How to assess intestinal viability during surgery: A review of techniques

Linas Urbanavičius, Piet Pattyn, Dirk Van de Putte, Donatas Venskutonis

Abstract
Objective and quantitative intraoperative methods of bowel viability assessment are essential in gastrointestinal surgery. Exact determination of the borderline of the viable bowel with the help of an objective test could result in a decrease of postoperative ischemic complications. An accurate, reproducible and cost effective method is desirable in every operating theater dealing with abdominal operations. Numerous techniques assessing various parameters of intestinal viability are described by the studies. However, there is no consensus about their clinical use. To evaluate the available methods, a systematic search of the English literature was performed. Virtues and drawbacks of the techniques and possibilities of clinical application are reviewed. Valuable parameters related to postoperative intestinal anastomotic or stoma complications are analyzed. Important issues in the measurement and interpretation of bowel viability are discussed. To date, only a few methods are applicable in surgical practice.

Further studies are needed to determine the limiting values of intestinal tissue oxygenation and flow indicative of ischemic complications and to standardize the methods.

Key words: Microperfusion; Tissue ischemia; Colon perfusion; Anastomotic leakage; Stoma

INTRODUCTION
Viability of the bowel must be evaluated frequently during abdominal surgery. Sufficient blood supply is very important for successful healing of the anastomosis and avoidance of intestinal ischemia and necrosis. Insufficient microcirculation of the anastomotic region leads to anastomotic leakage or stricture, especially in elderly patients. This is associated with an increased length of hospital stay, significant postoperative morbidity and mortality and recurrence after colorectal resections for malignant bowel tumors. The reported incidence of anastomotic leakage ranges between 1.2% and 19.2%. Up to 32% of patients with an anastomotic leak die from this postoperative complication [1,2].

Intestinal microcirculation and viability is usually estimated from the color of the serosal surface, presence of bowel peristalsis, pulsation and bleeding from the marginal arteries. This is subjective and based on the experience of the surgeon. Clinical assessment may be deceptive. A dark hue may be due to transient venous insufficiency and
the bowel may in fact be viable, whereas in early arterial occlusion it may appear normal. Absence of mesenteric pulsation may be due to hypotension or spasm. Peristalsis may persist even in a grossly ischemic bowel[6]. Karlíček et al[7] evaluated the surgeons’ predictive accuracy for anastomotic leakage in a prospective clinical study. Clinical risk assessment by the surgeons appeared to have a low predictive value for anastomotic leakage in gastrointestinal surgery. It has been shown that improvement in inadequate intraoperative colonic perfusion from increased collateral circulation is unlikely to develop during the first five postoperative days and therefore anastomotic perfusion is probably determined at the time of surgery and should be assessed intraoperatively[8]. Thus, objective and quantitative intraoperative methods of bowel microcirculation assessment are of paramount importance. The aim of this review is to survey and evaluate the valuable methods of intestinal viability assessment and the possibilities of their clinical application.

A systematic English literature review was performed. The electronic databases of ISI Web of Science, PubMed, Medline and SpringerLink were searched. Studies investigating intraoperative quantitative methods of microcirculation assessment predicting the healing of anastomosis or intestinal stoma were searched for in the databases. The search was performed using both MeSH (Medical Subject Heading) terms and free text terms. The following MeSH terms were used: “Intestines” [MeSH] AND “Ischemia” [MeSH] AND “Monitoring” [MeSH]. Free text terms: bowel, intestine, anastomosis, stoma, perfusion, microcirculation, viability, oxygenation, ischemia, evaluation, assessment, measurement and intraoperative. The type of surgery included in the search: operations for intestinal tumors, incarcerated hernias, intestinal ischemia, bowel perforations, ileus, restoration of bowel continuity, transplantation of bowel segment, abdominal aorta disorders etc., where to avoid bowel necrosis, anastomotic or stoma complications, assessment of bowel microcirculation and viability is essential. Both urgent and elective surgical procedures were included as well as open and laparoscopic.

Decision to resect the intestine and perform the anastomosis could be made either deliberately before the operation or during the operation due to intraoperative findings. All quantitative parameters which reflect intestinal microcirculation and viability intraoperatively were involved. The relationship of those parameters to postoperative anastomotic or stoma complications was analyzed.

**Pulse oximetry**
The principle of pulse oximetry is based on two light sources with different wavelengths (660 nm and 940 nm) emitted through the cutaneous vascular bed of a finger or earlobe. The Hb absorbs more light at 660 nm and HbO2 absorbs more light at 940 nm. A detector at the far side measures the intensity of the transmitted light at each wavelength and the arterial oxygen saturation (SpO2) is derived by the ratio between the red light (660 nm) and the infrared light (940 nm) absorbed[3]. Erkoglu et al and DeNobile et al measured oxygen saturation of the bowel by pulse oximetry and investigated the relationship between these measures and concomitant pathological grading. They found that intraoperative evaluation of intestinal viability by pulse oximetry may give an idea about the degree of pathological changes[9]. MacDonal and coworkers supported the notion that a pulse oximeter has the potential to be of value in the intraoperative assessment of intestinal blood flow[10]. A reflectance pulse oximetry of the colon mucosa was applied in an animal model during aortic reconstruction. It was shown to be useful in monitoring the blood flow of the distal colon[11]. Pulse oximetry has been shown to be applicable as an adjuvant technique in the assessment of small bowel ischemia in a patient with a strangulated ileus[3]. In a recent study, a novel reflectance pulse oximetry technique was introduced for intraoperative measurements of SpO2 in the esophagus and large bowel. The method has been proven to be able to measure SpO2 continuously in patients with a compromised peripheral perfusion[12]. However, according to Hadley and Mars, pulse oximeters do not measure blood flow or tissue viability; they only measure hemoglobin saturation. A low oximeter reading in the limbs would usually be interpreted as a reflection of inadequate central oxygenation and the authors doubt that the pulse oximetry readings taken from the bowel are different from that taken from the limbs. They agree that pulse oximetry could be, at best, an adjunct to established techniques[13]. Dyess et al[13] argued against the clinical value of pulse oximetry given it was found to result in a high rate of false-negative and false-positive evaluations.

**Polarographic measurement of oxygen tension**
The principle of tissue oxygen tension (PtO2) measurements relies on the reduction of molecular oxygen at a noble metal cathode affecting the current set-up in a polarized circuit. The current that is set up by the probe is linearly dependent on the partial pressure of oxygen in the tissue being measured. The PtO2 is an extravascular parameter as oxygen in the tissue is measured after capillary gas exchange. It correlated well with StO2 and IVM findings under stable respiratory conditions[13]. Sheridan et al measured PtO2 on the colon of 50 patients undergoing colonic resection and anastomosis and found the decreasing PtO2 levels at the colonic serosa to be predictive of anastomotic leakage[10]. Conversely, in a study by Jacob et al, no decrease of the submucosal PtO2 was seen in patients with anastomotic insufficiency after esophageal resections. Even increased PtO2 values were observed in the anastomotic leakage group[17]. These controversial findings have led to doubts about the role of impaired tissue oxygenation in anastomotic healing.

**Near-infrared and visible light spectrophotometry**
Spectrophotometry (spectroscopy) uses the principles of light transmission and absorption to measure the concentrations of Hb oxygen saturation in tissues (StO2). The amount of light passing through the substance is dependent upon the wavelength; thus, near-infrared and visible light have different characteristics for spectrophotometry.
Visible light spectrophotometry (VLS) relies on locally absorbed, shallow-penetrating visible light at 475-625 nm wavelengths and the near-infrared is the part of the spectrum with wavelengths just above the visible, typically beginning at 700-730 nm wavelengths. Visual light penetrates approximately 2 mm into the tissue, whereas near-infrared light has a deeper penetration. As a result, near-infrared spectrophotometry (NIRS) provides a global assessment of oxygenation in all vascular compartments (arterial, venous and capillary) and VLS is designed for monitoring of StO$_2$ in the capillaries.$^{[7,18]}$. In combination with an intravenous dye injection, NIRS can be used to directly measure perfusion.$^{[20]}$. Visible light spectroscopy is similar to NIRS in that the mean VLS StO$_2$ is in accordance with NIRS StO$_2$ (bias VLS–NIRS -1 ± 5%; $P = NS$)$^{[24]}$.

The spectroscopy or oximeter emits low-powered white or near-infrared light from a handheld or endoscopic probe placed near or on the bowel wall. The light penetrates and diffuses and reemerges colored according to the oxygenation level (StO$_2$). Tissue Hb is estimated as [deoxygenhemoglobin + oxyhemoglobin], and the tissue Hb oxygen saturation (StO$_2$) is determined as [oxyhemoglobin]/[deoxygenhemoglobin + oxyhemoglobin]$^{[7,18]}$. VLS and NIRS have been applied in recent studies.

Hirano and colleagues measured bowel StO$_2$ at the serosa using NIRS in a pilot study.$^{[21]}$. StO$_2$ was measured at the anastomotic site of the bowel in 20 patients during colorectal resections for colorectal cancer. It was shown that StO$_2$ of the anastomotic site can be safely and reliably measured by NIRS during colorectal surgery. Low StO$_2$ on both sides of the anastomosis may indicate an increased risk of anastomotic complications, although further study is needed to determine the cutoff value for StO$_2$ to prevent serious complications.

Lee and colleagues assessed colon mucosal oxygen saturation during aortic reconstruction surgery in a prospective observational study of 25 patients using a VLS oximeter with an endorectal spectrophotometer probe. In their opinion, intraoperative VLS is a sensitive measure and persistently low colon mucosal oxygen saturation suggests colon ischemia and a threat of colon infarction$^{[1]}$.

Karliczek et al. evaluated the predictive value of VLS for anastomotic leakage of the colon and the rectum in 77 patients undergoing colorectal resections in a prospective observational study.$^{[1]}$. StO$_2$ levels in colonic tissue were shown to be stable and reproducible. Rising values of colon serosal StO$_2$ were observed at the anastomotic site of the bowel after the construction of anastomosis. The mean StO$_2$ value at the proximal anastomotic end in the group of patients who healed uneventfully was 72.1 ± 9.0% and it increased to 76.7 ± 8.0% after construction of the anastomosis. The authors speculate that the underlying mechanism of increasing tissue oxygenation is a response to ischemic preconditioning caused by manipulating the bowel. There was no rising StO$_2$ in anastomoses that ultimately leaked. In anastomoses showing leakage, a significantly lower StO$_2$ was recorded in the cecum (73.6 ± 5.7 in non-leakage vs 69.6 ± 5.6 in leakage group).

Compared to VLS, the minimal sampled volume of the tissue by NIRS is relatively large, whereas in VLS the point measurements of small tissue samples are possible.$^{[18]}$. Advocates of VLS claim that a shallow penetrating visible light is more appropriate for the measurements of bowel wall oxygenation.$^{[1]}$. Another advantage of VLS is that, compared with NIRS, the normal range is significantly narrower: ± 3% vs ± 9% respectively.$^{[20,23]}$. A tissue contact is not required in VLS measurements as the instrument corrects for an uneven baseline and the full light spectrum is analyzed.$^{[1]}$. This is a great advantage compared to other techniques such as polarographic or tonometry measurements, NIRS or laser Doppler flowmetry (LDF) where the probe opposition to the tissue leads to decreased perfusion and StO$_2$.$^{[20]}$. Although there are no comparison studies, VLS is a newer technique for bowel oxygenation measurement, applied in the majority of studies and seems to be more promising.

Oximetry has a number of drawbacks. Firstly, a specific level of StO$_2$ that leads to intestinal tissue ischemia has not been defined to date. In studies where VLS of the skin was applied, the critical StO$_2$: level of microsurgical flap perfusion was between 10% and 15% and a level of 15% saturation has been shown to be clinically sensitive and specific in determining amputation level.$^{[22,25]}$. Secondly, there is no uniformity in StO$_2$: measurements as different algorithms are used by different oximetry systems for estimating StO$_2$. A variety of VLS and NIRS equipment is available where the measurements are performed with different amount of wavelengths and also at different wavelengths of light.$^{[26,27]}$. Thirdly, the reproducibility of the results can be affected by the presence of bile, stool or food within the intestine which can interfere with the passage of light when measurements are taken at the mucosa. Also, the optimal angle of the probe relative to the tissue is 90° and a different angle can lead to inaccurate measurements.$^{[24]}$. Measurements are not always feasible for colorectal anastomoses within 5 cm from the anal verge or when the site of measurement is situated behind sponges and retractors.$^{[1]}$. Finally, prices of the oximetry systems are currently high.

Intravital microscopy

Intravital microscopy (IVM) has been considered a gold standard for microcirculatory research because it can directly visualize and quantify changes at the capillary level using fluorescent-labeled plasma or blood cells.$^{[15]}$. Yasumura et al. performed microscopy of the serosal bowel layer and calculated the ratio of blood cell transition and the effective area of the vascular bed. These parameters were found to be useful indices for prediction of bowel survival.$^{[29]}$. This technique has not yet been introduced into human studies, probably because it is time consuming.

Doppler ultrasound

In earlier studies, intraoperative Doppler ultrasound of the marginal arteries was believed to be a more reliable
intraoperative predictor of intestinal viability than clinical assessment alone\textsuperscript{39}. The authors favored the low costs and simplicity of the technique and suggested its adjunctive use\textsuperscript{39}. In a study of 117 patients undergoing intestinal anastomosis or enterostomy, a Doppler ultrasound was applied to determine the adequacy of blood supply at the margins of resection. No postoperative complications were experienced when relying on a Doppler signal\textsuperscript{39}. In a more recent series of colorectal resections in 200 patients, only 1\% incidence of anastomotic insufficiency was observed when the bowel ends to be resected were assessed with a Doppler ultrasound\textsuperscript{33}. Conversely, other authors observed that this adds little if anything to clinical judgment\textsuperscript{34}. Sensitivity of Doppler ultrasound of 86\% was shown in an experimental study which was significantly lower than that of laser Doppler and perfusion fluorometry\textsuperscript{35}. Doppler ultrasonography resulted in a high rate of false-negative and false-positive results in an experimental study by Dyess et al\textsuperscript{41}. The superiority of laser Doppler flowmetry compared with ultrasound studies was shown\textsuperscript{39}. Widely discussed limitations of this technique are that it is considered to be vulnerable to the signals from the neighboring large vessels, it requires an artery exposure and a pulsatile blood flow and a tissue contact is required which can impair local blood flow\textsuperscript{11,29}.

\textbf{Hydrogen gas clearance}

Hydrogen gas clearance was attempted for intestinal microcirculation assessment in earlier experimental studies\textsuperscript{16,37,38}. The basic paradigm of hydrogen clearance consists of inserting a positively polarized electrode into tissue, administering H2 either by respiration or intra-arterially, allowing the H2 to be cleared from arterial blood, and then monitoring the exponential clearance rate of H2 from the tissue\textsuperscript{39}. This technique has been validated for measuring blood flow in different organs; however, it is not used routinely for evaluation of intestinal ischemia due to its invasiveness, inconvenience and insufficient accuracy\textsuperscript{21,29}.

\textbf{Radioisotope studies}

Radioisotopes were used in earlier studies to quantify the perfusion at the anastomotic or ischemic site of the bowel. In animal and human studies, intraperitoneal\textsuperscript{49}, intravenous\textsuperscript{41,42}, intra arterial\textsuperscript{43} or local submucosal\textsuperscript{44} injections of radioisotopes were applied to monitor ischemic sites and blood flow in the intestine or anastomosis. Disadvantages of radioactive isotopes are exposure to radiation for both the patient and personnel, the technique is expensive in terms of storage and disposal and it is rather cumbersome\textsuperscript{45}. These are the possible causes why this technique is not employed at present.

\textbf{Fluorescence studies}

Two techniques, the perfusion fluorometry and laser fluorescence angiography (LFA), have been applied for evaluation of intestinal viability. Perfusion fluorometry was tried in animal and human studies and gained wide acceptance in the diagnosis of acute bowel ischemia in earlier studies. Here, the sodium fluorescein is administered intravenously and the bowel is illuminated with an ultraviolet light investigating the perfusion. It can be used both for a laparotomy when the source of UV light is a Wood's lamp as well for laparoscopy when the optical filters are placed to the light source of the laparoscopic set to produce UV light\textsuperscript{16-20}. The earlier studies applied qualitative fluorometry and in the more recent studies, a fiber optic fluorometry technique was introduced to measure the blood flow in dye fluorescence units. Its superiority over the qualitative technique was shown\textsuperscript{39,40}. Previous studies reported adverse reactions of intravenous fluorescent dye injections, even anaphylactic reactions with fatal outcomes\textsuperscript{42,43}. However, a recent international multicenter study has shown intravenous administration of fluorescein to be safe for a confocal laser endomicroscopy of the gastrointestinal tract\textsuperscript{44}. The major drawback of fluorometry is the inability to perform repeated measurements since the fluorescein sticks around once it gets into the tissue\textsuperscript{45}. Very large standard deviations of quantitative fluorometry measurements were observed, showing insufficient accuracy of the technique\textsuperscript{45}. Some authors argued that the viability is not measured directly by fluorometry; it can also be overpredictive of nonviability and lead to unnecessary resections, particularly in patients with the isolated venous occlusion\textsuperscript{46,47}.

Recently a more sophisticated method, LFA, has been validated for intestinal microcirculation assessment. The method is based on intravenous injection of fluorescent dye (indocyanine green) and illumination of the bowel at the site of interest with a laser light. Digital videos of the fluorescence are recorded as a function of tissue perfusion\textsuperscript{48}. The system is reliable and the measurements can be repeated after the rapid clearance of the fluorescent dye by hepatic uptake and biliary excretion. This is an advantage compared to the conventional perfusion fluorometry. In a study by Kudzsus et al\textsuperscript{5}, the predictive value of LFA was analyzed in a retrospective matched-pairs analysis. Measurements by LFA led to extended resections of malperfused intestine in 14.2\% of patients, avoiding leaving nonviable bowel \textit{in situ}. In 2\% of the cases, resection of the viable bowel could be avoided. The use of intraoperative LFA reduced the risk of revision due to anastomotic leakage by 60\% in patients undergoing elective colorectal surgery irrespective of their age and by 64\% in patients above the age of 70. Hand-sewn anastomosis controlled by LFA reduced the risk of revision by 84\% compared to the same anastomotic technique without LFA. The authors recommend the technique for routine use in clinical practice. However, the technique has limitations too: the contents of the intestine can interfere with fluorescence and the limiting values of LFA representing irreversible necrosis are not yet defined. The low LFA values were not consistent with pathological grade of ischemia in an animal model\textsuperscript{59}. Moreover, the measurements are position dependent and not applicable for the assessment of colorectal anastomosis situated in the minor pelvis\textsuperscript{1,36}. 

Urbanavicius L et al. Intraoperative quantitative assessment of intestinal viability
**Infrared imaging**

Thermal or infrared imaging is a scanning technique for recording small temperature differences between adjacent structures on a photographic display. The current medical application of thermal imaging is mainly limited to the detection of peripheral circulatory disturbances or breast cancer and to assess graft patency in plastic or cardiac surgery. Low surface temperature can be interpreted to be the poor vascularity that may cause an anastomotic impairment\[89\].

Thermal imaging was applied for assessment of the intestinal blood supply in several studies. The first study investigating a reactive bowel hyperemia after an ischemia and reperfusion was published in 1978\[57\]. Brooks et al\[59\] compared thermal imaging to visual inspection, Doppler ultrasound and fluorescence with Wood’s lamp. All methods had a high positive predictive value in detecting bowel ischemia, except the visual inspection which was the only method unable to detect a difference between vascularized and devascularized bowel. Doppler ultrasound and thermal imaging were 100% sensitive for a necrotic bowel\[59\]. Roberts et al showed that infrared imaging is a potential tool for localizing anatomic structures and assessing tissue viability during laparoscopic surgical procedures in a porcine model\[60\]. Nishikawa et al examined the use of intraoperative thermal imaging to assess gastric vascularization and gastric tube viability in patients during esophagectomy. They found intraoperative thermal imaging to be a noninvasive and reliable technique\[57\]. However, this is an indirect indicator of perfusion and oxygenation and the measurements are dependent on ambient temperature.

**Laser Doppler flowmetry**

The principle of Laser Doppler flowmetry (LDF) is to measure the Doppler shift — the frequency change that light undergoes when reflected by moving objects such as red blood cells. LDF works by illuminating the tissue under observation with a monochromatic laser from a probe. When the tissue is illuminated, only 3%–7% of the light is reflected. The remaining 93%–97% is either absorbed by various structures or undergoes scattering. Another optical fiber collects the backscattered light from the tissue and returns it to the monitor. As a result, LDF produces an output signal that is proportional to the number of blood cells moving in the measured volume X mean velocity of the cells\[59\]. The measurements are expressed as mL/min per 100 g of tissue.

Vignali et al tested the reliability of intraoperative LDF measurements in predicting the occurrence of anastomotic leak in patients with colorectal cancer\[60\]. In a prospective study of 55 patients, the transmural colonic blood flow was measured during different stages of large bowel resection. Mean rectal stump flow reduction of 6.2% and proximal stump flow reduction of 5.1% was detected. The cut-off values of flow reduction, indicative of anastomotic insufficiency, were 16% and 12.9% respectively.

LDF measurements were also applied by Seike et al\[5\]. Colonic blood flow at the proximal site of the anastomosis was measured by LDF in 96 patients with cancer of the rectum and sigmoid colon while clamping inferior mesenteric artery (IMA) or left colic artery (LCA). Blood flow measured by LDF was significantly decreased by clamping the arteries. The flow reduction rate by IMA clamping (more than 50%) may be at risk for the anastomotic ischemia. In such cases, the authors recommend preservation of LCA.

Nakatsuka measured gastric mucosal pH by a gastric tonometry and colonic tissue blood flow at the serosal layer by LDF during infrarenal abdominal aortic surgery in a prospective comparison study of eight patients\[60\]. In this study, the borderline value 41.7 ± 7.4 mL/min per 100 g of the sigmoid colonic tissue blood flow determined by LDF was detected which is sufficient to prevent postoperative ischemic colitis. Decrease of gastric mucosal pH measured by a gastric tonometry was not clinically significant and it did not reflect changes in intestinal microcirculation following aortic cross-clamping.

Singh and coworkers investigated VLS and LDF for assessing bowel serosal and mucosal oxygenation and blood flow in a pilot study of seven patients during different stages of colon surgery\[60\]. The authors found that the mean sigmoid mucosal StO\(_2\) decreased after ligation of inferior mesenteric artery from the baseline of 73% to 55%. After complete devascularization, the mean sigmoid mucosal StO\(_2\) was reduced to 39%. The mean sigmoid mucosal flux decreased after ligation of inferior mesenteric artery and it further decreased after complete devascularization. A similar trend was seen on the serosal flux measurements. In contrast, sigmoid serosal StO\(_2\) measured by VLS did not decrease after ligation of inferior mesenteric artery and it decreased only slightly after complete devascularization from a baseline of 86% to 79%. The authors believe that mucosal StO\(_2\) measurements by VLS can accurately diagnose bowel ischemia but serosal StO\(_2\) measurements do not reflect a mucosal ischemia. Doppler flux measurements could be useful in detecting ischemia from the serosal surface of the bowel.

A major limitation of LDF is that it does not take into account the heterogeneity of blood flow as the velocity measurements represent the average of velocities in all vessels of the window studied.

LDF data are affected by motion artifacts in recording sites. In measurements of the oral mucosa, mucosa and serosa of the colon, large standard deviations of the flow parameters were observed\[60,61\]. Continuous measurement holding the probe securely may be necessary to overcome this limitation\[5\]. Pulsatile blood flow is required as the blood flow is measured in the deeper layers of the bowel containing arterioles. Changes in the patient’s cardiovascular status caused by intraoperative blood loss or drug administration through epidural anesthesia can also influence the measurements by LDF and might be time consuming since repeated measurements are necessary\[5,28\]. LDF re-
requires tissue contact and may disturb local blood flow. Scanning LDF was proposed for intraoperative use to overcome the limitations of single-point LDF. In an animal study, this technique has been shown to have a significant relationship with histological grade of ischemia. However, it is time consuming since the time needed to produce a perfusion image may be several minutes. The probability that movement artefacts will degrade the image quality increases with acquisition time. The cut-off level of flow indicative of intestinal ischemia varies in different studies. In an animal study, a value of 30% of flow in the intact colon measured by LDF was considered to be safe for anastomotic healing. In human studies, much lower decreases in LDF values showed risk of ischemia. The perfusion units are arbitrary and rather qualitative. Further studies are needed to create references in order to have quantitative values, the tools for distinction between capillary and global tissue perfusion and the tools providing measurements avoiding motion artifacts.

**Bowel wall contractility measurements**

In 1986, the electronic contractility meter (ECM) was introduced as a quantitative method of measuring contractile activity of ischemic bowel. The ECM consists of two major components, a specially designed probe and an electronic control unit. The probe is clipped onto the serosal surface of the bowel and the electromyogram reflecting peristalsis of the small intestine is recorded at each 2 cm interval and quantified in millivolts by a computer algorithm. Low electromyography (EMG) values referred to ischemic damage of the submucosal neuromuscular plexus.

Brolin et al have applied EMG, Doppler ultrasound and perfusion fluorometry. They showed that EMG might be a more sensitive indicator of ischemic damage than either ultrasonography or perfusion fluorometry in a model of acute intestinal ischemia. However, after reperfusion, a slow increase of EMG values was observed and after 15 min normal values were reached. This shows the technique to be time consuming when no definitive necrosis of the intestine is present and the site of bowel resection must be determined. Also, the limit values of bowel wall contractility are not precise. Brolin et al considered 50% of the contractility of a normal bowel to be sufficient for the anastomotic healing in a dog model. However, extrapolation to human conditions might be difficult considering that the bowels of different species are not equally resistant to ischemia. Electromyography has been used clinically in a study by Dutkiewicz et al. Myoelectrical small bowel activity was measured intraoperatively in patients with and without small bowel ischemia. The diminished myoelectrical activity of the ischemic bowel wall was observed, which well correlated with histological changes. It has not found a wider clinical acceptance, probably due to many unanswered questions and the complexity of the technique.

**pH measurement**

Tonometry is a noninvasive method to determine the intramuscular pH (pHi) in hollow organs which correlates with the oxygen supply to the mucosa. During mucosal hypoperfusion, acidosis develops, thereby resulting in a decrease of pHi. The tonometer is a silicone balloon catheter which is introduced into the lumen of the gut, then filled with isotonic sodium chloride solution and allows the free diffusion of carbon dioxide (CO2). After an equilibration period, pCO2 of the saline filling the balloon is proportionate to the intestinal mucosal pCO2. This value and that of the arterial bicarbonate are then used in the Henderson-Hasselbach equation to calculate the intramuscolar pH: pH = log10 [(HCO3-)/0.03 x pCO2 X F], where F is a time-dependent correction factor and [HCO3-] is the actual bicarbonate concentration (mmol/L) of the arterial blood.

Kamiya and coworkers monitored pHi levels in the intestinal lumen using a tonometer intraoperatively and after the operation. 35 patients who underwent free jejunal transfer following pharyngolaryngoesophagectomy for laryngeal, hypopharyngeal and cervical esophageal cancer were enrolled in the prospective observational study. The critical value of pHi < 7.10 was detected which leads to jejunal graft microcirculation disturbance and graft necrosis. It was shown that pHi measurement using a tonometer is useful for finding vascular problems in free jejunal grafts.

Millan, in a prospective study of 90 patients with colorectal resections, determined pHi levels at 24 and 48 h postoperatively and found that pHi < 7.28 in the first 24 h postoperatively is associated with 22 times higher risk of anastomotic leak.

Despite being an accurate technique, tonometry is rather used for postoperative monitoring of bowel ischemia. The necessity of leaving the catheters in situ may be considered a shortcoming of the technique.

**Microdialysis**

Deeba et al employed a momental intramural microdialysis to measure glucose and lactate levels in the bowel wall of specimens being resected intraoperatively and to monitor bowel ischemia in seven patients. After mobilization and before transecting any feeding vessel, a microdialysis probe was tunneled in the seromuscular layer of the left colon and fixed in place. Glucose and lactate concentrations were monitored until the bowel specimen was removed. After the transection of the feeding arteries, the glucose concentrations decreased whereas lactate concentrations increased leading to increase of lactate/glucose ratio. The study demonstrated the feasibility of using the microdialysis system in clinical practice. The authors suggest implanting the catheter near a bowel segment that is of questionable viability and to tunnel it outside the abdomen for postoperative bedside monitoring to alert the physician before ischemia manifests clinically.

**Assessment of electrical properties**

Matsuo et al evaluated the viability of a strangulated intestine by measuring its electrical properties in an experimental study. Correlation of changes in dielectric...
parameters with intestinal ischemia was found. Values suggesting the need for resection of the nonviable bowel were found; however, no intermediate value showing the possible recovery could be determined.

**CLINICAL APPLICATION OF THE METHODS**

Horgan and Gorey defined the requirements of an ideal bowel viability test: 1) The technique must have ready availability, preferably in every operating theater dealing with abdominal emergencies; 2) The necessary equipment must not be cumbersome or require specialized personnel; 3) The method must be accurate with a minimum of false-negative results and, more importantly, few false positives; 4) The technique must be objective and reproducible; and 5) The method must be cost effective.

Despite numerous techniques are available as aforementioned, only several have been used in human studies over the last ten years (Table 1). There is no agreement as to which method is the most accurate and best applicable. Some of the techniques are applicable for postoperative follow-up of intestinal microcirculation (tonometry and rapid sampling microdialysis). Various parameters are measured by different methods and the most widely used are those reflecting oxygenation and perfusion, measured by VLS and LDF respectively. Considering that oxygenation and perfusion would probably have to be both evaluated intraoperatively, these two techniques seem to be the most promising. However, only one study has made comparison between the LDF and VLS and the oximetry has not been compared to other techniques of intestinal viability assessment. No cut-off values of parameters indicative of intestinal ischemia have been determined yet. Several authors obtained different results applying the same technique. So far, there is no method that would fulfill all requirements stated by Horgan and Gorey.

**Site of measurements**

It has been estimated that blood flow in the mucosal and submucosal layers accounts for 70% of total blood flow in intestinal tissues; therefore, microcirculation should be
evaluated in mucosal and submucosal layer\[81\]. In other experimental studies using LDF and hydrogen gas clearance, a strong correlation between submucosal and subserosal blood flow was shown\[10,82\]. It was also confirmed in human studies\[1,20,21,63,47\]. Brolin et al\[23\] observed that in an ischemia model, extensive mucosal damage does not consistently result in bowel infarction and suggested that the measurements should be obtained from the serosal surface. This led to less invasive microcirculation assessment at the serosa of the intestine\[99\]. However, measurements performed by different authors and different systems yield unequal results. Karliczek et al have shown the reproducible measurements at the serosa of the resected bowel end whereas Singh et al have showed that the serosal StO\(_2\) measurements are not sensitive to ischemia and are only possible at the mucosa. Moreover, different baseline values of serosal StO\(_2\) were detected by the studies, 72.1 ± 9.0% and 86 ± 7.3% respectively\[1,64\]. The authors used different oximeter systems and the inter-device variability could possibly be the reason for the different results.

Evaluation of intestinal stoma viability

There are multiple risk factors predisposing stoma complications, including smoking, diabetes, grade of operating surgeon and emergency procedure. Necrosis is very important among other stoma complications. An insufficient perfusion and ischemia of the resected bowel end is one of the predisposing risk factors. In a prospective observational study of 97 patients with a newly created intestinal stoma, three patients developed necrosis and two experienced ischemia of their stoma\[80\]. In a nationwide prospective audit in the UK, the observed frequency of stoma necrosis was 8.7%/84]. The incidence of stoma ischemia and necrosis could be potentially diminished by objective intraoperative evaluation of stoma viability and timely surgical correction. However, it relies mainly on subjective intraoperative findings. Adequacy of blood supply at the enterostomy resection margin was assessed by Doppler ultrasound in a previous study\[32\]. In two studies, stoma microcirculation was assessed postoperatively. Boerma and coworkers compared sublingual and stoma microcirculation using orthogonal polarization spectral imaging technique in patients with abdominal sepsis\[85\]. The method has been validated previously for microcirculatory research in sepsis patients\[86\]. There was neither correlation between intestinal and sublingual blood flow; nor between intestinal and systemic hemodynamic parameters in abdominal sepsis patients on day one of sepsis and on day three this correlation appeared to be restored. These findings suggest that intestinal microcirculation cannot always be judged from the parameters of other microcirculatory beds or systemic hemodynamic parameters. Singh and Harrison investigated tissue oxygen saturation in end colostomy stomas with a minimum age of three months using a visible light spectroscopy. The normal oxygenation value of 77.6 ± 6.8 was detected. There were no significant diurnal variations in the stomal oxygenation values\[87\].

**Importance of systemic hemodynamics**

Duchs and Foitzik analyzed the influence of systemic hemodynamics on microcirculatory parameters. The authors used three techniques in parallel: an intraluminal bowel mucosal microscopy for the measurement of capillary blood flow, a spectroscopy for the measurement of Hb oxygen saturation in the tissue and a polarographic measurement of mucosal pO\(_2\). Capillary blood flow of the bowel mucosa measured by intraluminal microscopy did not demonstrate insufficient oxygen supply of the tissue under systemic hypoxia. This was demonstrated by another two techniques. Comparing microcirculation measurements by the three methods, the authors observed that the extent to which hypovolemia and hypoxia influence these parameters is different. Moreover, a poor correlation between measurements by the different methods was found. In conclusion, the mean arterial pressure, blood gases and hematocrit must be analyzed to correctly interpret microcirculatory parameters\[88\].

**CONCLUSION**

Although numerous objective quantitative techniques of intraoperative bowel viability assessment are available, only a few are applicable in gastrointestinal surgery. VLS and LDF have been the most frequently used in humans over the last decade. The majority of methods are still far from ideal. Further studies are needed to determine the limiting values of tissue oxygenation and flow indicative of ischemic complications and to standardize the methods. Rapid progression in development of new instruments and techniques will hopefully help to solve these problems.

**REFERENCES**

1. Karliczek A, Benaron DA, Baas PC, Zeebregts CJ, Wiggers T, van Dam GM. Intraoperative assessment of microperfusion with visible light spectroscopy for prediction of anastomotic leakage in colorectal anastomoses. *Colorectal Dis* 2010; 12: 1018-1025
2. Kudszus S, Roesel C, Schachtrupp A, Höer JJ. Intraoperative laser fluorescence angiography in colorectal surgery: a noninvasive analysis to reduce the rate of anastomotic leakage. *Langenbecks Arch Surg* 2010; 395:1025-1030
3. La Hei ER, Shun A. Intra-operative pulse oximetry can help determine intestinal viability. *Pediatr Surg Int* 2001; 17: 120-121
4. Karliczek A, Harlaar NJ, Zeebregts CJ, Wiggers T, Baas PC, van Dam GM. Surgeons lack predictive accuracy for anastomotic leakage in gastrointestinal surgery. *Int J Colorectal Dis* 2009; 24: 569-576
5. Seike K, Koda K, Saito N, Oda K, Kosugi C, Shimizu K, Miyazaki M. Laser Doppler assessment of the influence of division at the root of the inferior mesenteric artery on anastomotic blood flow in rectosigmoid cancer surgery. *Int J Colorectal Dis* 2007; 22: 689-697
6. Dworkin MJ, Allen-Mersh TG. Effect of inferior mesenteric artery ligation on blood flow in the marginal artery-depended sigmoid colon. *J Am Coll Surg* 1996; 183: 357-360
7. Lima A, Bakker J. Noninvasive monitoring of peripheral perfusion. *Intensive Care Med* 2005; 31: 1316-1326
Intraoperative quantitative assessment of intestinal viability

Erikoglou M, Kaynak A, Beyatli EA, Toy H. Intraoperative determination of intestinal viability: a comparison with transeroal pulse oximetry and histopathological examination. J Surg Res 2005; 128: 66-69

DeNoble J, Guzzetta J, Patterson K. Pulse oximetry as a means of assessing bowel viability. J Surg Res 1990; 48 : 21-23

MacDonald PH, Dinda PK, Beck IT, Mercer CD. The use of oximetry in determining intestinal blood flow. Surg Gynecol Obstet 1993; 176: 451-458

Gardner GP, LaMorte WW, Obi-Tabot ET, Menzoian JO. Transanal intracolonic pulse oximetry as a means of monitoring the adequacy of colonic perfusion. J Surg Res 1994; 57: 537-540

Phillips JP, Kyriacou PA, Jones DP, Shelley KH, Langford RM. Pulse oximetry and photoplethysmographic waveform analysis of the esophagus and bowel. Curr Opin Anaesthesiol 2008; 21: 779-783

Hadley GP, Mars M. Limitations of oximeters. Pediatr Surg Int 2003; 19: 130

Dyess DL, Bruner BW, Donnall CA, Ferrara JJ, Powell RW. Intraoperative evaluation of intestinal ischemia: a comparison of methods. South Med J 1991; 84: 966-99, 974

Düchs R, Foitzik T. Possible Pitfalls in the Interpretation of Microradiological Measurements. Eur Surg Res 2008; 40: 47–54

Sheridan GW, Lowndes RH, Young HL. Tissue oxygen tension as a predictor of colonic anastomotic healing. Dis Colon Rectum 1987; 30: 867-871

Jacobi CA, Zieren HU, Zieren J, Müller JM. Is tissue oxygen tension during esophagectomy a predictor of esophageagastrotic anastomotic healing? J Surg Res 1998; 74: 161-164

Benaron DA, Parachikov IH, Cheong WF, Friedland S, Rubinsky BE, Otten DM, Liu FW, Levinson CJ, Murphy AL, Price JW, Talmi Y, Weersing JP, Duckworth JL, Höchner UB, Kermit EL. Design of a visible-light spectroscopy clinical oximeter. J Biomed Opt; 10: 44005

Posma LA, Hendriks T, Verhofstad AA, de Man BM, Lomme RM, Bleichrodt RP. Reduction of oxygenation and blood flow in pedicled bowel segments in the rat and its consequences for anastomotic healing. Dis Colon Rectum; 53: 93-100

Benaron DA, Parachikov IH, Friedland S, Soetikno R, Brock-Utne J, van der Starre PJ, Nocbat C, Terasi MK, Maxim PG, Carson JJ, Razavi MK, Gladstone HB, Fincher EF, Hsu CP, Clark FL, Cheong WF, Duckworth JL, Stevenson DK. Continuous, noninvasive, and localized microvascular tissue oximetry using visible light spectroscopy. Anesthesiology 2004; 100: 1469-1479

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 anastomatic complications. World J Surg 2006; 30: 457-461

Lee ES, Bass A, Arko FR, Heikkinen M, Harris EJ, Zarin CK, van der Starre P, Ollcit C. Intraoperative colon mucosal oxygen saturation during aortic surgery. J Surg Res 2006; 136: 19-24

http://www.spectros.com/index.php?id=53

Schultze-Mosgau S, Wiltfang J, Bürklein F, Neukam FW. Micro-lightguide spectrophotometry as an intraoral monitoring method in free vascular soft tissue flaps. J Oral Maxillofac Surg 2003; 61: 292-27; discussion 297

Harrison DK, Hawthorn IE. Amputation level viability in critical limb ischaemia: setting new standards. Adv Exp Med Biol 2005; 566: 325-331

Myers DE, Anderson LD, Seifert RP, Ornert JP, Cooper CE, Beilman GJ, Mowlew JD. Noninvasive method for measuring local hemoglobin oxygen saturation in tissue using wide gap second derivative near-infrared spectroscopy. J Biomed Opt 2005; 10: 030417

Hirano Y, Omura K, Yoshihia H, Ohta N, Hiranuma C, Nitta K, Nishida Y, Watanabe G. Near-infrared spectroscopy for assessment of tissue oxygen saturation of transplanted jejunal autografts in cervical esophageal reconstruction. Surg Today 2005; 35: 67-72

Myers C, Mutafyan G, Petersen R, Pryor A, Reynolds J, Demaria E. Real-time probe measurement of tissue oxygenation during gastrointestinal stapling: mucosal ischemia occurs and is not influenced by staple height. Surg Endosc 2009; 23: 2345-2350

Yasumura M, Mori Y, Takagi H, Yamada T, Sakamoto K, Iwata H, Hirose H. Experimental model to estimate intestinal viability using charge-coupled device microscopy. Br J Surg 2009; 90: 461-465

Cooperman M, Martin EW Jr, Carey LC. Evaluation of ischemic intestine by Doppler ultrasound. Am J Surg 1989; 139: 73-77

Lynch TG, Hobson RW, Kerr JC, Brousseau DA, Silverman DG, Reilly CA, Tseng H. Doppler ultrasound, laser Doppler, and perfusion fluorometry in bowel ischemia. Arch Surg 1988; 123: 483-486

Cooperman M, Martin EW Jr, Keith LM, Carey LC. Use of Doppler ultrasound in intestinal surgery. Am J Surg 1979; 138: 856-859

Ambrosetti P, Robert J, Mathey P, Rohnner A. Left-sided colon and colorectal anastomoses: Doppler ultrasound as an aid to assess bowel vascularization. A prospective evaluation of 200 consecutive elective cases. Int J Colorectal Dis 1994; 9: 211-214

Bulkeley GB, Zuidema GD, Hamilton SR, O’Mara CS, Klacsmann PG, Horn SD. 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

Rotering RH, Dixon JA, Holloway GA, 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: 705-708

Aukland K, Bower BF, Berliner RW. Measurement of local blood flow with hydrogen gas. Circ Res 1964; 16: 164–187

Oohata Y, Miwu R, Notokezawa 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

Mishima Y, Shigematsu H, Horie Y, Satoh M. Measurement of local blood flow of the intestine by hydrogen clearance method; experimental study. Jpn J Surg 1979; 9: 63-70

Young W. H2 clearance measurement of blood flow: a review of technique and polarographic principles. Stroke ; 11: 592-564

Bulkeley GB, Gharagozloo F, Alderson PO, Horn SD, Zuidema GD. Use of intraperitoneal xenon- 133 for imaging of intestinal strangulation in small bowel obstruction. Am J Surg 1981; 141: 128-135

Hummel SJ, Delgado G, Butterfield A, Dritschilo A, Harbert J. Measurement of blood flow through surgical anastomosis using the radioactive microsphere technique. Obstet Gynecol 1985; 66: 579-581

Wheelers CR, Smith JJ. A comparison of the flow of iodine 125 through three different intestinal anastomoses: standard, Gambee, and stapler. Obstet Gynecol 1983; 62: 513-518

Hulten L, Jodal M, Lindhagen J, Lundgren O. Colonic blood flow in cat and man as analyzed by an inert gas washout technique. Gastroenterology 1976; 70: 36-44

Forrester DW, Spence VA, Walker WF. Colonic mucosal-submucosal blood flow and the incidence of faecal fistula
form following colostomy closure. Br J Surg 1981; 68: 541-544
45 Frits W, Prizen, James B. Bassingthwaighte. Blood flow distributions by microsphere deposition methods. Cardiovasc Res 2000; 45: 13-21
46 Bergman RT, Gloviczki P, Welch TJ, Naessens JM, Bower TC, Hallett JW, Pairolero PC, Cherry KJ. The role of intravascular fluorescent in the detection of colon ischemia during aortic reconstruction. Ann Vasc Surg 1992; 6: 74-79
47 McGinty JJ, Hogle N, Fowler DL. Laparoscopic evaluation of intestinal ischemia using fluorescent and ultraviolet light in a porcine model. Surg Endosc 2003; 17: 1140-1143
48 Silverman DG, Hurdow WE, Cooper HS, Robinson M, Broussseau DA. Quantification of fluorescent distribution to strangled rat ileum. J Surg Res 1983; 34: 179-186
49 Páral J, Subrt Z, Lochman P, Ferko A, Dusek T, Slaninka L, Cecka F, Louda M, Romzová M, Jon B, Kaska M. [Preoperative diagnostics of acute bowel ischemia using ultraviolet light and fluorescent dyes]. Rozhl Chir 2009; 88: 590-595
50 Holmes NJ, Cazi G, Reddell MT, Gorman JH, Fordorci B, Semmlow JL, Brolin RE. Intraoperative assessment of bowel viability. J Invest Surg 2006; 6: 211-221
51 Carter MS, Fantini GA, Sammartano RJ, Mitsudo S, Silverman DG, Boley SJ. Qualitative and quantitative fluorescent fluorescence in determining intestinal viability. Am J Surg 1984; 147: 117-123
52 LaPiana FG, Penner R. Anaphylactoid reaction to intravenously administered fluorescent. Arch Histol Cytol 1968; 79: 161-162
53 Cunningham EE, Balu V. Cardiac arrest following fluorescent angiography. JAMA 1979; 242: 2431-2431
54 Wallace MB, Meining A, Canto MJ, Fockens P, Miehkle S, Roesch T, Lightdale CJ, Pohl H, Carr-Locke D, Löhr M, Coletti D, Filoche B, Giovannini M, Moreau J, Schmidt C, Kieslich R. The safety of intravenous fluorescent for confocal laser endomicroscopy in the gastrointestinal tract. Aliment Pharmacol Ther 2010; 31: 548-552
55 Toens C, Krones CJ, Blum U, Fernandez V, Grömmes J, Hoelzl F, Stumpf M, Klinger U, Schumpelick V. Validation of the ICview fluorescence videography in a rabbit model of mesenteric ischemia and reperfusion. Int J Colorectal Dis 2005; 19: 1-7
56 Willis S, Hölzl F, Krones CJ, Titell A, Schumpelick V. Evaluation of the anastomotic microcirculation following its interruption. Tech Colonrectal Surg 2006; 10: 222-226
57 Nishikawa K, Matsudaiera H, Suzuki H, Mizuno R, Hanyuu N, Iwabuchi S, Yanaka K. Intraoperative thermal imaging in esophageal replacement: its use in the assessment of gastric tube viability. Surg Today 2006; 36: 802-806
58 Moss AA, Kressel HY, Brito AC. Thermographic assessment of intestinal viability following ischemic damage. Invest Radiol; 13: 16-20
59 Brooks JP, Perry WB, Putnam AT, Karulf RE. Thermal imaging in the detection of bowel ischemia. Dis Colon Rectum 2000; 43: 1319-1321
60 Roberts WW, Dinkel TA, Schum PG, Bonnell L, Kavousi LR. Laparoscopic infrared imaging. Surg Endosc 1997; 11: 1221-1223
61 Redaeli CA, Schilling MK, Carrel TP. Intraoperative assessment of intestinal viability by laser Doppler flowmetry for surgery of ruptured abdominal aortic aneurysm. World J Surg 1998; 22: 283-289
62 Vignali A, Gianotti L, Braga M, Redaelli G, Malvezzi L, Di Carlo V. Altered microperfusion at the rectal stump is predictive for rectal anastomotic leak. Dis Colon Rectum 2000; 43: 76-82
63 Nakatsu K. Assessment of gut mucosal perfusion and colonic tissue blood flow during abdominal aortic surgery with gastric tonometry and laser Doppler flowmetry. Vasc Endovascular Surg, 36: 195-198
64 Singh DB, Stansby G, Bain I, Harrison DK. Intraoperative measurement of colonic oxygenation during bowel resection. Adv Exp Med Biol 2009; 645: 261-266
65 Singh DB, Stansby G, Harrison DK. Assessment of oxygenation and perfusion in the tongue and oral mucosa by visible spectrophotometry and laser doppler flowmetry in healthy subjects. Adv Exp Med Biol 2008; 614: 227-233
66 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: 504-510
67 Hajivassiliou CA, Greer K, Fisher A, Finlay IG. Non-invasive measurement of colonic blood flow distribution using laser Doppler imaging. Br J Surg 1998; 85: 52-55
68 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
69 Humeau A, Steenbergen W, Nilsson H, Strömberg T. Laser Doppler perfusion monitoring and imaging: novel approaches. Med Biol Eng Comput 2007; 45: 421-435
70 Kashiwagi H. The lower limit of tissue blood flow for safe colonic anastomosis: an experimental study using laser Doppler velocimetry. Surg Today 1993; 2: 430-438
71 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
72 Brolin RE, Bibbo C, Petschenik A, Reddell MT, Semmlow JL. Comparison of ischemic and reperfusion injury in canine bowel viability assessment. Gastrointest Surg 1997; 1: 511-516
73 Brolin RE, Semmlow JL, Sehonanda A, Koch RA, Reddell MT, Marsh BA, Mackenzie JW. Comparison of five methods of assessment of intestinal viability. Surg Gynecol Obstet 1989; 168: 6-12
74 Dutkiewicz W, Thor P, Pawlicki R, Bobrzyński A, Budzynski A. Electromyographic and histologic evaluation of intestinal viability. Wiat Lak 1997; 50: 50-53
75 Kamiya K, Suzuki S, Mineta H, Konno H. Tonometer pH monitoring of free jejunal grafts following pharyngolaryngosphagostomy for hypopharyngeal or cervical esophageal cancer. Dig Surg 2007; 24: 214-220
76 Millan M, García-Granero E, Flor B, García-Botello S, Lledo S. Early prediction of anastomotic leak in colorectal cancer surgery by intramucosal pH. Dis Colon Rectum 2006; 49: 595-601
77 Deeba S, Corcoles EP, Hanna BG, Pareskevas P, Aziz O, Bouteille MG, Dari A. Use of Rapid Sampling Microdialysis for Intraoperative Monitoring of Bowel Ischemia. Dis Colon Rectum 2008; 51: 1408-1413
78 Sorensen HB. Free jejunal flaps can be monitored by use of microdialysis. J Reconstr Microsurg 2008; 24: 443-448
79 Matsuo H, Hirose H, Mori Y, Takagi H, Iwata H, Yamada T, Sakamoto K, Yasumura M. Experimental studies to estimate the intestinal viability in a rat strangulated ileus model using a diodelectric parameter. Dig Dis Sci 2004; 49: 633-638
80 Horgan PG, Gorny TF. Operative assessment of intestinal viability. Clin Gastroenterol North Am 1992; 72: 143-155
81 Gore RW, Bohlen HG. Microvascular pressures in rat intestinal muscle and mucosal villi. Am J Physiol 1977; 8: H685–H693
82 Aln H, Lindhagen J, Nilsen GE, Sailerud EG, Jodal M, Landgren O. Evaluation of laser Doppler flowmetry in the assessment of intestinal blood flow in cat. Gastroenterology 1985; 88: 951-957
83 Arunugam PJ, Bevan L, Macdonald L, Watkins AJ, Morgan AR, Beynon J, Carr ND. A prospective audit of stoma–analysis of risk factors and complications and their management. Colorectal Dis 2003; 5: 49-52
Urbanavičius L et al. Intraoperative quantitative assessment of intestinal viability

84 Cottam J, Richards K, Hasted A, Blackman A. Results of a nationwide prospective audit of stoma complications within 3 wk of surgery. Colorectal Dis 2007; 9: 834-838

85 Boerma EC, van der Voort PH, Sprook PE, Ince C. Relationship between sublingual and intestinal microcirculatory perfusion in patients with abdominal sepsis. Crit Care Med 2007; 35: 1055-1060

86 Boerma EC, Mathura KR, van der Voort PH, Sprook PE, Ince C. Quantifying bedside-derived imaging of microcirculatory abnormalities in septic patients: a prospective validation study. Crit Care 2005; 9: R601-R606

87 Singh DB, Bain I, Harrison DK. Use of visible spectrophotometry to assess tissue oxygenation in the colostomy stoma. Adv Exp Med Biol 2010; 662: 273-278

S- Editor Wang JL  L- Editor Roemmele A  E- Editor Zhang L