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ORIGINAL ARTICLE

Determination of the transection margin during colorectal resection with hyperspectral imaging (HSI)

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Abstract

Purpose This study evaluated the use of hyperspectral imaging for the determination of the resection margin during colorectal resections instead of clinical macroscopic assessment.

Methods The used hyperspectral camera is able to record light spectra from 500 to 1000 nm and provides information about physiologic parameters of the recorded tissue area intraoperatively (e.g., tissue oxygenation and perfusion). We performed an open-label, single-arm, and non-randomized intervention clinical trial to compare clinical assessment and hyperspectral measurement to define the resection margin in 24 patients before and after separation of the marginal artery over 15 min; HSI was performed each minute to assess the parameters mentioned above.

Results The false color images calculated from the hyperspectral data visualized the margin of perfusion in 20 out of 24 patients precisely. In the other four patients, the perfusion difference could be displayed with additional evaluation software. In all cases, there was a deviation between the transection line planed by the surgeon and the border line visualized by HSI (median 1 mm; range − 13 to 13 mm).

Tissue perfusion dropped up to 12% within the first 10 mm distal to the border line. Therefore, the resection area was corrected proximally in five cases due to HSI record. The biggest drop in perfusion took place in less than 2 min after devascularization.

Conclusion Determination of the resection margin by HSI provides the surgeon with an objective decision aid for assessment of the best possible perfusion and ideal anastomotic area in colorectal surgery.

Keywords Hyperspectral imaging (HSI) · Transection margin · Colorectal surgery · Tissue perfusion and oxygenation · Ideal anastomotic site · Prevention of anastomotic leak

Introduction

Hyperspectral imaging (HSI) is a new tool used in image-guided surgery, which has shown promising results for characterization of tissues and assessment of physiologic tissue parameters. It acquires a three-dimensional dataset called hypercube, with two spatial dimensions and one spectral dimension. Spatially resolved spectral imaging obtained by HSI provides diagnostic information about the tissue physiology, morphology, and composition. Moreover, it is well known to assess detailed circulatory pathology and wound healing, and it serves as a new tool for disease detection, in particular for cancer imaging and tissue classification [1]. Our own group, for the first time, was able to evaluate its impact on gastrointestinal anastomoses in visceral surgery in vivo [2]. In this context, HSI—as a contactless and non-invasive intraoperative imaging method—offers objective "real-time" measurement of physiologic anastomotic parameters with the aim to determine the optimal site of the anastomosis, potentially change the intraoperative strategy, and consecutively reduce complications, such as anastomotic leak [2]. Analysis software provides images of the recorded tissue area

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intraoperatively, containing tissue oxygenation (StO_2), perfusion (near-infrared (NIR) perfusion index), organ hemoglobin (OHI), and tissue water index (TWI).

HSI, as an upcoming guidance tool in the frame of precision surgery, holds the potential to enhance the surgeon's visualization beyond gross macroscopic assessment of intestinal perfusion and to objectively assess the complex perfusion system of the gastrointestinal tract with the ability to reproduce the results. Herewith, it overcomes the conventionally used methods, such as clinical judgements by assessment of pulsation intensity of supplying arteries of second or third order as well as of the vitality and motility of small and large intestine, which are highly subjective parameters and unable to predict the further course of tissue perfusion development or anastomotic healing.

The aim of our study was to evaluate the application of intraoperative HSI measurement in determining the transection line of the proximal colon during colorectal surgery before creation of the anastomosis. Our main goal was to show the temporal behavior of perfusion on both sides of the resection margin up to 15 min after devascularization. Moreover, our secondary goal was to investigate to which extent the subjective assessment of the surgeon corresponded to the objective measurements of HSI with regard to the border zone.

Patients and methods

Study population

From early February 2018 to mid September 2018, a clinical trial was conducted in a prospective, non-randomized, open-label, and single-arm study design at the University Hospital Leipzig, Germany. Twenty-four consecutive patients undergoing colorectal surgery were included. The study was approved by the local ethic committee of the Medical Faculty of the University of Leipzig, Germany (No. 026/18-ek, January 31, 2018). The clinical trial was registered under Clinicaltrials.gov NCT03667950. Written informed consent was obtained from all participants of this study to perform HSI measurements intraoperatively and to analyze their clinical data anonymously. As the camera is currently applicable in open surgery only, minimally invasive colorectal resections were included, if the colon was extracted from the abdominal cavity by a mini-laparotomy and evaluated extraabdominally in vivo. Measurements were undertaken during right/left hemicolectomies, sigmoid, and rectal resections. Exclusion criteria were age under 18 years, pregnant women, patient's inability to give informed consent, and already ruptured marginal arteries damaged by the exposure of the colon before the start of our measurements. As a result, we subsequently excluded four patients. Thus, we included a total of 20 patients in the evaluation of our study. This study was intended to prove the feasibility of our concept. The perfusion behavior of border line will also be recorded by hyperspectral imaging during future colorectal surgeries. We included the following demographic, clinical, and histopathological patient data in the study: age, gender, American Society of Anesthesiologists Classification System (ASA), body mass index (BMI), preoperative medication, dignity of the resected colorectal specimen (benign/malign entity), neoadjuvant therapy, location of the pathologic finding, operative procedure, intraoperative anesthesiologic parameters (peridural catheter (=PDC), catecholamines, cardiovascular and respiratory measurements, intraoperative medications), duration of surgery, UICC-TNM classification, diverting ileostomy, postoperative anastomotic leakage, and other postoperative complications according to the *Clavien-Dindo* classification [3]. In this study, we only considered class 3 complications according to Clavien-Dindo and higher. Anastomotic leakage was defined as any type of disruption of the anastomosis, which was proven by direct signs, such as radiologic examination (CT scan with rectal enema), endoscopy (rigid or flexible), or rectal-digital examination.

Patients

Patients' data were divided into preoperative, intraoperative, and postoperative findings (Tables 1, 2, and 3). The intraoperative parameters were recorded at least 2 h before until 30 min after the HSI measurements (Table 2).

HSI imaging

We used the TIVITA® Tissue System (Diaspective Vision GmbH, Am Salzhaff, Germany) for hyperspectral image acquisition. This HSI system provides hyperspectral data cubes with a high resolution in the spectral (5 nm) and spatial dimensions (0.1 mm/pixel at 30-cm distance). The measured light covers the visible and near-infrared range from 500 to 1000 nm. Furthermore, the illumination is directly integrated around the camera lens and consists of eight halogen spots (20 W each). For reproducible results, all surrounding light sources were switched off during measurement. After recording of the hyperspectral images for approximately 10 s, additional 8 s was needed for computing a RGB image and four false color images. All images had a number of effective pixels of 640×480 (*x*-axis, *y*-axis). The field of view and the spatial resolution were depending on the used camera lenses and distance between camera and object, which was standardized in our study. The intraoperatively generated false color images visualized physiologic parameters of the measured tissue area. The evaluation and assessment of the parameters was carried out using camera-specific software called TIVITA Suite. The relative tissue oxygenation in upper layers (< 1-mm penetration depth) was represented by tissue

Table 1 Preoperative findings, $N = 20$

Variables	N (%)	Median {range}
Age in years	–	63 {29–80}
Sex, males/females	11 (55):9 (45)	–
BMI	–	25 {21.6–33.5}
ASA classification		
Grade 1	1 (5)	–
Grade 2	14 (70)	–
Grade 3	4 (20)	–
Grade 4	1 (5)	–
Diagnosis		
Adenocarcinoma	12 (60)	–
Diverticulitis	7 (35)	–
Polyp	1 (5)	–
Previous surgeries		
Abdomen	9 (45)	–
Thorax	6 (30)	–
Joint	3 (15)	–
No surgery	5 (25)	–
Comorbidities		
Arterial hypertonia	14 (70)	–
Heart failure, CHD	3 (15)	–
Renal insufficiency	3 (15)	–
Diabetes II	6 (30)	–
Neuropathie	4 (20)	–
Tumor, *n* (%)	2 (10)	–
Liver disease	2 (10)	–
Thrombosis	2 (10)	–
Alcohol or nicotine abuse	4 (20)	–
Medication		
Blood pressure medicine	14 (70)	–
PPI inhibitors	5 (25)	–
Blood thinner	3 (15)	–
Metformin	5 (25)	–
Statins	3 (15)	–
Neoadjuvant therapy, $N = 3$		
Chemotherapy	2 (10)	–
Chemoradiotherapy	1 (5)	–

oxygenation (StO_2), while the NIR perfusion index constituted lower structures in 4–6 mm. The OHI and TWI represented the distribution of hemoglobin and water in the field of view (FOV). The StO_2 parameter was specified in percentage; the other parameters (NIR perfusion index, OHI, and TWI) were indices without units and represented in arbitrary units (a.u.). The measuring range was 0–100. The algorithms used to calculate the parameters and their validation can be found in the publication by Holmer et al. [4]. The presented parameters represent the mean value of the selected parameters in a circular field of 5 mm (calculated with the TIVITA Suite).

Table 2 Intraoperative findings, $N = 20$

Variables	N (%)	Median {range}
Surgery		
Hemicolectomy right	3 (15)	–
Hemicolectomy left	2 (10)	–
Sigmoid resection	10 (50)	–
Rectum resection	5 (25)	–
Access path		
Laparoscopic	20 (100)	–
Operation duration in min	–	290 {190–532}
Catecholamines		
Akrinor (mg)	–	82 {0–200}
Arterenol (mg)	–	2 {0–5}
Adrenaline (μg)	–	3 {0–15}
Blood pressure		
Systole (mmHg)	–	120 {100–135}
Diastole (mmHg)	–	70 {55–85}
Oxygen saturation (% peridural catheter)	− 11 (55)	99 {96–99}

Study design and surgical technique

Patients underwent bowel preparation and received standard laxative solutions the day before colorectal surgery and single-shot antibiotic prophylaxis 30 min before skin incision. The surgical technique for laparoscopic and open colorectal procedures were standardized in detail. High ligations of the central vessels (either of the inferior mesenteric artery and vein or the ileocolic/right colic artery and vein) were routinely performed in patients with malignancies. The flexures were

Table 3 Postoperative findings, $N = 20$

Variables	N (%)	Median {range}
Hospital stay in days	–	11 {7–19}
Anastomotic leakage	0 (0)	–
Clavien-Dindo classification		
Grades 3–5	0 (0) Po	–
Tumor characteristics, $N = 12$		
Dignity		
Malign	12 (100)	–
TNM classification		
T	–	3 {2–3}
N	–	0 {0–2}
M	–	0 {0}
UICC classification		
Stadium 0	1 (8)	–
Stadium 1	4 (33)	–
Stadium 2	4 (33)	–
Stadium 3	3 (25)	–

mobilized completely, depending on which side the resection took place. In patients with rectal cancer, after mobilization of the left colon, partial or total mesorectal excision (depending on the tumor location) was carried out. Finally, the colon was transected using the linear stapler (Echelon 60 mm or Endo-Cutter, *Ethicon Endo-Surgery*, Hamburg, Germany).

The specimens were extracted through the Alexis ring (*Applied Medical*, Düsseldorf, Germany) after extending the port incision to about 5–7 cm (either in the left lower abdomen for left-sided surgeries or in the right upper abdomen for right hemicolectomy). The position of the anastomosis was determined by the surgeon based on his personal assessment, and the mesentery was undercut close to the colon. A loop was placed around the mesentery to be resected, and the planned transection line was marked with the tip of a scissor (Fig. 1). Marking was done by the surgeon based on the subjective critical evaluation of the color and vitality of the proximal bowel serosa. Transection line was defined as the line, which was severed by the surgeon to resect the pathological area of the colon. The "cold steel test" (open division of the marginal artery with assessment of arterial bleeding) was used here before as a precondition. This guaranteed that—according to conventional estimation methods—an adequate perfusion was present, and performance of "risk anastomoses" was principally excluded. In addition, a ruler was placed at the transection line, and the HSI camera was positioned. The procedure of HSI measurement has been described by our group elsewhere in detail [2]. After the light was turned off, the first record (baseline) was taken before devascularization. The light was then switched on, and the marginal vessels were divided. The time between devascularization and the first measurement was recorded. After the first record, measurements were taken in a standardized manner as stated in our SOPs (standardized operating procedures) each minute according to our protocol until 15 min after section of the marginal artery. During each record, at least 25-mm distance were recorded proximally and distally to the planned transection line. The time was assigned to each recording. The recorded data pictures were analyzed after surgery. Border line was defined as a sharp border between good proximal and poor distal tissue perfusion and as the area with the biggest drop of perfusion (StO_2) visualized by TIVITA Suite. After defining the border, 10 markers, each 5 mm in diameter, were placed with the analysis software. The markers thereby layed on a straight line free of light reflections without overlapping. The software calculated the mean values from all values in this marker area. These markers were placed so that there were five markers at each side of the border line (Fig. 2). Thus, it was possible to analyze the temporal change of perfusion in an area up to 25 mm proximal and distal to the border line. In addition, the distance between the surgically planned transection line (marked with scissor) and the border line was measured with a ruler.

Statistical analysis

The camera-specific software TIVITA Suite was used as evaluation software. These data were transferred to IBM SPSS Statistics Standard v24 (year 2016) and evaluated statistically (mean, median, range). In addition, Microsoft Excel Version 14.4.4 for Mac (year 2011 Microsoft Corporation) was used to create the diagrams. Demographic and clinical as well as histopathological patient data were entered into Excel and transferred into SPSS.

Results

Patients

Twenty patients ($n = 11$ males; $n = 9$ females) were operated laparoscopically. The median age of patients was 61 years (range 29–80). Involved were 12 patients with colorectal adenocarcinomas, 7 patients with sigmoid diverticulitis, and 1 patient with endoscopically non-resectable adenoma. Further details with regard to preoperative, intraoperative, and

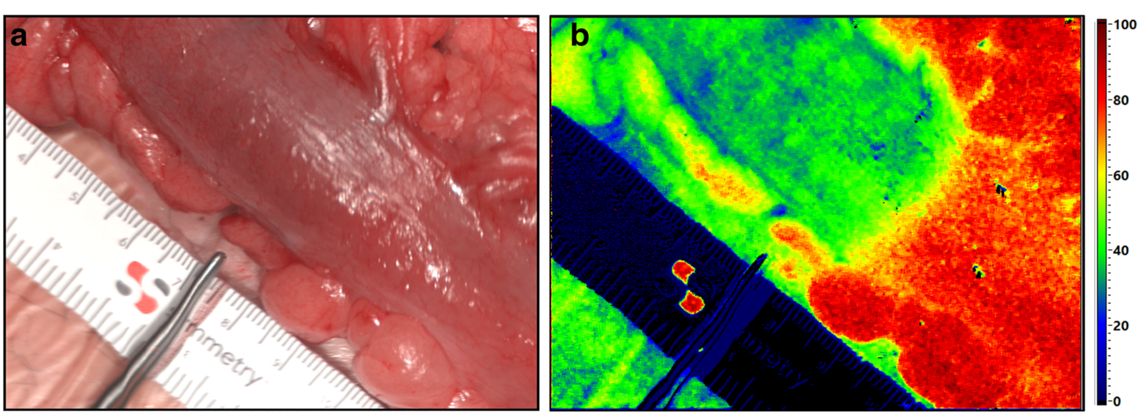

Fig. 1 Intraoperative test construction. Marked transection line by a scissor. The ruler was used to measure the distance to real border line visualized by the HSI camera

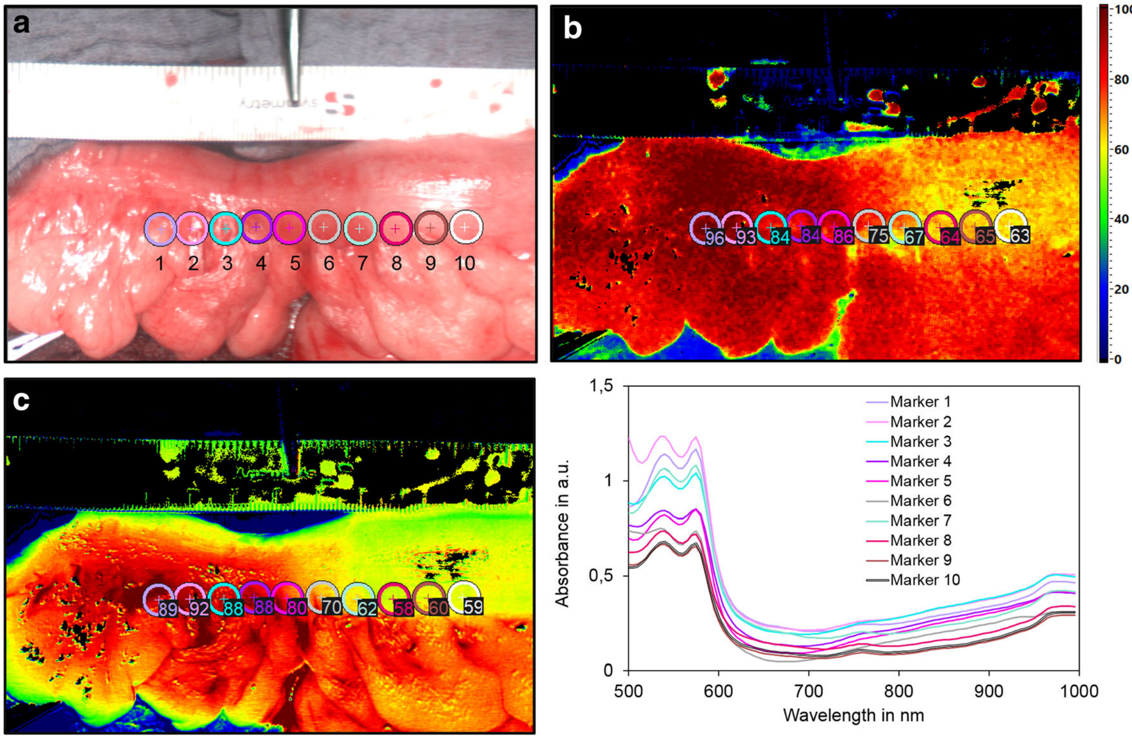

Fig. 2 Ten markers, each 5 mm in diameter, were placed on both sides of the border line on a straight line free of light reflections, to evaluate the tissue perfusion postoperatively

postoperative findings are depicted in Tables 1, 2, and 3 (*n*—number/%; median/range). There were no postoperative anastomotic leaks in our patients.

Hyperspectral imaging

The resection margin could be visualized with the help of intraoperative hyperspectral imaging in each measurement. We clearly showed that in all cases, there was a deviation between the planned transection line by the surgeon and the real border line visualized by HSI (median 1 mm; range − 13 to 13 mm; Fig. 3). Tissue perfusion dropped up to 12% within the first 10 mm distal to the border line. Therefore, the planned transection line was corrected in 13 cases, because it was too distal in the poor oxygenated area of the border line. In the other seven cases, this transection line was too far proximal in the well-supplied area and up to 13 mm of colorectal tissue were successfully saved by subsequent intraoperative correction. More details to perfusion behavior as a function of distance to the border line are illustrated in Fig. 4. In addition, the perfusion behavior of the border line was investigated as a function of time. The temporal change in the superficial (StO_2) and deeper tissue oxygenation (NIR perfusion) could be illustrated on both sides of the border line before severing of the marginal arteries until 15 min after intraoperative devascularization. Interestingly, the NIR perfusion index was always higher than the StO_2 of the colon. Within the first 3 min after devascularization, there was the biggest drop in

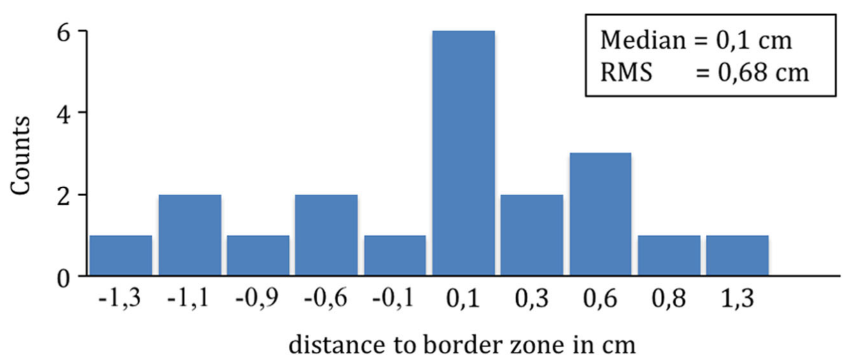

Fig. 3 Distance between the planned transection line and the real border line visualized intraoperatively by hyperspectral imaging as a sharp border between good proximal and low distal tissue perfusion in 20 patients (minus = planned resection line on the distal area of real border line in low oxygenated tissue; plus = planned transection line on the proximal area of real border line in better oxygenated tissue)

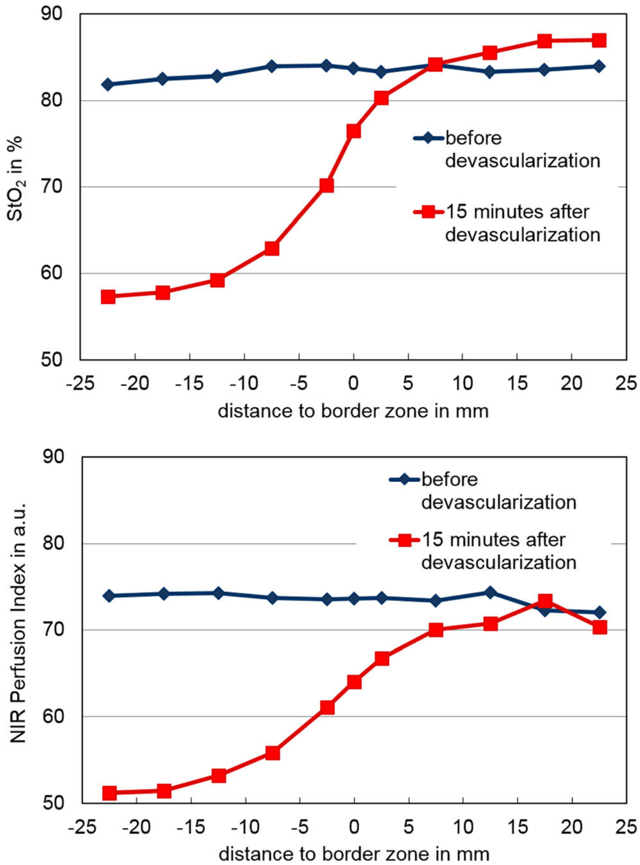

Fig. 4 Behavior of superficial (StO_2) and deep (NIR) tissue perfusion proximal (+) and distal (−) to the border line, depending on the distance to the border line before (blue) and 10 min after devascularization (red). (Mean values of all patients)

perfusion on the distal side of the border line, whereas hardly anything changed in the following minutes. Perfusion on the proximal side of the border line improved. Even 15 min after devascularization, oxygenation was better than before. Details of this dynamic behavior are depicted in Figs. 5 and 6.

Discussion

Selecting the transection line of the proximal colon before creation of the anastomosis is a key step during colorectal surgery. Up to date, the subjective assessment of the surgeon including bowel vitality, peristalsis, blood flow of the marginal zone, as well as the serosal color of the intestine has been applied to select the ideal area. Appropriate perfusion combined with technical perfection of the anastomosis, such as tension-free creation and sufficiently tight stitches/staples, is a well-known feature of an integer healing and the prevention of anastomotic leakage [5–7].

In this study, for the first time, we clearly showed the dynamic behavior on both sides of the border line before and after devascularization by hyperspectral imaging. The StO_2 value was always higher than the NIR value. Within the first 3 min after devascularization, there was the largest decrease of both values, which changed only slightly afterwards. On the other hand, StO_2 perfusion on the proximal side increased until 15 min after devascularization. In addition, we demonstrated that there was a clear deviation between the planned and real border line of proximal transection. In 13 cases, the planned resection line was up to 13 mm too distal in the poor oxygenated area. This is of high clinical relevance, because tissue oxygenation dropped by up to 12% within the first 10 mm distal of the border line. With the help of the HSI technique, we were able to offer a better oxygenated area and could possibly reduce the probability of anastomotic leakage. However, investigating the reduction of anastomotic leakage was not the primary target of the study. In the other cases, where the planned resection line was too far in the well-oxygenated proximal area, tissue savings of up to 13 mm were achieved.

These obvious and substantial differences between subjectively planned and HSI-determined transection line of the proximal anastomotic component in colorectal surgery might have an impact on future possibilities of increased precision and potentially reduced anastomotic leak, as perfusion is one of the known key factors in the process of anastomotic healing. Selection of the proper transection line is synonymous to the balance between a well-perfused proximal anastomotic component on the one hand and saving proper tissue on the other hand. However, anastomotic leakage was definitely not the primary end point of our current investigation, since we—moreover—aimed at the "proof of concept" applying this new intraoperative imaging-guided technique in colorectal resections. Currently, it is still largely unknown, which *cutoff* values are required to consecutively achieve a sufficiently perfused anastomosis and under which circumstances and below which thresholds an anastomotic leak will certainly develop.

In order to lead the surgeon to the precise extent of resection intraoperatively, different methods have been investigated [8, 9]. However, to date, most of them are either clinically not relevant in daily practice, still at an experimental stage, too expensive, or not reproducible [7]. Among newer technologies, NIR fluorescence with indocyanine green (ICG) is the most frequent used tool recently, aiming at the reduction of anastomotic leaks [10]. The group by Diana et al. proved that real-time navigation by fluorescence-based enhanced reality (FLER) might identify the future anastomotic site even after repetitive assessment and long-standing bowel ischemia [11]. In this study, capillary lactate values were measured simultaneously to compare clinical vs. FLER assessment, and basal and maximal mitochondrial respiration rates were determined according to FLER [11]. This modality of intraoperative fluorescence videography has shown to be flexible, rapid, and easily integrated in the routine surgical workflow also by

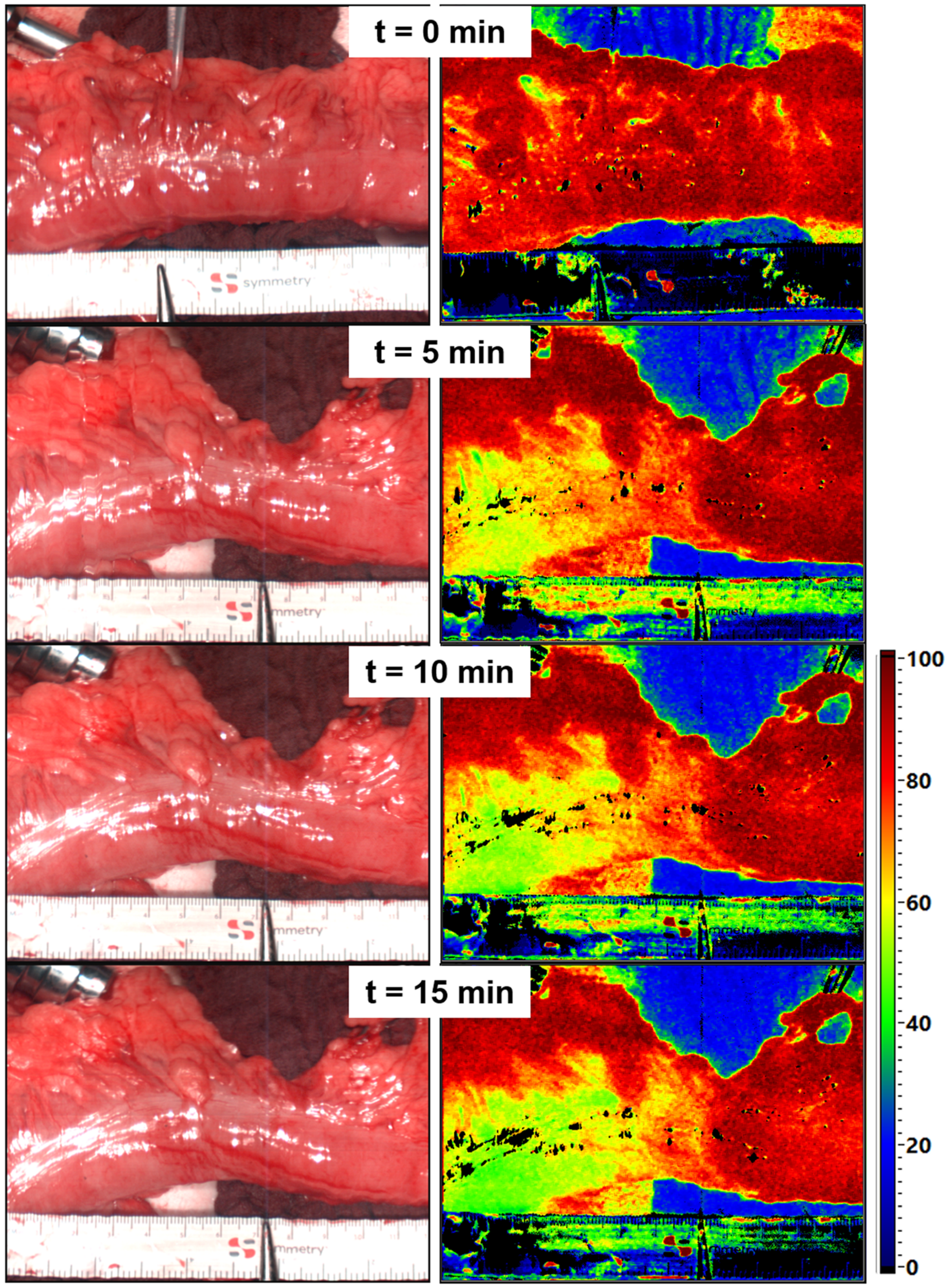

Fig. 5 Behavior of tissue perfusion at the border line before and after discontinuation of the marginal arteries depending on time (left side = RGB image; right side = StO_2 value)

others [11–13]. Moreover, Kawada et al. demonstrated by ICG fluorescence imaging that anastomotic leaks in colorectal resections occurred in the poor perfusion group in the late postoperative period [7]. Another study from the same group impressively showed that ICG is not only useful for assessing anastomotic perfusion but also results in more precise operative decisions tailored for an individual patient [14]. However, despite these achievements, ICG studies display several limitations. An inherent disadvantage of the ICG method is the invasiveness and a subjective evaluation. Feasibility and objectivity have not yet been demonstrated by well-founded data and the use of a control group. The subjective assessment of fluorescence intensity based on the surgeon's visual judgement has been described as the major drawback of ICG fluorescence imaging [14]. The technique of NIR fluorescence with ICG has been developed as a promising method to assess intestinal perfusion intraoperatively, with a special focus on colorectal surgery in the current literature [7, 15–19]. As decreased blood perfusion is a well-known and relevant risk factor for postoperative anastomotic leakage, the latter is the most important primary objective of published and ongoing ICG studies. ICG fluorescence imaging has proved useful for

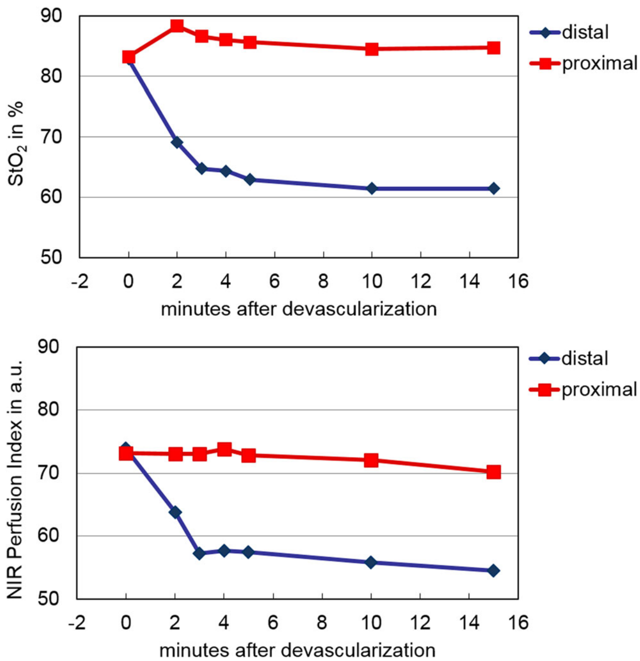

Fig. 6 Temporal behavior of superficial (StO_2) and deep (NIR) tissue perfusion proximal (red) and distal (blue) of the border line before (0 min) and up to 15 min after devascularization. (mean values of all patients)

determining the transection line of the proximal colon in laparsocopic colorectal surgery with double stapling anastomosis and resulted in relevant changes of the oral resection border, compared with the initially planned transection line [7]. Two multicenter clinical trials have investigated the impact of ICG fluorescence on anastomotic leak rates in colorectal surgery: the PILLAR II study from the USA ($n = 139$ patients) [20] and another prospective phase II study ("Decreasing leak rate in colorectal surgery using near infrared (NIR) imaging") (NCT02459405) by the European Network "Near-Infrared Anastomotic Perfusion Assessment Network VOIR" ($n = 460$ patients) [21]. NIR-ICG application drove a change in the surgical plan in a relevant proportion of patients with no subsequent leaks in this cohort [20, 21]. However, ICG is an invasive technique, in which the fluorescent dye is applied intravenously as an indicator substance. It is eliminated with a half-life time of 3–4 min, depending on individual liver function. Serious side effects, such as anaphylactic shock, critical decrease of blood pressure, tachycardia, dyspnea, and urticaria, have been described, and the risk of severe reactions increases in patients with chronic renal failure up to the rare occurrence of deaths. A further disadvantage of this method is the unspecific staining of the tissue and its subjective evaluation of the surgeon's visualization of fluorescence intensity. These drawbacks can all be overcome by HSI, in addition to its non-invasiveness. In contrast to major modifications of concepts, e.g., to resolve and recreate an already completed anastomosis, as in the abovementioned studies, it seems more preferable to select the ideal anastomotic site from the beginning, e.g., with the support of minimally time-consuming methods, such as HSI.

Visible light spectroscopy is another promising method to assess colon perfusion patterns during colorectal surgery. However, Hoffmann et al. revealed conflicting results that, in contrast to others, showed that colon perfusion significantly increased during surgery and one quarter of patients had suboptimal anastomotic perfusion without developing anastomotic leak [22]. A specific perfusion pattern associated with the development of anastomotic leakage could not be identified [22]. Further, currently used technologies include MSI (*multispectral imaging*), DRS (*diffuse reflectance spectroscopy*), OCT (*optical coherence tomography*), LDI (*laser Doppler imaging*), LSI (*laser speckle imaging*), SFDI (*spatial frequency domain imaging*), as well as *digital camera imaging*. These, as well as ICG, will have to be compared to HSI, and their prognostic relevance evaluated in the context of anastomotic healing.

In contrast to most other techniques applied before, such as fluorescence-based enhanced reality (FLER) and other ICG-derived methods, HSI offers a more "holistic" picture while representing comprehensive physiologic parameters of the recorded tissue area intraoperatively, which include tissue oxygenation (StO_2), perfusion (NIR perfusion index), OHI, and TWI.

"Cold steel testing" was a precondition for defining the resection margin clinically. With the help of this "conventional" method, sufficient anastomotic perfusion was guaranteed and it was assured that no "risk anastomoses" were performed in our study.

Thus, our study had several limitations. The small sample size aimed primarily at proving the concept and not at the effect of HSI taken at the transection line on anastomotic leak rate. In our case series, we did not experience any anastomotic leak. Due to the multifactorial nature of anastomotic healing, a much higher case number and a control group would have been essential. In addition, HSI measurement of the second component of the anastomosis, e.g., the rectal stump, as well as of the finally completed anastomosis would have been necessary. The latter was actually not possible, as the HSI camera can only be applied in open surgery and the current HSI documentation was performed through the mini-laparotomy during the process of extraabdominal translocation of the proximal colon after laparoscopic preparation and mobilization. The development of a minimally invasive camera device is being developed right now, but not on the market so far. Furthermore, intraoperative cardiovascular parameters, peridural catheter, volume management, and anesthesiologic medications are well-known factors influencing intestinal tissue perfusion. These were prospectively documented in our case series as well, but correlations with HSI parameters remain speculative due to the small numbers and the current lack of thresholds.

In summary and despite several advantages awaited to be further proven, HSI offers real-time determination of the resection margin of the proximal anastomotic component. Thus, it guides the surgeon with the help of an objective decision aid with regard to the best possible perfusion and ideal anastomotic area in colorectal surgery. Herewith, it serves as a promising new intraoperative image-guiding tool in the context of precision medicine.

References

1. Lu G, Fei B (2014) Medical hyperspectral imaging: a review. J Biomed Opt 19(1):10901
2. Jansen-Winkeln B, Maktabi M, Takoh JP, Rabe SM, Barberio M, Köhler H, Neumuth T, Melzer A, Chalopin C, Gockel I (2018) Hyperspectral imaging of gastrointestinal anastomoses. Chirurg 89(9):717–725
3. Dindo D, Demartines N, Clavien PA (2004) Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 240(2):205–213
4. Holmer A, Marotz J, Wahl P, Dau M, Kämmerer PW (2018) Hyperspectral imaging in perfusion and wound diagnostics—methods and algorithms for the determination of tissue parameters. Biomed Tech (Berl) 63:547–556
5. Kudszus S, Roesel C, Schachtrupp A, Hoer JJ (2010) Intraoperative laser fluorescence angiography in colorectal surgery: a noninvasive analysis to reduce the rate of anastomotic leakage. Langenbeck's Arch Surg 395:1025–1030
6. Kingham TP, Pachter HL (2009) Colonic anastomotic leak: risk factors, diagnosis, and treatment. J Am Coll Surg 208:269–278
7. Kawada K, Hasegawa S, Wada T, Takahashi R, Hisamori S, Hida K, Sakai Y (2017) Evaluation of intestinal perfusion by ICG fluorescence imaging in laparoscopic colorectal surgery with DST anastomosis. Surg Endosc 31:1061–1069
8. Nachiappan S, Askari A, Currie A, Kennedy RH, Faiz O (2014) Intraoperative assessment of colorectal anastomotic integrity: a systematic review. Surg Endosc 28:2513–2530
9. Urbanavicius L, Pattyn P, de Putte DV, Venskutonis D (2011) How to assess intestinal viability during surgery: a review of techniques. World J Gastrointest Surg 3:59–69
10. Sujatha-Bhaskar S, Jafari MD, Stamos MJ (2017) The role of fluorescent angiography in anastomotic leaks. Surg Technol Int 30:83–88
11. Diana M, Halvax P, Dallemagne B, Nagao Y, Diemunsch P, Charles AL, Agnus V, Soler L, Demartines N, Lindner V, Geny B, Marescaux J (2014) Real-time navigation by fluorescence-based enhanced reality for precise estimation of future anastomotic site in digestive surgery. Surg Endosc 28:3108–3118
12. Gioux S, Choi HS, Frangioni JV (2010) Image-guided surgery using invisible near-infrared light: fundamentals of clinical translation. Mol Imaging 9:237–255
13. Alander JT, Kaartinen I, Laakso A, Patila T, Spillmann T, Tuchin VV, Venermo M, Valisuo P (2012) A review of indocyanine green fluorescent imaging in surgery. Int J Biomed Imaging 2012:940585
14. Wada T, Kawada K, Takahashi R, Yoshitomi M, Hida K, Hasegawa S, Sakai Y (2017) ICG fluorescence imaging for quantitative evaluation of colonic perfusion in laparoscopic colorectal surgery. Surg Endosc 31:4184–4193
15. Carus TDR (2012) Laparoscop fluorescence angiography with indocyanine green to control the perfusion of gastrointestinal anastomoses intraoperatively. Surg Technol Int 22:27–32
16. Andersen HS, Gögenur I (2014) Optimized assessment of intestinal perfusion may reduce the risk of anastomotic leakage in the gastrointestinal tract. Ugeskr Laeger 176(30):1437–1441
17. Brisling S, Gögenur I (2015) Fluorescence angiography can change the operative strategy in performing colorectal anastomosis. Ugeskr Laeger 177(36)
18. Al Furajii H, Cahill RA (2015) Laparoscopic and endoscopic near-infrared perfusion assessment of in situ ileoileal, ileocolic, colocolic, colorectal and ileoanal anastomosis during intestinal operation for benign and malignant disease: a video vignette. Color Dis 17(Suppl 3):37
19. Degett TH, Andersen HS, Gögenur I (2016) Indocyanine green fluorescence angiography for intraoperative assessment of gastrointestinal anastomotic perfusion: a systematic review of clinical trials. Langenbeck's Arch Surg 401(6):767–775
20. Jafari MD, Wexner SD, Martz JE, McLemore EC, Margolin DA, Sherwinter DA, Lee SW, Senagore AJ, Phelan MJ, Stamos MJ (2015) Perfusion assessment in laparoscopic left-sided/anterior resection (PILLAR II): a multi-institutional study. J Am Coll Surg 220(1):82–92
21. Ris F, Liot E, Buchs NC, Kraus R, Ismael G, Belfontali V, Douissard J, Cunningham C, Lindsey I, Guy R, Jones O, George B, Morel P, Mortensen NJ, Hompes R, Cahill RA, Near-Infrared Anastomotic Perfusion Assessment Network VOIR (2018) Multicentre phase II trial of near-infrared imaging in elective colorectal surgery. Br J Surg 105(10):1359–1367
22. Hoffmann H, Delko T, Kirchhoff P, Rosenthal R, Schäfer J, Kraljevic M, Kettelhack C (2017) Colon perfusion patterns during colorectal resection using visible light spectroscopy. World J Surg 41:2923–2932