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ABOUT COVER

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Imaged guided surgery during arteriovenous malformation of gastrointestinal stromal tumor using hyperspectral and indocyanine green visualization techniques: A case report

Tristan Wagner, Onur Mustafov, Marielle Hummels, Anders Grabenkamp, Michael N Thomas, Lars Mortimer Schiffmann, Christiane J Bruns, Dirk L Stippel, Roger Wahba

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Abstract

BACKGROUND

This case report demonstrates the simultaneous development of a gastrointestinal stromal tumour (GIST) with arteriovenous malformations (AVMs) within the jejunal mesentery. A 74-year-old male presented to the department of surgery at our institution with a one-month history of abdominal pain. Contrast-enhanced computed tomography revealed an AVM. During exploratory laparotomy, hyperspectral imaging (HSI) and indocyanine green (ICG) fluorescence were used to evaluate the extent of the tumour and determine the resection margins. Intraoperative imaging confirmed AVM, while histopathological evaluation showed an epithelioid, partially spindle cell GIST.

CASE SUMMARY

This is the first case reporting the use of HSI and ICG to image GIST intermingled with an AVM. The resection margins were planned using intraoperative analysis of additional optical data. Image-guided surgery enhances the clinician's knowledge of tissue composition and facilitates tissue differentiation.

CONCLUSION

Since image-guided surgery is safe, this procedure should increase in popularity among the next generation of surgeons as it is associated with better postoperative outcomes.

Key Words: Imaged guided surgery; Hyperspectral imaging; Gastrointestinal stromal tumour; Arteriovenous malformation; Case report

Core Tip: Three imaging techniques and histopathology were used to determine the nature of the formation. Computed tomography diagnosed the arteriovenous malformation, but could not rule out any malignancies. Indocyanine green confirmed the initial diagnosis of the vascular malformation and helped with the resection margins. Hyperspectral imaging on the other hand, suggested the presence of a tumour, which was confirmed later by histological examination. The combination of both intraoperative techniques allowed students and surgical novices to understand the underlying anatomy and the vascular supply of the tumour.

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INTRODUCTION

Sarcomas are rare tumours that account for less than 1% of malignant tumours worldwide[1]. A gastrointestinal stromal tumour (GIST) is a soft tissue sarcoma that originates in the interstitial cells of Cajal[2]. This neoplasm most frequently occurs in the gastrointestinal tract and has an incidence of 66% in the stomach, 24% in the duodenum and 10% in other parts of the gastrointestinal tract[1]. GISTs may cause abdominal pain and GI bleeding. Arteriovenous malformations (AVMs) of the GI tract are vascular anomalies that manifest as upper or lower GI bleeding and abdominal pain.

Hyperspectral imaging and indocyanine green fluorescence are rising techniques in image guided surgery[3-6]. AVMs have already been diagnosed with indocyanine green (ICG)[7,8] and GIST were successfully detected with the HSI technique *ex-vivo*[9]. However, until now, there was no reported case that have used both innovative techniques to visualize this pathological finding and to plan the operative procedure regarding resection margins and local lymphadenectomy by synchronous development of GIST and AVM in the jejunum and jejunal mesentery.

CASE PRESENTATION

Chief complaints

Patient data: A 74-year-old, 65 kg, 156 cm tall, male known to have type II diabetes mellitus presented to the department of surgery at our institution with a one-month history of generalized abdominal pain. The patient did not complain of melena or GI bleeding. His past medical history included a cerebrovascular accident and a myocardial infarction.

History of present illness

His surgical history included an emergency Billroth I procedure performed after gastric ulcer perforation with uncontrollable bleeding. On physical examination, the patient had epigastric pain and tenderness. His preoperative laboratory findings were normal, with an erythrocyte count of $5.20 \times 10^{12}/L$, a haemoglobin concentration of 15.2 g/dL, a c-reactive protein (CRP) level of 1.0 mg/L, a leucocyte count of $7.16 \times 10^9/L$, and a haematocrit level of 46%.

Contrast-enhanced abdominal computerised tomography (CT) revealed a mass with a disorganised tangle of vessels in the proximal jejunum and jejunal mesentery, with the main arterial supply arising from the superior mesenteric artery and multiple arterialised veins. These findings indicated the presence of an AVM. However, malignancy still needed to be ruled out. Therefore, an exploratory laparotomy was indicated; eventual tumour resection was also indicated once malignancy was confirmed (Figure 1).

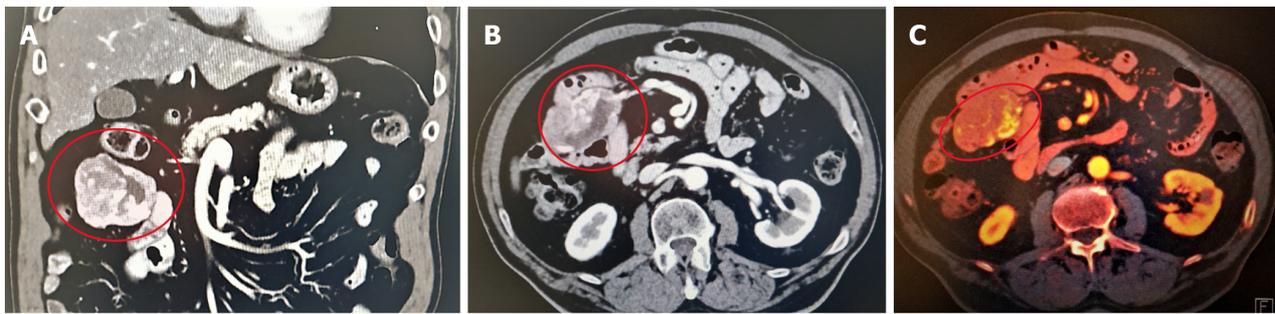
Since the patient was in good clinical condition (ECOG-scale 0, Eastern Cooperative Oncology Group performance scale[3]), did not present with active GI bleeding and all of his laboratory findings were normal, our primary choice for his management was surgery. Other interventions, including radiological embolization and endoscopy, were avoided to reduce the risk of bowel infarction or perforation[5].

History of past illness

His past medical history included a cerebrovascular accident and a myocardial infarction.

Personal and family history

There were no records of family history available and the patient had no information about related diseases in the familiar background.



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Figure 1 Preoperative diagnostics contrast enhanced computed tomography and axial positron emission tomography. A: Coronal contrast enhanced computed tomography; B: Axial contrast enhanced computed tomography shows an exophytic mass of the jejunum (measuring 7 cm × 4 cm), heterogenous contrast enhancement and irregular margins, with partial necrosis; C: Contrast enhanced computed tomography and axial positron emission tomography.

Physical examination

A 74-year-old, 65 kg, 156 cm tall male known to have type II diabetes mellitus presented to the department of surgery at our institution with a one-month history of generalised abdominal pain. The patient did not complain of melena or GI bleeding. His past medical history included a cerebrovascular accident and a myocardial infarction. His surgical history included an emergency Billroth I procedure performed after gastric ulcer perforation with uncontrollable bleeding. On physical examination, the patient had epigastric pain and tenderness.

Laboratory examinations

His preoperative laboratory findings were normal, with an erythrocyte count of $5.20 \times 10^{12}/L$, a haemoglobin concentration of 15.2 g/dL, a CRP level of 1.0 mg/L, a leucocyte count of $7.16 \times 10^9/L$, and a haematocrit level of 46%.

Imaging examinations

Contrast-enhanced abdominal CT revealed a mass with a disorganized tangle of vessels in the proximal jejunum and jejunal mesentery, with the main arterial supply arising from the superior mesenteric artery and multiple arterialized veins. These findings indicated the presence of an AVM. However, malignancy still needed to be ruled out. Therefore, an exploratory laparotomy was indicated; eventual tumour resection was also indicated once malignancy was confirmed (Figure 1).

Since the patient was stable, didn't experience any gastrointestinal bleeding and all the laboratory tests were normal, no further interventions, such as radiological embolization or endoscopic treatment, were performed to avoid the risk of bowel infarction or perforation[3]. Instead, elective surgery was scheduled.

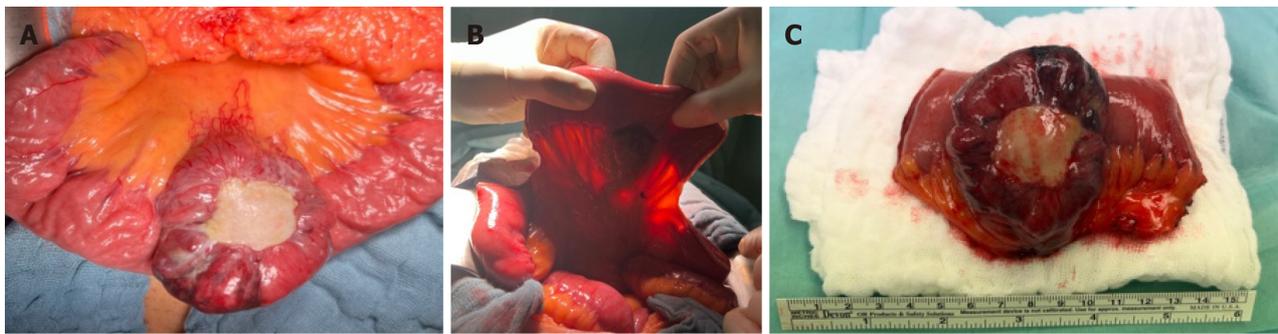
FINAL DIAGNOSIS

Intraoperative findings

An exploratory laparotomy was subsequently performed. There the AVM and a tumour mass were detected, located about 20 cm from the ligament of Treitz, in the jejunal mesentery and jejunum itself. The tumour was about 6 cm in diameter, solid, well discrete, slightly ischemic with necrotic sites and with central ulceration covered with fibrotic patch (Figure 2).

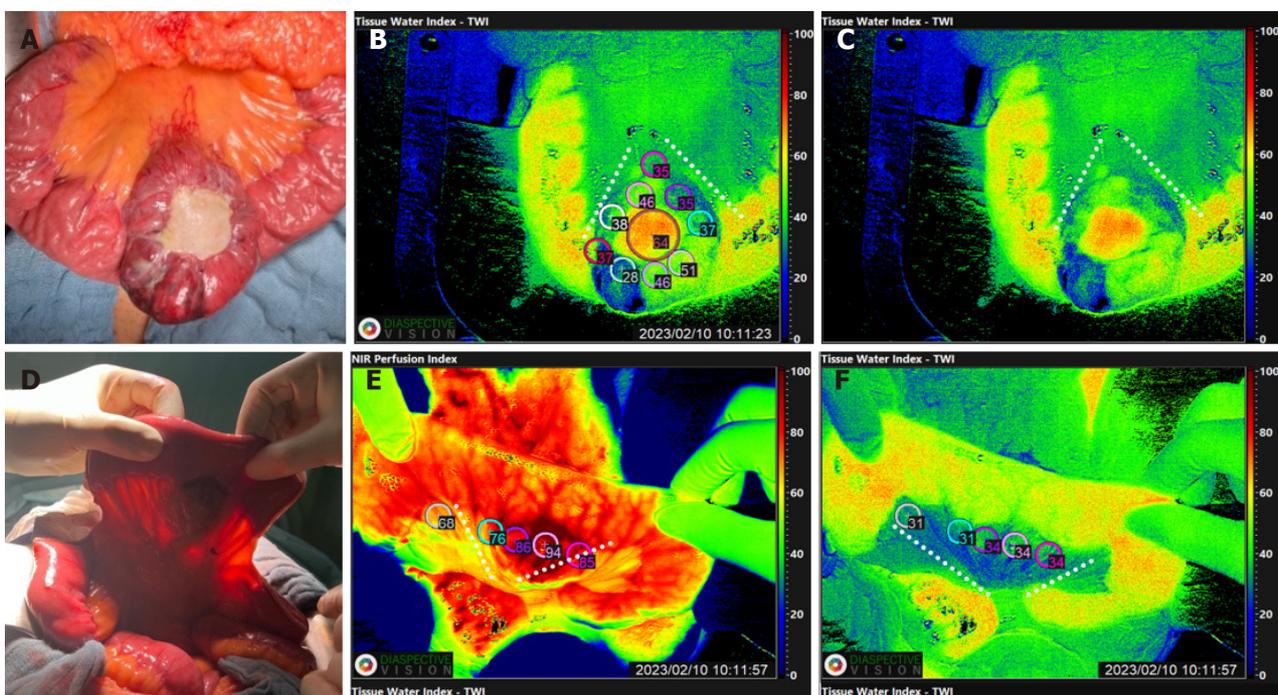
Intraoperatively image guidance was performed using HSI and ICG (Figures 3 and 4). This was done to evaluate the vascular anatomy and to delineate the tumour mass from the healthy tissue, enabling the selection of safe resection margins and the borders of the lymphadenectomy. HSI measurements were performed before resection according to our standard operational procedures and later evaluated in the way described by[5] (Figure 5). After a less than 8 s the analysis software (TIVITA Suite Tissue) provides an RGB image and 4 false colour images that represent physiologic parameters of the recorded tissue area. These parameters contain tissue oxygenation (StO_2), perfusion (NIR Perfusion index), organ hemoglobin index (OHI), and tissue water index (TWI). The relative blood oxygenation in the microcirculation of superficial tissue layers (approximately 1 mm) is represented by StO_2 (%), whereas the NIR perfusion index (0-100) represents tissue layers in 4-6 mm penetration depth. The indices OHI (0-100) and TWI (0-100) display the distribution of haemoglobin and water in the investigated tissue area, respectively[3,8,10,11].

In addition to the hyperspectral imaging, diluted 2-mL of indocyanine green was injected *via* the central line. This fluorescent, water-soluble dye, can bind plasma proteins and distribute evenly in the vascular system within seconds after injection[12]. After exposing the ICG molecules to near-infrared light and inducing fluorescence, the arteriovenous fistulae and the disorganized tangle of vessels, seen previously on the contrast-enhanced abdominal CT could be visualized (Figure 3). Furthermore, the jejunum with poor blood circulation, presumably due to a steal phenomenon caused by the AVM, could be shown.



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Figure 2 Intraoperative exploration and detection of the arteriovenous malformation and complete resection of the tumour and the supplying mesenteric arcade. A: Impression of the tumour after exploration; B: Diaphanoscopy of the tumour and the supplying arteries and veins; C: Tumour mass after resection.



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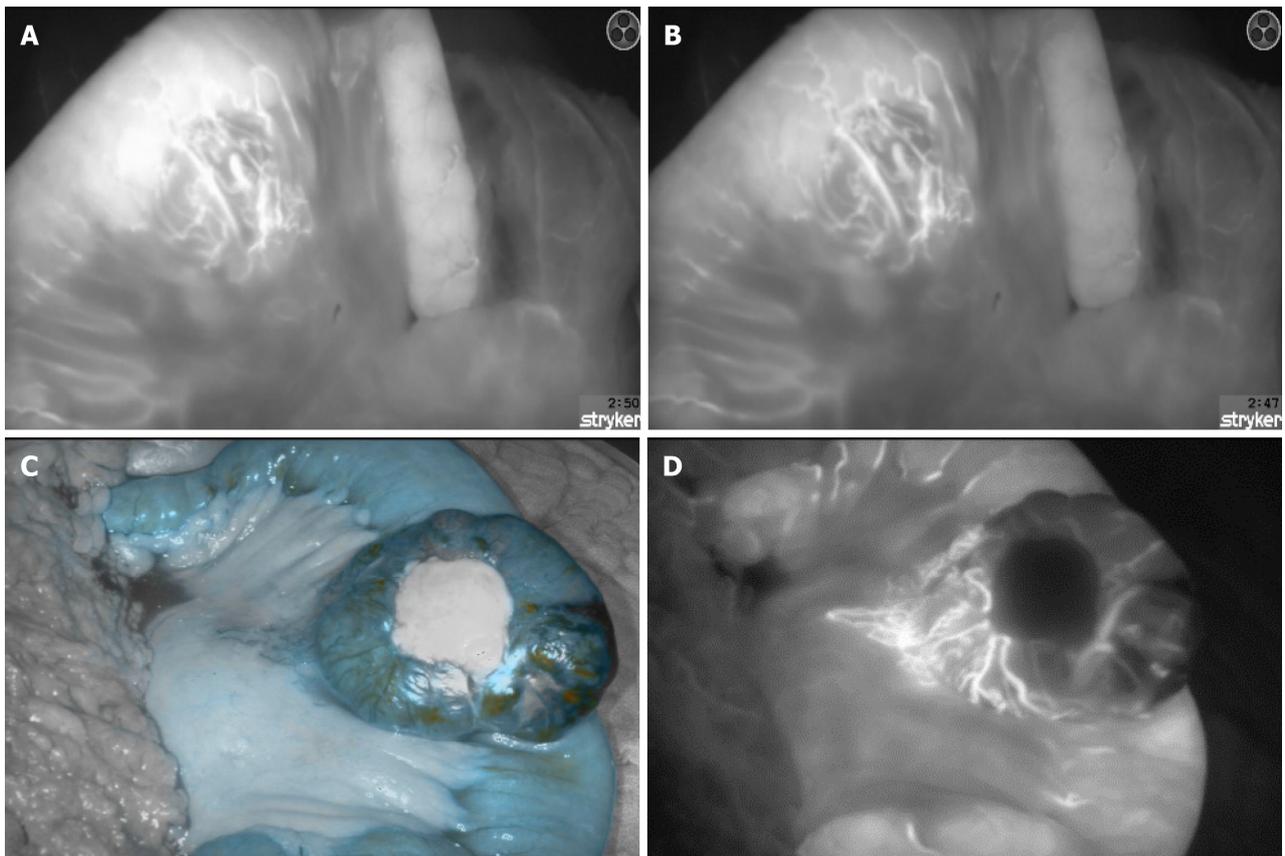
Figure 3 Intraoperative presentation and intraoperative calculation of the optical hyperspectral imaging parameters via TIVITA® tissue. Circles represent the “region of interest” and the dotted line shows the selected resection margins before incision. A: Red–green–blue (RGB) image of the tumour; B: Tissue water index (TWI) of the tumour with the regions of interest (ROI) and planned resection margins; C: TWI of the tumour focused only on the resection margins; D: RGB of the tumour, focused on the antimesenteric side; E: Near-Infra-Red of the tumour with the ROI and planned resection margins, focused on the antimesenteric side; F: TWI of the tumour focused only on the resection margins, focused on the antimesenteric side.

TREATMENT

After choosing the resection margins according to intraoperative imaging with HSI and ICG, a segmental jejunal resection was performed. The continuity was restored with a side-to-side anastomosis (Figure 3).

The resected segment of the jejunum measured 9 cm in length and the surgical margins were 3.5 cm and respectively 5.5 cm wide, clear of residual tumour including the intraoperative visualized part of the mesentery. The solid tumour measured up to 7.5 cm. Histology revealed an epithelioid, partially spindle cell gastrointestinal stromal tumour pT3, pNx, L0, V0, Pn0, R0 with arteriovenous Malformation, low mitosis rate [$< 5/50$ high power field (HPF)] and Ki67 8%. The tumour mass showed also necrotic and haemorrhagic areas with chronic inflammatory infiltrate similar to the description of [13].

During the postoperative recovery, the patient received antibiotics due to increase inflammatory markers. After the follow-up laboratory tests normalized, the patient was released from the hospital. The case was presented during a tumour board review, which proposed follow-up CT scans and aftercare.



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Figure 4 Early and late onset image of the anterior side posterior side of the tumor mass after indocyanine green application and simultaneous observation of the arteriovenous malformations using fluorescence imaging device. A: Anterior side, early onset image of the tumor mass after indocyanine green application; B: Anterior side, late onset image of the tumor mass after indocyanine green application; C: Posterior side, early onset image of the tumor mass after indocyanine green application; D: Posterior side, onset image of the tumor mass after indocyanine green application.

OUTCOME AND FOLLOW-UP

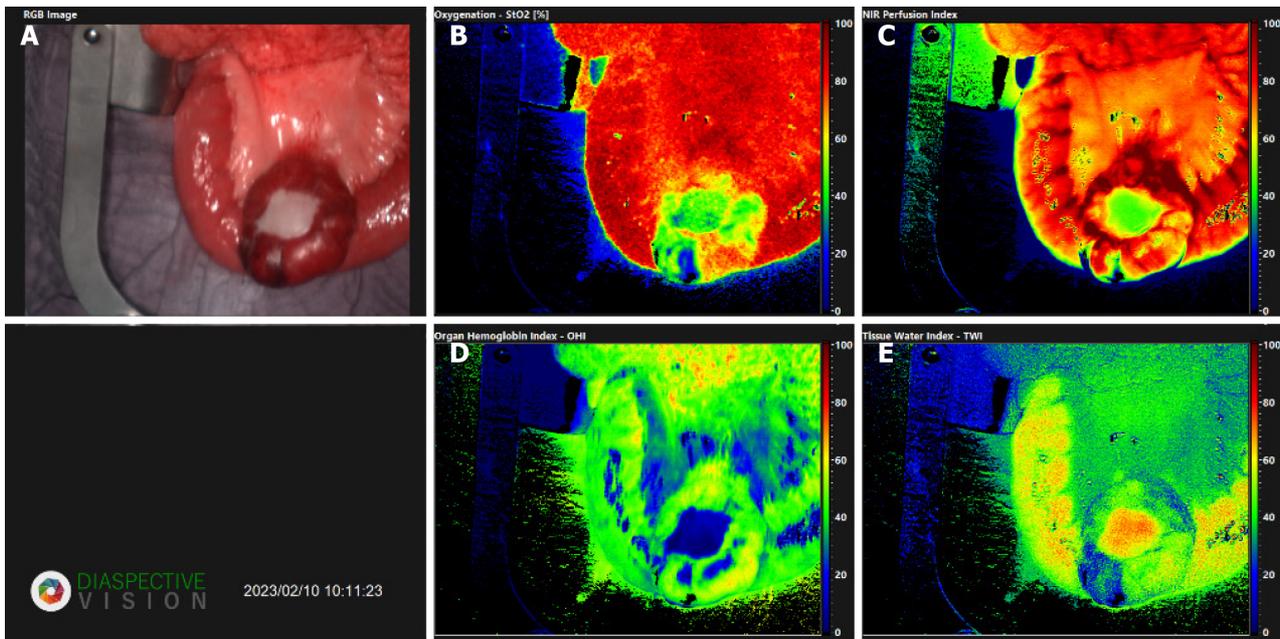
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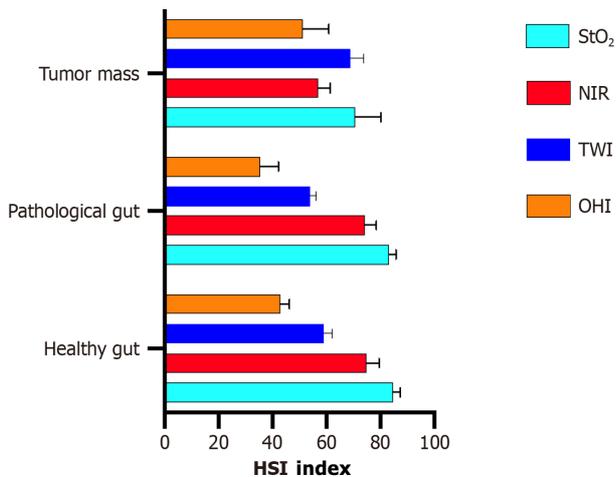
DISCUSSION

To our knowledge, this is the first case, which demonstrates the simultaneous application of HSI and ICG intraoperatively, of a gastrointestinal tumour combined with arteriovenous malformation and the third overall with this combination [13,14]. GISTs are relatively rare tumours and AVMs in the GI are unusual. The diagnosis of them both is quite challenging, as the symptoms being most commonly abdominal pain and GI bleedings are nonspecific. In this case ICG functioned as an intraoperative real-time angiography, showing the disorganized tangle of vessels, the arterial feeders, the arterialized veins and necrotic areas. In the context of the AVM, the application of ICG contributed to the confirming of the vascular malformation and enabled a more precise selection of the resection margins, however, it didn't contribute to diagnosing the gastrointestinal stromal tumour. In the context of the GIST, HSI could differentiate between normal and tumorous tissue, in addition to also successfully identifying the tissue necrosis. This allowed more precise delimitation of the tumour mass. The only HSI- parameter which could hardly distinguish between the tumour and the surrounding healthy tissue was NIR, as the spectra of GIST and that of a normal tissue are similar [9]. However, *via* the other parameters, such as oxygenation, haemoglobin index and water index, the tumour mass could be distinguished, as



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Figure 5 Images acquired via TIVITA® Tissue system (Diaspective Vision GmbH, Am Salzhaff, Germany). The software provides a red–green–blue image (RGB image) and four false-color images with an effective number of 640 × 480 pixels, which respectively represent tissue oxygenation, near-infrared perfusion index, tissue water index, and organ hemoglobin index[5]. A: Red–green–blue image; B: Oxygenation; C: Near infra-red perfusion index; D: Organ hemoglobin index; E: Tissue- water- index.



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Figure 6 Comparison of the hyperspectral parameters of the macroscopic healthy, pathological transformed gut and the tumor mass/AV-fistula. HSI: Hyperspectral imaging; TWI: Tissue water index.

changes in these parameters could correlate with tumour metabolic activities (Figure 6).

CONCLUSION

Three imaging techniques and histopathology were used to determine the nature of the formation. CT diagnosed the AVM, but couldn't rule out any malignancies. ICG confirmed the initial diagnosis of the vascular malformation and helped with the choosing of the resection margins, however, it didn't give any further input. HSI, on the other hand, presumed the presence of a tumour, which later was confirmed by histological examination. The combination of both intraoperative techniques allowed students and surgical novices to understand the underlying anatomy and the vascular supply of the tumour, however, it didn't play a crucial part in the decision of the surgical strategy. For better understanding more HSI data and ICG data have to be compared in more precise analysis during prospective studies to decide which technique is more preferable and beneficial for patients with similar cases. Furthermore, it is still to

determine if imaged guided surgeries have the potential to uncover tumours and tumorous tissues before histopathological findings.

FOOTNOTES

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