine APPLE<sub>fast</sub> scoring, noninvasive BP, or lactate.

\*Significant decreased in surface temperature at the site of the FBO after resolution.

31.7 °C (IQR, 30.2 to 33.6 °C). There was not a significant difference when comparing the T1 aboral and T2 aboral SI segments (Table 1). The median temperature for the T2 aboral was 31.6 °C (IQR, 29.9 to 32.9 °C). There was a significant difference between the T1 FBO and T2 FBO SI segments. The median temperature for the T2 FBO SI segment was 29.4 °C (IQR, 27.0 to 31.8 °C), which was 2.40 °C (IQR, -2.55 to 10.6 °C) colder than the T1 FBO SI segment, which was significant ( $P = .0043$ ). The differences in SI segment median temperatures were not correlated with the APPLE<sub>fast</sub> score, lactate, blood pressure at time of admission or image acquisition, surgery type, or foreign body material.

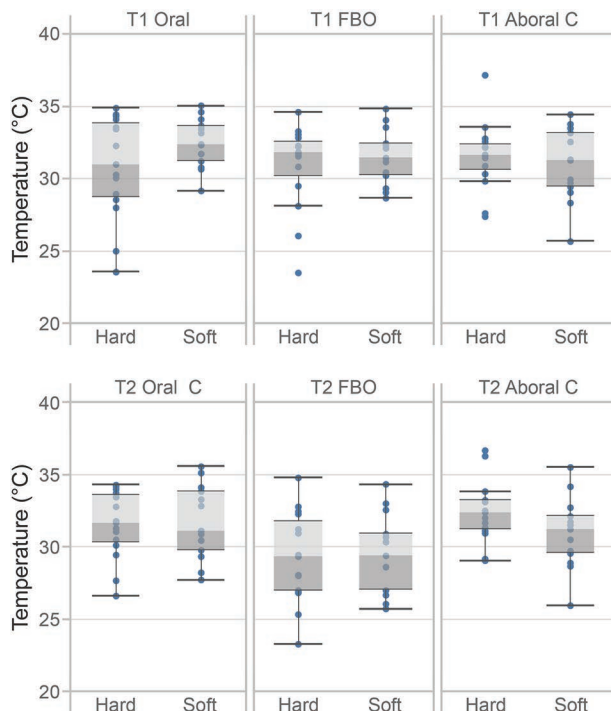
### Foreign body material

Foreign body material was classified as hard vs soft across the entire population. There were 19 instances of hard foreign body textures requiring enterotomies (13), gastrotomies (3), R&As (2), and via digital manipulation to the colon (1) to resolve the FBO. This included 44.2% of the total population (n = 43). There were 18 instances of soft foreign body textures requiring enterotomies (11), via digital manipulation to the colon (3), gastrotomies (2), and R&As (2) to resolve the FBO. This included

41.9% of the total population. There were 6 instances in which either the FBO was an unknown item or not recorded requiring enterotomies (2) and gastrotomies (2), digital manipulation to the colon (1), and R&A (1). The soft material included mostly cloth, and the hard material consisted of a variety of items including corn cobs, rocks, hard plastic, and other miscellaneous items.

A comparison was made between dogs with hard foreign body material vs soft (**Figure 3; Table 3**). The median T1 oral and aboral SI segment temperatures with a hard foreign body material were 31.0 °C (IRQ, 28.8 to 33.8 °C) and 31.7 °C (IRQ, 30.6 to 32.4 °C), respectively with a median difference of -1.7 °C (IQR, -5.2 to 3.4). The median T1 oral and aboral SI segment temperatures with a soft foreign body material were 32.4 °C (IRQ, 30.6 to 33.7 °C) and 31.3 °C (IRQ, 29.4 to 33.2 °C), respectively, with a median difference of +1.1 °C (IQR, 0.3 to 3.2 °C). These differences did not achieve significance ( $P = .08$ ). The difference between T1 oral and T1 FBO for hard material was 0.10 °C (IQR, -1.00 to 4.5 °C) and for soft material was 1.00 °C (IQR, -0.4 to 3.6 °C) and was not significant ( $P = .406$ ). The difference between T1 aboral and T1 FBO for hard material was 0.1 °C (IQR, -1.7 to 4) and for soft material





**Figure 3**—Box and whisker plot demonstrating the average small intestinal surface temperatures from dogs (n = 43) with FBO undergoing laparotomy from April 24, 2019, to July 19, 2020. Dogs were designated to have foreign material which was hard in texture or soft in texture. Small intestinal surface temperatures were obtained at time points T1 and T2. The center horizontal line inside the box represents the median temperature with upper and lower quartiles designated by the upper and lower margins of the box. Each individual dot represents the average ellipsoid temperature and whiskers represent 1.5 times the IQR. At the T1 time point, the intestinal segment oral to the FBO with soft material was warmer than both the site at the FBO and aboral to the soft FBO. In contrast the segment oral to the FBO with hard material was cooler than the segment aboral to the FBO. The difference between the T1 oral and aboral temperatures when correlated with foreign body texture was not significant ( $P = .08$ ).

**Table 3**—Table representing median differences in SI surface temperatures from dogs (n = 43) with foreign body obstruction undergoing laparotomy from April 24, 2019, to July 19, 2020.

Comparison	FB texture	Median difference (°C)	P value (Z value)
T1 oral to T1 aboral	Hard	-1.7 (IQR, -5.2 to 3.4)	.08 (1.75)
	Soft	+1.1 (IQR, 0.3 to 3.2)	
T1 oral to T1 FBO	Hard	+0.1 (IQR, -1 to 4.5)	.4066
	Soft	+1.0 (IQR, -0.4 to 3.6)	(0.83)
T1 aboral to T1 FBO	Hard	+0.1 (IQR, -1.7 to 4)	.269
	Soft	-1.3 (IQR, -2.2 to 1.4)	(-1.1)

Median differences in temperature compared between site of FBO with hard foreign material (n = 15) and soft foreign material (13) and adjacent oral and aboral SI segments at T1 of surgical resolution of mechanical obstruction.

was  $-1.3^{\circ}\text{C}$  (IQR,  $-2.2$  to  $1.4^{\circ}\text{C}$ ) and was not significant ( $P = .269$ ). The differences in SI segment median temperatures were not correlated with the APPLE<sub>fast</sub> score, lactate, or blood pressure at time of admission or blood pressure at the time of image acquisition.

All 43 dogs involved in the study survived to discharge with no incidence of dehiscence of the enterotomy, R&A, or gastrotomy sites before discharge. All dogs were alive at the 2-week recheck without clinical signs related to their previous mechanical obstruction or evidence of intestinal dehiscence.

## Discussion

Our findings support the feasibility of utilizing IRT in the intraoperative setting in dogs with FBO but were not definitive for its clinical utility. The utilization of IRT to assess local perfusion was elucidated, as we did not find a correlation between SI segment temperature differences and systemic parameters. This supports a potential application to for IRT to evaluate the local microcirculation of the small intestines in dogs or other species. We did find a significant decrease in average temperature at the segment of the intestine directly over the foreign body after the resolution of FBO. Previous studies<sup>18,19,22,23,30,31</sup> demonstrated a decrease in temperature was correlated with ischemic injury, histopathology, and decreased perfusion of the tissue. In our study, we found the temperature to be decreased at the site of FBO after resolution. A possible explanation for this decrease in temperature may be from local vasoconstriction secondary to incising the SI and placing sutures. Additionally, this area of the SI would have been outside of the body cavity longer than other areas of the SI resulting in a decreased surface temperature. There is a local inflammatory response induced by intraluminal damage, resulting in a release of vasodilatory mediators.<sup>4,17</sup> Therefore, if the FBO was causing significant inflammation but not to the point of ischemia, alleviating the obstruction could have diminished the local inflammation to the bowel, resulting in less dilation, blood flow and thereby a decrease in temperature.

Overall, we had considerable variations in mean surface temperature at all time points and SI segment locations as appreciated through the minimum and maximum temperatures (Figures 2 and 3). In some instances, there was a temperature range of over  $20^{\circ}\text{F}$ . While IRT is very effective at measuring temperature and sensitive to small changes, it is not without its own limitations.<sup>20</sup> Specific limitations in our study which could explain this variation include the length of time SI segments were exposed outside the body and differences in tissue moistening preferences between individual surgeons, variations in fluid resuscitation, variations in anesthetic medications administered, and variations in tissue handling especially with the many experience levels of surgeons in a teaching hospital. Radiometric thermal imaging is influenced by the ambient environment including the distance from the image and the angle

at which the image is obtained.<sup>20,32</sup> We attempted to control for these external factors by ensuring images were obtained within one meter of the tissue and at a 90° angle to the desired tissue site being evaluated. In addition, the operating room was set to a temperature of 68 °F and was observed to be within 1 °F at the time all images were acquired. When evaluating the thermal images using commercially available software, there can be great variation depending on the specific region of SI selected. The ellipsoid tool was utilized to help prevent these variables. The software averages the area incorporated within the ellipsoid icon to create an average surface temperature of that segment and avoid local discrepancies and personnel biases. This method has previously been successfully used in clinical feline aortic thromboembolism research.<sup>19</sup>

There was a surface temperature difference appreciated between the SI segments aboral and oral to the FBO when comparing soft and hard materials. While this did not achieve statistical significance, it suggests a potential impact of material on local blood flow. The differences appreciated relating to foreign body material may support changes in local blood flow to the SI segment. The segment oral to the FBO was warmer than both the site at the FBO and aboral to the soft FBO. This supports the pathophysiology of increased inflammation and blood flow orally to the FBO. In contrast, the cooler temperature appreciated with hard foreign body material may indicate that the more rigid material causes more ischemic injury and therefore more of a decrease in blood flow in comparison to the soft material. Soft material would less likely result in compression to the intraluminal wall, but still cause mucosal irritation, and thus inflammation over ischemic injury. This may represent an opportunity where the bowel may not require resection and IRT may be useful to elucidate this with further clinical studies. This difference appreciated between hard and soft materials failed to reach significance ( $P = .08$ ), which we suspect is type II error versus an insignificant difference relating to the limitations discussed above.

The population of dogs within our study may have led to the lack of significant difference in SI segment surface temperature appreciated. An initial power analysis was performed as part of an unpublished pilot study and suggested the temperature difference between FBO-affected and -nonaffected intestinal loops was approximately 2 °C, which is also consistent with the literature.<sup>23,31</sup> This would have required only 10 study dogs and 10 control dogs, and overall enrollment in the study group was intended to significantly exceed this. However, the temperature variability in this clinical patient population was much greater than the pilot group, which may have served to decrease the ability to detect significant differences. In addition, while there had been intent to compare dogs needing an enterotomy and dogs needing an R&A, only 5 out of 32 had the latter performed. This small number precluded statistical comparison. There was also no incidence of dehiscence in our population indicating that the

overall integrity of the bowel in our population was less compromised. Finally, our control population included dogs with a degree of diseased intestines, while we attempted to control for this by selecting bowel loops that were grossly normal future studies would benefit from using controls for patients having elective surgery not related to the small intestines.

Future directions for utilizing IRT to evaluate SI perfusion and account for limitations in our study could include a patient population exclusively with R&As as these demonstrate a more severe injury to the bowel. Additionally, utilizing other verified methods of evaluating microcirculation, such as side-stream dark field video microscopy, in addition to IRT may help validate changes in surface temperature.<sup>16</sup> Finally, ensuring the post-FBO SI segment had the opportunity to return to the abdomen may aid in the equilibration of temperature across the segments and thus provide a narrower variation in temperature. Alternatively, Pokorná et al<sup>18</sup> performed a “dynamic test” to help account for surface temperature changes that occur during a laparotomy, this same methodology could be applied in the clinical setting.

In conclusion, our study demonstrated that IRT remains a feasible diagnostic modality to identify changes in SI surface temperature relating to FBO. Further evaluation is warranted to determine if IRT may be a clinically applicable and noninvasive technique to evaluate intestinal perfusion.

## Disclosures

The authors declare that there were no conflicts of interest.

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## Supplementary Materials

Supplementary materials are posted online at the journal website: [avmajournals.avma.org](http://avmajournals.avma.org)