Intraoperative Assessment of Gastric Sleeve Oxygenation Using Hyperspectral Imaging in Esophageal Resection: A Feasibility Study

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Keywords
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Abstract

Introduction: Sufficient tissue oxygenation is essential for anastomotic healing in visceral surgery. Hyperspectral imaging (HSI) is a noncontact, noninvasive technique for clinical assessment of tissue oxygenation in real time. Methods: In this case series, HSI was used in 4 patients who were admitted for either esophageal cancer or cardiac carcinoma (AEG type I or II). Thoraco-abdominal surgical esophageal resection was performed after staging and neoadjuvant therapy. Intraoperative oxygenation of superficial (StO₂) and underlying tissue (NIR perfusion index) of the gastric sleeve were studied intrathoracic by means of the TIVITA® Tissue HSI camera. This was performed prior to esophagogastric anastomosis. The postoperative course, especially in view of surgical complications, was recorded. Results: Assessment of StO₂ and NIR perfusion index was performed in 4 regions of interest per gastric sleeve, aboral and oral of the clinically determined resection line. It allowed the fast quantification of gastric oxygenation prior gastroesophageal anastomosis. Median StO₂ aboral of the determined resection line was 69%, while median StO₂ in the oral part of the gastric sleeve was found at 53%. In contrast, the median NIR perfusion index was similar aboral (80) and oral (82) of the resection line. In none of the 4 studied patients, an anastomotic failure appeared. Discussion/Conclusion: This report suggests that HSI is a feasible technique for intraoperative assessment of tissue oxygenation before gastroesophageal anastomosis and might reduce the incidence of anastomotic failure in the gastrointestinal tract.

Introduction

Curative surgical therapy of esophageal cancer and cardiac carcinoma (AEG type I or II) involves thoracoabdominal operation with resection of tumor and lymph nodes and preparation of the gastric sleeve for esophagogastric anastomosis. Thereby, anastomosis failure is a major complication. Especially in upper gastrointestinal surgery, anastomotic failure is associated with markedly increased morbidity and mortality for the patient, resulting in significant burden to the health system [1, 2]. It requires a fast detection and respective surgical or endoscopic therapy. Reasons for anastomotic failure are multifactorial and include technical aspects like tension of the anastomosis, the used type of suture material, the technique of anastomosis, as well as patient-derived characteristics such as liver cirrhosis, smoking behavior, alcohol abuse, cachexia, systemic infections, immunosuppression, chronic kidney disease, arterial hypertension, or diabetes mellitus. Other extrinsic circumstances affecting anastomotic healing are neoadjuvant radiation or chemotherapy, perioperative volume therapy, and blood transfusion [3]. However, impaired perfusion of gastroesophageal anastomoses or the gastric sleeve is one of the most important factors for anastomotic complications [4–6].
sufficient intraoperative evaluation of esophageal and gastric perfusion is essential to reduce the risk for anastomotic failure. Recently, hyperspectral imaging (HSI), a noninvasive, noncontact technique for quantification of tissue perfusion, was successfully tested for intraoperative assessment of bowel perfusion during colorectal resections [7, 8] and during esophagectomy [6]. Here, we report the results of the first 4 cases of intraoperative HSI measurement to analyze gastric sleeve perfusion intraoperatively during esophageal resection in our department.

Materials and Methods

Patient Characteristics

All 4 patients were admitted to the Department for General, Visceral, Vascular and Transplantation Surgery at the University Medical Center Rostock, Rostock, Germany, for operation with histological ypT0 pN0(0/18) Operation Thoracoabdominal esophageal resection, gastric sleeve, cholecystectomy, jejunal catheter Histology ypT0 pN0(0/18) L0 V0 Pn0 R0 at the first image plane of the optical setup along the γ-axis to realize the image acquisition. With this system, a hyperspectral image can be acquired without the need of moving the camera or the patient. The distance between the camera and the investigated tissue is standardized at 50 cm. This distance is defined by 2 LED lights (red and green) that fuse to 1 light point on the investigated tissue when the respective distance of 50 cm is reached. The measurement creates the so-called 3-dimensional hyperspectral data cube with the spatial x- and y-axis as well as the spectral λ-axis. The hyperspectral data cube has an image resolution of 640 × 480 and comprises a spectral range from 500 to 1,000 nm with a resolution of 5 nm (100 spectral bands). The parameter calculation was developed by an empirical approach considering the known optical properties of tissues and blood and was calibrated by occlusion tests with healthy volunteers against a commercial tissue oximeter [9].

It is a noninvasive, noncontact imaging technique that enables spectroscopic measurement of tissue oxygenation over a larger area without the need for contrast agents or radiation. The TIVITA® Tissue is designed to detect and measure the chromophores hemoglobin with its derivatives oxyhemoglobin O2Hb and deoxyhemoglobin HHb and water to provide a 2-dimensional map of oxygenation pattern (StO2 and NIR perfusion index). StO2 and NIR perfusion index describe the relative oxygen saturation of hemoglobin in the microcirculatory system of the examined area in superficial tissues about 1 mm (StO2) and deeper tissues about a 3-mm depth (NIR perfusion index) [10].

Intraoperative Procedure of HSI

In principle, resection was performed as standard Ivor-Lewis operation. The abdominal preparation of the gastric sleeve was performed by means of the Echelon Flex Powered stapler (Johnson & Johnson, New Brunswick, NJ, USA). After positioning of the gastric sleeve in the thorax, tissue perfusion was assessed by means of HSI before shortening it to the optimal length for the esophago-gastric anastomosis. The resection line for the anastomosis was determined by clinical examination of the gastric sleeve and was not affected by the assessed oxygenation parameters. The oxygenation was assessed in 4 regions of interest (ROI) with a standardized diameter of 30 pixel. They were positioned oral and aboral of the clinically defined resection line of the gastric sleeve. The dis-
Hyperspectral Imaging in Esophageal Resection

Results

Patient 1
A 63-year-old male patient with a low-grade squamous cell carcinoma of the esophagus was discussed in our multidisciplinary tumor team and a neoadjuvant chemoradiotherapy prior surgical tumor resection was conducted. As a comorbidity, an arterial hypertension existed. After a cumulative radiotherapy with 41.4 Gy and carboplatin/paclitaxel treatment, the restaging after neoadjuvant therapy revealed no metastases. The preoperative esophagoscopy showed a persistent stenosis 29 cm from the incisors. Therefore, a thoracoabdominal esophageal resection was indicated and performed according to standard. After positioning the gastric sleeve in the thorax, HSI was performed (Fig. 1A). Postoperatively, the patient was admitted to the intensive care unit (ICU) for 3 days. The postoperative course was uneventful. Histologic analysis defined the tumor stage ypT0 pN0 (0/18) L0 V0 Pn0 R0. In the postoperative tumor board conference, an oncologic surveillance was recommended. The patient was discharged 11 days after the surgery.

Patient 2
A 69-year-old male patient with a cardiac carcinoma AEG I was discussed in our multidisciplinary tumor team, and a neoadjuvant chemotherapy (4x cycle FLOT) was conducted prior to surgical tumor resection. As a comorbidity, diabetes mellitus (dietary) and arterial hypertension existed. Thoracoabdominal esophageal resection was indicated and performed according to standard. As a comorbidity, arterial hypertension, aortic valve insufficiency grade II, and a mitral valve insufficiency grade II existed. A thoracoabdominal esophageal resection was indicated and performed according to standard as described for patient 1. Tissue perfusion was assessed like in patient 1 by means of HSI (Fig. 1B). Postoperatively, the patient was admitted to the ICU for 2 days. The postoperative course was uneventful except for a wound healing disorder, which was treated conservatively. Histologic analysis defined the tumor stage ypT3 pN1 (2mi/44) L0 V0 Pn0 R0. In the postoperative tumor board conference, an oncologic surveillance was recommended. The patient was discharged 25 days after the surgery.

Patient 3
A 63-year-old male patient with a cardiac carcinoma AEG I was discussed in our multidisciplinary tumor team, and a neoadjuvant chemotherapy (6x cycle FLOT) was conducted prior to surgical tumor resection. No comorbidity existed. Thoracoabdominal esophageal resection was indicated and performed according to standard and then tissue perfusion was assessed by means of HSI (Fig. 1C). Postoperatively, the patient was admitted to the ICU for 22 days. The postoperative course was characterized by an acute respiratory distress syndrome (ARDS) with pneumonia followed by dilatative tracheotomy. A gastroscopy due to increased infection signs on the 7th postoperative day showed an inconspicuous anastomosis. Histologic analysis defined the tumor stage G3 pT3 pN1 (2mi/44) L1 V0 Pn0 R1. Due to the R1 situation, the postoperative tumor board conference recommended a local radiation therapy. The patient was discharged 32 days after the surgery.

Patient 4
A 72-year-old female patient with a cardiac carcinoma AEG I was discussed in our multidisciplinary tumor team, and a neoadjuvant chemotherapy (4x cycle FLOT) was conducted prior to surgical tumor resection. As a comorbidity, an arterial hypertension, aortic valve insufficiency grade II, and a mitral valve insufficiency grade II existed. Thoracoabdominal esophageal resection was indicated and performed according to standard and also tissue perfusion was assessed by means of HSI (Fig. 1D). Postoperatively, the patient was admitted to ICU for 9 days. The postoperative course was characterized by a pneumonia and chyle fistula, both treated conservatively. A gastroscopy due to increased infection signs on the 6th postoperative day showed an inconspicuous anastomosis. Histologic analysis defined the tumor stage ypT0 ypN0 (0/22) L0 V0 Pn0 R0. In the postoperative tumor board conference, a completion of adjuvant chemotherapy was recommended. The patient was discharged 25 days after the surgery.

Intraoperative Oxygenation Assessment
The intraoperative oxygenation parameters StO2 and NIR perfusion index are shown in Figure 1. Referring to the defined resection line, quantification of both parameters in the aboral part of the gastric sleeve revealed a StO2 range from 51 to 84% and a NIR perfusion index range from 70 to 89 in all 4 patients. The median StO2 in the aboral part was 69% (25% percentile: 65.5%; 75% percentile: 75.5%), the median NIR perfusion index was 80 (25% percentile: 74.5%; 75% percentile: 84.5%). In contrast, the oxygenation parameters oral of the resection line were found lower, with StO2 ranging from 40 to 71% and NIR perfusion index ranging from 70 to 83 (Table 2). Here median StO2 was 53% (25% percentile: 51%; 75% percentile: 67%), median NIR perfusion index was found at 82 (25% percentile: 80; 75% percentile: 83).
Discussion/Conclusion

HSI bears the benefits of a noninvasive, mobile, easy to use technique that can visualize tissue oxygenation saturation in real time without the need for any contrast agents. This could be a benefit compared to other methods for intraoperative assessment of perfusion during esophagectomy like the indocyanine green (ICG) fluorescence technique [11]. ICG angiography indirectly measures tissue perfusion by emission of excitation of the ex-
Table 2. Intraoperative oxygenation parameter of the gastric sleeve

| Patient | StO₂, % | NIR perfusion index |
|---------|---------|--------------------|
| 1       |         |                    |
| Aboral  | 74      | 72                 |
| Oral    | 69      | 74                 |
| 2       | 67      | 70                 |
| 3       | 51      | 70                 |
| 4       |         |                    |
| Aboral  | 75      | 78                 |
| Oral    | 69      | 85                 |
| 3       | 76      | 89                 |
| 4       | 71      | 83                 |
| Aboral  | 84      | 80                 |
| Oral    | 79      | 75                 |
| 3       | 67      | 82                 |
| 4       | 40      | 83                 |
| Aboral  | 54      | 82                 |
| Oral    | 51      | 84                 |
| 3       | 64      | 85                 |
| 4       | 53      | 80                 |

StO₂ and NIR perfusion index were assessed in the gastric sleeve aboral and oral from the clinically defined resection line.

Oxygenation parameter of the gastric sleeve

In summary, this is a proof-of-principle study that successfully illustrates and supports the promising use of intraoperative HSI technique for oxygenation assessment during esophageal resection in visceral surgery. In future, this technique could be a valuable tool to reduce the still relevant high incidence of anastomotic leakage that is associated to a significant increase in morbidity and mortality.
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Statement of Ethics

The study was conducted ethically in accordance with the World Medical Association Declaration of Helsinki. The patient gave written informed consent to publish this case (including publication of the images).

Disclosure Statement

The authors have no conflicts of interest to declare.

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Author Contributions

All authors planned the hyperspectral analysis in the presented case. F.S. and E.G. contributed to writing and drafting of the manuscript and performed the hyperspectral analysis.

References

1 Markar SR, Karthikesalingam A, Vyas S, Hashemi M, Winslet M. Hand-sewn versus stapled oesophago-gastric anastomosis: systematic review and meta-analysis. J Gastrointest Surg. 2011 May;15(5):876–84.
2 Saluja SS, Ray S, Pal S, Sanjal S, Agrawal N, Dash NR, et al. Randomized trial comparing side-to-side stapled and hand-sewn esophagogastrogastric anastomosis in neck. J Gastrointest Surg. 2012 Jul;16(7):1287–95.
3 Marjanovic G, Hopt UT. [Physiology of anastomotic healing]. Chirurg. 2011 Jan;82(1):41–7. German.
4 Liebermann-Meffert DM, Meier R, Siewert JR. Vascular anatomy of the gastric tube used for esophageal reconstruction. Ann Thorac Surg. 1992 Dec;54(6):1110–5.
5 Yuan Y, Duranceau A, Ferraro P, Martin J, Liberman M. Vascular conditioning of the stomach before esophageal reconstruction by gastric interposition. Ann Thorac Surg. 2012 Nov-Dec;56(6):740–9.
6 Köhler H, Jansen-Winkeln B, Maktabi M, Barberio M, Takoh J, Holfert N, et al. Evaluation of hyperspectral imaging (HSI) for the measurement of ischemic conditioning effects of the gastric conduit during esophagectomy. Surg Endosc. 2019 Nov;33(11):3775–82.
7 Jansen-Winkeln B, Holfert N, Köhler H, Moulla Y, Takoh JP, Rabe SM, et al. Determination of the transection margin during colorectal resection with hyperspectral imaging (HSI). Int J Colorectal Dis. 2019 Apr;34(4):731–9.
8 Jansen-Winkeln B, Maktabi M, Takoh JP, Rabe SM, Barberio M, Köhler H, et al. [Hyperspectral imaging of gastrointestinal anastomoses]. Chirurg. 2018 Sep;89(9):717–25. German.
9 Grambow E, Dau M, Holmer A, Lipp V, Freich B, Klar E, et al. Hyperspectral imaging for monitoring of perfusion failure upon microvascular anastomosis in the rat hind limb. Microvasc Res. 2018 Mar;116:64–70.
10 Grambow E, Dau M, Sandkühler NA, Leuchter M, Holmer A, Klar E, et al. Evaluation of peripheral artery disease with the TIVITATM Tissue hyperspectral imaging camera system. Clin Hemorheol Microcirc. 2019;73(1):3–17.
11 Schloßmann F, Patti MG. Evaluation of Gastric Conduit Perfusion During Esophagectomy with Indocyanine Green Fluorescence Imaging. J Laparoendosc Adv Surg Tech A. 2017 Dec;27(12):1305–8.
12 Calvin MA, Coman T, Parasca SV, Bercaru N, Savastru R, Manea D. Hyperspectral imaging-based wound analysis using mixture-tuned matched filtering classification method. J Biomed Opt. 2015 Apr;20(4):046004.
13 Daeschlein G, Langner I, Wild T, von Podewils S, Sicher C, Kiefer T, et al. Hyperspectral imaging as a novel diagnostic tool in microcirculation of wounds. Clin Hemorheol Microcirc. 2017;67(3-4):467–74.
14 Fabelo H, Ortega S, Ravi D, Kiran BR, Sosa C, Bulters D, et al. Spatio-spectral classification of hyperspectral images for brain cancer detection during surgical operations. PLoS One. 2018 Mar;13(3):e0193721.
15 Fabelo H, Halicke M, Ortega S, Shahedi M, Sztolna A, Piñeiro JF, et al. Deep Learning-Based Framework for In Vivo Identification of Glioblastoma Tumor using Hyperspectral Images of Human Brain. Sensors (Basel). 2019 Feb;19(4):E920.
16 Promny D, Billner M, Reichert B. [Objective burn depth assessment of hand burns]. Handchir Mikrochir Plast Chir. 2019 Sep;51(5):362–6. German.
17 Langner I, Sicher C, von Podewils S, Henning E, Kinn S, Daeschlein G. [Hyperspectral imaging demonstrates microcirculatory effects of postoperative exercise therapy in Dupuytren’s disease]. Handchir Mikrochir Plast Chir. 2019 Jun;51(3):171–6. German.
18 Holmer A, Marotz J, Wahl P, Dau M, Kämmerer PW. Hyperspectral imaging in perfusion and wound diagnostics – methods and algorithms for the determination of tissue parameters. Biomed Tech (Berl). 2018 Oct;63(5):547–56.