Am J Cancer Res 2025;15(11):4737-4752
www.ajcr.us /ISSN:2156-6976/ajcr0167720

Original Article

A new oblique-to-side esophagogastric anastomosis approach reduces the incidence of postoperative anastomotic leak after esophagectomy for esophageal carcinoma: a propensity score-matched retrospective study

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Received July 27, 2025; Accepted October 30, 2025; Epub November 15, 2025; Published November 30, 2025

Abstract: Anastomotic leakage is one of the most severe postoperative complications following esophagectomy for esophageal carcinoma. This study compared the incidence of postoperative anastomotic leakage after esophagectomy between a novel oblique-to-side esophagogastric anastomosis and the conventional end-to-side esophagogastric anastomosis. Clinical data from 318 patients with esophageal carcinoma (106 cases treated with the new anastomosis and 212 with the conventional approach) who underwent radical esophagectomy between January 2018 and November 2021 were retrospectively collected. Propensity score matching (PSM) was applied to balance baseline characteristics, yielding 188 matched patients (94 in each group). The primary outcome was the incidence of anastomotic leakage, while secondary outcomes included anastomotic stenosis, incisional infection, and pulmonary, cardiovascular, and digestive complications. After PSM, the new anastomosis group showed a significantly lower incidence of anastomotic leakage than the conventional group (6.4% vs. 22.3%, P=0.002). Besides, the incidence of postoperative fever was lower in the new anastomosis (10.6% vs. 27.7%, P=0.003). No significant differences were observed between the groups regarding anastomotic stenosis, incisional infection, or other systemic complications. Multivariate analysis identified the new oblique-to-side esophagogastric anastomosis as an independent protective factor against leak (OR=0.294, P=0.020). In conclusion, the oblique-to-side anastomosis effectively reduces postoperative anastomotic leak after radical esophagectomy without increasing other postoperative complications, demonstrating both safety and clinical efficacy.

Keywords: Anastomotic leak, esophageal carcinoma, propensity score-matched

Introduction

Esophageal carcinoma (EC) is a common malignant tumor with high incidence and mortality rates [1]. According to the GLOBOCAN 2020 database, EC ranks 7th in incidence and 6th in mortality among all malignant tumors [2]. Currently, the management for EC primarily relies on a comprehensive approach centered on surgical resection [3]. However, esophagectomy remains a technically demanding procedure involving various surgical approaches and anastomotic techniques. Due to the unique anatomical and physiological features of the esophagus, patients undergoing radical esophagectomy are particularly susceptible to various perioperative complications, such as anastomotic leakage [4].

Previous studies have reported that the incidence of anastomotic leakage following radical esophagectomy ranges from approximately 5% to 30% [5-7]. Anastomotic leakage is not only one of the most severe postoperative complica-

https://doi.org/10.62347/CUDI3212

tions of EC but also a major contributor to postoperative mortality [8]. This complication significantly affects the efficacy of surgical treatment and the long-term prognosis, while also imposing a considerable psychological and economic burden on patients and their families [9]. Consequently, reducing the incidence of anastomotic leakage following radical esophagectomy has emerged as a crucial challenge in the clinical management of EC.

Previous studies have shown that the approach of esophagogastric anastomosis is a key determinant of postoperative complications [10]. Experienced surgeons can reduce the risk of anastomotic leakage by preserving the right gastric omental artery during surgery, reinforcing the anastomotic suture with tension-reducing fixation, and optimizing infection control and postoperative nutritional support [11]. Nevertheless, the overall incidence of anastomotic leakage remains relatively high. Therefore, developing a new anastomotic approach to reduce leakage after esophagectomy remains an urgent clinical priority. To this end, several innovative anastomotic methods have been proposed, including end-to-side anastomosis using a circular stapler [12], side-to-side anastomosis using a linear stapler [13], layered hand-sewn esophagogastric anastomosis [14], and embedded three-layer anastomosis [15].

Based on extensive clinical experience, our team has innovated a novel oblique-to-side esophagogastric anastomosis using a circular stapler, building upon the conventional end-to-side approach. This study retrospectively compared the incidence of anastomotic leakage and other postoperative complications between the new oblique-to-side and conventional anastomotic approaches to evaluate the safety and feasibility of this technique in esophagectomy.

Material and methods

Study design and patient selection

This retrospective, observational, and matched cohort study included adult patients with EC who underwent esophagectomy using either a novel anastomotic approach or the conventional approach at the Department of Cardiothoracic Surgery, First Affiliated Hospital of Guangxi Medical University, between January 2018 and November 2021. This study was approved by the Medical Ethics Committee of the First Affiliated Hospital of Guangxi Medical University (No. 2023-E512-01) and complied with the Helsinki Declaration and relevant ethical guidelines. All patient data were anonymized (including removal of names, addresses, ID numbers, and medical record numbers). Given the retrospective design, the Institutional Review Board waived the requirement for informed consent. Clinical data, including diagnostic information, procedural details, medication use, and perioperative and follow-up data, were retrieved from the hospital's electronic medical records.

Inclusion criteria: (1) Patients who underwent preoperative electronic endoscopy with histopathological confirmation of EC; (2) Patients who received preoperative high-resolution computed tomography (CT) of the chest and upper abdomen, barium gastrointestinal imaging, and cervical lymph node ultrasounography to evaluate tumor size, invasion depth, lymph node metastasis, and distant metastasis. Exclusion criteria: (1) Distant metastasis of EC; (2) Poor surgical tolerance due to severe comorbidities or poor physical status (e.g., hypothyroidism, myocarditis) with ASA grade ≥ IV or cardiac function class III-IV; (3) Patients who underwent manual or linear stapler anastomosis. The study flowchart is shown in **Figure 1**.

Operation method

All procedures were performed by the same surgical team under general anesthesia. A single-lumen endotracheal tube was used to establish the airway. Patients were first placed in the left lateral decubitus position. Four trocars were inserted into the right chest wall, and artificial pneumothorax was created and maintained at a pressure of 7-8 mmHg. The thoracic esophagus and tumor were carefully mobilized, followed by systematic dissection of the mediastinal and para-esophageal lymph nodes.

After completion of the thoracic procedure, the patient was repositioned to the supine position. A 3 cm incision was made in the left neck to expose and transect the cervical esophagus. The proximal esophageal stump was preserved for anastomosis, while the distal end was secured with a traction suture.

A 1 cm periumbilical incision was created to establish pneumoperitoneum, maintaining an

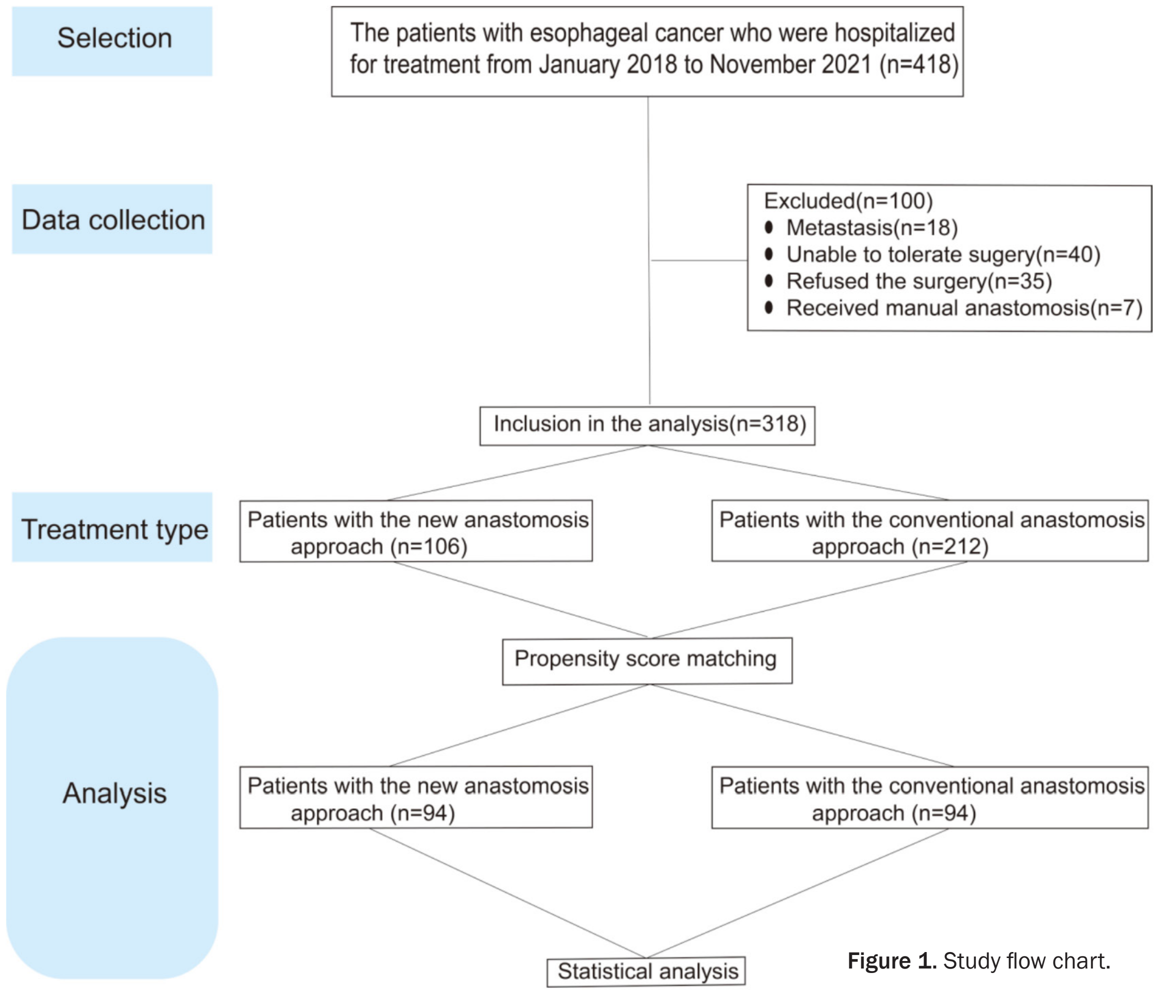

Figure 1. Study flow chart.

intra-abdominal pressure of 13 mmHg. Laparoscopic ports were placed for visualization and manipulation. The stomach was mobilized with preservation of the right gastroepiploic artery, and regional lymph nodules were dissected. The incision beneath the xiphoid process was extended to approximately 4 cm, allowing externalization of the stomach. A tubular stomach, 3-4 cm in width, was fashioned along the greater curvature while preserving the right gastroepiploic artery. A traction suture was placed at the gastric fundus, and the tubular stomach was drawn to the cervical incision through the esophageal bed. The cervical esophagus was sutured with purse string.

Conventional anastomosis: the plane of the purse-string suture was perpendicular to the longitudinal axis of the esophagus. New anastomosis: the plane of the purse-string suture was oblique (30-45°) to the longitudinal axis of the esophagus, with the dorsal side of the esophagus longer than the trachea side.

The base of the circular stapler was inserted into the esophageal lumen, and the purse-string suture was tightened. The tubular stomach and esophagus were side-to-side anastomosed with a 24 # circular stapler (**Figure 2**). By using a pouch clamp with a fixed inclination angle fixed of 30° or 45°, the suture could be applied consistently, ensuring uniform surgical technique across different surgeons.

Clinical outcomes

The follow-up period was one month after the surgery. The primary outcome was the occurrence of anastomotic leakage. The diagnosis of anastomotic leakage was confirmed if any of the following criteria were met [16]: (1) Drainage of intestinal contents through the drainage tube or the appearance of blue dye in the drainage fluid after oral administration of methylene blue; (2) Extravasation of contrast agent observed on contrast radiography or CT; (3) Presences of free gas or exudation around the

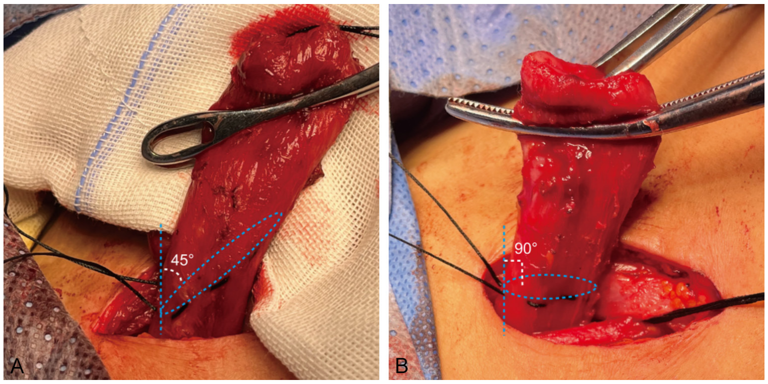

Figure 2. Different Anastomotic methods. A. Oblique-to-side anastomosis: oblique-to-side anastomosis of the esophagus and stomach (45°); B. Conventional anastomosis: end-to-side anastomosis of the esophagus and tubular stomach (90°).

anastomosis on CT; (4) Direct visualization of the leakage site by gastroscopy; (5) Detection of the leakage site during the second surgical exploration. Manifestations appearing more than 48 hours postoperatively surgery were considered diagnostic of anastomotic leakage. Secondary outcomes included surgery-related complications, such as anastomotic stricture, incisional infection, and pulmonary, cardiovascular, or digestive complications. Postoperative pulmonary complications included respiratory failure, acute respiratory distress syndrome (ARDS), pulmonary embolism, and fluid pneumothorax. Cardiovascular complications included heart failure, pericardial effusion, and atrial fibrillation. Gastrointestinal complications included abdominal distention, gastric perforation, gastrointestinal bleeding, and reflux esophagitis. Postoperative fever was defined as an axillary temperature >38°C on three consecutive measurements within a 12-hour period.

Statistical analysis

Statistical software SPSS version 23.0 (IBM SPSS Statistics 23.0) was used for statistical analysis in this study. To minimize selection bias between the two groups caused by potential confounding factors, propensity score matching (PSM) was applied. Propensity scores were calculated using logistic regression based on the following 18 covariates: age, sex, body mass index (BMI), hypertension, diabetes, coronary artery disease, history of smoking/alcohol consumption, neoadjuvant therapy, and history of cerebral infarction, chronic obstructive pulmonary disease (COPD), and pulmonary bulla, as well as tumor location, histological type, clinical grade, pathological T grade and N grade, and degree of differentiation. A 1:1 nearest-neighbor matching without replacement was performed using a caliper (match tolerance) of 0.02, yielding 94 matched pairs for subsequent analysis.

The normality of the continuous variables was firstly estimated using the normality test. Normally distributed data were expressed as mean ± standard deviation (SD), and compared between groups using the independent sample t-test. Non-normally distributed data were expressed as the M (P25, P75) and compared using the Wilcoxon rank sum test. Categorical variables were described as n (%) and analyzed using the χ^2 test or Fisher's exact test, as appropriate. Potential risk factors influencing clinical outcomes were evaluated using logistic regression analysis. Differences were considered statistically significant with a two-sided *P*-value <0.05.

Results

Comparison of baseline characteristics between the two groups

A total of 318 patients with esophageal carcinoma were included in this study, including 106 in the new anastomosis group and 212 in the conventional anastomosis group. After PSM, 94 pairs of patients were successfully matched. No perioperative death occurred in either group.

As shown in **Table 1**, before PMS, there were statistical differences between the two groups in terms of neoadjuvant therapy, tumor location, and pathological T-stage (*P*<0.05). The proportion of patients receiving neoadjuvant therapy was higher in the new anastomosis group than in the conventional anastomosis group (13 [12.3%] vs. 9 [4.2%], *P*=0.008). In terms of tumor location, the new anastomosis group had 10 cases (9.4%) in the upper thoracic segment, 40 cases (37.7%) in middle thoracic

Table 1. Comparison of baseline characteristics between the two groups before and after PSM

Variables	Before PSM (n=318)		*p*	After PSM (n=188)		*p*
	New anastomosis approach (n=106)	Conventional anastomosis approach (n=212)		New anastomosis approach (n=94)	Conventional anastomosis approach (n=94)	
Age (years)	61.29±9.33	61.04±9.02	0.815	61.15±9.20	61.20±8.50	0.941
BMI (kg/m^2)	21.08±2.50	20.97±3.05	0.945	21.10±2.50	20.93±3.09	0.679
Sex			0.495			0.83
Female	13 (12.3%)	32 (15.1%)		13 (13.8%)	12 (12.8%)	
Male	93 (87.7%)	180 (84.9%)		81 (86.2%)	82 (87.2%)	
History of hypertension			0.557			0.716
No	82 (77.4%)	170 (80.2%)		74 (78.7%)	76 (80.9%)	
Yes	24 (22.6%)	42 (19.8%)		20 (21.3%)	18 (19.1%)	
History of diabetes			0.364			0.351
No	99 (93.4%)	203 (95.8%)		87 (92.6%)	90 (95.7%)	
Yes	7 (6.6%)	9 (4.2%)		7 (7.4%)	4 (4.3%)	
History of coronary heart disease			0.292			0.494
No	98 (92.5%)	188 (88.7%)		88 (93.6%)	91 (96.8%)	
Yes	8 (7.5%)	24 (11.3%)		6 (6.4%)	3 (3.2%)	
Smoking history			0.751			0.884
No	52 (49.1%)	108 (50.9%)		48 (51.1%)	49 (52.1%)	
Yes	54 (50.9%)	104 (49.1%)		46 (48.9%)	45 (47.9%)	
Alcohol consumption history			0.111			0.559
No	54 (50.9%)	88 (41.5%)		48 (51.1%)	44 (46.8%)	
Yes	52 (49.1%)	124 (58.5%)		46 (48.9%)	50 (53.2%)	
Family history			0.738			0.756
No	99 (93.4%)	200 (94.3%)		89 (94.7%)	88 (93.6%)	
Yes	7 (6.6%)	12 (5.7%)		5 (5.3%)	6 (6.4%)	
Neoadjuvant therapy			0.008			0.601
No	93 (87.7%)	203 (95.8%)		85 (90.4%)	87 (92.6%)	
Yes	13 (12.3%)	9 (4.2%)		9 (9.6%)	7 (7.4%)	
History of cerebral infarction			1			1
No	103 (97.2%)	207 (97.6%)		93 (98.9%)	92 (97.9%)	
Yes	3 (2.8%)	5 (2.4%)		1 (1.1%)	2 (2.1%)	
COPD			1			1
No	105 (99.1%)	211 (99.5%)		93 (98.9%)	93 (98.9%)	
Yes	1 (0.9%)	1 (0.5%)		1 (1.1%)	1 (1.1%)	

Pulmonary bulla			0.220			0.169
No	86 (81.1%)	159 (75%)		75 (79.8%)	82 (87.2%)	
Yes	20 (18.9%)	53 (25%)		19 (20.2%)	12 (12.8%)	
Tumor Location			0.033			0.174
Upper thoracic	10 (9.4%)	7 (3.3%)		7 (7.4%)	3 (3.2%)	
Middle thorax	40 (37.7%)	91 (42.9%)		35 (37.2%)	47 (50%)	
Lower thoracic	40 (37.7%)	65 (30.7%)		39 (41.5%)	29 (30.9%)	
Overlap	16 (15.1%)	49 (23.1%)		13 (13.8%)	15 (16%)	
Histological type			0.910			1
Adenocarcinoma	4 (3.8%)	6 (2.8%)		4 (4.3%)	3 (3.2%)	
Squamous cell carcinoma	102 (96.2%)	206 (97.2%)		90 (95.7%)	91 (96.8%)	
Clinical staging			0.773			0.672
I	24 (22.6%)	45 (21.2%)		21 (22.3%)	23 (24.5%)	
II	56 (52.8%)	107 (50.5%)		50 (53.2%)	44 (46.8%)	
III	26 (24.5%)	60 (28.3%)		23 (24.5%)	27 (28.7%)	
T staging			<0.001			0.822
T1	18 (17%)	22 (10.4%)		13 (13.8%)	15 (16%)	
T2	41 (38.7%)	45 (21.2%)		34 (36.2%)	29 (30.9%)	
T3	44 (41.5%)	143 (67.5%)		44 (46.8%)	48 (51.1%)	
T4	3 (2.8%)	2 (0.9%)		3 (3.2%)	2 (2.1%)	
N staging			0.051			0.178
N0	60 (56.6%)	111 (52.4%)		55 (58.5%)	48 (51.1%)	
N1	21 (19.8%)	70 (33%)		17 (18.1%)	29 (30.9%)	
N2	21 (19.8%)	26 (12.3%)		18 (19.1%)	12 (12.8%)	
N3	4 (3.8%)	5 (2.4%)		4 (4.3%)	5 (5.3%)	
Differentiation grade			0.165			0.373
Unknown	21 (19.8%)	43 (20.3%)		19 (20.2%)	22 (23.4%)	
Undetermined	3 (2.8%)	3 (1.4%)		3 (3.2%)	2 (2.1%)	
Poorly differentiate	12 (11.3%)	16 (7.5%)		11 (11.7%)	6 (6.4%)	
Moderately differentiated	43 (40.6%)	113 (53.3%)		36 (38.3%)	46 (48.9%)	
Well differentiated	27 (25.5%)	37 (17.5%)		25 (26.6%)	18 (19.1%)	

COPD: chronic obstructive pulmonary disease; PSM: propensity score matching.

segment, 40 cases (37.7%) in lower thoracic segment, and 16 cases (15.1%) in overlapping regions. In contrast, the conventional anastomosis group had 7 (3.3%) thoracic, 91 (42.9%) middle thoracic, 65 (30.7%) lower thoracic, and 49 (23.1%) overlapping cases (P=0.033). For T staging, the distribution in the new anastomosis group was T1 in 18 cases (17%), T2 in 41 cases (38.7%), T3 in 44 cases (41.5%), and T4 in 3 cases (2.8%), while these numbers in the conventional anastomosis group were 22 (10.4%), 45 (21.2%), 143 (67.5%), and 2 (0.9%), respectively (P<0.001).

After PSM, all baseline covariates were well balanced between the two matched cohorts, with no statistically significant differences (*P*>0.05).

Comparison of postoperative complications between the two groups

After PSM, the incidence of anastomotic leakage in the new anastomosis group was significantly lower than that in the conventional anastomosis group (6.4% vs. 22.3%, *P*=0.002). The distribution of leakage sites, including the anterior, posterior, left, and right sides of the anastomosis, as well as the tubular stomach, also differed significantly between the two groups (*P*=0.008). In the new anastomosis group, leakage occurred mainly at the posterior (33.3%) and tubular stomach (33.3%), followed by the left side (16.7%) and right side (16.7%). In contrast, in the conventional anastomosis group, most leakage occurred at the posterior wall (61.9%), and the other sites were less frequent (14.3% at the left side, 4.8% right side, 4.8% anterior wall, and 14.3% tubular stomach). The incidence of postoperative fever was significantly lower in the new anastomosis group (10.6%) than the conventional anastomosis approach group (10.6% vs. 27.7%, *P*=0.003). There were no significant differences in other postoperative complications, including anastomotic stricture, incisional infection/liquefaction, chylothorax, pulmonary, cardiac, or gastrointestinal complications (*P*>0.05). These results are shown in **Table 2**.

Comparison of intraoperative conditions and postoperative outcomes between the two groups

As illustrated in **Table 3**, significant differences were observed between the two groups in terms of surgical approach, anastomotic site, number of lymph nodes dissected, and postoperative nutritional support, both before and after PSM (*P*<0.05).

In the new anastomosis group, 55.3% of patients underwent open esophagectomy, while 44.7% underwent minimally invasive surgery. In contrast, in the conventional anastomosis group, the vast majority (98.1%) underwent open esophagectomy.

Regarding the anastomotic sites, most anastomoses in both groups were located in the intrathoracic region, specifically at the supra-arch, infra-arch, or pleural apex levels. A higher proportion of patients in the new anastomosis group underwent cervical anastomosis compared with the conventional anastomosis group (38.3% vs. 9.6%).

Additionally, number of lymph nodes dissected was greater and the operative time was longer in the new anastomosis group compared with the conventional anastomosis group, although only the difference in the number of lymph nodes dissected reached statistical significance (*P*=0.002).

In terms of postoperative nutritional support, total intravenous nutrition was the primary method in both groups (87.2% vs. 74.5%). However, the proportion of patients receiving intravenous plus nasal-enteral tube nutrition was significantly lower in the new anastomosis group compared with the conventional anastomosis group (9.6% vs. 23.4%, *P*=0.037).

No statistically significant differences were observed between the two groups in other postoperative outcomes, including ICU stay >3 days, mechanical ventilation >48 hours, tracheal reintubation, and revision operation.

Analysis of factors affecting postoperative anastomotic leakage

Patients were grouped into two groups according to the occurrence of postoperative anastomotic leakage: 35 cases in the leakage group and 283 cases in the non-leakage group.

Comparisons of preoperative and intraoperative variables between the two groups revealed significant differences in several parameters (*P*<0.05), as shown in **Table 4**. Six variables, including pulmonary bulla, tumor location, an-

Table 2. Comparison of postoperative complications between the two groups before and after PSM

Variables	Before PSM		p	After PSM		p
	New anastomosis approach (n=106)	Conventional anastomosis approach (n=212)		New anastomosis approach (n=94)	Conventional anastomosis approach (n=94)	
Surgery-related Complications						
Anastomotic leakage			0.031			0.002
No	100 (94.3%)	183 (86.3%)		88 (93.6%)	73 (77.7%)	
Yes	6 (5.7%)	29 (13.7%)		6 (6.4%)	21 (22.3%)	
Location of the anastomotic leakage			0.269			0.008
Anterior	0 (0%)	1 (0.5%)		0 (0%)	1 (1.1%)	
Posterior	2 (1.9%)	15 (7.1%)		2 (2.1%)	13 (13.8%)	
Left side	1 (0.9%)	4 (1.9%)		1 (1.1%)	3 (3.2%)	
Right side	1 (0.9%)	6 (2.8%)		1 (1.1%)	1 (1.1%)	
Tubular stomach	2 (1.9%)	3 (1.4%)		2 (2.1%)	3 (3.2%)	
No anastomosis leakage	100 (94.3%)	183 (86.3%)		88 (93.6%)	73 (77.7%)	
Anastomotic stricture			0.538			1
No	106 (100%)	209 (98.6%)		94 (100%)	93 (98.9%)	
Yes	0 (0%)	3 (1.4%)		0 (0%)	1 (1.1%)	
Incision infection			0.538			-
No	106 (100%)	209 (98.6%)		94 (100%)	94 (100%)	
Yes	0 (0%)	3 (1.4%)		0 (0%)	0 (0%)	
Resuscitation			0.717			1
No	100 (94.3%)	202 (95.3%)		90 (95.7%)	89 (94.7%)	
Yes	6 (5.7%)	10 (4.7%)		4 (4.3%)	5 (5.3%)	
Chylothorax			1			1
No	105 (99.1%)	211 (99.5%)		93 (98.9%)	93 (98.9%)	
Yes	1 (0.9%)	1 (0.5%)		1 (1.1%)	1 (1.1%)	
Diaphragmatic hernia			0.333			1
No	105 (99.1%)	212 (100%)		93 (98.9%)	94 (100%)	
Yes	1 (0.9%)	0 (0%)		1 (1.1%)	0 (0%)	
Delirium			1			1
No	106 (100%)	211 (99.5%)		94 (100%)	93 (98.9%)	
Yes	0 (0%)	1 (0.5%)		0 (0%)	1 (1.1%)	
Sepsis			1			0.678
No	104 (98.1%)	208 (98.1%)		92 (97.9%)	90 (95.7%)	
Yes	2 (1.9%)	4 (1.9%)		2 (2.1%)	4 (4.3%)	

Hypoproteinemia			0.914			1
No	103 (97.2%)	204 (96.2%)		91 (96.8%)	91 (96.8%)	
Yes	3 (2.8%)	8 (3.8%)		3 (3.2%)	3 (3.2%)	
Fever (>38°C)			0.173			0.003
No	92 (86.8%)	171 (80.7%)		84 (89.4%)	68 (72.3%)	
Yes	14 (13.2%)	41 (19.3%)		10 (10.6%)	26 (27.7%)	
Pulmonary Complications						
Respiratory failure			0.483			1
No	100 (94.3%)	205 (96.7%)		90 (95.7%)	91 (96.8%)	
Yes	6 (5.7%)	7 (3.3%)		4 (4.3%)	3 (3.2%)	
ARDS			1			1
No	105 (99.1%)	211 (99.5%)		93 (98.9%)	94 (100%)	
Yes	1 (0.9%)	1 (0.5%)		1 (1.1%)	0 (0%)	
Pulmonary embolism			1			1
No	106 (100%)	211 (99.5%)		94 (100%)	93 (98.9%)	
Yes	0 (0%)	1 (0.5%)		0 (0%)	1 (1.1%)	
Liquid Pneumothorax			0.097			0.262
No	74 (69.8%)	166 (78.3%)		63 (67%)	70 (74.5%)	
Yes	32 (30.2%)	46 (21.7%)		31 (33%)	24 (25.5%)	
Cardiac Complications						
Heart failure			0.333			-
No	105 (99.1%)	212 (100%)		94 (100%)	94 (100%)	
Yes	1 (0.9%)	0 (0%)		0 (0%)	0 (0%)	
Pericardial effusion			1			-
No	106 (100%)	211 (99.5%)		94 (100%)	94 (100%)	
Yes	0 (0%)	1 (0.5%)		0 (0%)	0 (0%)	
Atrial fibrillation			1			-
No	106 (100%)	211 (99.5%)		94 (100%)	94 (100%)	
Yes	0 (0%)	1 (0.5%)		0 (0%)	0 (0%)	
Gastrointestinal Complications						
Gastrointestinal distention			1			-
No	106 (100%)	211 (99.5%)		94 (100%)	94 (100%)	
Yes	0 (0%)	1 (0.5%)		0 (0%)	0 (0%)	
Gastric perforation			0.333			1
No	105 (99.1%)	212 (100%)		93 (98.9%)	94 (100%)	
Yes	1 (0.9%)	0 (0%)		1 (1.1%)	0 (0%)	

Gastrointestinal bleeding			0.859			1
No	104 (98.1%)	210 (99.1%)		92 (97.9%)	93 (98.9%)	
Yes	2 (1.9%)	2 (0.9%)		2 (2.1%)	1 (1.1%)	
Reflux esophagitis			0.333			1
No	105 (99.1%)	212 (100%)		93 (98.9%)	94 (100%)	
Yes	1 (0.9%)	0 (0%)		1 (1.1%)	0 (0%)	

PSM: propensity score matching; ARDS: acute respiratory distress syndrome.

Table 3. Comparison of intraoperative and postoperative conditions between the two groups before and after PSM

Variables	Before PSM		*p*	After PSM		*p*
	New anastomosis approach (n=106)	Conventional anastomosis approach (n=212)		New anastomosis approach (n=94)	Conventional anastomosis approach (n=94)	
Surgical approach			<0.001			<0.001
Open esophagectomy	61 (57.5%)	209 (98.6%)		52 (55.3%)	93 (98.9%)	
Minimally invasive	45 (42.5%)	3 (1.4%)		42 (44.7%)	1 (1.1%)	
Anastomosis site			<0.001			<0.001
Supra-arch	46 (43.4%)	140 (66%)		41 (43.6%)	60 (63.8%)	
Infra-arch	19 (17.9%)	53 (25%)		16 (17%)	25 (26.6%)	
Pleural apex	1 (0.9%)	4 (1.9%)		1 (1.1%)	0 (0%)	
Neck	40 (37.7%)	15 (7.1%)		36 (38.3%)	9 (9.6%)	
Number of lymph node dissected	10 [6, 15]	7 [3, 11.5]	<0.001	10 [6, 15]	7.5 [3, 12]	0.002
Operation time (min)	216.5 [162.0, 275.0]	196 [169.50, 240.0]	0.059	215.5 [160.0, 277.0]	196 [170.0, 240.0]	0.158
Post-operative nutritional support			0.002			0.037
Total intravenous nutrition	92 (86.8%)	153 (72.2%)		82 (87.2%)	70 (74.5%)	
Intravenous + jejunal nutrition	3 (2.8%)	2 (0.9%)		3 (3.2%)	2 (2.1%)	
Intravenous + nasal-enteral tube nutrition	11 (10.4%)	57 (26.9%)		9 (9.6%)	22 (23.4%)	
Hospitalization days after surgery	9 [8, 11]	9 [7, 11]	0.500	9 [8, 10]	9 [7, 11]	0.849
Postoperative ICU stay >3 d			0.860			0.516
No	100 (94.3%)	201 (94.8%)		90 (95.7%)	88 (93.6%)	
Yes	6 (5.7%)	11 (5.2%)		4 (4.3%)	6 (6.4%)	
Postoperative mechanical ventilation >48 h			0.755			1
No	103 (97.2%)	203 (95.8%)		91 (96.8%)	90 (95.7%)	
Yes	3 (2.8%)	9 (4.2%)		3 (3.2%)	4 (4.3%)	
Tracheal re-intubation after surgery			0.426			1
No	101 (95.3%)	207 (97.6%)		90 (95.7%)	91 (96.8%)	
Yes	5 (4.7%)	5 (2.4%)		4 (4.3%)	3 (3.2%)	
Reoperation			0.724			0.266
No	101 (95.3%)	200 (94.3%)		89 (94.7%)	85 (90.4%)	
Yes	5 (4.7%)	12 (5.7%)		5 (5.3%)	9 (9.6%)	

PSM: propensity score matching.

Table 4. Univariate logistic regression analysis of anastomotic leakage

Variables	Leakage group (n=35)	Non-leakage group (n=283)	$t/\chi^2/Z$	p
Age (years)	61.14±9.75	61.12±9.05	0.014	0.989
BMI (kg/m^2)	21.02±2.72	21.01±2.90	0.011	0.991
Sex			0.290	0.590
Female	6 (17.14%)	39 (13.78%)		
Male	29 (82.86%)	244 (86.22%)		
History of hypertension			0.014	0.907
No	28 (80%)	224 (79.15%)		
Yes	7 (20%)	59 (20.85%)		
History of diabetes				
No	31 (88.57%)	271 (95.76%)	3.368	0.066
Yes	4 (11.43%)	12 (4.24%)		
History of coronary heart disease				
No	29 (82.86%)	257 (90.81%)	2.178	0.140
Yes	6 (17.14%)	26 (9.19%)		
Smoking history				
No	14 (40%)	146 (51.59%)	1.674	0.196
Yes	21 (60%)	137 (48.41%)		
Alcohol consumption history				
No	15 (42.86%)	127 (44.88%)	0.051	0.821
Yes	20 (57.14%)	156 (55.12%)		
Family history				
No	32 (91.43%)	267 (94.35%)	0.472	0.492
Yes	3 (8.57%)	16 (5.65%)		
Neoadjuvant therapy				
No	34 (97.14%)	262 (92.58%)	1.007	0.316
Yes	1 (2.86%)	21 (7.42%)		
History of cerebral infarction			0.019	0.891
No	34 (97.14%)	276 (97.53%)		
Yes	1 (2.86%)	7 (2.47%)		
COPD				
No	34 (97.14%)	282 (99.65%)	3.124	0.077
Yes	1 (2.86%)	1 (0.35%)		
Pulmonary bulla				
No	32 (91.43%)	213 (75.27%)	4.601	0.032
Yes	3 (8.57%)	70 (24.73%)		
Tumor Location			8.073	0.045
Upper thoracic	2 (5.71%)	15 (5.3%)		
Middle thorax	16 (45.71%)	115 (40.64%)		
Lower thoracic	5 (14.29%)	100 (35.34%)		
Overlap	12 (34.29%)	53 (18.73%)		
Histological type			0.011	0.918
Adenocarcinoma	34 (97.14%)	274 (96.82%)		
Squamous cell carcinoma	1 (2.86%)	9 (3.18%)		
Clinical staging			2.532	0.282
I	4 (11.43%)	65 (22.97%)		
II	21 (60%)	142 (50.18%)		
III	10 (28.57%)	76 (26.86%)		

T staging			5.834	0.120
T1	3 (8.57%)	37 (13.07%)		
T2	7 (20%)	79 (27.92%)		
T3	23 (65.71%)	164 (57.95%)		
T4	2 (5.71%)	3 (1.06%)		
N staging			2.579	0.461
N0	21 (60%)	150 (53%)		
N1	11 (31.43%)	80 (28.27%)		
N2	2 (5.71%)	45 (15.9%)		
N3	1 (2.86%)	8 (2.83%)		
Differentiation grade			4.315	0.365
Unknown	9 (25.71%)	55 (19.43%)		
Undetermined	18 (51.43%)	138 (48.76%)		
Poorly differentiate	0 (0%)	28 (9.89%)		
Moderately differentiated	1 (2.86%)	5 (1.77%)		
Well differentiated	7 (20%)	57 (20.14%)		
Surgical approach			0.739	0.390
Open esophagectomy	28 (80%)	242 (85.51%)		
Minimally invasive	7 (20%)	41 (14.49%)		
Anastomotic methods			4.639	0.031
Conventional approach	29 (82.86%)	183 (64.66%)		
A new oblique-to-side esophagogastric anastomosis approach	6 (17.14%)	100 (35.34%)		
Number of lymph node dissected	5 [2, 12]	9 [5, 13]	-2.083	0.037
Operation time (min)	246.11±80.21	209.33±67.52	2.976	0.003
Post-operative nutritional support			13.253	0.001
Total intravenous nutrition	23 (65.71%)	222 (78.45%)		
Intravenous + jejunal nutrition	9 (25.71%)	59 (20.85%)		
Intravenous + nasal-enteral tube nutrition	3 (8.57%)	2 (0.70%)		

COPD: chronic obstructive pulmonary disease.

astomotic methods, number of lymph node dissected, operation time, and postoperative nutritional support, were included in the multivariate logistic regression analysis. The variable assignment scheme is shown in **Table 5**.

Test for variable multicollinearity showed that the variance inflation factor (VIF) for each variable was less than 2, indicating no multicollinearity among predictors and confirming that the regression model met the statistical assumptions. The regression analysis identified anastomotic methods (new oblique-to-side esophagogastric anastomosis) as an independent protective factor against anastomotic leakage (OR=0.294, *P*=0.020), as shown in **Table 6**.

Discussion

Currently, there is no universally accepted consensus on the optimal approach for esophagogastric anastomosis [17]. Several meta-analyses have reported similar outcomes between hand-sewn (HS) and stapled anastomotic techniques. In a network meta-analysis, Kamarajah et al. [18] compared HS, circular stapled (CS), linear stapled (LS), and triangular stapled (TS) anastomoses, demonstrating the superiority of LS techniques in reducing the incidence of anastomotic leakage and stricture following esophagectomy for esophageal cancer. However, substantial variability persists among institutions and surgeons regarding anastomotic techniques.

Between 2018 and 2021, our center accumulated clinical experience with this new oblique-to-side esophagogastric anastomosis technique. The incidence of anastomotic leakage was significantly lower in the new anastomosis group compared to the conventional anastomosis group (6.7% vs. 13.7%). After PSM, this dif-

Table 5. Variable assignment table

Variables	Assignment
Pulmonary bulla	No =0; Yes =1
Tumor Location	Upper thoracic =1; Middle thorax =2; Lower thoracic =3; Overlap =4
Anastomotic methods	Conventional approach =0; A new oblique-to-side esophagogastric anastomosis approach =1
Number of lymph node	original value
Operation time (min)	original value
Post-operative nutritional support	Total intravenous nutrition =1; Intravenous + jejunal nutrition =2; Intravenous + nasal-enteral tube nutrition =3

Table 6. Multivariate logistic regression analysis of factors independently associated with anastomotic leakage

Variables	β	S.E.	Wald	P	OR	95% CI-L	95% CI-H
Pulmonary bulla	-1.282	0.632	4.121	0.042	0.277	0.080	0.957
Tumor Location	0.050	0.216	0.052	0.819	1.051	0.688	1.606
Anastomotic methods	-1.223	0.526	5.397	0.020	0.294	0.105	0.826
Number of lymph node	-0.026	0.034	0.589	0.443	0.974	0.910	1.042
Operation time (min)	0.007	0.002	8.881	0.003	1.007	1.002	1.012
Post-operative nutritional support	0.448	0.364	1.519	0.218	1.565	0.768	3.191
Constant	-3.732	0.984	14.372	1	0.000	0.024	

ference remained significant (6.4% vs. 22.3%). Additionally, the incidence of fever was lower in the new anastomosis group than in the conventional anastomosis group, whereas other complications, including pulmonary, cardiac, and gastrointestinal events, did not show significant differences between the two groups.

Over the past four years, 106 patients underwent esophagectomy using the new anastomosis method. Among them, 6 patients (5.7%) developed postoperative anastomotic leakage, including 2 cases of tubular gastric leakage unrelated to the anastomosis. This incidence was lower than the previously reported incidence of 5% to 30% [5, 6]. Notably, in 2019, none of the 42 patients treated with the new technique experienced anastomotic leakage. In contrast, 29 out of the 212 patients (13.7%) who received conventional end-to-side anastomosis developed leakage, including 3 cases of tubular gastric leakage. Consistent with these findings, statistical analysis after PSM confirmed that the incidence of anastomotic leakage was significantly lower in the new anastomosis group compared with the conventional anastomosis group.

We investigated the causes of anastomotic leakage following surgeries performed using a circular stapler and found that most leakage sites were at the posterior wall of the anastomosis. We hypothesize that this phenomenon may be attributed to the uneven tension distribution around the anastomotic ring, a mechanical consequence of the end-to-side configuration. Theoretically, in the traditional end (esophageal)-to-side (gastric) anastomosis, the distal tubular stomach is influenced by gravity, resulting in asymmetric peri-anastomotic tension. Previous studies have shown that surgical wounds are most susceptible to delayed healing or leakage at regions of maximal tension [19]. Therefore, we infer that the posterior wall experiences the mechanical stress following after end-to-side anastomosis, predisposing it to leakage. Uneven tension around the anastomosis thus represents a principal cause of anastomotic leakage in circular-stapled end-to-side anastomosis [20]. In contrast, the new

Figure 3. CT images of the postoperative anastomosis site. A. Oblique-to-side anastomosis. B. Conventional anastomosis.

oblique-to-side anastomosis showed no difference in leakage rates among different anastomotic sites, suggesting that this configuration may redistribute and balance tension circumferentially, thereby reducing leakage risk.

To validate this hypothesis, we measured circumferential anastomotic tension experimentally at various anastomotic plane angles - 90°, 60°, 45°, and 30° (see Table S1). The results demonstrated that at 90°, the posterior wall exhibited maximum tension and the anterior wall showed minimal tension, creating the greatest tension disparity. As the anastomotic plane angle decreased, this difference progressively diminished and approached zero at ≤45°, particularly at 30°. These experimental findings confirm that when the anastomosis plane is inclined ≤45°, circumferential tension across the anastomotic site becomes balanced.

Regarding other postoperative complications, including anastomotic stricture, incision infection, gastroesophageal reflux, pulmonary complications, and cardiac complications, no significant differences were observed between the two groups. However, the incidence of fever (>38°C) was lower in the new anastomosis group than the conventional anastomosis group (10.6% vs. 27.7%). After analyzing the post-PSM data within each anastomosis group, we found that among patients with the new anastomosis, 3 of 6 (50%) who developed leakage had fever, accounting for 30% of all 10 fever cases in this group, which was lower than that in the conventional anastomosis approach group (11 of the 21 patients with anastomotic leak had fever, accounting for 42.3% of the 26 fever patients in this group). These findings suggest a potential association between postoperative fever and anastomotic leakage. Leakage allows digestive fluid to enter the mediastinum or thoracic cavity, potentially causing mediastinal or pulmonary infection, which manifests clinically as fever. In this study, all patients with fever underwent postoperative chest CT re-examination (**Figure 3**) to differentiate between mediastinal infection secondary to anastomotic leakage and isolated pulmonary infection. Therefore, the possibility of an anastomotic leakage should always be considered in postoperative patients who develop unexplained fever [21]. Since May 2019, minimally invasive esophagectomy (MIE) has been increasingly adopted in our center and has gradually become the predominant surgical approach. Interestingly, all six patients in the new anastomosis group who developed anastomotic leakage underwent thoracoscopic surgery. Although this might suggest that MIE is more likely to result in anastomotic leakage than open surgery, this observation contradicts previous reports, which have shown either lower or comparable leakage rates between MIE and open procedures [22-25]. A possible explanation is that MIE is technically more demanding, as thoracoscopic operations limit direct visualization of the surgical field, increase procedural complexity, and require a high level of technical proficiency [26]. In addition, the number of patients undergoing MIE using the conventional anastomosis was relatively small, which may limit the statistical reliability of this finding. Therefore, large-scale prospective clinical studies are warranted to further clarify the relationship between the surgical approach and the risk of anastomotic leakage.

Besides, there were no significant differences between the two groups in terms of ICU stay >3 days, mechanical ventilation >48 hours, reintubation rate, or reoperation rate, suggesting that the new anastomosis method did not increase the risk of postoperative adverse events compared with the conventional end-to-side anastomosis.

In order to further verify the impact of the new anastomosis method on postoperative leakage, we conducted a binary logistic regression analysis to identify the independent predictors of anastomotic leakage in patients undergoing esophagectomy for EC. The results of multivariate logistic regression analysis showed that the anastomotic method (oblique-to-side esophagogastric anastomosis) was a protective factor against anastomotic leakage.

However, this study has several limitations. The sample size was relatively small, and the single-center, retrospective design may limit the generalizability of the findings. Therefore, to further verify the safety and efficacy of this novel anastomosis method. Future multicenter, large-scale randomized controlled trials are warranted. Additionally, due to the retrospective nature of data collection, preoperative laboratory parameters such as albumin levels were not available, preventing a comprehensive assessment of patients' nutritional status and risk of postoperative complication. Future research should incorporate more comprehensive preoperative laboratory data and nutritional data to achieve a more accurate evaluation of patients' preoperative conditions and prognosis.

Conclusions

New oblique-to-side esophagogastric anastomosis effectively reduces the incidence of anastomotic leakage after radical esophagectomy. Moreover, the procedure is technically feasible, does not increase surgical complexity, and shows potential for broader clinical application as a safe and practical alternative to conventional end-to-side anastomosis.

Acknowledgements

The authors are extremely grateful to the patients who participated in this study. This study was partly funded by the Development and Application of Medical and Health Appropriate Technology of Guangxi (Grant No. S2020032), and Guangxi Key Clinical Specialty Construction Project, and Guangxi Medical and Health Key Discipline Construction Project.

Disclosure of conflict of interest

None.

Abbreviations

PSM, Propensity score-matched; EC, Esophageal carcinoma; ARDS, Acute respiratory distress syndrome; COPD, Chronic obstructive pulmonary disease; BMI, Body mass index; SD, Standard deviation.

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Table S1. Tension of different plane anastomosis

Direction	90° (Traditional anastomosis method)	60°	45°	30°
Anterior wall (purple line)	65.30	67.00	70.88	70.40
Posterior wall (red line)	79.60	74.00	71.18	70.50
Left wall (blue line)	71.06	69.00	71.26	70.90
Right wall (yellow line)	71.10	69.00	70.80	70.40
Total	287.06	279.00	284.12	282.20