International Journal of Colorectal Disease (2025) 40:71
https://doi.org/10.1007/s00384-025-04864-3

RESEARCH

Evaluation of anastomotic blood supply during digestive tract reconstruction with the use of the oxygen saturation index: A pooling up analysis

Xiao-Qiang Zhang[1] · Chao-Fu Zhang[1] · Xiang-Jun Zhou[1] · Lei-Yuan Shuai[2] · Dong Peng[1] · Guang-Yan Ji[1]

Accepted: 23 October 2024

Abstract

Purpose Anastomotic leakage (AL) is one of the most serious clinical complications in digestive tract reconstruction (DTR) surgery, and it is currently hypothesized that this may be related to insufficient anastomotic blood supply. Thus, Therefore, we aimed to assess the ability of tissue oxygen saturation(StO_2) as a measure to evaluate anastomotic blood supply.

Methods A comprehensive literature search was performed using Embase, PubMed and Cochrane Library. StO_2 was used as an evaluation index of anastomotic blood supply after DTR to analyze the potential association between this index and the occurrence of AL in the postoperative period.

Results A total of eleven articles involving 867 participants were included in this systematic review and meta-analysis. After pooling the standardized mean difference (SMD) and 95% confidence intervals (Cls), low StO_2 was found to be an independent risk factor for AL (P < 0.00001; 95%CI: 1.02 [0.53–1.51]). The mean StO_2 in the AL group (62.3%) was significantly lower than that in the non-AL group (74.3%); AL incidence increased with the reduction of StO_2 to a certain value to 201.8% and 338.1% respectively.

Conclusion Oxygen saturation index can be utilized in DTR to accurately and quantitatively evaluate the anastomotic blood supply to reduce the probability of postoperative AL.

Keywords Oxygen saturation · Digestive System Surgical Procedures · Anastomotic Leak; Meta-analysis

Introduction

Cancer of the digestive tract is one of the cancers with a high incidence rate in clinical practice, and in recent years there has been a trend of gradual increase. The latest statistics published by the American Cancer Society indicate that in 2023, there will be nearly 170,000 people in the United States who will die from cancer of the digestive tract [1]. As the preferred option for treatment, digestive tract reconstruction (DTR) surgery still has many complications, and the most fatal complication is anastomotic leakage (AL) [2, 3]. The rate of AL after colorectal anastomosis ranges from 1%−19% and gastric conduit reconstruction after esophagectomy is as high as 6.2%−27% statistically [4, 5]. Whereas postoperative AL significantly increases perioperative morbidity and mortality [4, 6–8]. Therefore, the prevention of AL is a key issue after DTR reconstruction, whether colorectal anastomosis or gastric conduit reconstruction.

AL may be a multifactorial event [9, 10], including patient's gender, age, body mass index(BMI), nutritional status, history of neoadjuvant therapy, tumor site, operative duration, intraoperative bleeding, surgeon's experience, and anastomotic tension [11–14], of which insufficient anastomotic blood supply is considered to be one of the possible risk factors for the development of AL. Up to the present, surgeons mostly adopt competent assessment to determine anastomotic vascular perfusion by visual observation, which includes observation of the color of the tube wall, peristalsis, pulsation of vessels at the margins, and hemorrhage from the cut edge. However, it has been demonstrated that this method is poorly predictive [15].

✉ Guang-Yan Ji
jiguangyan168@163.com

[1] Department of Gastrointestinal Surgery, The First Affiliated Hospital of Chongqing Medical University, No.1 Youyi Road, Yuanjiagang District, Chongqing 400016, China

[2] Department of Anorectal Surgery, Jiangjin Central Hospital of Chongqing, Chongqing 404000, China

Published online: 18 March 2025

Currently, techniques for evaluating the intraoperative anastomotic site blood supply have matured, representative of which is the indocyanine green fluorescence angiography (ICG-FA), and the use of which significantly reduces the incidence of AL [16]. Although it has been shown that the routine use of ICG-FA in colorectal anastomosis can result in cost savings [17]. We would like to find a technique that is even less costly and has a predictive effect that is equivalent to or even superior to ICG-FA. In recent years, the feasibility of tissue oxygen saturation measurement has been confirmed in animal models and human models [18–20]. The technique of determining anastomotic blood supply by measuring StO_2 has received widespread attention by virtue of being rapid, quantitative, noninvasive, and low-cost [21–23]. This technology has the potential to replace or combine indocyanine green, which is safer, more economical, and accurately determines the condition of anastomotic perfusion, and reduce the incidence of AL.

Therefore, the aim of this meta-analysis was to analyze the ability of StO_2 to predict AL after DTR reconstruction by combining data from multiple studies. We hypothesized that low anastomotic StO_2 was one of the factors predisposing to AL, and that the lower the anastomotic StO_2, the higher the probability that the patient would develop AL after surgery.

Materials and methods

Technical background

This systematic review was conducted in accordance with the PRISMA Checklist (Supplementary Information) and was pre-registered with PROSPERO (registration number: 42023458764).

StO_2 is the percentage of the volume of oxygen-bound oxygenated hemoglobin (HbO_2) in the tissue blood to the volume of all bindable hemoglobin (Hb, hemoglobin), StO_2 is an important physiological parameter of the respiratory cycle. The oxygen saturation of normal human arterial blood is 98%, and venous blood is 75%. Oxygen saturation tends to be significantly affected when the digestive tract blood supply is poor [24, 25].

Inclusion and exclusion criteria

The studies included in this meta-analysis were performed according to the PICOS principle, the inclusion criteria were: the study population was required to be human patients who underwent digestive tract reconstruction surgery (P); The exposure factor was the occurrence of AL in the postoperative period (I); The AL group and the non-AL group were used as the control (C); The outcome of the study was the anastomotic StO_2 value (O); The types of the study were the RCT (Randomized Controlled Trial) study, the single arm studies, and cohort studies (S);The language of publication was limited to English. There was no limit on the sample size and time of publication;

The exclusion criteria were as follows: 1, studies with incomplete data; 2, data was repeated (When two studies had overlapped data, the study with a larger sample size would be included); 3, wrong site of StO_2 measurement (any part except the digestive tract); 4, change the anastomosis position after the measurement; 5, ischemic pretreatment was performed prior to surgery; 6, case reports, case series, letters to the editor, comments, conferences, and reviews.

Search strategy

The databases searched included Embase, Cochrane library, Pubmed. The StO_2 search terms utilized were "oxygen saturation" OR "Blood Oxygen Level" OR "Saturation of Peripheral Oxygen" OR "Peripheral Oxygen Saturation" OR "SpO_2" OR "StO_2" OR "tissue oxygenation"; AL search terms are: "Anastomotic Leak" OR "Anastomotic Leakage" OR "Leakage, Anastomotic" OR "anastomotic complication"; DTR search terms were "Digestive System Surgical Procedures" OR "Anastomosis, Roux-en-Y" OR "Colectomy" OR "Endoscopy, Digestive System " OR "Enterostomy" OR "Esophagectomy" OR "Esophagoplasty" OR "Esophagostomy" OR "Fundoplication" OR "Gastrectomy" OR "Gastroenterostomy" OR "Gastropexy" OR "Gastroplasty" OR "Jejunoileal Bypass" OR "ancreaticoduodenectomy" OR "Pancreaticojejunostomy" OR "Proctectomy" OR "Colorectal Surgery" OR "colorectal resection"; The search was conducted until July 23, 2023,

Data extraction

Extracted data included: first author, year, country, study design content, and measurement device, number of patients, age, sex, and BMI, American Society of Anesthesiologists(ASA) grade, cardiopulmonary disease, smoking status, alcohol abuse, neoadjuvant therapy, diabetes mellitus (DM), surgical site, anastomotic StO_2., the location of the anastomosis, the time of the anastomosis, and the method of anastomosis. The selected articles were independently evaluated by two researchers who completed the data extraction. Both extractors were trained before starting the work. Disagreements that arose during the process were resolved by negotiation.

Assessment of risk of bias in included studies

The quality of the included literature was assessed by using the Newcastle–Ottawa Quality Assessment Scale (NOS), which was independently scored by two investigators, with a third investigator adjudicating when there was a large discrepancy in the ratings. Studies with a NOS score < 7 points were classified as having a risk of bias. Specific scoring details of the included studies can be found in the Supplementary Materials.

Statistical analysis

The primary outcome of the study was anastomosis StO_2 in the AL group versus the non-AL group. Used a random effects model (dersimon-laird method). Selected Standardized Mean Difference (SMD) as the effect scale index. The secondary outcome was the occurrence of AL in StO_2 at different intervals. The grouping approach of M. Salusjärvi in his study was considered [22], and StO_2 was divided into three groups: excellent group $StO_2 \in [100–90)$, qualified group $StO_2 \in [90–80)$, and low group $StO_2 \leq 80$. RR was chosen as the effect scale indicator using a random effects model. Considering the possible differences in StO_2 measured in the intestine and the stomach and esophagus. We pre-planned a subgroup analysis, we divided the data into an intestinal group and an esophagogastric group according to the surgical site and analyzed the data separately.

A sensitivity analysis of the primary endpoint (StO_2) of this systematic review was performed, excluding low-quality studies after assessment using the NOS scale and excluding studies with small sample sizes (defined as those with fewer than 30 patients) in order to maximize the validity of the metric to StO_2. Due to the small number of included studies, funnel plots were not used to check for potential publication bias in the outcome measures; Forest plots were used to illustrate the presence or absence of heterogeneity in the studies. The degree of heterogeneity of the studies was quantified by the I^2 statistic, which was considered to be moderately to highly heterogeneous when I^2 was greater than 50%. When included studies reported continuous data in the form of median (range) or median (IQR: Interquartile Range), the mean (SD: Standard Deviation) was calculated using the methods suggested by Hozo et al. and Wan et al. [26, 27]. All data in this paper were analyzed using Stata statistically (version 18.0).

Results

Study characteristics

A total of 178 studies were initially retrieved, and after removing 33 duplicate articles, the abstracts of the remaining 145 articles were screened, and a total of 124 studies were excluded. After a further full-text review, 10 studies were excluded, resulting in a total of eleven studies that were included in the present systematic review [21–23, 28–35] (Fig. 1).

The eleven included studies were all single-center studies, including nine cohort studies [21, 23, 28, 30–35], one single-arm study [22], and one medical record series [29]. A total of 867 patients were involved, including 87 patients with AL, with a mean incidence of AL of 10.0%; The primary outcomes of the studies included 10 studies with a total of 445 patients divided into the AL group (65 patients) and the non-AL group (380 patients). In the subgroup analysis, six studies with 267 cases of gastroesophageal reconstruction and four studies with 178 cases of colorectal anastomosis were included; The secondary outcome was addressed in five studies, which included a total of 616 patients divided into an excellent group ($StO_2 \in [100–90)$, 388 cases), a qualified group ($StO_2 \in [90–80)$, 147 cases), and a low group ($StO_2 \leq 80$, 81 cases). Five of the included studies were defined as having a high risk of bias [29, 31, 34, 35]. (Appendix for more detailed information on key assessments).

The studies came from a total of six countries, including four studies conducted in Japan, three studies conducted in the United States, and one each from Germany, Switzerland, Finland, and the Netherlands in the remaining countries included in the study. The publication years range from 2006 to 2022; The equipment used in the studies basically covers commercially available oximetry instruments and is not limited to those developed independently by the investigators (Table 1). The equipment used, the timing of the coincidence, the location and the method used vary from study to institute (Table 2).

Outcome assessment

A total of 11 studies were included in this study containing 867 patients, the baseline characteristics of the patients were: mean age 67.4 (n = 8), male percentage 72.1% (305/423, n = 9), mean BMI was 24.7 (n = 4); ASA grade 2 and above was 65.0% (72/206, n = 3). Among the risk factors for AL: mean operative time was 148.3 min (n = 3), the average intraoperative blood loss was 172.1 ml (n = 2), the percentage of

DM was 11.4% (34/298, n = 5), having respiratory disease was 7.7% (17/221, n = 4), and the hypertensive population was 41.2% (63/153, n = 2); The percentage of people receiving neoadjuvant treatment was 50.9% (142/279, n = 2), other specific patient information is detailed in Table 3.

The main outcome of this meta-analysis was the anastomotic StO_2 after DTR reconstruction, and 10 studies involving 445 individuals were included, including 65 patients with AL, and the mean AL rate was 14.6%. The results showed: after DTR reconstruction, there was a statistically significant difference in the anastomotic StO_2 in the AL group (65) compared with the non-AL group (380) ($P < 0.0001$; 95% CI: 1.02 [0.53–1.51]). The mean StO_2 in the AL group was 62.3%, which was significantly lower than that in the non-AL group, which was 74.3%, with a high degree of heterogeneity between the data (I2 = 62.7%, P = 0.004) (Fig. 2).

After excluding highly biased studies and performing sensitivity analyses, there was still a statistically significant difference in StO_2 between the AL group and the non-AL group ($P = 0.004$; 95%CI: 1.02 [0.53–1.51]). There was no heterogeneity between the data ($I^2 = 0\%$, $P = 0.667$) (Fig. 3).

In subgroup analysis, anastomotic StO_2 in the intestinal subgroup was statistically different between the two groups ($P = 0.018$; 95%CI: 0.85 [0.15–1.56]); There was significant heterogeneity between studies ($I^2 = 63.3\%$, $P = 0.043$); In the gastroesophageal subgroup it was also statistically different ($P = 0.002$, 95%CI: 1.17 [0.43–1.91]), with significant inter-study variability ($I^2 = 66.8\%$, $P = 0.001$). Evidently, our data support the application of StO_2 as an indicator of anastomotic blood supply evaluation for predicting AL in patients undergoing DTR reconstruction, whether it is intestinal reconstruction or reconstruction of the gastric conduit after esophagectomy (Fig. 4, Fig. 5).

Fig. 1 PRISMA 2020 study selection flow diagram

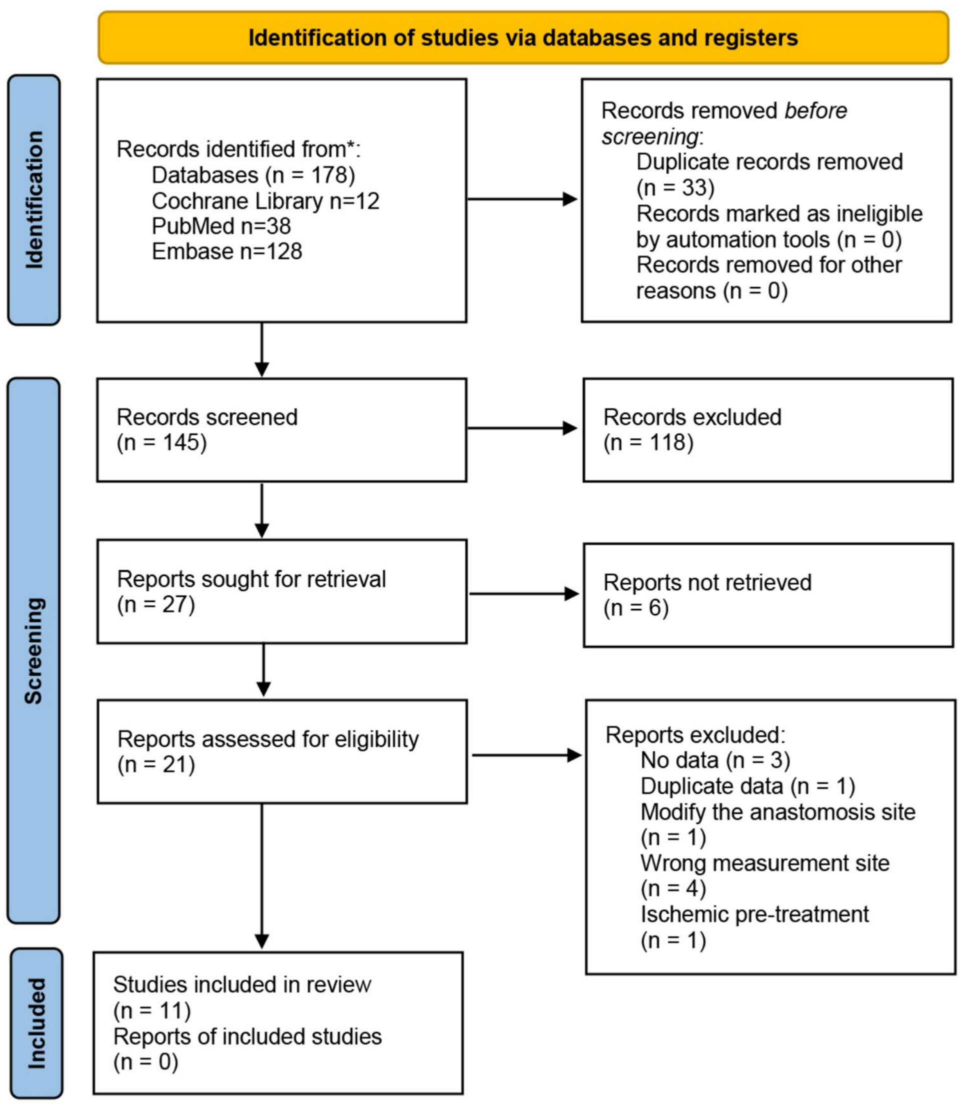

Table 1 Characteristics of included studies

Author	Year	Country	Study Design	Equipment	Surgical site	N	N(AL)	Number of men	Age	Mean BMI(kg/m^2)	StO_2 (%)			NOS
											non-AL	AL	P *	
Salusjärvi, J. M	2018	Finland	Single-arm Single center	Datex Ohmeda S/5, Finland	Colorectal	422	22	NA	NA	NA	NA	NA	NA	7
Adusumilli, P. S	2020	USA	Retrospective cohort Single center	WiPOX, USA	Gastroesophagus	114	7	97(85%)[a]	NA	NA	92.7 ± 12.8[b]	91.2 ± 12.9[b]	0.764	7
Gräfitsch, A	2021	Switzerland	Retrospective cohort Single center	T-Stat, USA	Colorectal	50	8	34(68%)[a]	66.0[c]	23.6[c]	67.9 ± 10.8[b]	62.1 ± 16.1[b]	0.203	8
Ishii, K	2022	Japan	A Case Series Single center	Toccare, Japan	Gastroesophagus	18	6	12(67%)[a]	73.0[c]	20.4[d]	54.9 ± 4.6[b]	46.3 ± 6.7[b]	0.005	6
Fujita, T	2022	Japan	Retrospective cohort Single center	EP-0002, Japan	Gastroesophagus	51	3	40(78%)[a]	69.9[d]	21.5[d]	57.1 ± 7.9[b]	48.3 ± 7.3[b]	0.065	7
Tsutsumi, R	2019	Japan	Retrospective cohort Single center	Multispectral Cameras, Japan	Gastroesophagus	39	2	31(79%)[a]	65.9[d]	NA	92.6 ± 4.1[b]	79.0 ± 1.4[b]	< 0.001	6
Darwich, I	2019	Germany	Retrospective cohort Single center	O2C, Germany	Colorectal	31	9	15(48%)[a]	66.7[d]	NA	88.0 ± 17.5[b]	73.0 ± 26.0[b]	0.068	8
Pham, T. H	2011	USA	Retrospective cohort Single center	Combined devices, USA	Gastroesophagus	23	8	17(74%)[a]	63.0[d]	28.3[d]	84.9 ± 42.2[b]	47.5 ± 16.8[b]	0.025	7
Karliczek, A	2010	Holland	Retrospective cohort Single center	T-Stat, USA	Colorectal	77	14	42(55%)[a]	68.0[d]	26.8[d]	76.7 ± 8.0[b]	73.1 ± 7.4[b]	0.126	9
Gareau, D. S	2010	USA	Retrospective cohort Single center	Combined devices, USA	Gastroesophagus	22	6	NA	NA	NA	42.1 ± 19.4[b]	21.0 ± 15.1[b]	0.025	6
Hirano, Y	2006	Japan	Retrospective cohort Single center	PSA-500, Japan	Colorectal	20	2	17(85%)[a]	67.0[d]	NA	71.0 ± 4.2[b]	58.0 ± 2.4[b]	0.001	6

Abbreviations: BMI, body mass index; StO_2, tissue oxygen saturation; AL, anastomotic leakage; NA, measurement not available; NOS, Newcastle–Ottawa Scale

[a] means (percentage)

[b] means ± standard

[c] median

[d] means*

$p < 0.05$, AL versus non-AL

Table 2 Method, time and location of StO_2 measurements in the included studies

Author	Equipment	Surgical site	Time	Location	Method
Salusjärvi, J. M	Datex Ohmeda S/5, Finland	Colorectal	After the division of the mesentery	StO_2 of the colonic anastomosis	NA
Adusumilli, P. S	WiPOX, USA	Gastroesophagus	After the gastric conduit was mobilized and the anastomotic site was identified by the surgeon	On the serous surface of the planned anastomotic site	The measurement was deemed accurate when the heart rate reading by the device matched the heart rate on the operating room monitors
Gräfitsch, A	T-Stat, USA	Colorectal	Three measurements: ①before mobilization ②after mobilization ③after anastomosis	Five parts: ①Caecum ②Prox. Planned resection ③Distal planned resection ④1 cm prox. Anastomosis ⑤1 cm distal anastomosis	Using a 5-mm sensor above the intestine until the values stabilized within a 5% margin
Ishii, K	Toccare, Japan	Gastroesophagus	When The gastric tube was raised to the cervical site via the retrosternal route	StO_2 was measured at the tip, and 2, 4, and 6 cm on the distal side of the tip of the gastric tube Then, StO_2 was measured at the anastomotic site	NA
Fujita, T	EP-0002, Japan	Gastroesophagus	After gastric tube preparation	At each site on the gastric tube (prepylorus, gastric angle, end of right gastroepiploic vessel area of the conduit, demarcation line of the conduit, demarcation line of the conduit, and tip of the conduit)	An oxygen saturation imaging evaluation of the gastric tube obtained in real time during surgery
Tsutsumi, R	Multispectral Cameras, Japan	Gastroesophagus	Preserving the right gastric artery/vein and the bilateral gastroepiploic arteries/veins was created. The gastric tube was placed on the body surface anterior to the sternum	StO_2 of the anastomosis	The oxygen saturation imaging system
Darwich, I	O2C, Germany	Colorectal	After the mesentery is separated and the bowel is severed	StO_2 of the anastomosis	Utilizing laser Doppler flowmetry as well as tissue spectrometry, was used to measure three different parameters: SO_2, rHb and blood flow velocity A minimal time cost of 3–4 min per measurement

Table 2 (continued)

Author	Equipment	Surgical site	Time	Location	Method
Pham, T. H	Combined devices, USA	Gastroesophagus	Four measurements: ①Short gastric vessel division ②Left gastric vessel division ③Completion of conduit ④Pull-up	Five independent recordings were taken at each of three adjacent locations in the region of the anastomosis and averaged	NA
Karliczek, A	T-Stat, USA	Colorectal	Before taking the descending colon down into the pelvis, and were repeated after completion of the anastomosis	Measurements were taken approximately 1.5 cm away from the cut edge of the proximal and distal colon and simultaneously at the caecal serosa	A sterile handheld probe was placed in the operative field and held a few millimeters above the gauze-cleaned serosal or adventitial surface until values stabilized within a 5% margin
Gareau, D. S	Combined devices, USA	Gastroesophagus	Spectra were collected at five time points during the surgery: ①a baseline value ②after division of the short gastric arteries ③after division of the left gastric artery ④after creation of the gastric conduit ⑤after completion of the anastomosis	At each time point, five measurements were taken in rapid succession at each of three locations within 2 cm of a marking stitch	The endoscope light was turned off for spectral measurements The integration time for each measurement was about 200 ms
Hirano, Y	PSA-500, Japan	Colorectal	After completion of the anastomosis	Except for patients with anterior resection, StO_2 measurements were obtained at two points (proximal and distal side of anastomosis) on the anti-mesentric position of the bowel	Each StO_2 measurement was performed for 10 s and was duplicated. The mean of the two values was used for StO_2. When StO_2 measurements were obtained at two points, the lower value was used

Abbreviations: StO_2, tissue oxygen saturation; AL, anastomotic leakage; NA, not available

Table 3 Summary of characteristics between AL group and non-AL group

Characteristics	Studies	Participants(AL/non-AL)	SMD/OR (95% Cl)	Heterogeneity
Basic information of patients				
Male	6	263/47	0.755 [0.374, 1.528]; P = 0.435 *	$I^2 = 0\%$; P = 0.462 ✣
Age	2	54/14	0.330 [−0.273, 0.933]; P = 0.284 *	$I^2 = 0\%$; P = 0.650 ✣
Risk factors of AL				
DM	5	260/38	1.082 [0.341, 3.431]; P = 0.894 *	$I^2 = 0\%$; P = 0.658 ✣
Respiratory dysfunction	4	197/24	1.163 [0.303, 4.457]; P = 0.826 *	$I^2 = 0\%$; P = 0.478 ✣
Cardiovascular	2	148/16	2.798 [0.615, 12.737]; P = 0.183 *	$I^2 = 39.6\%$; P = 0.198 ✣
Smoking history	3	160/22	0.839 [0.315, 2.238]; P = 0.726 *	$I^2 = 0\%$; P = 0.602 ✣
Post radiation therapy	5	240/39	1.447 [0.514, 4.079]; P = 0.484 *	$I^2 = 34.4\%$; P = 0.192 ✣
Hypercholesterinemia	2	79/10	0.986 [0.155, 6.262]; P = 0.988 *	$I^2 = 0\%$; P = 0.448 ✣
Hypertension	2	143/10	2.210 [0.592, 8.251]; P = 0.238 *	$I^2 = 0\%$; P = 0.705 ✣
Surgery-related information				
Thoracotomy	4	94/25	0.956 [0.328, 2.788]; P = 0.935 *	$I^2 = 0\%$; P = 0.566 ✣
Thoracoscope	4	94/25	1.046 [0.359, 3.048]; P = 0.935 *	$I^2 = 0\%$; P = 0.566 ✣
ASA Grade: 1–2	2	103/22	0.507 [0.153, 1.675]; P = 0.265 *	$I^2 = 0\%$; P = 0.329 ✣
ASA Grade: 3–4	2	103/22	1.974 [0.597, 6.528]; P = 0.265 *	$I^2 = 0\%$; P = 0.329 ✣
Hand sewn	2	104/21	1.390 [0.247, 7.821]; P = 0.708 *	$I^2 = 34.6\%$; P = 0.216 ✣
Stapler	2	104/21	0.719 [0.128, 4.046]; P = 0.708 *	$I^2 = 47.4\%$; P = 0.216 ✣

Abbreviations: AL, anastomotic leakage; OR, Odds ratio; SMD, standardized mean difference; Cl, confidence intervals; DM, diabetes mellitus; ASA, American Society of Anesthesiologists classification of physical status

* $p < 0.05$, AL versus non-AL

✣ $p > 0.1$, AL versus non-AL

The secondary outcome of the study was the probability of AL. We divided the collected StO_2 into three groups, excellent ($StO_2 \in [100–90)$), normal ($StO_2 \in [90–80)$), and low ($StO_2 \leq 80$), to determine whether there was an obvious relationship between reduced StO_2 and AL (Table 4).

A total of 616 patients were included in the secondary results, of which 42 patients had AL after surgery, with a mean AL rate of 6.82%; There were 388 patients in the excellent StO_2 group (17 AL patients), 147 patients in the normal StO_2 group (13 AL patients), and 81 patients in the poor StO_2 group (12 AL patients) (Table 4).

The results showed that there was a statistically significant difference in the incidence of AL between the StO_2-excellent group and the normal group (P = 0.034); RR = 0.47 (95%Cl: 0.29 to 2.67); There was no inter-study heterogeneity ($I^2 = 0\%$, P = 0.933); The incidence of AL in the StO_2-excellent group was 47% of that in the normal group (Fig. 6).

There was no statistically markedly discrepancy in the incidence of AL between the normal and low StO_2 groups (P = 0.837); RR = 0.83 (95%Cl: 0.14 to 5.03), with significant between-study heterogeneity ($I^2 = 57.2\%$, P = 0.072). The incidence of AL in the normal StO_2 group was 83% of that in the low group.

The test for the incidence of AL between the StO_2 superior and low groups (P = 0.337) found no significant differences; RR = 0.31 (95%Cl: 0.03 to 3.38). There was significant heterogeneity between the studies ($I^2 = 68.6\%$, P = 0.041); The incidence of AL in the StO_2 superior group was 31% of that in the low group.

From the above results, there was a significant difference in the probability of AL only between the StO_2 excellent group and the normal group. However, according to statistics, the probability of AL in the StO_2 excellent group was 4.38% (17/388), the probability of AL in the StO_2 normal group was 8.84% (13/147), and the probability of AL in the low StO_2

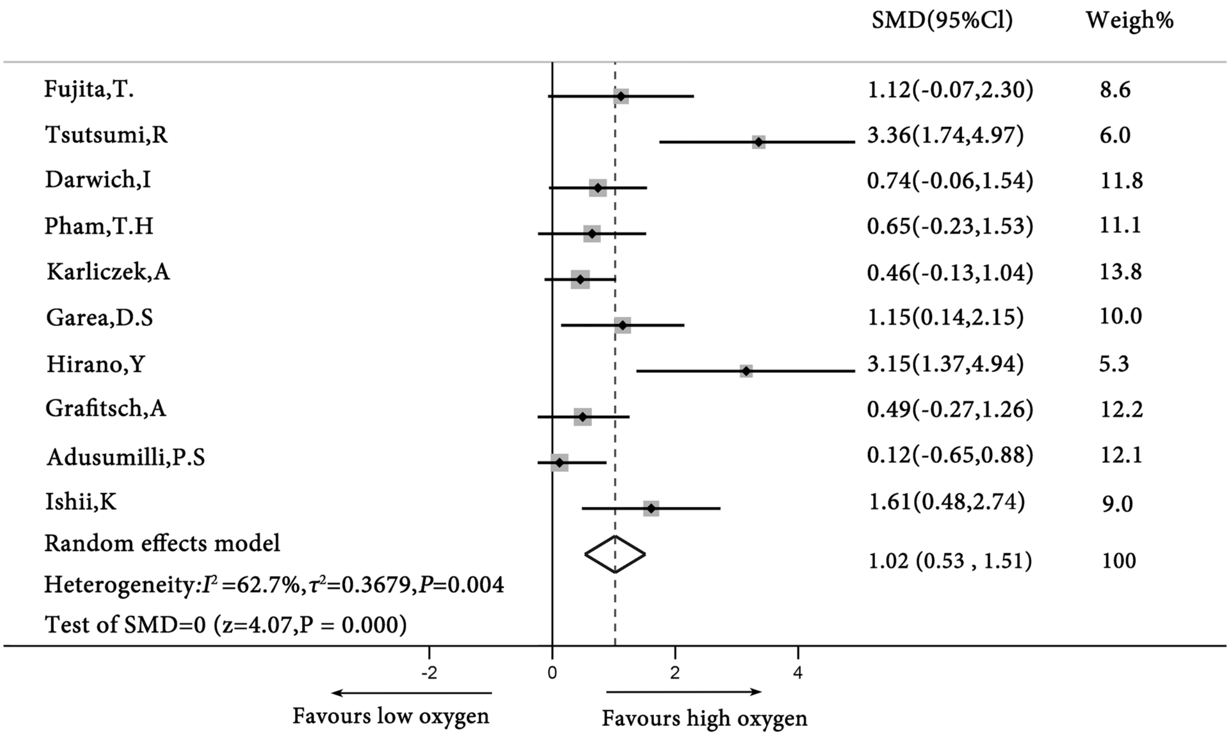

Fig. 2 Anastomotic StO_2 in the AL group versus the non-AL group

group was 14.81% (12/81). Using the StO_2 excellent group as a control, the incidence of AL was elevated to 201.8% and 338.1% after the anastomotic StO_2 was lowered respectively to the [90–80) and [80-0] intervals. The incidence of AL tended to be significantly higher with the reduction of StO_2.

Discussion

This meta-analysis included 867 patients from 11 studies, and we found that anastomotic low StO_2 was an independent risk factor for developing AL. Further subgroup analyses showed that low StO_2 was a potential predictor of postoperative AL in both bowel cancer patients, esophageal cancer patients. In addition, there was a correlation between the incidence of AL and reduced StO_2.

Cancer of the digestive tract is one of the most common cancers in clinical practice today. The prognosis of DTR reconstruction is particularly important as a means of radical treatment, and AL is still the most serious postoperative complication of this procedure. Considering the patient's intestines after performing a break-end anastomosis, the formation of the anastomosis depends on the healing of collagen connections to form a stable ductal structure. Kivisaari J in his study pointed out that there exists a threshold level of tissue oxygen tension for collagen synthesis (15-20mmHg), below which collagen synthesis is markedly impaired in experimental wounds [36–38]. The collagen synthesis is an important process in the healing of scar and its synthesis also depend on the supply of oxygen up to the threshold level, which predicts that StO_2 may be used as a predictor of anastomotic healing.

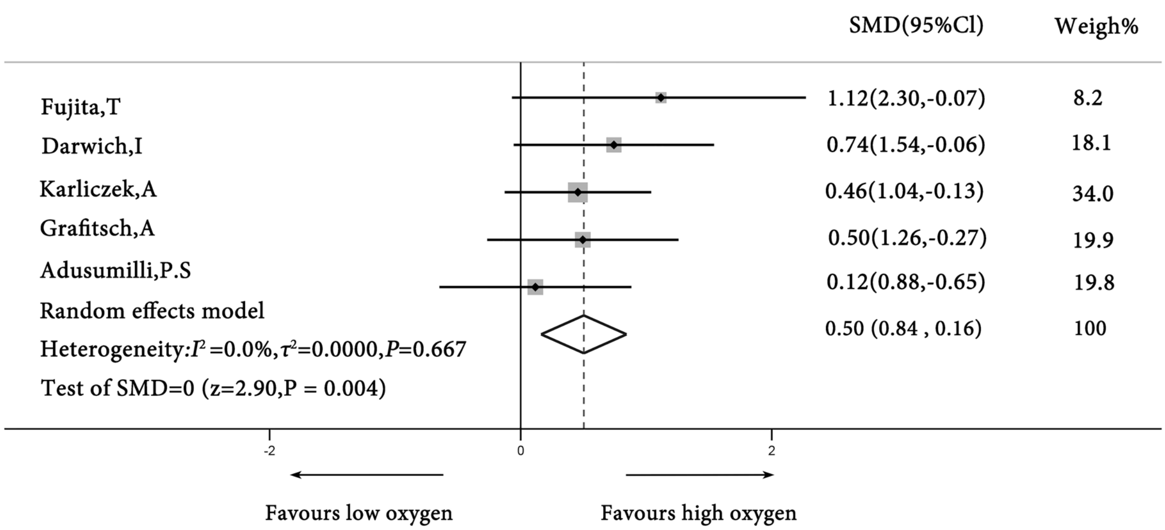

Fig. 3 The predefined sensitivity analysis of anastomotic StO_2 in the AL group versus the non-AL group

Current studies are controversial regarding the predictive value of StO_2.Adusumilli, P. S. et al. and Gräfitsch, A. et al. concluded after their experiments that anastomotic StO_2 did not significantly correlate with postoperative AL formation [28, 30]. In turn, Salusjärvi, J. M. et al. and Ishii, K. et al. concluded that this method seems to be useful in assessing anastomotic viability [22, 29]. Therefore, further comprehensive analysis of the potential relationship between AL and StO_2 is needed.

For evaluating anastomotic blood supply, there are two main clinical approaches. One is the clinician's visual judgment, but in addition to the disadvantage of the surgeon's low predictive value of the anastomosis in DTR [15]. When performing NOSES and NOTES surgeries in the upcoming minimally invasive surgical era, the abdominal wall is not opened and the intestinal tubes have not been dragged out of the peritoneal cavity. Therefore, it is difficult to directly visualize and evaluate the color, mobility, and bleeding of the severed ends of the digestive tract. In addition to extracorporeal surgery, the surgeon needs to use an endoscope to make indirect observations of the digestive tract in most cases.

The second is the ICG-FA, which, according to literature reports In laparoscopic colorectal cancer surgery, ICG-FA can enhance the visualization of tumor lesions, improve the detection rate of lymph nodes, and reduce the incidence of AL [39]. In addition, the quantitative measurement of ICG-FA is also an area of concern, but most of the studies are unable to achieve real-time decision-making [40–42]. The study of Kim, J. C., and Gomez-Rosado, J. C. closed this gap and demonstrated that quantitative ICG-FA can help prevent anastomotic complications more precisely [39, 43]. On the contrary, there are still some problems with ICG-FA, such as the need to give fluorescent substances, the possibility of ICG allergies, and the cost problem [19]. And the judging criteria and operation specifications need to be supported by multicenter, large-sample, and high-level evidence-based medical evidence.

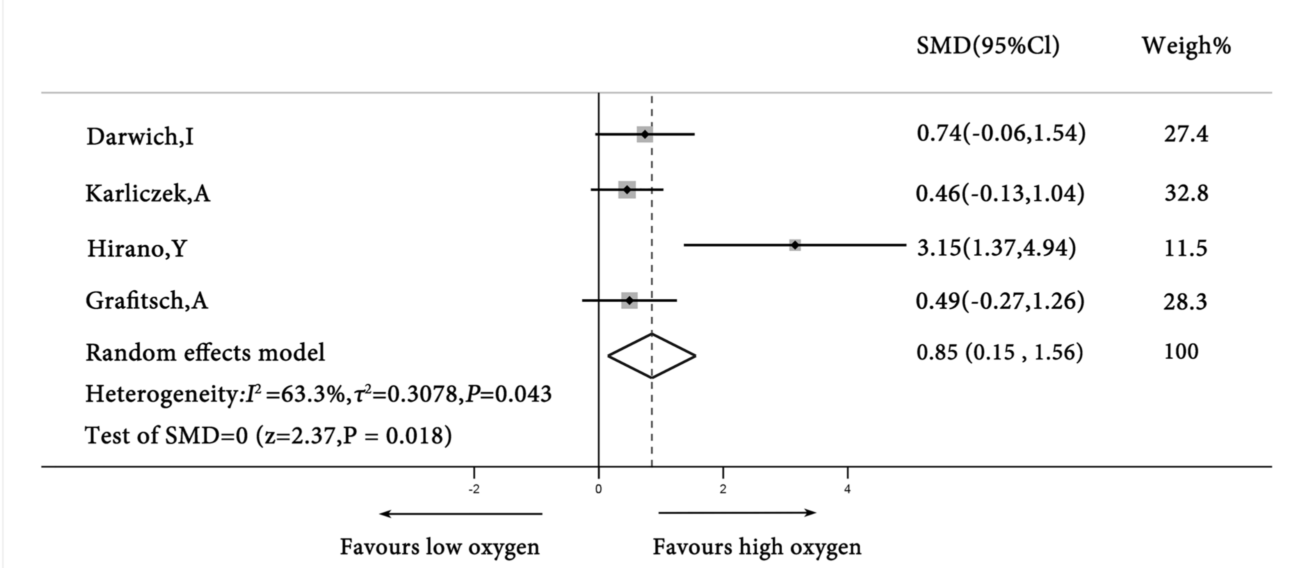

Fig. 4 Forest plot assessment of anastomotic StO_2 in the AL versus non-AL groups in the intestinal subgroups

In addition to ICG-FA and StO_2, there are several other intraoperative techniques for measuring tissue perfusion at anastomosis sites, such as laser speckle contrast imaging (LSCI), Doppler flow, and angiography. However, these methods have not been widely accepted and research data is limited due to limited feasibility, reproducibility issues, or cost issues [44].

Comparing the above two ways of judging anastomotic blood supply, using StO_2 as an evaluation index seems to be a better solution. This technique can realize qualitative and quantitative evaluation of blood supply at the anastomosis, and output the results in the form of images or numerical values to assist clinicians in choosing the anastomotic margins. The measurement process does not require the injection of any substance, and the measurement method is safe and convenient. Several oxygen saturation measurement instruments are currently available on the market: IntraOx (USA) and WiPOX (USA) have been used in preliminary clinical trials [28, 45].

To the best of our knowledge, this is the first meta-analysis to analyze the use of StO_2 as an indicator to evaluate blood supply after DTR reconstruction. We resolved the controversy of whether StO_2 can be an independent risk factor for AL. In addition, we included studies from multiple countries and multiple measurement devices, which means that the results are not limited to a particular geographic region or device and have broad applicability.

However, this meta-analysis still has some limitations. First, only 867 patients from 11 studies were included in the statistics, not including any large RCT, which leads to possible bias in the results. Second, due to the lack of standardization, different studies varied regarding specific intraoperative measurements, which can lead to a certain degree of heterogeneity between studies. Third, we were unable to compare the distance of the tumor from the anal margin or its location in the esophagus between the two groups, as this part of the data was missing from some studies. Finally,

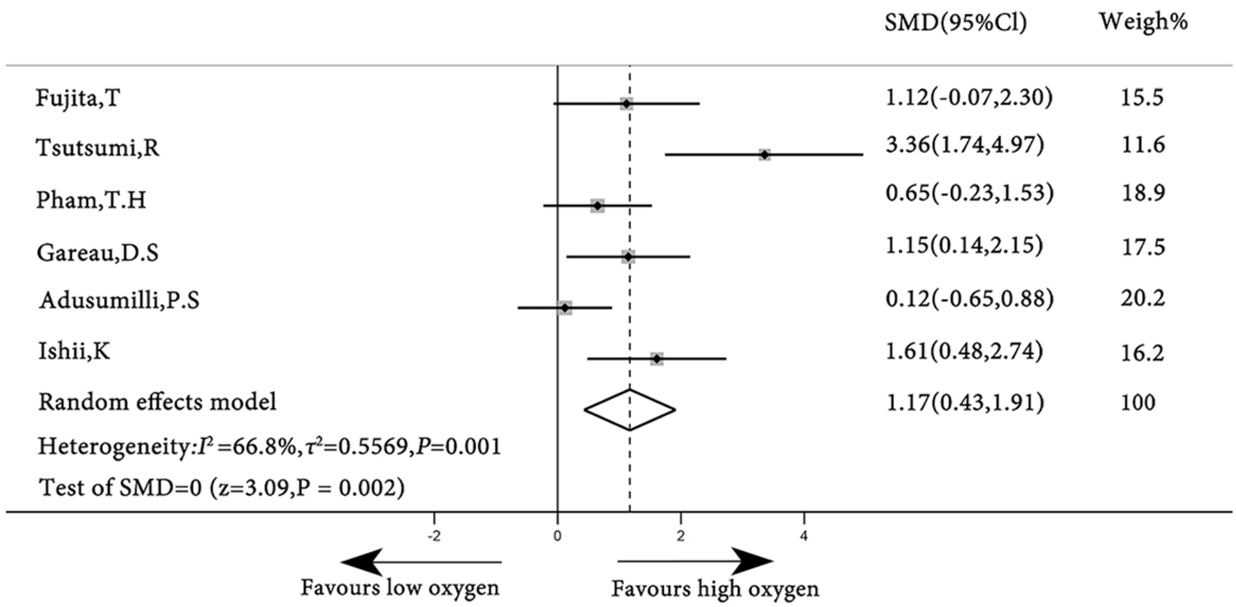

Fig. 5 Forest plot assessment of anastomotic StO_2 in gastroesophageal subgroups in the AL and non-AL groups

Table 4 Number of people with different StO_2 ranges and number of people with AL

Author	N	N(AL)	StO2 > 90%		80% < StO2 ≤ 90%		StO2 ≤ 80%	
			N	N(AL)	N	N(AL)	N	N(AL)
Salusjärvi, J. M	422	22	293	11	111	9	18	2
Hirano, Y	20	2	0	0	1	0	19	2
Tsutsumi, R	49	2	25	0	12	0	2	2
Adusumilli, P. S	113	10	70	6	23	4	20	0
Gareau, D. S	22	6	0	0	0	0	22	6
Summary	626	42	388	17	147	13	81	12

Abbreviations: AL, anastomotic leakage; StO_2, tissue oxygen saturation

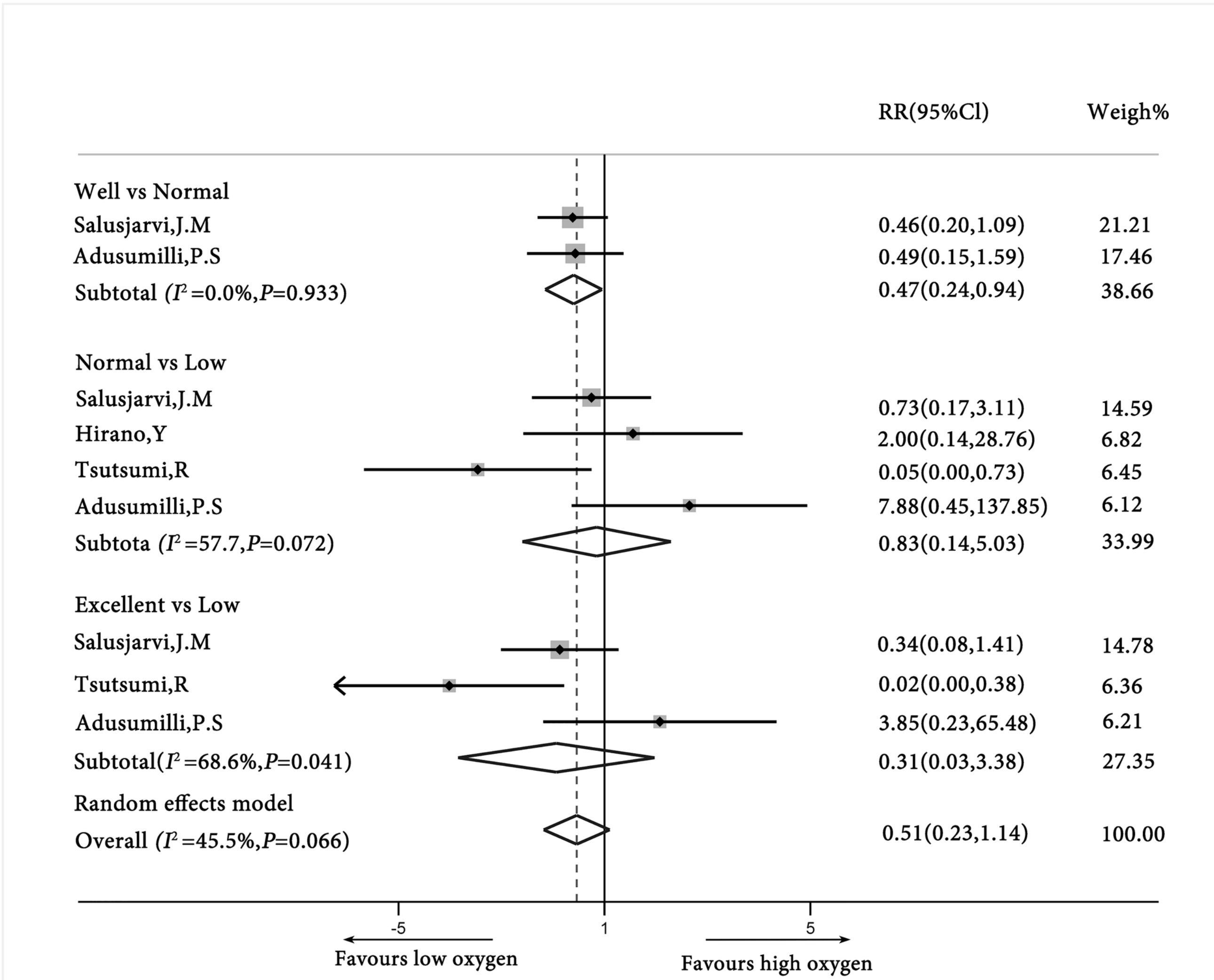

Fig. 6 Integrated estimation of AL incidence with forest plots at different intervals of StO_2

although different measurement devices indicate generalizability of the study results, the total number of measurement devices as well as missing device parameters reduces the confidence in the data (which is a likely source of inter-study heterogeneity).

Currently, there are no uniform international standards for measurement of DTR oxygen saturation and no measurement instruments that are widely recognized internationally, and the timing of measurements, the site of measurement, and the sensitivity of the measurement instruments have varied from study to study. Further clinical trials of this technique in the future will require international organizations to develop standardized protocols to facilitate the collection and use of data. Surgical centers wishing to adopt the new technique should consider these factors.

Conclusion

StO_2 can be utilized to accurately and quantitatively evaluate anastomotic blood supply in DTR. It can help clinicians select anastomotic margins with adequate blood supply to reduce the probability of postoperative AL.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00384-025-04864-3.

Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Xiao-Qiang Zhang, Xiang-Jun Zhou and Chao-Fu Zhang. Quality assessments was finished by Guang-Yan Ji, Dong Peng and Lei-Yuan Shuai. The first draft of the manuscript was written by Xiao-Qiang Zhang. Review and editing were performed by Guang-Yan Ji and Dong Peng. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data Availability Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Declarations

Ethics approval and consent to participate Not appliance.

Consent to publish Not appliance.

Competing Interests The authors have no relevant financial or non-financial interests to disclose.

References

1. R. L. Siegel, K. D. Miller, N. S. Wagle and A. Jemal. Cancer statistics, 2023. CA: a cancer journal for clinicians. 2023; 73: 17–48 https://doi.org/10.3322/caac.21763.
2. Nordlinger B, Sorbye H, Glimelius B et al (2013) Perioperative FOLFOX4 chemotherapy and surgery versus surgery alone for resectable liver metastases from colorectal cancer (EORTC 40983): long-term results of a randomised, controlled, phase 3 trial. Lancet Oncol 14:1208–1215. https://doi.org/10.1016/s1470-2045(13)70447-9
3. Huisman DE, Reudink M, van Rooijen SJ et al (2022) LekCheck: A Prospective Study to Identify Perioperative Modifiable Risk Factors for Anastomotic Leakage in Colorectal Surgery. Ann Surg 275:e189–e197. https://doi.org/10.1097/sla.0000000000003853
4. Turrentine FE, Denlinger CE, Simpson VB et al (2015) Morbidity, mortality, cost, and survival estimates of gastrointestinal anastomotic leaks. J Am Coll Surg 220:195–206. https://doi.org/10.1016/j.jamcollsurg.2014.11.002
5. Lee Y, Fujita H, Yamana H, Kakegawa T (1994) Factors affecting leakage following esophageal anastomosis. Surg Today 24:24–29. https://doi.org/10.1007/bf01676880
6. Koedam TWA, Bootsma BT, Deijen CL et al (2022) Oncological Outcomes After Anastomotic Leakage After Surgery for Colon or Rectal Cancer: Increased Risk of Local Recurrence. Ann Surg 275:e420–e427. https://doi.org/10.1097/sla.0000000000003889
7. Lv Q, Yuan Y, Qu SP et al (2024) Development and validation of a nomogram to predict the risk factors of major complications after radical rectal cancer surgery. Front Oncol 14:1380535. https://doi.org/10.3389/fonc.2024.1380535
8. Diao YH, Rao SQ, Shu XP et al (2024) Prognostic prediction model of colorectal cancer based on preoperative serum tumor markers. World journal of gastrointestinal surgery 16:1344–1353. https://doi.org/10.4240/wjgs.v16.i5.1344
9. Midura EF, Hanseman D, Davis BR et al (2015) Risk factors and consequences of anastomotic leak after colectomy: a national analysis. Dis Colon Rectum 58:333–338. https://doi.org/10.1097/dcr.0000000000000249
10. Peng D, Li ZW, Liu F, Liu XR, Wang CY (2024) Predictive value of red blood cell distribution width and hematocrit for short-term outcomes and prognosis in colorectal cancer patients undergoing radical surgery. World J Gastroenterol 30:1714–1726. https://doi.org/10.3748/wjg.v30.i12.1714
11. Chadi SA, Fingerhut A, Berho M et al (2016) Emerging Trends in the Etiology, Prevention, and Treatment of Gastrointestinal Anastomotic Leakage. Journal of gastrointestinal surgery : official journal of the Society for Surgery of the Alimentary Tract 20:2035–2051. https://doi.org/10.1007/s11605-016-3255-3
12. Kang CY, Halabi WJ, Chaudhry OO et al (2013) Risk factors for anastomotic leakage after anterior resection for rectal cancer. JAMA Surg 148:65–71. https://doi.org/10.1001/2013.jamasurg.2
13. Qu H, Liu Y, Bi DS (2015) Clinical risk factors for anastomotic leakage after laparoscopic anterior resection for rectal cancer: a systematic review and meta-analysis. Surg Endosc 29:3608–3617. https://doi.org/10.1007/s00464-015-4117-x
14. Kingham TP, Pachter HL (2009) Colonic anastomotic leak: risk factors, diagnosis, and treatment. J Am Coll Surg 208:269–278. https://doi.org/10.1016/j.jamcollsurg.2008.10.015
15. Karliczek A, Harlaar NJ, Zeebregts CJ et al (2009) Surgeons lack predictive accuracy for anastomotic leakage in gastrointestinal surgery. Int J Colorectal Dis 24:569–576. https://doi.org/10.1007/s00384-009-0658-6
16. Renna MS, Grzeda MT, Bailey J et al (2023) Intraoperative bowel perfusion assessment methods and their effects on anastomotic leak rates: meta-analysis. Br J Surg. https://doi.org/10.1093/bjs/znad154
17. Liu RQ, Elnahas A, Tang E et al (2022) Cost analysis of indocyanine green fluorescence angiography for prevention of anastomotic leakage in colorectal surgery. Surg Endosc 36:9281–9287. https://doi.org/10.1007/s00464-022-09166-1
18. Servais EL, Rizk NP, Oliveira L et al (2011) Real-time intraoperative detection of tissue hypoxia in gastrointestinal surgery by wireless pulse oximetry. Surg Endosc 25:1383–1389. https://doi.org/10.1007/s00464-010-1372-8
19. Hasegawa H, Takeshita N, Ito M (2020) Novel oxygen saturation imaging endoscopy to assess anastomotic integrity in a porcine ischemia model. BMC Surg 20:250. https://doi.org/10.1186/s12893-020-00913-6
20. Posma LA, Bleichrodt RP, van Goor H, Hendriks T (2007) Transient profound mesenteric ischemia strongly affects the strength of intestinal anastomoses in the rat. Dis Colon Rectum 50:1070–1079. https://doi.org/10.1007/s10350-006-0822-9
21. Fujita T, Sato K, Ozaki A et al (2022) A novel imaging technology to assess oxygen saturation of the gastric conduit in thoracic

esophagectomy. Surg Endosc 36:7597–7606. https://doi.org/10.1007/s00464-022-09199-6

22. Salusjärvi JM, Carpelan-Holmström MA, Louhimo JM, Kruuna O, Scheinin TM (2018) Intraoperative colonic pulse oximetry in left-sided colorectal surgery: can it predict anastomotic leak? Int J Colorectal Dis 33:333–336. https://doi.org/10.1007/s00384-018-2963-4
23. Darwich I, Rustanto D, Friedberg R, Willeke F (2019) Spectrophotometric assessment of bowel perfusion during low anterior resection: a prospective study. Updat Surg 71:677–686. https://doi.org/10.1007/s13304-019-00682-9
24. Kimberger O, Fleischmann E, Brandt S et al (2007) Supplemental oxygen, but not supplemental crystalloid fluid, increases tissue oxygen tension in healthy and anastomotic colon in pigs. Anesth Analg 105:773–779. https://doi.org/10.1213/01.ane.0000277490.90387.96
25. H. W. Hopf, T. K. Hunt, J. M. West, et al. Wound tissue oxygen tension predicts the risk of wound infection in surgical patients. Archives of surgery (Chicago, Ill. : 1960). 1997; 132: 997–1004; discussion 1005 https://doi.org/10.1001/archsurg.1997.01430330063010.
26. Hozo SP, Djulbegovic B, Hozo I (2005) Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol 5:13. https://doi.org/10.1186/1471-2288-5-13
27. Wan X, Wang W, Liu J, Tong T (2014) Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol 14:135. https://doi.org/10.1186/1471-2288-14-135
28. P. S. Adusumilli, M. Bikson, N. P. Rizk, et al. A prospective trial of intraoperative tissue oxygenation measurement and its association with anastomotic leak rate after Ivor Lewis esophagectomy. Journal of Thoracic Disease. 2020; 12: 1449–1459 https://doi.org/10.21037/jtd.2020.02.58.
29. Ishii K, Tsubosa Y, Mayanagi S, Inoue M, Haneda R (2022) Tissue Oxygen Saturation during Gastric Tube Reconstruction with Cervical Anastomosis for Esophagectomy: A Case Series. Journal of investigative surgery : the official journal of the Academy of Surgical Research 35:809–813. https://doi.org/10.1080/08941939.2021.1968080
30. A. Gräfitsch, P. Kirchhoff, S. D. Soysal, S. Däster and H. Hoffmann. Dynamic Serosal Perfusion Assessment during Colorectal Resection Using Visible Light Spectroscopy. European surgical research. Europaische chirurgische Forschung. Recherches chirurgicales europeennes. 2021; 62: 25–31 https://doi.org/10.1159/000514921.
31. Tsutsumi R, Ikeda T, Nagahara H et al (2019) Efficacy of Novel Multispectral Imaging Device to Determine Anastomosis for Esophagogastrostomy. J Surg Res 242:11–22. https://doi.org/10.1016/j.jss.2019.04.033
32. Pham TH, Perry KA, Enestvedt CK et al (2011) Decreased conduit perfusion measured by spectroscopy is associated with anastomotic complications. Ann Thorac Surg 91:380–385. https://doi.org/10.1016/j.athoracsur.2010.10.006
33. Karliczek A, Benaron DA, Baas PC et al (2010) Intraoperative assessment of microperfusion with visible light spectroscopy for prediction of anastomotic leakage in colorectal anastomoses. Colorectal Dis 12:1018–1025. https://doi.org/10.1111/j.1463-1318.2009.01944.x
34. Gareau DS, Truffer F, Perry K et al (2010) Optical fiber probe spectroscopy for laparoscopic monitoring of tissue oxygenation during esophagectomies. J Biomed Opt 15:061712
35. Hirano Y, Omura K, Tatsuzawa Y et al (2006) Tissue oxygen saturation during colorectal surgery measured by near-infrared spectroscopy: pilot study to predict anastomotic complications. World J Surg 30:457–461. https://doi.org/10.1007/s00268-005-0271-y
36. Kivisaari J, Vihersaari T, Renvall S, Niinikoski J (1975) Energy metabolism of experimental wounds at various oxygen environments. Ann Surg 181:823–828. https://doi.org/10.1097/00000658-197506000-00011
37. Hunt TK, Pai MP (1972) The effect of varying ambient oxygen tensions on wound metabolism and collagen synthesis. Surgery, gynecology & obstetrics 135:561–567
38. Sheridan WG, Lowndes RH, Young HL (1987) Tissue oxygen tension as a predictor of colonic anastomotic healing. Dis Colon Rectum 30:867–871. https://doi.org/10.1007/bf02555426
39. Kim JC, Lee JL, Park SH (2017) Interpretative Guidelines and Possible Indications for Indocyanine Green Fluorescence Imaging in Robot-Assisted Sphincter-Saving Operations. Dis Colon Rectum 60:376–384. https://doi.org/10.1097/dcr.0000000000000782
40. Wada T, Kawada K, Takahashi R et al (2017) ICG fluorescence imaging for quantitative evaluation of colonic perfusion in laparoscopic colorectal surgery. Surg Endosc 31:4184–4193. https://doi.org/10.1007/s00464-017-5475-3
41. Son GM, Kwon MS, Kim Y et al (2019) Quantitative analysis of colon perfusion pattern using indocyanine green (ICG) angiography in laparoscopic colorectal surgery. Surg Endosc 33:1640–1649. https://doi.org/10.1007/s00464-018-6439-y
42. H. Iwamoto, K. Matsuda, S. Hayami, et al. Quantitative Indocyanine Green Fluorescence Imaging Used to Predict Anastomotic Leakage Focused on Rectal Stump During Laparoscopic Anterior Resection. Journal of laparoendoscopic & advanced surgical techniques. Part A. 2020; 30: 542–546 https://doi.org/10.1089/lap.2019.0788.
43. Gomez-Rosado JC, Valdes-Hernandez J, Cintas-Catena J et al (2022) Feasibility of quantitative analysis of colonic perfusion using indocyanine green to prevent anastomotic leak in colorectal surgery. Surg Endosc 36:1688–1695. https://doi.org/10.1007/s00464-021-08918-9
44. Van Daele E, Van Nieuwenhove Y, Ceelen W et al (2019) Near-infrared fluorescence guided esophageal reconstructive surgery: A systematic review. World J Gastrointest Oncol 11:250–263. https://doi.org/10.4251/wjgo.v11.i3.250
45. Gonzalez-Jacobo A, Chandler P, Martz J, Sherwinter D (2023) Tissue Oximetry as a Potential Alternative to Indocyanine Green (ICG) Perfusion Assessment in Colorectal Anastomotic Cases. Surgical laparoscopy, endoscopy & percutaneous techniques 33:207–210. https://doi.org/10.1097/sle.0000000000001161