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Review Article

Evaluation of gastric tube blood flow by multispectral camera and fluorescence angiography

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HIGHLIGHTS

- Multispectral camera showed a decrease in oxygen saturation at the anastomotic site.
- Multispectral camera revealed an increase in Hb levels at the anastomotic site.
- The multispectral camera assessed gastric tube blood flow more accurately.

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Venous blood flow

ABSTRACT

Background: Evidence regarding the application of the multispectral camera for blood flow measurement is insufficient, and its performance has not been compared with the conventional indocyanine green (ICG) method. Therefore, we retrospectively compared the effectiveness of a new multispectral camera for non-invasive, real-time, quantitative imaging of tissue oxygen (O_2) saturation and hemoglobin (Hb) levels and commercially available ICG fluorescence imaging in hemodynamic assessment of gastric tubes in esophagectomy.
Methods: Thirty patients who underwent thoracoscopic esophagectomy and gastric tube reconstruction for esophageal cancer were included in this study. The multispectral camera was used to measure tissue O_2 saturation and Hb levels. The ICG fluorescence imaging, with the analysis software tool Lumi view, was employed to record ICG luminance changes, with values measured at the anastomotic site. Furthermore, the usefulness of each assessment device was examined using the arterial and venous blood flow indices as cutoff lines for cases with anastomotic failure.
Results: In the evaluation of arterial perfusion, anastomotic leak occurred in three of the five (60 %) patients with arterial insufficiency as assessed by the ICG imaging, while anastomotic leakage occurred in all three patients (100 %) who were assessed as having arterial insufficiency by the multispectral camera. In the evaluation of venous perfusion, anastomotic leakage occurred in three of the nine (33.3 %) patients diagnosed with venous stasis by the IC imaging and in three of the five (60 %) patients assessed by the multispectral camera.
Conclusion: The multispectral camera assessed gastric tube blood flow more accurately than the ICG fluorescence method.

Introduction

Among 5354 patients who underwent esophagectomy for esophageal cancer registered in the Japanese national database in 2014, 711 (13.3 %) were reported to have experienced anastomotic leakage [1]. Perioperative complications, including anastomotic leakage, adversely affect hospital stay, patient quality of life, and long-term postoperative prognosis [2–6]. Various surgical and patient-related factors have been reported to cause anastomotic leakage, such as insufficient blood flow to the reconstructed organs, tension on the anastomosis, suture techniques,

Abbreviations: O_2, oxygen; Hb, hemoglobin; ICG, indocyanine green.

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surgical site infections, and nutritional status of the patients [7–10]. Among these factors, insufficient blood flow to the reconstructed organs is considered a major risk factor for anastomotic leakage. Studies have reported the usefulness of the indocyanine green (ICG) fluorescence imaging method for evaluating blood flow in reconstructed organs, and it is widely used in clinical practice [11–19]. However, the ICG fluorescence imaging method does not accurately reflect tissue oxygen metabolism because ICG binds to serum protein in the blood and evaluates blood flow. Additionally, repeated measurements cannot be taken immediately with this method because of the metabolism rate of ICG. ICG also migrates into the bile duct, lymphatic system, digestive tract, and urinary tract; repeated measurements will increase the chance of error due to this dispersion. Previously, we focused on a technique for measuring tissue oxygen saturation using near-infrared light to establish a less invasive and more accurate organ blood flow assessment. We developed a special multispectral camera that quantifies oxygen saturation and hemoglobin (Hb) levels in tissues [20]. This camera measures tissue oxygen saturation using the ratio of oxyhemoglobin to deoxyhemoglobin, and Hb levels are measured as the sum of oxyhemoglobin and deoxyhemoglobin. The camera does not require ICG administration; however, it enables repeated quantitative evaluation. It can evaluate venous congestion by quantifying the accumulation of Hb levels in tissues. However, evidence regarding the usage of the multispectral camera is insufficient, and its performance has not been compared with the conventional ICG fluorescence imaging method of blood flow measurement. Therefore, this study aimed to verify the efficacy of the multispectral camera compared to a standard-of-care by evaluating blood flow in the gastric tube using the multispectral camera and ICG fluorescence imaging method in the same patient and comparing the results.

Material and methods

Patients

Thirty patients who underwent esophagectomy at the Kyushu University Hospital between April 1, 2016, and September 30, 2017, were included in this study. This study was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans, and its protocol was approved by the Kyushu University Certified Institutional Review Board for Clinical Trials (approval number: 30-211). Informed consent was obtained from the study participants.

Table 1 presents the clinical characteristics of the study patients. The mean age of the 30 patients who underwent esophagectomy was 66.7 (56–86) years. In this study, hypertension, diabetes mellitus, and hyperlipidemia were considered lifestyle-related diseases (i.e., diseases that are closely related to and/or stemming from lifestyle habits, such as diet, exercise, rest, smoking, and drinking). In total, 11 (36.7 %) and 4 (13.3 %) patients had lifestyle diseases and arteriosclerosis lesions, respectively. Neoadjuvant chemotherapy or chemoradiotherapy was performed in 20 (66.7 %) patients.

Table 1
Clinical features.

Characteristic	
Age, years	
Mean (range)	66.7 (56–86)
Sex, n	
Males/females	24/6
Disease, n (%)	
Esophageal cancer	29 (96.7)
other	1 (3.3)
Clinical stage	
0–II/III, IV	18/11
Pre-operative therapy	
Yes/no	20/10
Lifestyle disease	
Yes/no	11/19
Vascular disease	
Yes/no	4/26
Anastomotic leakage	
Yes/no	3/27

Operative procedure

The esophagectomy surgeries were performed using the McKeown technique. Gastric mobilization and tubularization were performed using a laparoscopic technique. After subtotal esophagectomy, a long and narrow gastric tube was created to preserve the right gastroepiploic artery with a diameter of 3.5 cm. Next, the gastric tube was raised to the surface in front of the sternum, and an image was captured with a multispectral camera 70 cm above the body surface. Quantitative imaging of oxygen saturation and Hb levels was performed using the multispectral camera. ICG fluorescence angiography was conducted, and the planned anastomosis site was determined with reference to the brightness of the gastric tube. Subsequently, the gastric tube was brought up through the retrosternal ($n = 21$) or mediastinal ($n = 9$) route. We anastomosed the esophagus and gastric tube by everted triangular anastomosis using stapling devices or hand-sewn end-to-end anastomosis.

Multispectral camera

The principles and developmental history of the multispectral camera used in this study were published in *Surgery and Operating Room Innovation* in 2021 [21]. Details of the method for determining gastric tube blood flow were described in a previously published paper by Tsutsumi et al. [21] Briefly, a halogen light emitting near-infrared light was used to irradiate the gastric tube, and the reflected light with wavelengths between 671 nm and 830 nm was measured. Tissue oxygen saturation was evaluated using the ratio of the two reflected lights, and the Hb level was evaluated by the sum of the two reflected lights. As shown in Fig. 1, point C was determined to be the area where the final branch of the right gastroepiploic artery flows into the gastric tube, and the planned anastomosis site was determined to be point A [20]. The oxygen saturation and Hb level at point C were specified as 100 %, and point A data were expressed as a ratio with respect to point C.

Indocyanine green fluorescence angiography (Hyper Eye Medical System, Mizuho Corporation)

After creating the gastric tube, 0.1 mg/kg of ICG was injected intravenously. Blood flow in the gastric tube was evaluated based on the change in brightness at two points (points C and A, which are the final branch of the right gastroepiploic artery and the planned anastomosis site, respectively). The change in brightness was recorded as a graph in the video image (Fig. 1a). ICG fluorescence angiography was assessed based on a previous study [18]. Briefly, T-in was the time from an increase in luminance to a maximum at point A, and T-out was the time from maximum luminance to 20 % attenuation from a maximum value at point A. The elapsed time from the maximum to minimum luminance in 5 min was defined as T-out when luminance did not reach 0.8 times. T-in A divided by T-in C was written as T-in A/T-in C, and T-out A divided by T-out C was expressed as T-out A/T-out C. Furthermore, T-in A/T-in C and T-out A/T-out C were measured as arterial and venous blood flows, respectively.

The reference value for the ICG fluorescence method was set based on the patient who experienced anastomotic leakage.

Postoperative course

Details regarding the postoperative course for each patient,

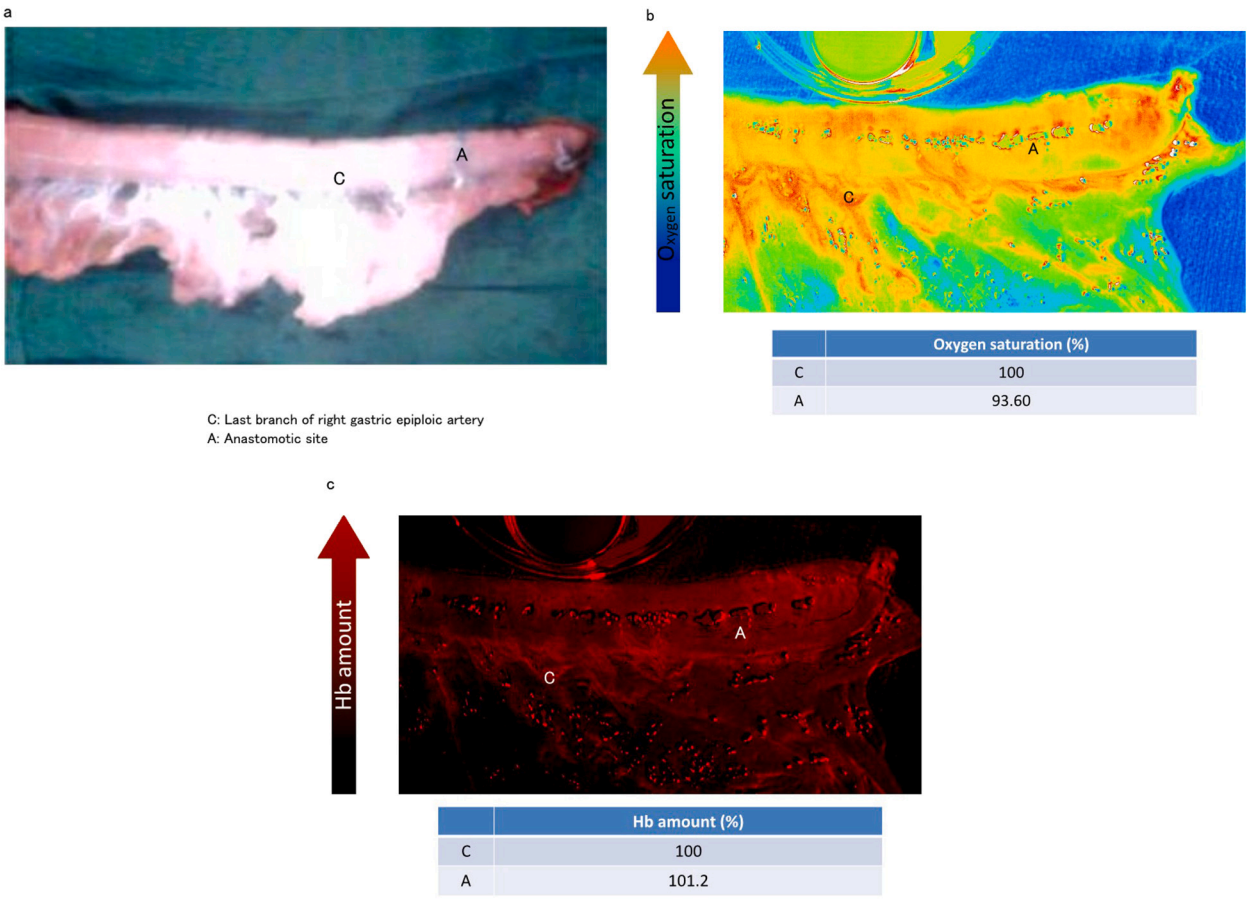

Fig. 1. Images obtained from the ICG fluorescence method and the multispectral camera
A. The state 120 s after intravenous ICG injection.
B. Oxygen saturation visualized using a multispectral camera. The arrows on the left indicate good and poor oxygen saturations as they approach red and blue, respectively.
C. Hb levels visualized using a multispectral camera. The arrows on the left indicate that the closer to red, the higher the Hb levels, and the closer to black, the lower the Hb levels.
C: Control point, A: Anastomosis site, Hb, hemoglobin; ICG, indocyanine green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

including anastomotic leakage, were obtained from medical records. The postoperative complications were assumed to have occurred within 30 days of surgery. The patient was diagnosed with anastomotic leakage if contrast was leaking from the anastomotic site on esophagography or clinical signs of leakage were evident at the neck incision.

Statistical analysis

The dispersion of data in each group was evaluated using the JMP Pro software, version 14 (SAS Institute Inc., Cary, NC, USA, 2019 model year). The normality of data was confirmed using the Shapiro–Wilk test. Normally and non-normally distributed data were assessed using the *t*-test and Mann–Whitney *U* test, respectively. Statistical significance was considered at $p \leq 0.05$.

Results

Three (10 %) patients experienced postoperative anastomotic leakage; however, all three patients recovered through antibiotic administration and local drainage (Clavien–Dindo classification grade III). For patients with anastomotic leakage, the ICG fluorescence method, multispectral camera arterial blood flow evaluation (T-in A/T-in C, oxygen saturation), and venous blood flow evaluation (T-out A/T-out C, Hb level) were confirmed. Three of the five patients with T-in A/T-in C of ≥2.62 and T-out A/T-out C of ≥3.0 using the ICG fluorescence method had anastomotic leakage. Meanwhile, the multispectral camera showed anastomotic leakage in all three cases, with oxygen saturation and Hb levels of ≤79.56 % and ≥123.73 %, respectively. Based on these results, we tentatively established a target value for each examination method to determine the appropriate anastomosis site. Specifically, in the ICG fluorescence method, T-in A/T-in C of ≥2.6 and T-out A/T-out C of ≥3.0 were defined as arterial insufficiency and venous blood stasis, respectively. With a multispectral camera, oxygen saturation of ≤79.6 % and Hb level of ≥123.7 % were defined as arterial insufficiency and venous stasis, respectively.

Regarding anastomotic leakage cases, T-in A/T-in C and T-out A/T-out C were significantly higher in patients with anastomotic leakage as measured by ICG fluorescence angiography than in those with anastomotic leakage as measured by the multispectral camera (1.66 vs. 3.59, $p = 0.006$ and 2.29 vs. 5.34, $p = 0.02$, respectively). Tissue oxygen saturation was significantly reduced (92.31 % vs. 77.77 %, $p < 0.0001$), and the Hb level increased (102.4 % vs. 131.09 %, $p = 0.004$) in cases of anastomotic leakage evaluated by the multispectral camera (Table 2).

Fig. 2 shows the evaluation of arterial and venous blood flows in each case using the ICG fluorescence method and multispectral camera. Anastomotic leakage occurred in three of the five patients assessed by the ICG fluorescence method as having arterial insufficiency and venous stasis (Fig. 2a). In contrast, all three patients evaluated by multispectral

Table 2
Relationship between clinical features and each parameter.

		ICG fluorescence angiography				Multispectral camera			
		T-in A/ T-in C	*p*-value	T-out A/ T-out C	*p*-value	Oxygen saturation (%)	*p*-value	Hemoglobin levels (%)	*p*-value
Age, years	65 < (*n* = 15)	1.65	0.36	2.82	0.58	90.79	0.97	108.82	0.17
	65 ≥ (n = 15)	2.05		2.36		90.85		101.14	
Sex	Males (*n* = 24)	1.88	0.65	2.60	0.94	90.14	0.21	108.39	0.01
	Females (*n* = 6)	1.74		2.54		93.53		88.84	
Disease	Cancer (*n* = 29)	1.85	0.91	2.64	0.49	90.57	0.22	105.00	0.38
	Other (n = 1)	1.73		1.07		98.00		89.41	
cStage	0–II (*n* = 18)	2.03	0.24	2.90	0.43	89.69	0.30	107.78	0.27
	III, IV (*n* = 11)	1.57		2.22		92.01		100.44	
Pre-operative therapy	No (*n* = 10)	1.90	0.86	2.38	0.52	88.13	0.10	105.69	0.87
	Yes (*n* = 20)	1.83		2.20		91.85		104.63	
Lifestyle disease	No (*n* = 19)	1.67	0.30	2.30	0.36	92.84	0.03	100.34	0.08
	Yes (n = 11)	2.16		3.09		87.33		111.63	
Vascular disease	No (*n* = 26)	1.89	0.61	2.60	0.96	91.63	0.07	104.30	0.48
	Yes (*n* = 4)	1.56		2.55		86.00		110.98	
Anastomotic leakage	No (*n* = 27)	1.66	0.006	2.29	0.02	92.31	< 0.0001	102.40	0.004
	Yes (*n* = 3)	3.59		5.34		77.77		131.09	

ICG: indocyanine green; C: Control point; A: Anastomosis site; T-in A/T-in C: T-in A divided by T-in C; T-out A/T-out C: T-out A divided by T-in C.

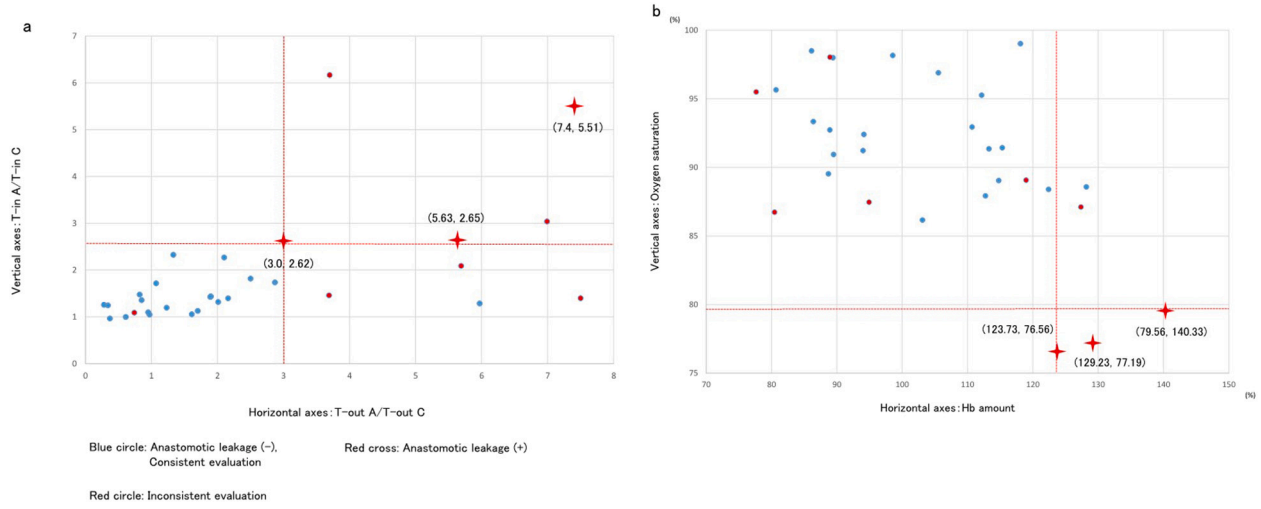

Fig. 2. Relationship between arterial and venous blood flow evaluations using each measurement method.
A. The relationship between arterial (T-in A/T-in C) and venous (T-out A/T-out C) blood flow evaluations using the ICG fluorescence method.
B. The relationship between arterial (oxygen saturation) and venous (Hb levels) blood flow evaluations by the multispectral camera.
C: Control point, A: Anastomosis site, Hb, hemoglobin; ICG, indocyanine green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

camera as having arterial insufficiency and venous stasis experienced anastomotic leakage (Fig. 2b).

Regarding arterial blood flow assessment, anastomotic leakage occurred in three of the five patients (60.0 %) judged to have insufficient arterial blood flow with the ICG fluorescence method and in all three (100 %) determined to have insufficient arterial blood flow by the multispectral camera (Fig. 3a). In the evaluation of venous blood flow, anastomotic leakage occurred in three of the nine patients (33.3 %) determined to have venous stasis by the ICG fluorescence method and in three of the five patients (60.0 %) determined using the multispectral camera to have venous stasis (Fig. 3b).

Figs. 4 and 5 present the cases where arterial and venous blood flow evaluations were consistent and those in which they were inconsistent. In the arterial blood flow assessment, 28 (93.3 %) patients had concordant test results. All three patients diagnosed as having insufficient arterial blood flow by both examinations experienced an anastomotic leakage (Fig. 4). Only two (6.7 %) patients had inconsistent evaluations from the ICG fluorescence method and the multispectral camera. In these two patients, insufficient and sufficient arterial blood flows were determined using the ICG fluorescence method and the multispectral camera, respectively. Furthermore, 24 (80.0 %) patients had consistent venous blood flow evaluation. Anastomotic leakage occurred in three of the four patients diagnosed with venous stasis by both examination methods (Fig. 5). Six (20 %) patients had inconsistent evaluations from the ICG fluorescence method and the multispectral camera. Five of these patients were assessed as having venous congestion by the ICG fluorescence method rather than with the multispectral camera. For example, the tissue oxygen saturation measured using the multispectral camera remained at 98.04 %, and the Hb level was 88.95 % (Fig. 6). Based on the results from the ICG fluorescence method, T-in A/T-in C was 1.4, <2.6, whereas T-out A/ T-out C was 7.5, exceeding 3.0. However, no anastomotic leakage occurred in this case.

The ICG fluorescence and multispectral camera images of one of the three patients who had anastomotic leakages are shown in Fig. 7. However, the multispectral camera showed a decrease in oxygen saturation and an increase in Hb levels at the anastomotic site. In this case, the tissue oxygen saturation measured using the multispectral camera was 77.19 %, which was lower than the reference value, and the Hb level

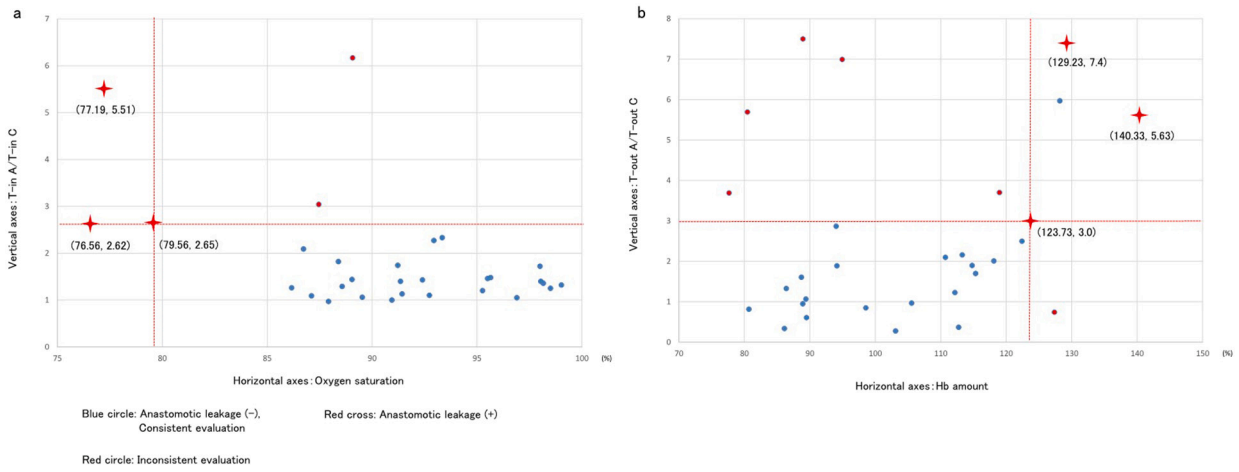

Fig. 3. Relationship between each parameter of the ICG fluorescence method and the multispectral camera.
A. Correlation between T-in A/T-in C observed with the ICG fluorescence method and oxygen saturation assessed by the multispectral camera with respect to arterial blood flow.
B. Correlation between T-out A/T-out C observed with the ICG method and the Hb levels noted by the multispectral camera in terms of venous blood flow.
Blue circle: Represents cases with no anastomotic leakage and two test results concordant.
Red circle: Represents cases with no anastomotic leakage; test results were inconsistent.
Red cross: Represent cases with anastomotic leakage.
C: Control point, A: Anastomosis site, Hb, hemoglobin; ICG, indocyanine green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

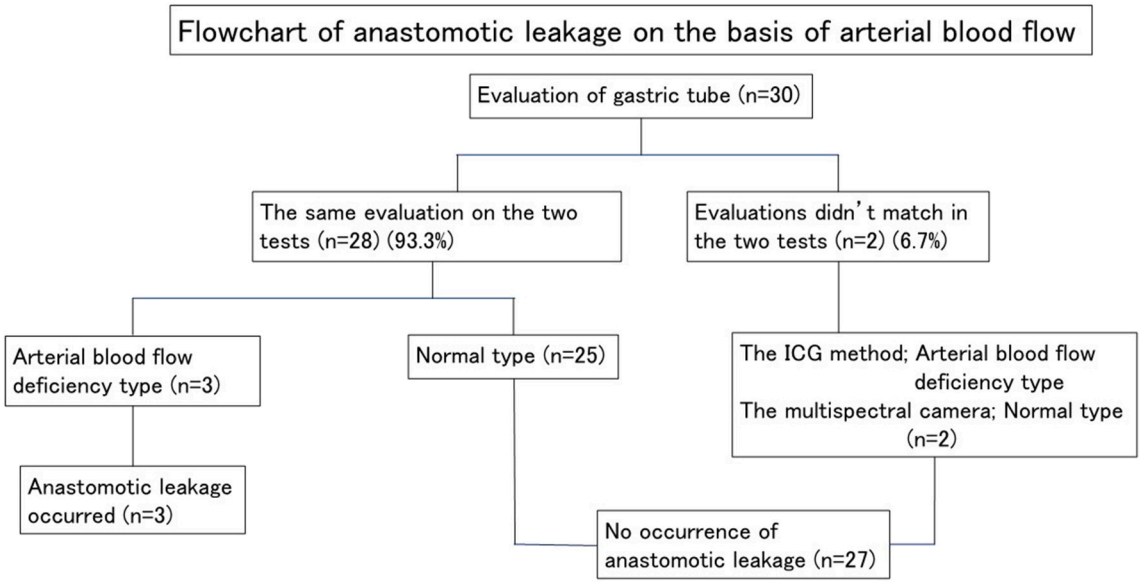

Fig. 4. Flow chart of the assessment of arterial blood flow in the two tests
Anastomotic leakage occurred in the two tests; both cases are evaluated for arterial blood flow deficiency type.

was 129.23 %, which was higher than the reference value, suggesting strong congestion. According to the ICG fluorescence method, T-in A/T-in C was 5.51, and T-out A/T-out C was 7.4, exceeding the standard value and suggesting strong congestion.

Discussion

This study compared the effectiveness of a new multispectral camera for non-invasive, real-time, quantitative imaging of tissue oxygen saturation and Hb levels compared to the commercially available ICG fluorescence imaging for the hemodynamic assessment of gastric tubes in esophagectomy. The results of this study suggest that the multispectral camera can assess gastric tube blood flow more accurately than ICG fluorescence method. A borderline can be found between the cases with anastomotic failure, with the highest score of 79.56, and those without anastomotic failure, with the lowest score of 86.16. The Hb level in the case with anastomotic insufficiency was 123.73, and the highest in the case without anastomotic insufficiency was 128.19. Oxygen saturation is calculated by the ratio of saturated Hb to unsaturated Hb; Hb level is calculated by the sum of saturated Hb and unsaturated Hb, and Hb is easily affected by ambient light. The tissue is usually bleeding or bruised due to surgical manipulation, making quantification of Hb levels more difficult.

Ultimately, when determining the anastomosis site through blood flow assessment using a multispectral camera, it appears desirable that the oxygen saturation level should be ≥80 %. The multispectral camera

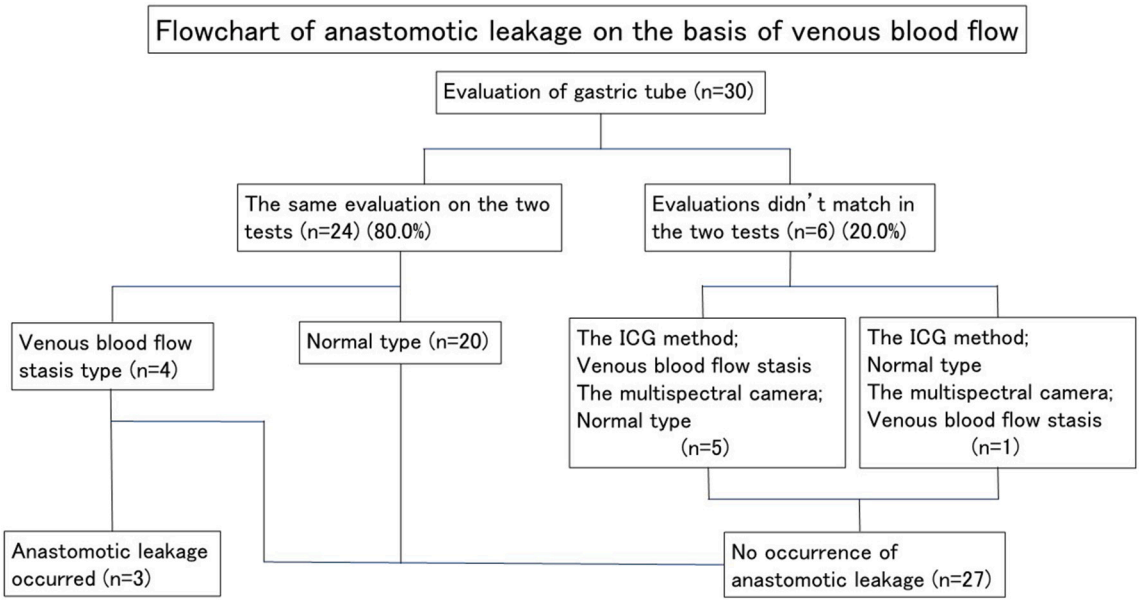

Fig. 5. Flow chart of the assessment of venous blood flow in the two tests
Anastomotic leakage occurred in the two tests; both cases are evaluated for venous blood flow stasis type.

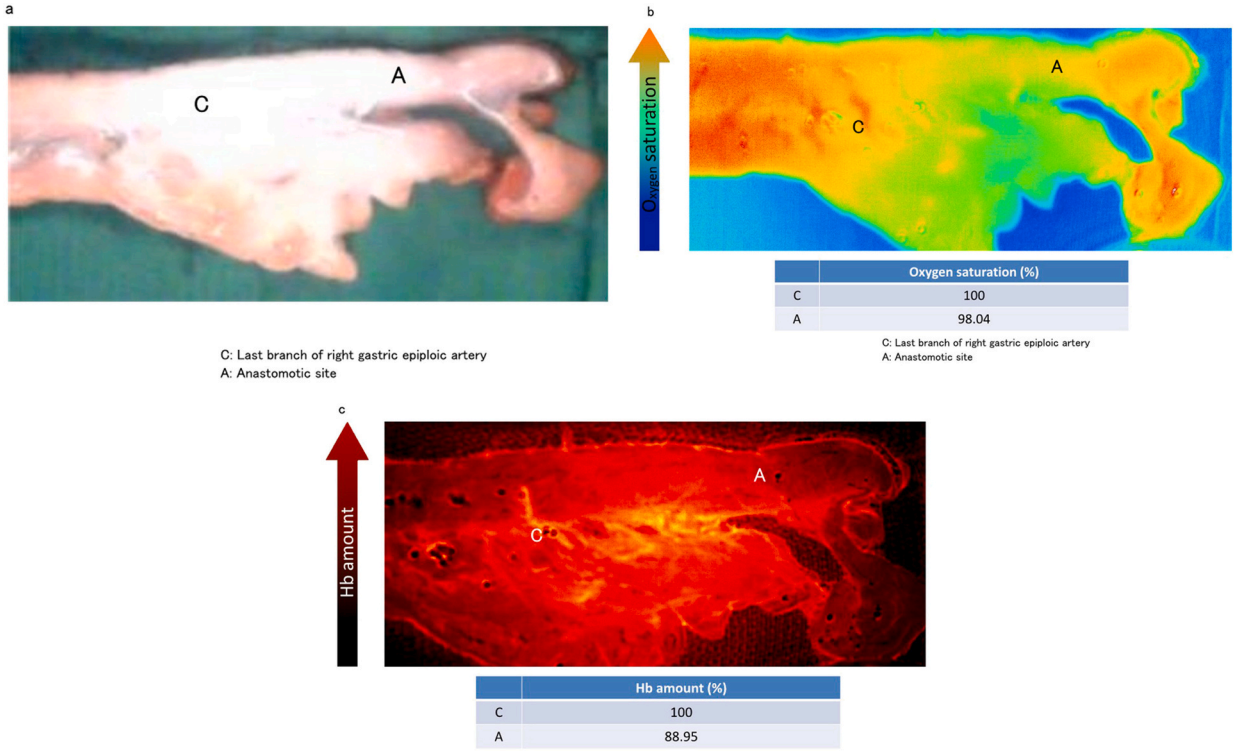

Fig. 6. A case assessed as having venous stasis with the ICG method rather than with the multispectral camera.
A. The ICG fluorescence method diagnosed venous blood stasis.
B. The multispectral camera diagnosed sufficient arterial blood flow.
C. The multispectral camera diagnosed sufficient venous blood flow.
ICG, indocyanine green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

is not used for viewing anastomotic leakage but for evaluating tissue oxygen saturation and Hb level. If tissue oxygen saturation is <80 %, the anastomotic position may need to be modified. However, there may be severe congestion if the Hb level is ≥120 % and the tissue oxygen saturation is ≤80 %; therefore, a clinician may act by changing the anastomosis position or adding super charge, super drainage, or free jejunal transplantation during surgery.

ICG binds to proteins with a mass of 50–200 μg in plasma and fluoresces by excitation to near-infrared rays, allowing visualization of the existing blood vessels and showing blood flow. However, it does not bind to Hb and has several disadvantages in the quantification of blood flow; therefore, only morphological observations can be performed.

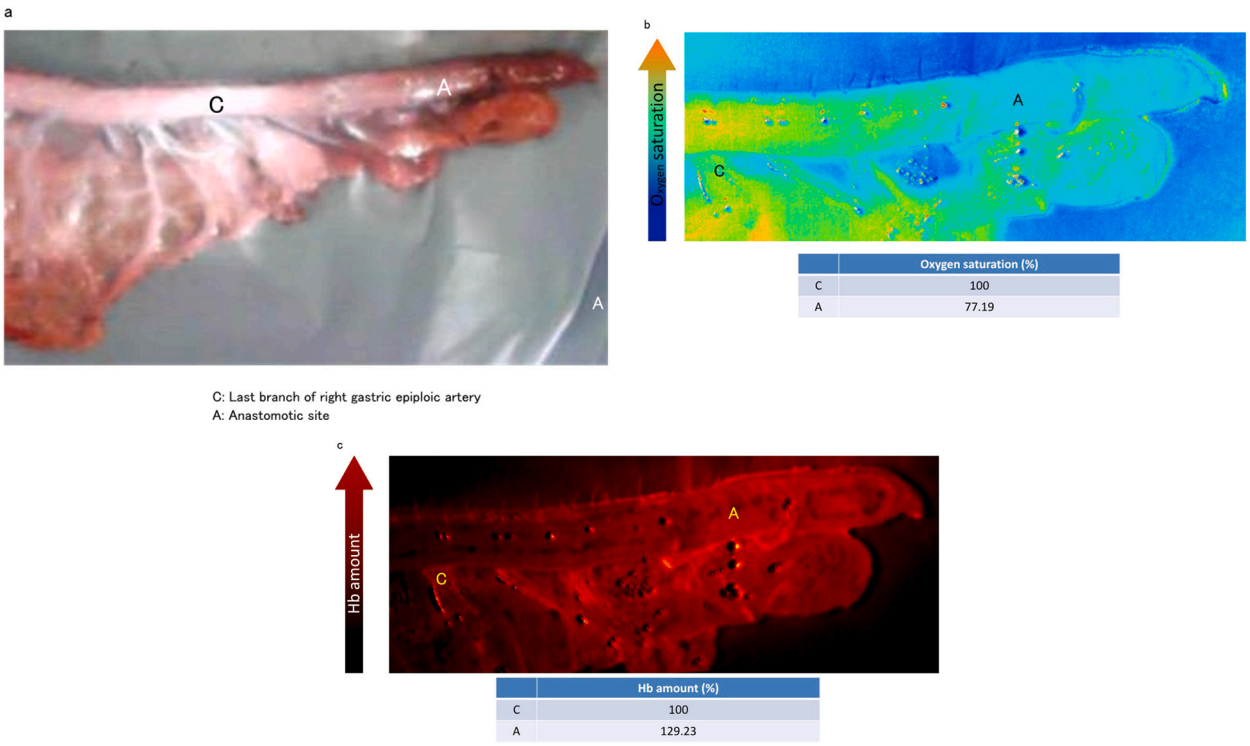

Fig. 7. Multispectral camera and ICG fluorescence images of a case with anastomotic leakage
A. Low tissue oxygen saturation at point A indicates insufficient arterial blood flow at the planned anastomotic site.
B. High Hb levels at point A indicate venous blood flow stasis at the planned anastomotic site.
C. The moment when ICG reaches maximum brightness at point A.
A: Anastomosis site, Hb, hemoglobin; ICG, indocyanine green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Furthermore, observing the conditions in which the administered ICG reaches the gastric tube, such as through systemic circulation, leakage into the tissue from the capillary, or reflux inside the vein, is necessary. Accurately visualizing and quantifying blood flow is challenging because ICG migrates to the bile duct, urinary tract, and digestive tract and deposits in the lymph nodes and cancerous tissue. Additionally, administering ICG each time the test is conducted and waiting until the ICG is metabolized before reimaging is necessary. In contrast, the multispectral camera quantitatively images tissue oxygen metabolism and Hb levels in real-time using oxidized and reduced Hb. Therefore, multispectral cameras may assess arterial and venous blood flow more accurately.

Nevertheless, conducting a prospective multicenter study in the future is necessary to verify the results of this study. Reselecting a site with good anastomotic conditions may be necessary to prevent anastomotic leakage, particularly in cases where the oxygen saturation and Hb level exceed the standard value with a multispectral camera. Furthermore, additional super-drainage may be necessary when congestive changes at the planned anastomotic site are expected to be strong.

This study had some limitations. All surgical operations were performed by the same team using a uniform method; however, anastomotic leakage is caused by various factors, including insufficient blood flow in the gastric tube, insufficient blood flow in the esophagus, tension in the anastomosis, and incomplete surgical technique.

Therefore, concluding that insufficient blood flow alone affected the anastomotic leakage may be challenging. In the cases of this study, one surgical group specializing in esophageal surgery performed suturing using the same method, and we believe the suturing method was not different. Regarding blood flow in the esophagus, we attempted to determine the blood flow status of the esophagus, including the anastomotic site and the gastric tube after anastomosis, using the multispectral camera; however, obtaining positionally accurate images after the anastomosis was difficult. The sample size in this study was small; therefore, a clear correlation between anastomotic leakage and the test results cannot be concluded. We believe that collecting data on more cases is necessary in the future.

Furthermore, this study solely focused on esophagectomy for esophageal cancer; therefore, the usefulness of multispectral cameras for other surgical procedures should be clarified in the future. Currently, the target disease has been changed from the esophagus to the rectum, where anastomosis can be performed within the abdominal cavity, and the target patients have also changed.

Conclusion

Blood flow at the anastomotic site of the reconstructed gastric tube was evaluated using the ICG fluorescence method and a multispectral camera. Notably, multispectral cameras assessed gastric tube blood flow more accurately than the ICG fluorescence method.

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This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics approval

This study was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans, and its protocol was approved by the Kyushu University Certified Institutional Review Board for Clinical Trials (approval number: 30-211). Informed consent was obtained from the study

participants.

CRediT authorship contribution statement

Yasuhiro Haruta: Conceptualization, Data curation, Formal analysis, Investigation, Methodology. **Yuichiro Nakashima:** Methodology. **Tetsuo Ikeda:** Conceptualization, Investigation, Methodology, Project administration. **Eiji Oki:** Methodology, Project administration. **Tomoharu Yoshizumi:** Methodology, Project administration.

Declaration of competing interest

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.

References

[1] Takeuchi H, Miyata H, Gotoh M, Kitagawa Y, Baba H, Kimura W, et al. A risk model for esophagectomy using data of 5354 patients included in a Japanese nationwide web-based database. Ann Surg 2014;260:259–66. https://doi.org/10.1097/SLA.0000000000000644.

[2] Saeki H, Tsutsumi S, Tajiri H, Yukaya T, Tsutsumi R, Nishimura S, et al. Prognostic significance of postoperative complications after curative resection for patients with esophageal squamous cell carcinoma. Ann Surg 2017;265:527–33. https://doi.org/10.1097/SLA.0000000000001692.

[3] Rizk NP, Bach PB, Schrag D, Bains MS, Turnbull AD, Karpeh M, et al. The impact of complications on outcomes after resection for esophageal and gastroesophageal junction carcinoma. J Am Coll Surg 2004;198:42–50. https://doi.org/10.1016/j.jamcollsurg.2003.08.007.

[4] Hirai T, Yamashita Y, Mukaida H, Kuwahara M, Inoue H, Toge T. Poor prognosis in esophageal cancer patients with postoperative complications. Surg Today 1998;28:576–9. https://doi.org/10.1007/s005950050187.

[5] Rutegård M, Lagergren P, Rouvelas I, Mason R, Lagergren J. Surgical complications and long term survival after esophagectomy for cancer in a nationwide Swedish cohort study. Eur J Surg Oncol 2012;38:555–61. https://doi.org/10.1016/j.ejso.2012.02.177.

[6] Lagarde SM, de Boer JD, ten Kate FJ, Busch OR, Obertop H, van Lanschot JJ. Postoperative complications after esophagectomy for adenocarcinoma of the esophagus are related to timing of death due to recurrence. Ann Surg 2008;247:71–6. https://doi.org/10.1097/SLA.0b013e31815b695e.

[7] Cooke DT, Lin GC, Lau CL, Zhang L, Si MS, Lee J, et al. Analysis of cervical esophagogastric anastomotic leaks after transhiatal esophagectomy: risk factors, presentation, and detection, presentation. Ann Thorac Surg 2009;88:177–84. https://doi.org/10.1016/j.athoracsur.2009.03.035 (discussion 184).

[8] Dewar L, Gelfand G, Finley RJ, Evans K, Inculet R, Nelems B. Factors affecting cervical anastomotic leak and stricture formation following esophagogastrectomy and gastric tube interposition. Am J Surg 1992;163:484–9. https://doi.org/10.1016/0002-9610(92)90393-6.

[9] Patil PK, Patel SG, Mistry RC, Deshpande RK, Desai PB. Cancer of the esophagus: Esophagogastric anastomotic leak-a retrospective study of predisposing factors. J Surg Oncol 1992;49:163–7. https://doi.org/10.1002/jso.2930490307.

[10] Briel JW, Tamhankar AP, Hagen JA, DeMeester SR, Johansson J, Choustoulakis E, et al. Prevalence and risk factorsfor ischemia, leak, and stricture of esophageal anastomosis: gastric pull-up versus colon interposition. J Am Coll Surg 2004;198:536–41. https://doi.org/10.1016/j.jamcollsurg.2003.11.026 (discussion 541).

[11] Ohi M, Toiyama Y, Mohri Y, Saigusa S, Ichikawa T, Shimura T, et al. Prevalence of anastomotic leak and the impact of indocyanine green fluorescein imaging for evaluating blood flow in the gastric conduit following esophageal cancer surgery. Esophagus 2017;14:351–9. https://doi.org/10.1007/s10388-017-0585-5.

[12] Koyanagi K, Ozawa S, Oguma J, Kazuno A, Yamazaki Y, Ninomiya Y, et al. Blood flow speed of the gastric conduit assessed by indocyanine green fluorescence: new predictive evaluation of anastomotic leakage after esophagectomy. Medicine (Baltimore) 2016;95:e4386. https://doi.org/10.1097/MD.0000000000004386.

[13] Pacheco PE, Hill SM, Henriques SM, Paulsen JK, Anderson RC. The novel use of intraoperative laser-induced fluorescence of indocyanine green tissue angiography for evaluation of the gastric conduit in esophageal reconstructive surgery. Am J Surg 2013;205:349–52. https://doi.org/10.1016/j.amjsurg.2012.11.005 (discussion 352).

[14] Diana M, Noll E, Diemunsch P, Dallemagne B, Benahmed MA, Agnus V, et al. Enhanced-reality video fluorescence: a real-time assessment of intestinal viability. Ann Surg 2014;259:700–7. https://doi.org/10.1097/SLA.0b013e31828d4ab3.

[15] Wada T, Kawada K, Takahashi R, Yoshitomi M, Hida K, Hasegawa S, et al. ICG fluorescence imaging for quantitative evaluation of colonic perfusion in laparoscopic colorectal surgery. Surg Endosc 2017;31:4184–93. https://doi.org/10.1007/s00464-017-5475-3.

[16] Ishige F, Nabeya Y, Hoshino I, Takayama W, Chiba S, Arimitsu H, et al. Quantitative assessment of the blood perfusion of the gastric conduit by indocyanine green imaging. J Surg Res 2019;234:303–10. https://doi.org/10.1016/j.jss.2018.08.056.

[17] Ritschl LM, Schmidt LH, Fichter AM, Hapfelmeier A, Wolff KD, Mücke T. Multimodal analysis using flowmeter analysis, laser-Doppler spectrophotometry, and indocyanine green videoangiography for the detection of venous compromise in flaps in rats. J Craniomaxillofac Surg 2018;46:905–15. https://doi.org/10.1016/j.jcms.2018.03.016.

[18] Yukaya T, Saeki H, Kasagi Y, Nakashima Y, Ando K, Imamura Y, et al. Indocyanine green fluorescence angiography for quantitative evaluation of gastric tube perfusion in patients undergoing esophagectomy. J Am Coll Surg 2015;221:e37–42. https://doi.org/10.1016/j.jamcollsurg.2015.04.022.

[19] Nakashima Y, Saeki H, Yukaya T, Tsutsumi S, Nakanishi R, Sugiyama M, et al. Blood flow assessment with indocyanine green fluorescence angiography for the pedicled omental flap on cervical esophagogastric anastomosis after esophagectomy. J Am Coll Surg 2016;222:e67–9. https://doi.org/10.1016/j.jamcollsurg.2016.01.048.

[20] Tsutsumi R, Ikeda T, Nagahara H, Saeki H, Nakashima Y, Oki E, et al. Efficacy of novel multispectral imaging device to determine anastomosis for esophagogastrostomy. J Surg Res 2019;242:11–22. https://doi.org/10.1016/j.jss.2019.04.033.

[21] Yasuhiro H, Ryosuke T, Kuriyama N, et al. Novel multispectral device for quantitative imaging of tissue oxygen saturation and hemoglobin as surgical navigation device. Surg Oper Room Innov 2021;10:93–106. https://doi.org/10.1007/978-981-15-8979-9_10.