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REVIEW

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Real-time ancillary diagnostics for intraoperative assessment of intestinal viability in horses–looking for answers across species

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Abstract

Clinical intestinal viability assessment is associated with significant limitations, and there is an undisputable need for ancillary diagnostics during colic surgery. Human and companion animal surgeons struggle with similar intraoperative issues, yet there is little exchange between specialists. Therefore, this narrative review aimed to create an overview of real-time ancillary diagnostics with the potential for intraoperative intestinal viability assessment in horses. Most real-time ancillary diagnostics can be classified as either tissue perfusion or oxygenation assessments. Intestinal perfusion may be quantified using dark field microscopy, laser Doppler flowmetry, or fluorescence angiography (FA). In particular, indocyanine green FA has gained popularity in human medicine and is increasingly employed to predict intestinal injury. Intestinal oxygen saturation can be measured by pulse oximetry or mixed tissue oximetry. The latter can be conducted using visible light or near-infrared spectrophotometry, and these measurements correlate with clinical outcomes in various species. Other real-time diagnostics include thermography and techniques currently under development, such as laser speckle flowgraphy or photoacoustic imaging. The modalities discussed are minimally invasive and may be used for intraoperative assessments of the intestine. However, limitations include the occurrence of artifacts and the subjective nature of some modalities. Techniques such as indocyanine green FA and tissue oximetry are already available in veterinary practice and have the potential for use during colic surgery. However, blinded clinical trials are lacking in all species, and more research is needed to determine the accuracy and cutoff values in equine-specific intestinal lesions.

Abbreviations: AMI, acute mesenteric ischemia; FA, fluorescence angiography; Hb, hemoglobin; ICG, indocyanine green; LDF, laser Doppler flowmetry; NIR, near-infrared; NIRS, near-infrared spectrophotometry; POX, pulse oximetry; PPG, photoplethysmography; StO_2, tissue oxygen saturation; ViS, visible light spectrophotometry.

1 | INTRODUCTION

Intestinal viability assessment during colic surgery is currently based on clinical judgment.[1,2] For this evaluation, serosal or mucosal color, intramural hemorrhage, strictures, wall thickness, and intestinal contractions can be assessed.[1–3] Furthermore, the pulse in the mesenteric arteries and hemorrhage at an enterotomy site can be used as measures for local macroperfusion.[1–3] However, clinical assessment was shown to be unreliable for the prediction of injury in experimental models of small intestinal ischemia.[4] Furthermore, clinical studies have reported injury progression in small and large intestinal segments that looked viable, as well as segments deemed unviable that survived.[5–7] A semiquantitative score has been published to enable a more outcome-oriented clinical assessment of the small intestine.[3] Nonetheless, this cannot predict the progression of injury, and the applicability of this score in the ileum and colon remains unclear.

Despite the questionable accuracy of clinical viability assessment,[4] reliable ancillary diagnostics are lacking. A handful of studies have investigated different modalities for application in the ischemic equine intestine (Figure 1).[4,6–14] However, most studies date back to the previous century, and experimentally tested diagnostics have not found their way into clinical practice. The limitations of clinical viability assessment are also apparent in other species, with the accuracy for predicting irreversible intestinal injury ranging between 36% and 73% in experimental animal models.[15–21] In human medicine, intestinal injury has also been over- or underestimated, leading either to unnecessary intestinal resection or to an increased risk of postoperative complications.[22–26] Therefore, one can conclude that human and veterinary surgeons struggle with comparable intraoperative issues.

When comparing intestinal viability assessment between species, interspecies differences in pathogenesis and indications for intraoperative viability assessment should be considered. In dogs, foreign body obstruction with pressure necrosis of the intestinal wall is an important indication for intestinal viability assessment.[27] In human medicine, colorectal resection and anastomosis for cancer pose a significant risk for poor vascularization associated with ischemia and concurrent anastomotic leakage.[28] These ischemic lesions do not resemble the hemorrhagic strangulating obstructions typically seen in horses.[2] However, intestinal diseases such as volvulus, hernias, and intussusceptions occur in all species.[29–40] Despite this overlap in intestinal disease and the concurrent issue of viability assessment, there is little exchange of methods between respective specialists. Therefore, this narrative review aimed to create an overview of the real-time ancillary diagnostics for intestinal viability assessment, including the potential and availability for use during equine colic surgery.

2 | MATERIALS AND METHODS

The online databases Pubmed, CAB Abstracts, and Google Scholar were searched using combinations of "intestine," "bowel," "viability," and "assessment." Based on this search, a list of potential diagnostic modalities was compiled. Subsequently, further searches were conducted in the aforementioned databases using all individual modalities along with their

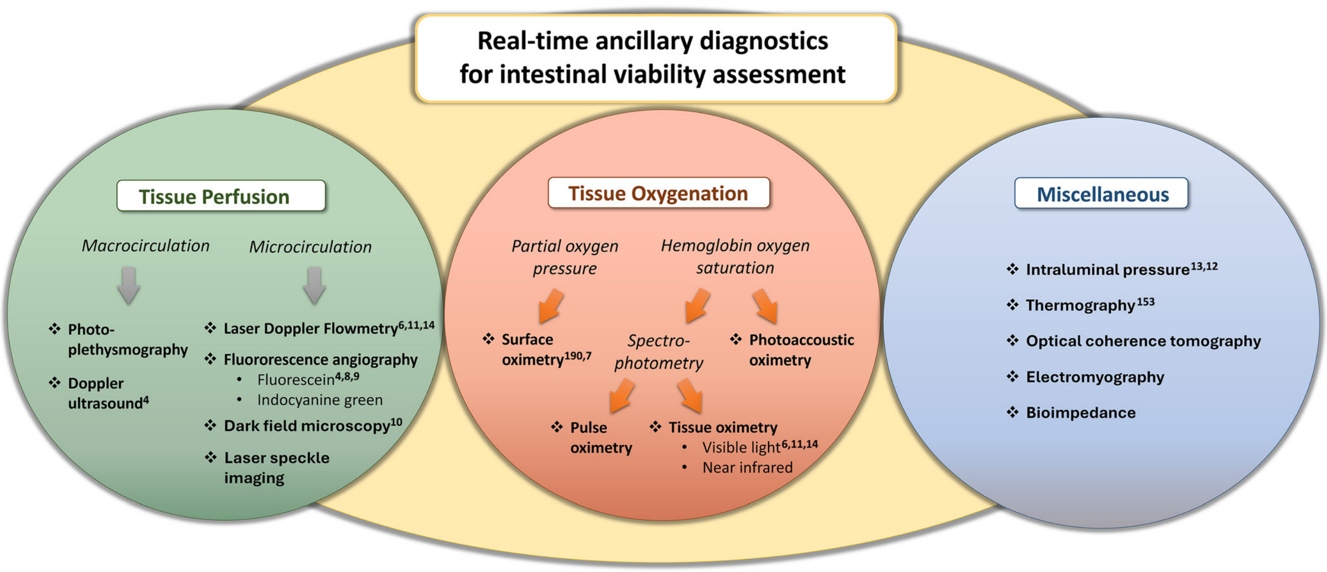

FIGURE 1 Diagram depicting the possible ancillary methods for intraoperative viability assessment of ischemic intestine. Sources that have reported the use of the modality in horses for intestinal viability assessment in experimental or naturally occurring intestinal ischemia are referenced as superscript numbers. Freeman et al.,[4] Verhaar et al.,[6] Verhaar et al.,[11] Verhaar et al.,[14] Sullins et al.,[8] Brusie et al.,[9] Hurcombe et al.,[10] Snyder et al.,[190] Snyder et al.,[7] Moore et al.,[13] Mathis et al.,[12] Purohit et al.[153]

synonyms, in combination with "equine," "horse," "intestine," "bowel," "strangulation," or "obstruction." During the preparation of the manuscript, additional searches were undertaken to gather further background information on the respective techniques. There was no restriction on the date of publication; however, papers written in a language other than English or German were excluded.

The titles and abstracts were evaluated for eligibility, and papers were included if they met the following criteria:

- Prospective or retrospective studies on the intraoperative use of a real-time measuring technique at some location in the gastrointestinal tract, with the goal of viability assessment in either experimental or naturally occurring ischemia of any species.
- Studies were also included if the technique was applied in healthy, non-ischemic intestine in the horse.

The following papers were excluded:

- Papers discussing modalities, such as the retrieval of microspheres, that are solely utilized for experimental purposes without any perspective for clinical use.
- Papers reporting histology as a single diagnostic modality.
- Retrospective single case reports in human medicine in the presence of >5 larger case series of the same diagnostic modality.

3 | REAL-TIME ANCILLARY DIAGNOSTICS WITH CLINICAL AVAILABILITY

Most techniques for assessing ancillary intraoperative intestinal viability quantify either tissue perfusion or tissue oxygenation (Figure 1). In addition, techniques that quantify tissue injury, metabolism, and motility were included in the miscellaneous category. The included modalities were restricted to those that are commercially available for clinical practice.

3.1 | Perfusion

Perfusion can be used as a measure of intestinal viability, and microvascular patency is associated with outcome after ischemic injury.[41] Because visual and palpatory assessment of perfusion is not considered reliable, minimally invasive diagnostic modalities have been developed to quantify tissue blood flow. Important characteristics of these modalities are the ability to obtain qualitative or quantitative measurements and whether they reflect either macro- or microperfusion (Figure 2). A quantitative assessment of microperfusion would be preferable as an objective and representative measure of tissue damage.

3.1.1 | Photoplethysmography

Photoplethysmography (PPG) detects volumetric changes of blood in the tissue, and it can therefore, be used to measure peripheral macroperfusion.[42] This technique is available in clinical practice because it is applied with pulse oximetry (POX) for anesthetic monitoring.[43,44] This modality has also been used without oximetry to assess intestinal perfusion in an experimental model of canine ischemia.[45,46] Limitations are the semiquantitative nature of the measurement and the detection of macroperfusion instead of microperfusion. Furthermore, blood flow under a certain threshold cannot be detected, thereby limiting the sensitivity of this instrument.[46] Because of these limitations, PPG is less suitable for intestinal viability assessment despite its widespread availability.

3.1.2 | Doppler flowmetry

Doppler ultrasound flowmetry was the first to apply the Doppler principle to assess intestinal viability. This technique has been implemented with varying results in experimental ischemia models in horses, dogs, rabbits, baboons, and human patients.[4,19,21,22,41,46–64] It was less reliable than other ancillary diagnostics,[45,61–64] and only yielded non-quantitative measurements of local macroperfusion.[22,46] Because of these limitations, the device has not found its way into clinical practice.

In contrast to Doppler ultrasound flowmetry, laser Doppler flowmetry (LDF) is a quantitative measurement of microperfusion, also referred to as laser Doppler velocimetry or fluxmetry. This modality is not routinely used in veterinary or human clinical practice, but devices are commercially available. This technique determines the velocity of the erythrocytes by detecting the Doppler shift induced by laser light on the moving erythrocytes. This is then used to quantify tissue blood flow.[65] The measurement can be obtained within seconds through direct contact with a probe on the serosal side of the intestine. The main limitation of this technique is the risk of significant motion artifacts that may occur due to intestinal motility or mechanical ventilation of the horse.[66,67] Furthermore, severe intramural hemorrhage could interfere with the light reflection, resulting in a limited penetration depth or the inability to obtain measurements in such cases.[6] One should also be aware of the small field of view, necessitating

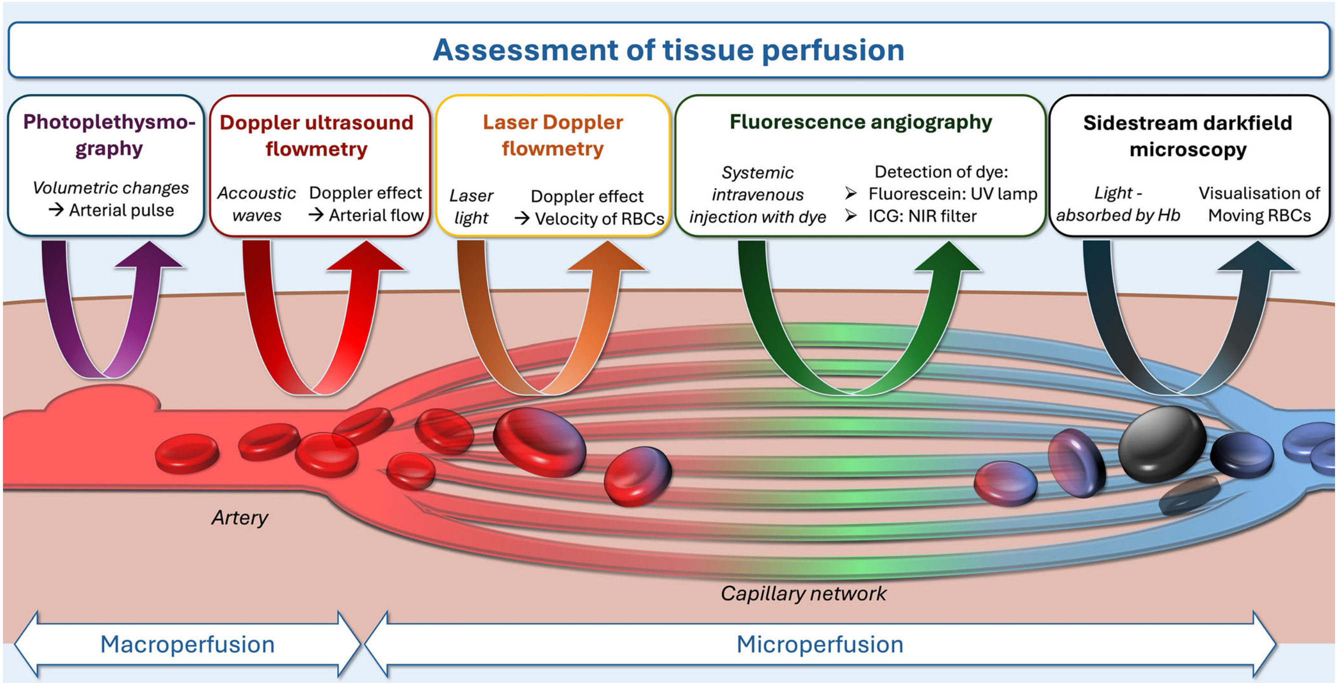

FIGURE 2 Schematic illustration depicting common techniques to assess tissue perfusion in the intestine. Hb, hemoglobin; ICG, indocyanine green; NIR, near infrared; RBCs, red blood cells; UV, ultraviolet.

multiple measurements to obtain information on the microperfusion in a larger area. Routine LDF has been adapted to measure larger tissue sections by scanning LDF.[68] However, this is not commercially available.

Evaluating the available evidence in horses, a device combining LDF with tissue oximetry has been used in naturally occurring intestinal strangulations during colic surgery.[6,11,14] One study, including 40 horses with small intestinal lesions, found lower tissue blood flow values in the affected segments compared to measurements in healthy anesthetized horses.[6,69] Furthermore, segments with more severe histological injury were associated with lower blood flow measurements.[6] Although cutoff values could not be determined due to the low sample size, tissue blood flow values <5% of previously determined reference values were indicative of intestinal necrosis.[6,69] Another clinical study, including 18 horses with large colon volvulus and descending colon strangulations, found lower colonic blood flow in non-survivors compared to survivors.[14]

In studies evaluating LDF in other species, a clinical trial in dogs with gastric dilatation and volvulus found that gastric tissue blood flow was lower in cases that required partial gastrectomy compared to those that did not necessitate resection.[36] Furthermore, LDF correlated well with histology, anastomotic leakage, and submucosal blood flow quantified with hydrogen gas clearance in experimental studies in dogs, pigs, cats, and rats.[70–75] A comparison of LDF to other modalities showed that LDF was more reliable than Doppler ultrasound flowmetry and POX.[18,62,63] Rabbit and canine studies comparing LDF to fluorescence angiography (FA) provided conflicting results, with both lower and higher accuracies for LDF reported in these studies.[18,62]

Laser Doppler flowmetry has also been applied in human patients with acute mesenteric ischemia (AMI) and intestinal strangulations. The modality was more accurate than clinical assessment in both small and large intestines, and it enabled the resection of shorter intestinal segments.[25,76] Furthermore, LDF could identify severe ischemic injury in the jejunum that was underestimated by clinical assessment.[77,78]

In summary, LDF has been successfully applied in horses with naturally occurring colic to identify intestinal ischemia, but more research is needed to determine its accuracy. Artifacts may be overcome by measuring at different locations and for more extended periods.[6] However, due to its susceptibility to motion artifacts, this technique requires handling by a trained operator, and the results need to be interpreted in the context of the intraoperative findings.

3.1.3 | Fluorescence angiography

Fluorescence angiography assesses intestinal microperfusion by evaluating the fluorescence pattern in the intestine following intravenous injection of dye agents. Older studies have used fluorescein as dye, assessing perfusion by the illumination of the intestine with ultraviolet light.[4] In the past decade, indocyanine green (ICG) dye has gained popularity in human medicine.[28,79–81] Indocyanine green is visualized using a near-infrared (NIR) imaging device or filter, and it can easily be applied in an endoscopic setting because no special light source is needed. Furthermore, vessels located deeper within the tissue can be visualized with this dye.[82] The fluorescence pattern can be evaluated within minutes following intravenous dye injection, either by direct visual qualitative evaluation or by quantitative fluorimetry.[83,84] Vessels that are not perfused cannot be visualized, so it is impossible to determine the proportion of perfused arterioles and capillaries contributing to the fluorescence.[85] With visual analysis, there is a lack of objectivity and poor agreement between operators, even with standardized protocols.[22,86,87] This can be improved using quantitative fluorimetry to monitor dye elimination and uptake or by implementing artificial intelligence for pixel analysis.[88,89] Another limitation of this technique is the persistence of dye in the tissue. Therefore, the measurement cannot be repeated within a short timeframe. Quantitative fluorimetry may solve this issue by subtracting the remaining fluorescence of previous injections from new post-injection values.[88] It has been hypothesized that FA is less applicable in thicker tissue, such as the stomach wall,[36] yet primary sources are lacking. No adverse reactions to dye application have been described.

In horses, only fluorescein dye has been used for intestinal viability assessment. One equine experimental small intestinal study found that FA had a worse overall accuracy than Doppler ultrasound flowmetry.[4] Another small intestinal study reported both patchy and normal fluorescence patterns in ischemic segments. More importantly, these segments were not normal at second-look laparotomy 1 month after the first surgery, thereby questioning the sensitivity of this technique to detect irreversible changes.[8] Fluorescein FA could differentiate small intestinal hemorrhagic strangulating obstructions from uninjured control segments and ischemic strangulating obstructions. However, FA could not distinguish between ischemic strangulating obstructions and uninjured control segments.[9] Consequently, FA appeared to be less reliable in ischemic strangulating obstructions. There are no reports on using FA in naturally occurring ischemia in horses.

Evaluating the evidence in other animals, there is only one report of the clinical use of FA in the canine intestine. These authors reported the application of ICG for the resection of intestinal neoplasia but not for viability assessment.[90] In experimental ischemia in rats, pigs, and dogs, fluorescein FA was more reliable than clinical assessment, and FA could differentiate between ischemic and viable bowel segments in both open surgery and laparoscopic settings.[41,85,91,92] However, it should be noted that two studies identified hyperfluorescent patterns that incorrectly suggested viability in intestinal segments that would progress to necrosis.[83,88] According to a study using ICG FA in rats and pigs with experimental small intestinal ischemia, a filling defect in the fluorescence pattern was 85% accurate in predicting histological injury grade.[84]

In human medicine, fluorescein FA has successfully been used for intestinal viability assessment in AMI and strangulating lesions, as well as for the transplantation of a free jejunal graft for esophageal resection.[22,26,58,93] In two of these studies, FA was more accurate than Doppler ultrasound.[22,58] Furthermore, FA could predict intestinal perforation in patients with intramural hemorrhage following abdominal trauma.[94] Nonetheless, all studies using fluorescein as a dye date back to the previous century, and all newer reports have focused on ICG FA. Looking at the available evidence for the use of ICG FA in patients with strangulating lesions or AMI, only one prospective trial was published. In 38 patients with strangulating lesions, a laparotomy with clinical assessment only was compared to a laparoscopic procedure with ICG FA. The authors reported a higher complication rate in the laparotomy group, but the allocation of the patients was not randomized, thereby limiting the value of this trial.[95] Furthermore, many authors have reported the use of ICG FA during laparotomy or laparoscopy without comparing it to other techniques.[87,96–102] The main result of these case series was that ICG FA was a useful intraoperative tool to determine the need for and/or the location of intestinal resection.[87,96–102] No adverse effects were reported, and the additional surgery time was considered minor. The only negative finding was that ICG FA underestimated ischemic injury in 3/91 and 2/52 patients in two larger case series.[101,102] Despite these positive reports, a recent survey among emergency surgeons found that ICG FA is still not established as a routine technique in an emergency setting.[103] This is most likely the result of limited training, the availability of NIR imaging during emergency surgeries, and a lack of standardized protocols for this procedure. The main indication to use ICG FA in human medicine is to evaluate the viability and determine the location of resection margins in colorectal surgery. Although one randomized controlled multicenter clinical trial failed to identify a difference in anastomotic leakage rate,[104] meta-analyses based on retrospective studies have generally concluded that the use of ICG FA reduces the occurrence of anastomotic leakage.[28,79–81]

In summary, this technique may be suitable as an intraoperative ancillary diagnostic during colic surgery despite the identified limitations. The clearance of ICG has been investigated in horses,[105,106] and ICG has been used for ocular FA and experimental endoscopic laser surgery of upper airway tissue.[107,108] Modern endoscopy units in equine practice can be equipped with NIR filters, and ICG dye is readily available. Based on one early study using fluorescein as a dye, FA may be more useful in hemorrhagic strangulating obstructions.[9] Still, more research is needed to determine the applicability of (ICG) FA in naturally occurring intestinal diseases. The subjective nature of visual assessment remains a significant limitation. Quantitative methods may improve this, but these are currently unavailable in clinical practice.

3.1.4 | Sidestream darkfield microscopy

Sidestream darkfield microscopy is based on the principle of orthogonal polarization spectral imaging. With this technique, the tissue is illuminated with a wavelength absorbed by hemoglobin, making red blood cells appear dark. This enables visualization of the red blood cells flowing through the tissue.[109] These microperfusion measurements are performed with a videoscope handpiece coupled to a monitor for real-time evaluation. Devices are commercially available but not routinely used in clinical practice. The main limitation of this technique is the superficial nature of the measurements, which only reflect serosal microperfusion. Furthermore, bowel peristalsis and pressure of the device on the tissue surface can lead to significant artifacts.[110]

In horses, darkfield microscopy has been applied during colic surgery. Perfusion patterns were compared between 9 control horses and 23 horses with different large intestinal diseases, including simple obstruction, non-strangulating colon displacement, and large colon volvulus.[10] Although differences were found between the cases with simple obstructions and strangulating lesions, dark field microscopy could not differentiate between strangulating and non-strangulating colon displacements.[10]

Looking at the evidence in other species, dark field microscopy failed to detect a difference between viable and nonviable intestinal segments in dogs with intestinal foreign body obstructions.[111] In contrast, one human study found lower perfusion indices in patients with colorectal anastomotic leakage compared to patients without anastomotic leakage.[112,113]

In conclusion, it is technically feasible to apply darkfield microscopy during colic surgery, but based on the current evidence, the sensitivity and diagnostic value of this modality may be limited.

3.2 | Oxygenation

The oxygenation of intestinal tissue reflects the quality of tissue perfusion and may be used as a measure for tissue injury and the ability to restore blood flow.[114] Tissue oxygen saturation is determined by the ratio of oxygenated and deoxygenated hemoglobin (Figure 3). This can be quantified by spectral measurements referred to as spectrophotometry or spectroscopy. The spectral properties of horse hemoglobin are nearly identical to those of other species, including humans, thereby facilitating interspecies comparison and the use of devices developed for human application.[115,116] Many oximetry devices are readily available in veterinary practice because of their use in anesthetic monitoring. Measurements are performed in real time through direct contact with the intestinal tissue. To ensure sterility, transparent ultrasound sleeves have been used around the sensor without any reported effects on the measurements,[6,117] but the risk of light attenuation should be considered. Oximetry is less susceptible to motion artifacts than flow measurements, but severe intramural hemorrhage, local pigmentation, and ambient light can interfere with spectrophotometric measurements.[43,44,69,118]

3.2.1 | Pulse oximetry

Pulse oximetry assesses arterial oxygen saturation in the tissue by combining the principle of spectrophotometry with PPG. As stated previously, PPG determines the peak of the arterial pulse, enabling the calculation of arterial saturation in the tissue at this time.[43,44] In addition to the limitations mentioned above for spectrophotometric measurements, POX may fail to obtain readings in tissue with local vasoconstriction or decreased blood flow.[43,44,118]

In horses, POX has only been applied to the small and large intestines of healthy individuals.[116] It was possible to measure oxygen saturation in the equine intestine, but POX measurements were lower than calculated arterial measurements.

In other species, POX has also been used to assess ischemic intestine. The only available clinical animal study was performed in cows, investigating the use of intestinal POX in cases with abomasal displacements.[119] Decreasing saturation was associated with increasing intraluminal pressures, but the study did not correlate the measurements with histology or outcome. Several experimental studies in models of canine small intestinal ischemia found that POX correlated well with mucosal injury.[61,120–123] One study indicated a cutoff value of 70% to predict anastomotic leakage.[120] In contrast to the positive results in dogs, experimental studies in rabbit small intestines reported relatively low accuracies of 58%–76% in detecting ischemic intestines.[18,20,124,125]

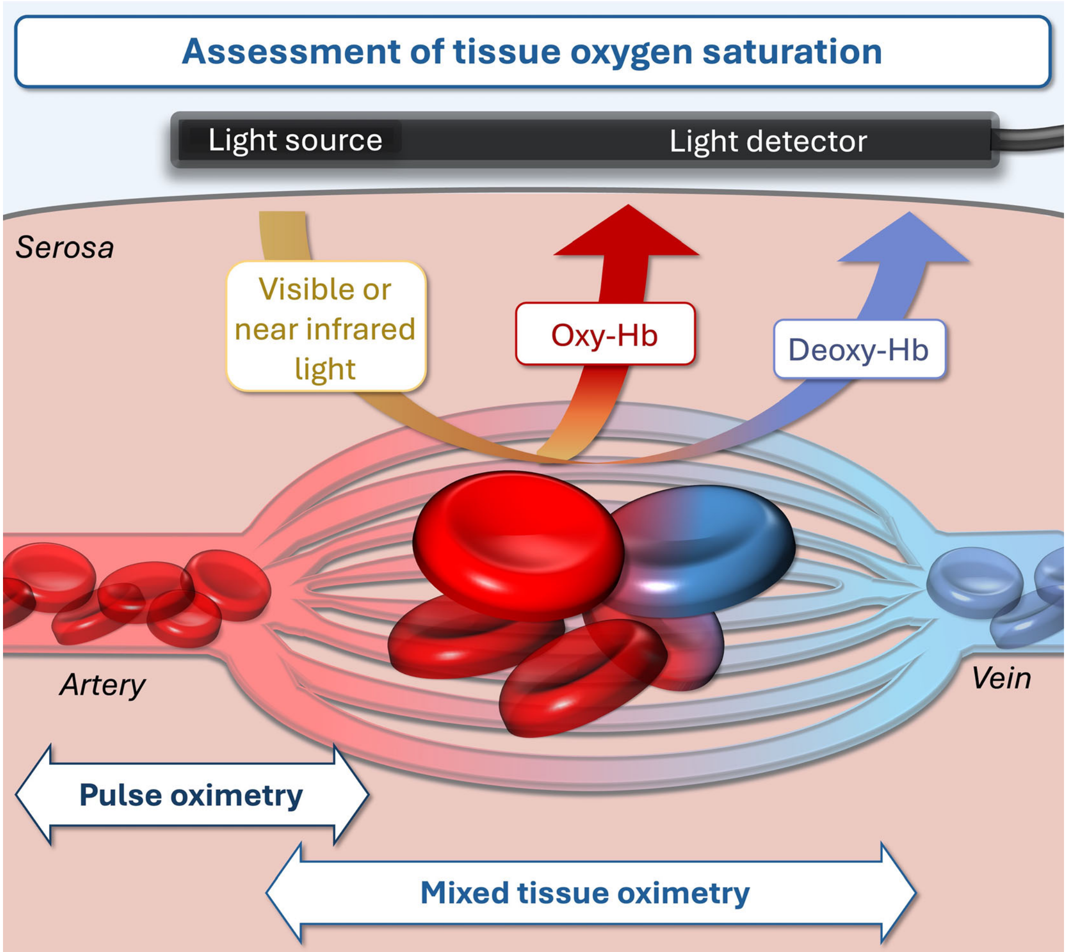

FIGURE 3 Schematic illustration depicting techniques to assess oxygen saturation of the intestine. Hb, hemoglobin.

In human medicine, there have been larger clinical trials applying POX in patients undergoing colorectal cancer surgery. These studies found that patients with <90% oxygen saturation at the resection margins were more likely to develop anastomotic leakage.[126,127] The application of POX in human strangulating intestinal disease has only been documented in single case reports. These authors found that POX was useful in determining the resection location in a colon volvulus and a strangulated stomach.[128,129]

In summary, despite several positive reports and the widespread availability of POX in clinical practice, it is not generally used for intestinal viability assessment. This technique may be useful in individual cases, but its low accuracy in the presence of decreased blood flow or vasoconstriction would limit its applicability in many clinical cases.

3.2.2 | Tissue oximetry

Tissue oximetry differs from POX because it assesses the mixed tissue saturation (StO_2) independent of the arterial pulsative signal. For this purpose, the spectral properties of total tissue hemoglobin are determined by diffuse reflectance spectrophotometry. These measurements are performed with either near-infrared light spectrophotometry (NIRS) or with white or visible light spectrophotometry (ViS). Mainly NIRS is commonly used in human practice to monitor muscle and cerebral StO_2 during anesthesia,[130] and it has also been used for this purpose in horses.[131–133] Compared to ViS, NIRS can obtain deeper measurements due to its longer wavelength.[134] Generally, these are larger monitoring systems with sensors connected by cables. However, small handheld devices are now available for intraoperative use in humans.[135,136]

Evaluating the evidence in horses, a device combining ViS and LDF has been applied in naturally occurring small and large intestinal strangulating lesions. Similar to the results of the LDF measurements described in the perfusion section, the affected intestines exhibited lower StO_2 values compared to reference values.[6,14,69] In the small intestinal study, no significant difference in StO_2 could be found between different degrees of histological injury, possibly caused by the low number of horses with mild histological injury. The StO_2 was also measured in the small intestinal segment orad to the strangulation, and cases with StO_2 <35% were more likely to suffer from postoperative reflux compared to cases with StO_2 >69%.[11] In the large intestinal study, survivors had significantly higher colonic StO_2 values than non-survivors. Similar to the LDF perfusion measurements, StO_2 values <10% of previously determined reference values were indicative of intestinal necrosis.[6,14] These studies did not calculate the sensitivity and specificity of this modality because the case numbers were too low. It should also be noted that StO_2 could not be measured in some of the cases with severe intramural hemorrhage.[6,14] One other equine study investigated the association between StO_2 and small intestinal wall thickness but found no correlation.[137] Devices using NIRS technology have not been applied in the equine intestine.

Looking at the available literature in other animals, ViS and NIRS have been applied in experimental ischemia in rats and pigs. Tissue oxygen saturation of severely affected segments did not return to baseline, and StO_2 aided in predicting anastomotic leakage and the survival of free jejunal grafts.[117,138–143]

In human medicine, both ViS and NIRS have been used in patients undergoing colorectal surgery. Anastomoses with increasing StO2 values during surgery would go on to heal uneventfully.[144] Furthermore, a StO_2 of <60% was indicative of anastomotic complications.[144–146] Two studies using ICG FA as the gold standard found sensitivities and specificities >90% with a handheld NIRS device, and none of the patients suffered any anastomotic complications.[135,136]

In summary, the evidence suggests that ViS and NIRS may be useful for intraoperative viability assessment, with increasing availability in clinical practice due to their use in anesthetic monitoring. Nonetheless, it should be noted that measurements may not be feasible in all cases with severe intramural hemorrhage. Higher case numbers are necessary to assess the accuracy in different types of strangulating lesions, and cutoff values must be determined before widespread clinical use.

3.3 | Miscellaneous

3.3.1 | Intraluminal pressure

Intraluminal pressure measurements can quantify intestinal distention, and this has been proposed as a possible indicator of intestinal damage in horses with large colon volvulus.[12] This technique can be performed by introducing a needle into the intestinal lumen, connected by tubing to a manometer to measure intraluminal pressure as a measure for colonic distention in a real-time fashion. The initial report, including 69 horses with non-strangulating and strangulating obstructions of the ascending colon, yielded promising results with sensitivity and specificity of around 90% to detect non-survival.[13] However, another research group found this technique inaccurate in predicting survival in 57 horses with large colon volvulus.[12] To the authors' knowledge, this modality has not been applied as a diagnostic parameter for intestinal viability assessment in other species. How intraluminal pressure would relate to intestinal viability in different disease entities and anatomical sections remains questionable. This technique may be applicable in certain large intestinal cases to determine the postoperative prognosis, but it will not be of use as a general measure of intestinal viability.

3.3.2 | Thermography

Thermography uses an infrared camera to detect changes in tissue surface temperature, which can be used as an indicator for tissue metabolism and perfusion.[147] It is a widely available and cost-effective technique, but some limitations should be considered. The ambient environment influences the measurement, and factors such as angle and distance affect the thermal image.[148,149] The analysis of the color patterns can be done visually, but quantitative software analysis allows for a more detailed and objective evaluation.[150]

In the horse, this technique is available for orthopedic indications,[151,152] but it is not used during abdominal surgery. One preliminary experimental equine study reported temperature differences between the mesenteric border of the ischemic and nonischemic bowel, possibly indicating inadequate revascularization.[153] However, there are no reports on the application of thermography in clinical cases during colic surgery.

Evaluating the evidence in other species, reactive hyperthermia following ischemia was associated with survival in small intestinal experimental ischemia in dogs and rats.[15,154,155] Furthermore, intestinal surface temperature was evaluated in 49 dogs undergoing surgery for small intestinal foreign body obstruction.[150] There was a decrease in temperature over the foreign body following the resolution of the obstruction, but the study did not assess the association with histology or outcome. In a porcine model for colon anastomoses, thermography was more reliable than ICG FA, especially when evaluating the return to normal temperature following active cooling of the intestine.[156] Thermography has also been used for viability assessments in human patients during colorectal surgery. Here, it was successfully used for sequential viability assessments in addition to ICG FA.[157–159]

Thermography could be feasible for intraoperative viability assessment due to its availability in clinical practice and noninvasiveness. However, the risk of inconsistent measurements due to differences in environment and operator handling needs to be considered. Furthermore, current evidence may support the use of thermography in ischemic strangulating obstructions, but studies in hemorrhagic strangulating obstructions are lacking.

3.3.3 | Electromyography

Electromyography can be used as a measure of intestinal viability by assessing the contractile ability of the intestine in response to electric stimuli. In equine medicine, this technique is currently only used for measurements in skeletal muscle to diagnose myopathies and neuropathies.[160] Larger veterinary facilities may be equipped with this device, mainly for diagnostic purposes in small animal neurology.[161,162] There is some evidence for the diagnostic value of electromyography in rabbit and canine ischemia models, as well as in human patients with intestinal ischemia.[21,53,54,163–166] However, electromyography cannot be considered a non-invasive diagnostic because it necessitates puncturing the tissue, with reported complications in musculoskeletal tissue.[167] An adaptation of this technique using surface electrodes has been described, but to the authors' knowledge, this has not been applied for the purpose of intestinal viability assessment.[168]

3.3.4 | Bioimpedance measurements

Comparable to electromyography, bioimpedance applies an electric current to the tissue, but instead of measuring tissue contractility, bioimpedance measures tissue resistance as an indicator of tissue composition.[169,170] Surface electrodes are used for this purpose; hence, puncturing of the tissue is not necessary. Commercial devices have been used in horses in experimental settings to assess body composition, transcranial impedance, and the state of muscle tissue.[171–173] However, bioimpedance has only been applied in the intestine in a porcine ischemia model and in human intestines ex vivo.[174,175] In these studies, bioimpedance could differentiate ischemic from normal intestine, and machine learning was shown to increase the reliability of this assessment.[175] However, it has not been applied in naturally occurring ischemia cases, and its applicability in intestinal viability assessment remains unclear.

4 | TECHNIQUES IN DEVELOPMENT

In addition to the techniques mentioned in the previous section, new modalities have been developed to meet the need for improved ancillary diagnostics. These techniques have not been applied in the equine intestine and are currently unavailable in clinical practice. However, these modalities may hold promise for future applications and are briefly summarized in the following section.

4.1 | Laser speckle contrast flowgraphy

Laser speckle contrast flowgraphy measures the movement of red blood cells by analyzing speckle patterns generated by the reflection of laser light.[176] It relies on a principle similar to LDF, but it is used in a non-contact fashion, creating a velocity map of the blood flow.[176] Consequently, it can measure a much greater tissue area than LDF. In a porcine model for colon anastomoses, laser speckle contrast imaging was used to assess local intestinal perfusion in a laparoscopic setting.[177–180] Subsequently, the technique was applied in human patients undergoing colorectal anastomosis.[181–183] It could detect differences in perfusion after the ligation of marginal vessels, and inter-rater reliability was high. However, the use of this device did not reduce the incidence of anastomotic leakage. A limitation of this technique is the semiquantitative and subjective nature of speckle pattern assessment, which is also influenced by the positioning of the imaging device.[176,184] Artificial intelligence has been used to facilitate a more quantitative analysis and may increase the accuracy.[179]

4.2 | Photoacoustic imaging

Photoacoustic imaging also uses laser light, but this technique assesses tissue oxygen saturation instead of perfusion. The laser light generates ultrasonic waves that detect the tissue's relative amounts of oxygenated and deoxygenated hemoglobin.[185] In rats and mice, photoacoustic imaging could detect intestinal ischemia and it correlated well with histology.[186–188] This technique is seen as an emerging imaging modality for specific fields in human medicine, but its limited availability and complicated technique restrict its current use in clinical practice.

4.3 | Oximetry chip technology

Surface oximetry using a modified Clark electrode[189] has been used to determine serosal pO_2 in experimental and naturally occurring large intestinal ischemia in horses.[7,190] However, nonviable colon was only accurately identified in 53% of the cases,[7] and research in canine and rabbit ischemia models has also yielded varying accuracies.[19,52,122,191] Furthermore, the equipment is not readily available, and the technique has several limitations, such as the very localized nature of the measurement and the necessity to puncture the intestine with the electrode.[189] Nonetheless, a more recent study investigated the use of a small chip that could measure pO_2 following implantation in rat intestine.[192] This technique enables continuous perioperative pO_2 measurement, which could be useful for postoperative monitoring of segments with questionable viability. Currently, this chip is not commercially available, and it has not been validated for clinical application.

4.4 | Optical coherence tomography

Optical coherence tomography is a relatively new imaging modality that can assess tissue structure in real-time. It can be regarded as optical histology by detecting changes in tissue structure or microcirculation through differences in light reflection.[193,194] In horses, this modality has only been used to visualize Descemet's membrane detachments.[195] In other species, studies have mainly focused on intraluminal imaging of gastric lesions, polyps, and inflammatory bowel disease.[196] However, optical coherence tomography has also successfully been used for real-time imaging of tissue injury in experimental rodent ischemia and human patients with AMI.[197,198]

5 | LIMITATIONS

Evaluating the current evidence for real-time intraoperative intestinal viability assessment, reveals several limitations. First, most studies were performed under experimental conditions. Using experimental ischemia models to validate intestinal viability assessment should be questioned because ischemia models are not necessarily representative of clinical ischemia. In some studies, the accuracy of a modality was based on the ability to differentiate between normal and ischemic intestines. This does not represent the clinical situation, where ancillary methods are mainly needed for cases with dubious viability according to clinical judgment. Looking at the available clinical trials, this reveals that most were single-center and that they were not controlled, randomized, or blinded. Most experimental studies that compared different modalities were also not blinded when comparing different modalities. For the validation of a device for intraoperative use, blinding the surgeon for the result of the measurement can ensure that intraoperative decisions are taken irrespective of the measurement. Not doing so poses a risk of bias, which needs to be considered when interpreting study results. Only a few authors have reported cutoff values or reference ranges, and many studies had low case numbers or a heterogeneous case population. Furthermore, research groups tended to focus on one single modality, and initial positive results could not always be matched in subsequent trials.

6 | FUTURE DIRECTIONS

The limited accuracy of clinical intestinal viability assessment has long been established, and the intraoperative use of ancillary diagnostics may improve these assessments. The considerable analogies between intestinal diseases in different species can be used to adapt existing strategies for use in horses. When extrapolating the research destined for companion animals and humans to the equine intestine, one should critically reflect on which ischemia model and outcome variable was used. Regardless of interspecies differences, these studies give valuable information on the functionality of a diagnostic modality in intestinal tissue, as well as the quantitative potential and possible limitations. Modalities such as tissue oximetry, ICG FA, and thermography are available in veterinary practice, and larger facilities may already be in possession of appropriate devices, such as NIRS monitoring equipment. Although these devices are currently not used for intestinal viability assessment in horses, they can potentially be used during colic surgery. However, the available evidence also highlights limitations that must be investigated in equine-specific strangulating lesions before basing any intraoperative decisions on these measurements. The techniques discussed are minimally invasive, potentially justifying research in clinical patients following initial testing of the modality. Consequently, validating techniques for an equine colic surgery setting may be facilitated by collecting data from multiple centers and higher case numbers. Furthermore, blinded clinical trials are required in both veterinary and human medicine to determine the accuracy and cutoff values of the different techniques. Interspecies exchange may facilitate the adaptation of quantitative assessment strategies and establishing reference ranges for intestinal saturation or perfusion indices.

AUTHOR CONTRIBUTIONS

Verhaar N, DVM, PhD, DECVS: Contributed to conception and design, data acquisition, analysis and interpretation and preparation of manuscript and figures. Geburek

F, Dr med vet, DECVS, DECVSMR: Contributed to conception and design and edited the draft. All authors provided a critical review of the manuscript and endorse the final version. All authors are aware of their respective contributions and have confidence in the integrity of all contributions.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

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REFERENCES

1. Cook VL, Blikslager AT, Marschall JF. Chapter 34 principles of intestinal injury and determination of intestinal viability. In: Auer JA, Stick JA, Kuemmerle JM, et al., eds. *Equine Surgery*. 5th ed. Elsevier; 2019.
2. Gonzalez L. Chapter 43 intestinal viability. In: Blikslager AT, White NA, Moore JN, et al., eds. *The Equine Acute Abdomen*. 3rd ed. John Wiley & Sons; 2017.
3. Freeman DE, Schaeffer DJ, Cleary OB. Long-term survival in horses with strangulating obstruction of the small intestine managed without resection. *Equine Vet J*. 2014;46:711-717.
4. Freeman D, Gentile D, Richardson D, et al. Comparison of clinical judgment, Doppler ultrasound, and fluorescein fluorescence as methods for predicting intestinal viability in the pony. *Am J Vet Res*. 1988;49:895-900.
5. Mair T, Smith L. Survival and complication rates in 300 horses undergoing surgical treatment of colic. Part 4: early (acute) relaparotomy. *Equine Vet J*. 2005;37:315-318.
6. Verhaar N, Grages AM, Bienert-Zeit A, et al. Flowmetry and spectrophotometry for the assessment of intestinal viability in horses with naturally occurring strangulating small intestinal lesions. *Equine Vet J*. 2024;56(6):1138-1148.
7. Snyder JR, Pascoe JR, Meagher DM, Thurmond MC. Surface oximetry for intraoperative assessment of colonic viability in horses. *J Am Vet Med Assoc*. 1994;204:1786-1789.
8. Sullins KE, Stashak TS, Mero KN. Evaluation of fluorescein dye as an indicator of small intestinal viability in the horse. *J Am Vet Med Assoc*. 1985;186:257-261.
9. Brusie R, Sullins K, Silverman D, Rosenberger JL. Fluorometric evaluation of large and small intestinal ischaemia in the horse. *Equine Vet J*. 1989;21:358-363.
10. Hurcombe SD, Welch BR, Williams JM, Cooper ES, Russell D, Mudge MC. Dark-field microscopy in the assessment of large colon microperfusion and mucosal injury in naturally occurring surgical disease of the equine large colon. *Equine Vet J*. 2014;46:674-680. doi:10.1111/evj.12202
11. Verhaar N, Grages AM, Sauer FJ, et al. Measuring tissue oxygen saturation in the orad intestinal segment during equine colic surgery may aid in predicting the occurrence of postoperative ileus. *Am J Vet Res*. 2024;85(7):ajvr.23.12.0286.
12. Mathis SC, Slone DE, Lynch TM, et al. Use of colonic luminal pressure to predict outcome after surgical treatment of strangulating large colon volvulus in horses. *Vet Surg*. 2006;35:356-360.
13. Moore RM, Hance SR, Hardy J, et al. Colonic luminal pressure in horses with strangulating and nonstrangulating obstruction of the large colon. *Vet Surg*. 1996;25:134-141.
14. Verhaar N, Reineking W, Hewicker-Trautwein M, et al. Flowmetry and spectrophotometry can detect reduced intestinal microperfusion in nonsurvivors during equine colic surgery for large intestinal strangulation. *Am J Vet Res*. 2024;85(10):ajvr.24.05.0142.
15. Bussemaker J, Lindeman J. Comparison of methods to determine viability of small intestine. *Ann Surg*. 1972;176:97.
16. Strand-Amundsen RJ, Reims HM, Reinholt FP, et al. Ischemia/reperfusion injury in porcine intestine - viability assessment. *World J Gastroenterol*. 2018;24:2009-2023.
17. Papachristou D, Fortner JG. Prediction of intestinal viability by intra-arterial dye injection: a simple test. *Am J Surg*. 1976;132:572-574.
18. Liao X-p, She Y-x, Shi C-r, Zhang Z-d, Li M. Comparison of methods for the determination of viability of ischemic rabbit intestine. *Pediatr Surg Int*. 1994;9(3):193-195. doi:10.1007/BF00179610
19. Holmes NJ, Cazi G, Reddell MT, et al. Intraoperative assessment of bowel viability. *J Invest Surg*. 1993;6:211-221.
20. Erikoglu M, Kaynak A, Beyatlı EA, Toy H. Intraoperative determination of intestinal viability: a comparison with transserosal pulse oximetry and histopathological examination. *J Surg Res*. 2005;128:66-69.
21. Brolin R, Semmlow J, Sehonanda A, et al. Comparison of five methods of assessment of intestinal viability. *Surg Gynecol Obstet*. 1989;168:6-12.
22. Bulkley GB, Zuidema GD, Hamilton SR, et al. Intraoperative determination of small intestinal viability following ischemic injury: a prospective, controlled trial of two adjuvant methods (Doppler and fluorescein) compared with standard clinical judgment. *Ann Surg*. 1981;193:628-637.
23. Käser SA, Willi N, Maurer CA. Mandatory resection of strangulation marks in small bowel obstruction? *World J Surg*. 2014;38:11-15.
24. Karliczek A, Harlaar N, Zeebregts C, et al. Surgeons lack predictive accuracy for anastomotic leakage in gastrointestinal surgery. *Int J Colorectal Dis*. 2009;24(5):569-576. doi:10.1007/s00384-009-0658-6
25. Redaelli CA, Schilling MK, Büchler MW. Intraoperative laser Doppler flowmetry: a predictor of ischemic injury in acute mesenteric infarction. *Dig Surg*. 1998;15:55-59.
26. Bala M, Catena F, Kashuk J, et al. Acute mesenteric ischemia: updated guidelines of the world Society of Emergency Surgery. *World J Emerg Surg*. 2022;17:54.
27. Mullen KM, Regier PJ, Ellison GW, Londoño L. The pathophysiology of small intestinal foreign body obstruction and intraoperative assessment of tissue viability in dogs: a review. *Top Companion Anim Med*. 2020;40:100438.
28. Zhang W, Che X. Effect of indocyanine green fluorescence angiography on preventing anastomotic leakage after colorectal surgery: a meta-analysis. *Surg Today*. 2021;51:1415-1428.

29. Proudman C, Edwards G, Barnes J, French NR. Factors affecting long-term survival of horses recovering from surgery of the small intestine. *Equine Vet J*. 2005;37:360-365.
30. Mair T, Smith L. Survival and complication rates in 300 horses undergoing surgical treatment of colic. Part 1: short-term survival following a single laparotomy. *Equine Vet J*. 2005;37:296-302.
31. Martin LC, Merkle EM, Thompson WM. Review of internal hernias: radiographic and clinical findings. *Am J Roentgenol*. 2006;186:703-717.
32. Lee SH, Lee SH. Spontaneous transomental hernia. *Ann Coloproctol*. 2016;32:38.
33. Chen P, Huang L, Yang W, et al. Risk factors for bowel resection among patients with incarcerated groin hernias: a meta-analysis. *Am J Emerg Med*. 2020;38:376-383.
34. Bayeh AB, Abegaz BA. Seasonality of primary small bowel volvulus and its variations based on sex and place of residence, North Western Ethiopia. *Cureus*. 2022;14(7):e27478.
35. Marsicovetere P, Ivatury SJ, White B, et al. Intestinal intussusception: etiology, diagnosis, and treatment. *Clin Colon Rectal Surg*. 2017;30:30-39.
36. Monnet E, Pelsue D, Macphail C. Evaluation of laser Doppler flowmetry for measurement of capillary blood flow in the stomach wall of dogs during gastric dilatation-volvulus. *Vet Surg*. 2006;35:198-205.
37. Gagnon D, Brisson B. Predisposing factors for colonic torsion/volvulus in dogs: a retrospective study of six cases (1992-2010). *J Am Anim Hosp Assoc*. 2013;49:169-174.
38. Hassinger KA. Intestinal entrapment and strangulation caused by rupture of the duodenocolic ligament in four dogs. *Vet Surg*. 1997;26:275-280.
39. McLaughlin R Jr, Kuzma AB. Intestinal strangulation caused by intra-abdominal lipomas in a dog. *J Am Vet Med Assoc*. 1991;199:1610-1611.
40. Itoh T, Kojimoto A, Kojima K, Shii H. Retrospective study on clinical features and treatment outcomes of nontraumatic inguinal hernias in 41 dogs. *J Am Anim Hosp Assoc*. 2020;56:301.
41. Gorey TF. The recovery of intestine after ischaemic injury. *Br J Surg*. 1980;67:699-702.
42. Park J, Seok HS, Kim S-S, et al. Photoplethysmogram analysis and applications: an integrative review. *Front Physiol*. 2022;12:808451.
43. Lamont L, Grimm K, Robertson S, et al. *Veterinary Anesthesia and Analgesia*. 4th ed. John Wiley & Sons; 2024.
44. Alexander CM, Teller LE, Gross JB. Principles of pulse oximetry: theoretical and practical considerations. *Anesth Analg*. 1989;68:368-376.
45. Alós R, Garcia-Granero E, Calvete J, Uribe N. The use of photoplethysmography and Doppler ultrasound to predict anastomotic viability after segmental intestinal ischaemia in dogs. *Eur J Surg*. 1993;159:35-41.
46. Whitehill TA, Pearce WH, Rosales C, Yano T, van Way CW, Rutherford RB. Detection thresholds of nonocclusive intestinal hypoperfusion by Doppler ultrasound, photoplethysmography, and fluorescein. *J Vasc Surg*. 1988;8:28-32.
47. Moore RM, Hardy J, Muir WW. Mural blood flow distribution in the large colon of horses during low-flow ischemia and reperfusion. *Am J Vet Res*. 1995;56:812-818.
48. Cooperman M, Martin EW Jr, Carey LC. Determination of intestinal viability by Doppler ultrasonography in venous infarction. *Ann Surg*. 1980;191:57.
49. Cooperman M, Pace W, Martin E Jr, et al. Determination of viability of ischemic intestine by Doppler ultrasound. *Surgery*. 1978;83:705-710.
50. Wright CB, Hobson IIRW. Prediction of intestinal viability using Doppler ultrasound technics. *Am J Surg*. 1975;129:642-645.
51. Cooperman M, Martin E Jr, Evans W, et al. Assessment of anastomotic blood supply by Doppler ultrasound in operations upon the colon. *Surg Gynecol Obstet*. 1979;149:15-16.
52. Dyess DL, Bruner BW, Donnell CA, et al. Intraoperative evaluation of intestinal ischemia: a comparison of methods. *South Med J*. 1991;84:966-969.
53. Orland PJ, Cazi GA, Semmlow JL, Reddell MT, Brolin RE. Determination of small bowel viability using quantitative myoelectric and color analysis. *J Surg Res*. 1993;55:581-587.
54. Brolin RE, Orland PJ, Bibbo C, et al. Comparison of blood flow and myoelectric measurements in two chronic models of mesenteric ligation. *Arch Surg*. 1995;130:147-152.
55. Hanquinet S, Anooshiravani M, Vunda A, le Coultre C, Bugmann P. Reliability of color Doppler and power Doppler sonography in the evaluation of intussuscepted bowel viability. *Pediatr Surg Int*. 1998;13:360-362.
56. Shah SD, Andersen CA. Prediction of small bowel viability using Doppler ultrasound. Clinical and experimental evaluation. *Ann Surg*. 1981;194:97-99.
57. O'Donnell JA, Hobson RW 2nd. Operative confirmation of Doppler ultrasound in evaluation of intestinal ischemia. *Surgery*. 1980;87:109-112.
58. Ballard JL, Stone WM, Hallett JW, Pairolero PC, Cherry KJ. A critical analysis of adjuvant techniques used to assess bowel viability in acute mesenteric ischemia. *Am Surgeon*. 1993;59:309-311.
59. Lee BY, Trainor FS, Kavner D, McCann W. Intraoperative assessment of intestinal viability with Doppler ultrasound. *Surg Gynecol Obstet*. 1979;149:671-675.
60. Cooperman M, Martin EW Jr, Keith LM, Carey LC. Use of Doppler ultrasound in intestinal surgery. *Am J Surg*. 1979;138(6):856-859. doi:10.1016/0002-9610(79)90311-8
61. Tollefson DF, Wright DJ, Reddy DJ, Kintanar EB. Intraoperative determination of intestinal viability by pulse oximetry. *Ann Vasc Surg*. 1995;9(4):357-360. doi:10.1007/BF02139407
62. Lynch TG, Hobson RW 2nd, Kerr JC, et al. Doppler ultrasound, laser Doppler, and perfusion fluorometry in bowel ischemia. *Arch Surg*. 1988;123(4):483-486. doi:10.1001/archsurg.1988.01400280093017
63. Rotering RH Jr, Dixon JA, Holloway GA Jr, McCloskey DW. A comparison of the He Ne laser and ultrasound Doppler systems in the determination of viability of ischemic canine intestine. *Ann Surg*. 1982;196(6):705-708. doi:10.1097/00000658-198212001-00016
64. Mann A, Fazio VW, Lucas FV. A comparative study of the use of fluorescein and the Doppler device in the determination of intestinal viability. *Surg Gynecol Obstet*. 1982;154:53-55.
65. Obeid A, Barnett N, Dougherty G, et al. A critical review of laser Doppler flowmetry. *J Med Engin Technol*. 1990;14:178-181.

66. McGuinness-Abdollahi Z, Thaha MA, Ramsanahie A, et al. Intraoperative monitoring of intestinal viability: evaluation of a new combined sensor. *Proceedings 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. Institute for Electrical and Electronics Engineers; 2015.
67. Grages AM, Verhaar N, Pfarrer C, et al. Low flow versus no flow: ischaemia reperfusion injury following different experimental models in the equine small intestine. *Animals*. 2022; 12:2158.
68. Boyle NH, Manifold D, Jordan MH, Mason RC. Intraoperative assessment of colonic perfusion using scanning laser Doppler flowmetry during colonic resection. *J Am Coll Surg*. 2000; 191(5):504-510. doi:10.1016/s1072-7515(00)00709-2
69. Reichert C, Kästner SB, Hopster K, Rohn K, Rötting AK. Use of micro-lightguide spectrophotometry for evaluation of microcirculation in the small and large intestines of horses without gastrointestinal disease. *Am J Vet Res*. 2014;75(11): 990-996. doi:10.2460/ajvr.75.11.990
70. Oohata Y, Mibu R, Hotokezaka M, Ikeda S, Nakahara S, Itoh H. Comparison of blood flow assessment between laser Doppler velocimetry and the hydrogen gas clearance method in ischemic intestine in dogs. *Am J Surg*. 1990;160:511-514.
71. Johansson K. Gastrointestinal application of laser Doppler flowmetry. An experimental and clinical study in cat and man. *Acta Chir Scand Suppl*. 1988;545:1-64.
72. Krohg-Sørensen K, Line PD, Haaland T, et al. Intraoperative prediction of ischaemic injury of the bowel: a comparison of laser Doppler flowmetry and tissue oximetry to histological analysis. *Eur J Vasc Surg*. 1992;6:518-524.
73. Senagore A, Milsom JW, Walshaw RK, et al. Intramural pH: a quantitative measurement for predicting colorectal anastomotic healing. *Dis Colon Rectum*. 1990;33:175-179.
74. Aksoy N, Kaplan DS, Örkmez M, et al. Evaluation of intestinal necrosis with laser Doppler in experimental mesenteric ischemia model. *Turk J Trauma Emerg Surg*. 2024;30:1.
75. Yamada T, Taguchi T, Suita S. Energy metabolism and tissue blood flow as parameters for the assessment of graft viability in rat small bowel transplantation. *J Pediatr Surg*. 1996;31: 1475-1481.
76. Käser S, Glauser P, Maurer C. Venous small bowel infarction: intraoperative laser Doppler flowmetry discriminates critical blood supply and spares bowel length. *Case Rep Med*. 2012;1:195926.
77. Johansson K, Ahn H, Lindhagen J. Assessment of small-bowel ischemia by laser Doppler flowmetry. Some case reports. *Scand J Gastroenterol*. 1986;21:1147-1152.
78. Johansson K, Ahn H, Lindhagen J. Intraoperative assessment of blood flow and tissue viability in small-bowel ischemia by laser Doppler flowmetry. *Acta Chir Scand*. 1989;155:341-346.
79. Trastulli S, Munzi G, Desiderio J, et al. Indocyanine green fluorescence angiography versus standard intraoperative methods for prevention of anastomotic leak in colorectal surgery: meta-analysis. *Br J Surg*. 2021;108:359-372.
80. Pang HY, Chen XL, Song XH, et al. Indocyanine green fluorescence angiography prevents anastomotic leakage in rectal cancer surgery: a systematic review and meta-analysis. *Langenbecks Arch Surg*. 2021;406:261-271.
81. Chan DKH, Lee SKF, Ang JJ. Indocyanine green fluorescence angiography decreases the risk of colorectal anastomotic leakage: systematic review and meta-analysis. *Surgery*. 2020; 168:1128-1137.
82. Alander JT, Kaartinen I, Laakso A, et al. A review of indocyanine green fluorescent imaging in surgery. *Int J Biomed Imaging*. 2012;1:940585.
83. Carter MS, Fantinl GA, Sammartano RJ, Mttsudo S, Silverman DG, Boley SJ. Qualitative and quantitative fluorescein fluorescence in determining intestinal viability. *Am J Surg*. 1984;147:117-123.
84. Matsui A, Winer JH, Laurence RG, et al. Predicting the survival of experimental ischaemic small bowel using intraoperative near-infrared fluorescence angiography. *J Br Surg*. 2011; 98:1725-1734.
85. Ellison G, Jokinen M, Park R. End-to-end approximating intestinal anastomosis in the dog: a comparative fluorescein dye, angiographic and histopathologic evaluation. *J Am Anim Hosp Assoc*. 1982;18(5):729-736.
86. Dalli J, Joosten JJ, Jindal A, et al. Impact of standardising indocyanine green fluorescence angiography technique for visual and quantitative interpretation on interuser variability in colorectal surgery. *Surg Endosc*. 2024;38:1306-1315.
87. Guerra F, Coletta D, Greco PA, et al. The use of indocyanine green fluorescence to define bowel microcirculation during laparoscopic surgery for acute small bowel obstruction. *Colorect Dis*. 2021;23:2189-2194.
88. Silverman DG, Hurford WE, Cooper HS, Robinson M, Brousseau DA. Quantification of fluorescein distribution to strangulated rat ileum. *J Surg Res*. 1983;34:179-186.
89. Larsen PO, Nerup N, Andersen J, et al. Anastomotic perfusion assessment with indocyanine green in robot-assisted low-anterior resection, a multicenter study of interobserver variation. *Surg Endosc*. 2023;37:3602-3609.
90. Choi J, Lee S. Excision of a gastrointestinal stromal tumour in a dog using short-wave infrared fluorescence imaging and indocyanine green. *Vet Med Sci*. 2024;10:e1506.
91. Jiri P, Alexander F, Michal P, et al. Laparoscopic diagnostics of acute bowel ischemia using ultraviolet light and fluorescein dye: an experimental study. *Surg Laparosc Endosc Percutan Tech*. 2007;17:291-295.
92. McGinty J, Hogle N, Fowler D. Laparoscopic evaluation of intestinal ischemia using fluorescein and ultraviolet light in a porcine model. *Surg Endosc Interv Tech*. 2003;17:1140-1143.
93. Jones NF, Kuzon WM Jr, Shestak KC, Roth AG. Use of fluorescein to predict survival of a free jejunal transfer after disruption of the arterial pedicle on postoperative day 12. *Br J Plast Surg*. 1994;47:375-377.
94. Johansson L, Norrby K, Lennquist S. Fluorescein angiography in the evaluation of intestinal intramural haemorrhage after trauma. *Acta Chir Scand*. 1984;150:57-61.
95. Ryu S, Hara K, Goto K, et al. Fluorescence angiography vs. direct palpation for bowel viability evaluation with strangulated bowel obstruction. *Langenbecks Arch Surg*. 2022;407: 797-803.
96. Ahmed T, Pai MV, Mallik E, et al. Applications of indocyanine green in surgery: a single center case series. *Ann Med Surg*. 2022;77:103602.
97. Iinuma Y, Hirayama Y, Yokoyama N, et al. Intraoperative near-infrared indocyanine green fluorescence angiography (NIR-ICG AG) can predict delayed small bowel stricture after

ischemic intestinal injury: report of a case. *J Pediatr Surg*. 2013;48:1123-1128.

98. Liot E, Assalino M, Buchs NC, et al. Does near-infrared (NIR) fluorescence angiography modify operative strategy during emergency procedures? *Surg Endosc*. 2018;32:4351-4356.
99. Nowak K, Sandra-Petrescu F, Post S, et al. Ischemic and injured bowel evaluation by fluorescence imaging. *Colorect Dis*. 2015;17:12-15.
100. Nakagawa Y, Kobayashi K, Kuwabara S, Shibuya H, Nishimaki T. Use of indocyanine green fluorescence imaging to determine the area of bowel resection in non-occlusive mesenteric ischemia: a case report. *Int J Surg Case Rep*. 2018; 51:352-357.
101. Joosten JJ, Longchamp G, Khan MF, et al. The use of fluorescence angiography to assess bowel viability in the acute setting: an international, multi-centre case series. *Surg Endosc*. 2022;36:7369-7375.
102. Karampinis I, Keese M, Jakob J, et al. Indocyanine green tissue angiography can reduce extended bowel resections in acute mesenteric ischemia. *J Gastrointest Surg*. 2018;22:2117-2124.
103. De Simone B, Abu-Zidan FM, Saeidi S, et al. Knowledge, attitudes and practices of using Indocyanine green (ICG) fluorescence in emergency surgery: an international web-based survey in the artificial intelligence in emergency and trauma surgery (ARIES)-WSES project. *Updates Surg*. 2024;76:1969-1981.
104. Jafari MD, Pigazzi A, McLemore EC, et al. Perfusion assessment in left-sided/low anterior resection (PILLAR III): a randomized, controlled, parallel, multicenter study assessing perfusion outcomes with PINPOINT near-infrared fluorescence imaging in low anterior resection. *Dis Colon Rectum*. 2021;64:995-1002.
105. Engelking LR, Anwer MS, Lofstedt J. Hepatobiliary transport of indocyanine green and sulfobromophthalein in fed and fasted horses. *Am J Vet Res*. 1985;46:2278-2284.
106. Parry BW, Bayly WM, Tarr B. Indocyanine green clearance and estimation of plasma volume in the normal horse. *Equine Vet J*. 1989;21:142-144.
107. Pirie CG, LoPinto AJ, Tenney WA. Comparison of angiographic dyes and injection techniques for ocular anterior segment angiography in horses. *Am J Vet Res*. 2018;79:562-567.
108. Tate LP, Blikslager AT, Papich MG. Performance of the 808-nm diode laser on equine upper airway tissue is enhanced by intravenous administration of indocyanine green. *Photomed Laser Surg*. 2007;25:443-448.
109. Groner W, Winkelman JW, Harris AG, et al. Orthogonal polarization spectral imaging: a new method for study of the microcirculation. *Nat Med*. 1999;5:1209-1212.
110. De Bruin A, Kornmann V, van der Sloot K, et al. Sidestream dark field imaging of the serosal microcirculation during gastrointestinal surgery. *Colorect Dis*. 2016;18:O103-O110.
111. Mullen KM, Regier PJ, Fox-Alvarez WA, Portela D, Londoño L, Colee J. A quantitative evaluation of the effect of foreign body obstruction and enterectomy technique on canine small intestinal microvascular health. *Vet Surg*. 2023; 52:554-563.
112. Xu T, Gao X, Yuan H, et al. Real-time semi-quantitative assessment of anastomotic blood perfusion in mini-invasive rectal resections by Sidestream dark field (SDF) imaging technology: a prospective in vivo pilot study. *Langenbecks Arch Surg*. 2023;408:186.
113. De Bruin A, Tavy A, van der Sloot K, et al. Can sidestream dark field (SDF) imaging identify subtle microvascular changes of the bowel during colorectal surgery? *Tech Coloproctol*. 2018;22(10):793-800. doi:10.1007/s10151-018-1872-4
114. Kawcak C, Baxter G, Getzy D, et al. Abnormalities in oxygenation, coagulation, and fibrinolysis in colonic blood of horses with experimentally induced strangulation obstruction. *Am J Vet Res*. 1995;56:1642-1650.
115. Grosenbaugh DA, Alben JO, Muir WW. Absorbance spectra of inter-species hemoglobins in the visible and near infrared regions. *J Vet Emerg Crit Care*. 1997;7:36-42.
116. Schmotzer WB, Riebold TW, Rowe KE, Scott EA. Steady-state response characteristics of a pulse oximeter on equine intestine. *Am J Vet Res*. 1991;52:619-625.
117. Suzuki Y, Yamamoto M, Sugiyama K, et al. Usefulness of a finger-mounted tissue oximeter with near-infrared spectroscopy for evaluating the intestinal oxygenation and viability in rats. *Surg Today*. 2021;51:931-940.
118. Matthews N, Hartsfield S, Boutros C. Evaluation of pulse oximeters in horses. *Vet Anaesth Analg*. 2002;29:97-112.
119. Wittek T, Constable PD, Fürll M. Comparison of abomasal luminal gas pressure and volume and perfusion of the abomasum in dairy cows with left displaced abomasum or abomasal volvulus. *Am J Vet Res*. 2004;65:597-603.
120. Türkyilmaz Z, Sönmez K, Başaklar AC, et al. Assessment of anastomotic reliability with pulse oximetry in graded intestinal ischemia: an experimental study in dogs. *J Pediatr Surg*. 1997;32:1728-1731.
121. DeNobile J, Guzzetta P, Patterson K. Pulse oximetry as a means of assessing bowel viability. *J Surg Res*. 1990;48:21-23.
122. MacDonald P, Dinda P, Beck I, Mercer CD. The use of oximetry in determining intestinal blood flow. *Surg Gynecol Obstet*. 1993;176:451-458.
123. Avino AJ, Oldenburg WA, Gloviczki P, Miller VM, Burgart LJ, Atkinson EJ. Inferior mesenteric venous sampling to detect colonic ischemia: a comparison withlaser Doppler flowmetry and photoplethysmography. *J Vasc Surg*. 1995;22: 271-279.
124. Ando M, Ito M, Nihei Z, Sugihara K. Assessment of intestinal viability using a non-contact laser tissue blood flowmeter. *Am J Surg*. 2000;180:176-180.
125. Ateş O, Ağartan CA, Hakgüder G, Olguner M, Yenici O, Akgür F. Can pulse oxymetry be used for measuring intestinal blood flow? *Eur J Pediatr Surg*. 2007;17:199-202.
126. Omar HS, Farag AF, Sah VP, et al. Evaluation of the efficacy of wireless sterilizable pulse oximeter in assessment of bowel viability during surgery. *Egypt J Surg*. 2020;39:879-888.
127. Salusjärvi JM, Carpelan-Holmström MA, Louhimo JM, Kruuna O, Scheinin TM. Intraoperative colonic pulse oximetry in left-sided colorectal surgery: can it predict anastomotic leak? *Int J Colorectal Dis*. 2018;33:333-336.
128. La Hei E, Shun A. Intra-operative pulse oximetry can help determine intestinal viability. *Pediatr Surg Int*. 2001;17:120-121.
129. Katz Y, Shoshani G. Intraoperative assessment of blood flow to strangulated stomach by pulse oximetry. *J Pediatr Surg*. 1992;27:509-510.

130. Ali J, Cody J, Maldonado Y, Ramakrishna H. Near-infrared spectroscopy (NIRS) for cerebral and tissue oximetry: analysis of evolving applications. *J Cardiothorac Vasc Anesth*. 2022;36:2758-2766.
131. Gingold BM, Killos MB, Griffith E, et al. Measurement of peripheral muscle oxygen saturation in conscious healthy horses using a near-infrared spectroscopy device. *Vet Anaesth Analg*. 2019;46:789-795.
132. McConnell EJ, Rioja E, Bester L, et al. Use of near-infrared spectroscopy to identify trends in regional cerebral oxygen saturation in horses. *Equine Vet J*. 2013;45:470-475.
133. Stefanik E, Drewnowska O, Lisowska B, Turek B. Causes, effects and methods of monitoring gas exchange disturbances during equine general anaesthesia. *Animals*. 2021;11(7):2049.
134. Jöbsis FF. Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. *Science*. 1977;198:1264-1267.
135. Gonzalez-Jacobo A, Chandler P, Martz J, Sherwinter D. Tissue oximetry as a potential alternative to Indocyanine green (ICG) perfusion assessment in colorectal anastomotic cases. *Surg Laparosc Endosc Percutan Tech*. 2023;33:207-210.
136. Sherwinter D, Chandler P, Martz J. The use of tissue oxygen measurements compared to indocyanine green imaging for the assessment of intraoperative tissue viability of human bowel. *Surg Endosc*. 2022;36:2192-2196.
137. Mirle E, Wogatzki A, Kunzmann R, Schoenfelder AM, Litzke LF. Correlation between capillary oxygen saturation and small intestinal wall thickness in the equine colic patient. *Vet Rec Open*. 2017;4(1):e000197.
138. Kohlenberg E, Payette JR, Sowa MG, Levasseur MA, Riley CB, Leonardi L. Determining intestinal viability by near infrared spectroscopy: a veterinary application. *Vib Spectrosc*. 2005;38:223-228.
139. Sowa MG, Kohlenberg E, Payette JR, Leonardi L, Levasseur MA, Riley CB. Detecting intestinal ischemia using near infrared spectroscopy. *J near Infrared Spectrosc*. 2006;14:1-7.
140. Hou J, Ness SS, Tschudi J, et al. Assessment of intestinal ischemia–reperfusion injury using diffuse reflectance vis-nir spectroscopy and histology. *Sensors*. 2022;22:9111.
141. Karakaş BR, Sırcan-Küçüksayan A, Elpek OE, et al. Investigating viability of intestine using spectroscopy: a pilot study. *J Surg Res*. 2014;191:91-98.
142. Hirano Y, Omura K, Yoshiba H, et al. Near-infrared spectroscopy for assessment of tissue oxygen saturation of transplanted jejunal autografts in cervical esophageal reconstruction. *Surg Today*. 2005;35:67-72.
143. Khosrawipour T, Li S, Steward E, et al. Assessment of anastomotic viability with spectroscopic real-time oxygen saturation measurement in a porcine study. *Surg Innov*. 2023;30:349-355.
144. Karliczek A, Benaron D, Baas P, et al. Intraoperative assessment of microperfusion with visible light spectroscopy for prediction of anastomotic leakage in colorectal anastomoses. *Colorect Dis*. 2010;12:1018-1025.
145. Hirano Y, Omura K, Tatsuzawa Y, Shimizu J, Kawaura Y, Watanabe G. Tissue oxygen saturation during colorectal surgery measured by near-infrared spectroscopy: pilot study to predict anastomotic complications. *World J Surg*. 2006;30:457-461.
146. Yoshinaka H, Takakura Y, Egi H, et al. Prediction of anastomotic leakage after left-sided colorectal cancer surgery: a pilot study utilizing quantitative near-infrared spectroscopy. *Surg Today*. 2022;52:971-977.
147. Love TJ. Thermography as an indicator of blood perfusion. *Ann N Y Acad Sci*. 1980;335:429-437.
148. Westermann S, Stanek C, Schramel J, et al. The effect of airflow on thermographically determined temperature of the distal forelimb of the horse. *Equine Vet J*. 2013;45:637-641.
149. Westermann S, Buchner HH, Schramel JP, Tichy A, Stanek C. Effects of infrared camera angle and distance on measurement and reproducibility of thermographically determined temperatures of the distolateral aspects of the forelimbs in horses. *J Am Vet Med Assoc*. 2013;242(3):388-395. doi:10.2460/javma.242.3.388
150. Finstad JB, Cooper E, Ten Cate SC, et al. Infrared thermography is a novel tool to assess small intestinal surface temperature in dogs undergoing laparotomy for foreign body obstruction. *Am J Vet Res*. 2023;84(11):ajvr.23.04.0082.
151. Zaha C, Schuszler L, Dascalu R, et al. Evaluation of thermal changes of the sole surface in horses with palmar foot pain: a pilot study. *Biology*. 2023;12(3):423.
152. Turner TA. Diagnostic thermography. *Vet Clin North Am Equine Pract*. 2001;17:95-113.
153. Purohit RC, Hammond LS, Rossi A, et al. Use of thermography to determine intestinal viability. *Proceedings Equine Colic Symposium*. University of Georgia; 1982.
154. Moss AA, Kressel HY, Brito AC. Use of thermography to predict intestinal viability and survival after ischemic injury: a blind experimental study. *Invest Radiol*. 1981;16:24-29.
155. Malafaia O, Brioschi ML, Aoki SMS, et al. Infrared imaging contribution for intestinal ischemia detection in wound healing. *Acta Cirurg Bras*. 2008;23:511-519.
156. Pokorná J, Staffa E, Čan V, et al. Intestinal resection of a porcine model under thermographic monitoring. *Physiol Meas*. 2019;40:014003.
157. Kako T, Kimura M, Nomura R, et al. A case of laparoscopic sigmoidectomy using thermography for colonic blood flow assessment. *Surg Case Rep*. 2023;9:170.
158. Tokunaga T, Shimada M, Higashijima J, et al. Intraoperative thermal imaging for evaluating blood perfusion during laparoscopic colorectal surgery. *Surg Laparosc Endosc Percutan Tech*. 2021;31:281-284.
159. Bernard V, Čan V, Staffa E, et al. Infrared thermal imaging: a potential tool used in open colorectal surgery. *Minerva Chir*. 2017;72(5):442-446. doi:10.23736/S0026-4733.17.07366-7
160. Wijnberg ID, Franssen H. The potential and limitations of quantitative electromyography in equine medicine. *Vet J*. 2016;209:23-31.
161. Porcarelli L, Cauduro A, Bianchi E, Pauciulo C, Maurelli C, Corlazzoli D. Early neurophysiological abnormalities in suspected acute canine polyradiculoneuropathy. *Vet Sci*. 2024;11(4):178.
162. Harcourt-Brown TR, Granger NP, Fitzpatrick N, Jeffery ND. Electrodiagnostic findings in dogs with apparently painful lumbosacral foraminal stenosis. *J Vet Intern Med*. 2019;33:2167-2174.
163. Lapido J, Bradshaw L, Halter S, et al. Changes in intestinal electrical activity during ischaemia correlate to pathology. *West Afr J Med*. 2003;22:1-4.

164. Brolin RE, Semmlow JL, Koch RA, et al. Myoelectric assessment of bowel viability. *Surgery*. 1987;102:32-38.
165. Basdanis G, Zisiadis A, Michalopoulos A, Papadopoulos V, Apostolidis S, Katsohis C. Myoelectric assessment of large bowel viability: an experiment in dogs. *Eur J Surg*. 1999;165:1182-1186.
166. Dutkiewicz W, Thor P, Pawlicki R, et al. Electromyographic and histologic evaluation of intestinal viability. *Wiad Lek*. 1997;50:50-53.
167. Cushman DM, Strenn Q, Elmer A, Yang AJ, Onofrei L. Complications associated with electromyography: a systematic review. *Am J Phys Med Rehabil*. 2020;99(2):149-155. doi:10.1097/PHM.0000000000001304
168. St George L, Spoormakers TJP, Roy SH, et al. Reliability of surface electromyographic (sEMG) measures of equine axial and appendicular muscles during overground trot. *PLoS One*. 2023;18:e0288664. doi:10.1371/journal.pone.0288664
169. Wanamaker R, Grimm I. Encyclopedia of gastroenterology. *Gastroenterology*. 2004;127:1274-1275.
170. Cornish B, Thomas B, Ward L. Improved prediction of extracellular and total body water using impedance loci generated by multiple frequency bioelectrical impedance analysis. *Phys Med Biol*. 1993;38:337.
171. Harrison AP, Elbrønd VS, Riis-Olesen K, Bartels EM. Multifrequency bioimpedance in equine muscle assessment. *Physiol Meas*. 2015;36(3):453-464.
172. Ward LC, White KJ, van der Aa Kuhle K, et al. Body composition assessment in horses using bioimpedance spectroscopy. *J Anim Sci*. 2016;94:533-541.
173. Gregson RA, Shaw M, Piper I, Clutton RE. Transcranial bioimpedance measurement in horses: a pilot study. *Vet Anaesth Analg*. 2019;46:620-626.
174. Hou J, Strand-Amundsen R, Hødnebø S, Tønnessen TI, Høgetveit JO. Assessing ischemic injury in human intestine ex vivo with electrical impedance spectroscopy. *J Electr Bioimpedance*. 2021;12:82-88.
175. Strand-Amundsen RJ, Tronstad C, Reims HM, Reinholt FP, Høgetveit JO, Tønnessen TI. Machine learning for intraoperative prediction of viability in ischemic small intestine. *Physiol Meas*. 2018;39:105011.
176. Briers JD, Webster S. Laser speckle contrast analysis (LASCA): a nonscanning, full-field technique for monitoring capillary blood flow. *J Biomed Opt*. 1996;1:174-179.
177. Wildeboer A, Heeman W, van der Bilt A, et al. Laparoscopic laser speckle contrast imaging can visualize anastomotic perfusion: a demonstration in a porcine model. *Life*. 2022;12(8):1251.
178. Heeman W, Wildeboer ACL, Al-Taher M, et al. Experimental evaluation of laparoscopic laser speckle contrast imaging to visualize perfusion deficits during intestinal surgery. *Surg Endosc*. 2023;37:950-957.
179. Wang Y, Tiusaba L, Jacobs S, et al. Unsupervised and quantitative intestinal ischemia detection using conditional adversarial network in multimodal optical imaging. *J Med Imaging*. 2022;9:064502.
180. Zheng C, Lau LW, Cha J. Dual-display laparoscopic laser speckle contrast imaging for real-time surgical assistance. *Biomed Opt Express*. 2018;9:5962-5981.
181. Kojima S, Sakamoto T, Nagai Y, Matsui Y, Nambu K, Masamune K. Laser speckle contrast imaging for intraoperative quantitative assessment of intestinal blood perfusion during colorectal surgery: a prospective pilot study. *Surg Innov*. 2019;26:293-301.
182. Shah SK, Nwaiwu CA, Agarwal A, et al. First-in-human (FIH) safety, feasibility, and usability trial of a laparoscopic imaging device using laser speckle contrast imaging (LSCI) visualizing real-time tissue perfusion and blood flow without fluorophore in colorectal and bariatric patients. *J Am Coll Surg*. 2021;233:S45-S46.
183. Kaneko T, Funahashi K, Ushigome M, et al. Noninvasive assessment of bowel blood perfusion using intraoperative laser speckle flowgraphy. *Langenbecks Arch Surg*. 2020;405:817-826.
184. Rønn JH, Nerup N, Strandby RB, et al. Laser speckle contrast imaging and quantitative fluorescence angiography for perfusion assessment. *Langenbecks Arch Surg*. 2019;404:505-515.
185. Jung U, Ryu J, Choi H. Optical light sources and wavelengths within the visible and near-infrared range using photoacoustic effects for biomedical applications. *Biosensors*. 2022;12(12):1154.
186. Sugiura T, Okumura K, Matsumoto J, et al. Predicting intestinal viability by consecutive photoacoustic monitoring of oxygenation recovery after reperfusion in acute mesenteric ischemia in rats. *Sci Rep*. 2021;11:19474.
187. Wang R, Pan T, Huang L, et al. Photoacoustic imaging in evaluating early intestinal ischemia injury and reperfusion injury in rat models. *Quant Imaging Med Surg*. 2021;11:2968-2979.
188. Rowland KJ, Yao J, Wang L, et al. Immediate alterations in intestinal oxygen saturation and blood flow after massive small bowel resection as measured by photoacoustic microscopy. *J Pediatr Surg*. 2012;47:1143-1149.
189. Sheridan WG, Lowndes RH, Young HL. Intraoperative tissue oximetry in the human gastrointestinal tract. *Am J Surg*. 1990;159:314-319.
190. Snyder J, Pascoe J, Holland M, et al. Surface oximetry of healthy and ischemic equine intestine. *Am J Vet Res*. 1986;47:2530-2535.
191. Locke R, Hauser CJ, Shoemaker WC. The use of surface oximetry to assess bowel viability. *Arch Surg*. 1984;119:1252-1256.
192. Fisher EM, Khan M, Salisbury R, Kuppusamy P. Noninvasive monitoring of small intestinal oxygen in a rat model of chronic mesenteric ischemia. *Cell Biochem Biophys*. 2013;67:451-459.
193. Cahill RA, Mortensen NJ. Intraoperative augmented reality for laparoscopic colorectal surgery by intraoperative near-infrared fluorescence imaging and optical coherence tomography. *Minerva Chir*. 2010;65:451-462.
194. Tsai TH, Leggett CL, Trindade AJ, et al. Optical coherence tomography in gastroenterology: a review and future outlook. *J Biomed Opt*. 2017;22:1-17.
195. Rodriguez Galarza RM, McMullen RJ Jr. Descemet's membrane detachments, ruptures, and separations in ten adult horses: clinical signs, diagnostics, treatment options, and preliminary results. *Vet Ophthalmol*. 2020;23:611-623.
196. Lee H-C, Fass O, Ahsen OO, et al. Mo1993 Endoscopic optical coherence tomography microangiography identifies the

altered microvasculature of the terminal ileum in Crohn's disease. *Gastrointest Endosc*. 2017;85:AB511-AB512.
197. Kiseleva EB, Ryabkov MG, Sizov MA, et al. Effect of surgical technique on the microstructure and microcirculation of the small intestine stump during delayed anastomosis: multimodal OCT data. *Sovrem Tekhnologii Med*. 2021;13:36-45.
198. Kiseleva E, Ryabkov M, Baleev M, et al. Prospects of intraoperative multimodal OCT application in patients with acute mesenteric ischemia. *Diagnostics*. 2021;11(4):705.

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