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ORIGINAL ARTICLE

Wider Gastric Conduit Morphology Is Associated with Improved Blood Flow During Esophagectomy

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Abstract

Background It remains unclear what is the ideal conduit shape. The aim of this study was to evaluate association between specific gastric conduit morphology, considering width and length, with its perfusion and the incidence of anastomotic leaks after esophagectomy.

Methods Patients who underwent an esophagectomy with cervical esophagogastric anastomosis between 2015 and 2021 were evaluated. Indocyanine green angiography was performed to evaluate gastric conduit perfusion, and ingress index (arterial inflow) and ingress time (venous outflow) were measured. The conduit width at the middle of the conduit and the short gastric length as the length from the last gastroepiploic branch to the perfusion assessment point were measured. Propensity score matching was performed to compare wide conduits with narrow conduits. Narrow and wide conduits were defined as <4 and ≥ 5 cm, respectively.

Results Three hundred fifty-eight patients were reviewed. After applying matching, the wide conduits had higher ingress index (48.2 vs 33.3%, $p<0.001$) and shorter ingress time (51.2 vs 66.3 s, $p=0.004$) compared to the narrow conduits. Including the short gastric length in analysis, creating a wide conduit is a significant factor for better ingress index ($p=0.001$), especially when the perfusion assessment point is 5 cm or farther from the last gastroepiploic branch. Anastomotic leaks did not differ between the groups.

Conclusions Conduit width is a significant factor of gastric conduit perfusion, especially when the estimated anastomotic site was >5 cm from the last gastroepiploic branch. Wide conduits seem to have better perfusion and creating a wider conduit might reduce anastomotic leaks.

Keywords Esophagectomy · Gastric conduit · Perfusion · Anastomotic leak · Indocyanine green

Introduction

Esophagectomy with gastric conduit reconstruction is the most common surgery for esophageal cancer. There are many ways to shape the gastric conduit during an esophagectomy; however, it is unclear what is the ideal shape for the gastric conduit. The creation of narrower gastric conduits allows for longer distal margins as well as longer conduits when following the greater curvature of the stomach. In a meta-analysis study, leak rates did not significantly differ between whole-stomach conduits and narrower gastric tube conduits.[1] Wide conduits are reported to have better perfusion than narrow conduits because the vascular plexus in the stomach wall is preserved.[2] On the other hand, narrow conduits have sufficient length to perform an anastomosis in the neck.[3] There is limited knowledge of what shape has the best perfusion when evaluating gastric conduit perfusion quantitatively.

Indocyanine green (ICG) fluorescence angiography allows for the analysis of arterial inflow and venous outflow to measure the perfusion of the conduit, which if impaired

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can lead to higher leak rates after surgery. The length from the blood supply is an important factor of gastric conduit perfusion at the tip of the conduit, as perfusion greatly depends on the distance from the last gastroepiploic branch on the greater curvature.

The aim of this study was to evaluate association between specific gastric conduit morphology, considering width and length, with its perfusion and the incidence of anastomotic leaks after esophagectomy. We hypothesized that wider conduits would have better perfusion and a lower leak rate than narrow conduits.

Method

Ethical Statements.

All procedures were performed with the approval of the Ethics Committee of the University of Michigan Hospital and in accordance with the Helsinki Declaration of 1964 and its later versions. Informed consent was obtained from all patients before inclusion in the study. The study has been approved through our Institutional Review Board (ID: HUM 00,012,731).

Patients

Patient data for those who received an esophagectomy and gastric conduit reconstruction between July 2015 and December 2021 at a single, high-volume, quaternary hospital was evaluated. Inclusion criteria were all patients with cervical esophagogastric anastomosis (CEGA) after an open or minimally invasive transhiatal or McKeown esophagectomy and who underwent ICG fluorescence angiography using the SPY Elite system (Stryker, Kalamazoo, MI, USA) during the operation. Gastric ischemic preconditioning,[4] when undertaken, was completed 4–6 weeks prior to definitive surgery, or prior to neoadjuvant therapy. Patients were excluded from analysis if (a) ICG fluorescence angiography had not been performed properly, (b) non-gastric conduit was utilized, and (c) if patients underwent Ivor Lewis esophagectomy. Six surgeons performed the procedures, each having performed at least 50 esophagectomies prior to the study period.

Esophagectomy

Patients underwent a transhiatal or McKeown esophagectomy including utilizing open, laparoscopic, thoracoscopic, and robot-assisted approaches. A gastric conduit was created extracorporeally with multiple applications of the Endo GIA 60 mm (Covidien, MA, USA), and the staple suture line was oversewn. The width of the conduit was determined by a surgeon's preference. The conduit was then evaluated using the SPY Elite system (Stryker, MI, USA) with the conduit placed laid flat outside the abdomen. A concomitant pyloromyotomy was performed in almost all (98%) cases. The gastric conduit was advanced through the posterior mediastinal route and CEGA was performed by an end-to-side partially stapled anastomosis technique with the Endo GIA 30 mm. A jejunostomy tube was routinely placed during operation for postoperative enteral feeding. A nasogastric tube was also routinely placed during operation and discontinued on postoperative day 3 or later depending on the volume of drained fluid.

Quantitative Assessment of Gastric Conduit Perfusion

We have previously reported the feasibility of ICG fluorescence angiography to predict postoperative anastomotic leaks.[5] Briefly, after creating a gastric conduit, ICG fluorescence angiography was performed and recorded using the SPY Elite system to evaluate gastric conduit perfusion. We adjusted and standardized the distance and angle of the camera to the gastric conduit using the function of the SPY Elite system in all cases. Five milligrams (2 ml of solution) of ICG followed by 10-ml saline push was administered to the patient and the fluorescence video was recorded for 2 min. Quantitative perfusion was assessed at 5 cm from the tip of the conduit, which is considered an estimated anastomotic site (Fig. 1). As a target region on the conduit is set, the fluorescence curve at that point is automatically drawn and

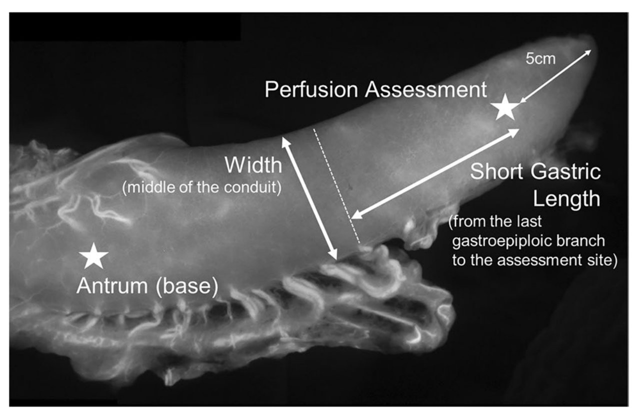

Fig. 1 Image of measurement of gastric conduit. We use the fluorescence at the antrum as the gold standard for perfusion. Perfusion assessment point, where the anastomosis is likely to be made, is 5 cm from the tip of the conduit. The fluorescence at the perfusion assessment point is measured relative to the antrum. The "short gastric length" is defined as the distance from the last gastroepiploic branch to the perfusion assessment point

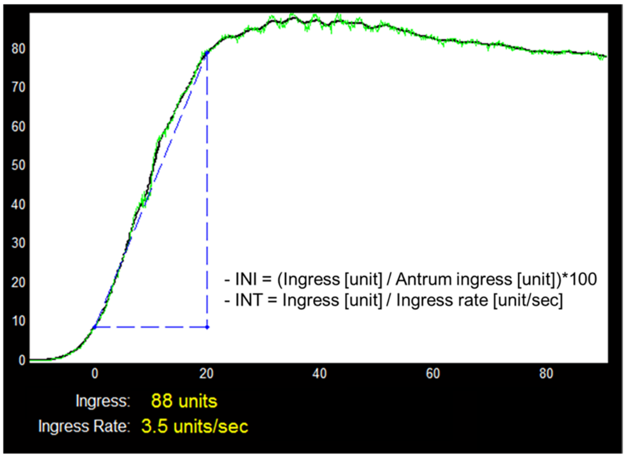

Fig. 2 Quantitative assessment of gastric conduit perfusion. The SPY Elite © system generates the perfusion images, but also this graph in real time. An ingress triangle is automatically drawn based on the "inflow" of ICG dye and then values are provided as a target region is set

values are provided. To standardize these values, ingress index (INI, arterial inflow) and ingress time (INT, venous outflow) were calculated by determining the percentage of ingress value relative to that at the antrum and the estimated time to reach the peak of the ingress curve, respectively (Fig. 2). Conduit dimensions, width and length, were measured as well: with conduit width defined at the middle of the conduit, and short gastric length as length from the last gastroepiploic branch to the perfusion assessment point.

Data Items

Analyzed variables were patient demographics and characteristics, perfusion study data, and operative factors. Patient demographics included age, sex, body mass index (BMI), diabetes mellitus, chronic heart failure, artery diseases (coronary artery disease, cerebrovascular disease, major vascular disease, and peripheral artery disease), Eastern Cooperative Oncology Group performance status, and smoking history. Patient characteristics included histology, neoadjuvant chemoradiation therapy, and gastric ischemic preconditioning. Perfusion study data included conduit width and short gastric length, INI, and INT. Operative factors included surgical approach (transhiatal or McKeown, minimally invasive including laparoscopy and thoracoscopy, and robot-assisted), concomitant pyloromyotomy, postoperative nasogastric tube placement, operation time, postoperative anastomotic leaks, strictures, delayed conduit emptying, and pathological TNM classification according to the 8th edition of the American Joint Committee on Cancer TNM Classification.[6] Anastomotic leaks were diagnosed clinically and by endoscopy or barium fluoroscopy and classified according to the definition stated by the Esophagectomy Complications Consensus Group.[7] Anastomotic stricture was diagnosed by endoscopy or fluoroscopy. Delayed conduit emptying was diagnosed when a surgical or endoscopic intervention was required.

Statistical Analysis

All data were presented as mean (range) or frequency (%). We used the Fisher exact test (and the Bonferroni correction for multiple comparisons) to compare categorical variables and the Mann–Whitney *U* test to compare continuous/ordinal variables. Multiple linear regression analysis was used to compare effects of variables on INI and INT. Perfusion pattern was grouped according to ICG fluorescence angiography: good inflow and outflow, good inflow/poor outflow, poor inflow/good outflow, and poor inflow and outflow. Poor inflow and outflow were defined as below the cutoff values of INI and INT, respectively, from each ROC curve. Patients were classified into three groups according to conduit width: narrow conduit (middle of the conduit <4 cm), medium conduit (≥ 4 cm, <5 cm), and wide conduit (≥ 5 cm). We compared the leak group with the no-leak group, and the wide conduit group with the narrow conduit group. When comparing the narrow with wide conduit groups, propensity score matching was performed to overcome the bias caused by the difference of patient demographics and characteristics. All variables observed before creating a gastric conduit were included in the regression model to estimate propensity scores: age, sex, BMI, diabetes, chronic heart failure, artery disease, performance status, smoking, chemoradiation therapy, ischemic preconditioning, and surgical procedure. A matching ratio was 1:1 and nearest neighbor method was used (within $0.25 \times$ standard deviation). The differences were considered significant at $p < 0.05$. Statistical analyses were performed using R version 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria). R markdown for all analyses is available upon request.

Results

Three hundred and fifty-eight patients who underwent an esophagectomy over the study period were evaluated, with 85 patients having developed anastomotic leaks (23.7%). The mean patient age was 65.9 years in the leak group and 64.6 in the no-leak group. There were no significant differences in patient demographics and procedures between the leak and no-leak groups (Table 1). The incidence of anastomotic stricture in the leak group was significantly higher than that in the no-leak group (47.1 vs 14.7%, $p < 0.001$). The short gastric length was longer in the leak group than the no-leak group (7.8 vs 7.1 cm, $p = 0.037$). INI was lower (36.3 vs 46.1%, $p = 0.002$) and INT was longer in the leak

Table 1 Patient characteristics and operative outcomes in the leak and no-leak groups

	Leak ($n = 85$)		No leak ($n = 273$)		p
Age (year)	65.9	(36–83)	64.6	(21–95)	0.119
Sex (male)	69	(81.2)	216	(79.1)	0.759
BMI (kg/m^2)	28.4	(16.8–46.2)	28.0	(16.2–51.2)	0.317
Diabetes (medication)	16	(18.8)	41	(15.0)	0.400
Chronic heart failure	3	(3.5)	5	(1.8)	0.401
Artery disease [a]	21	(24.7)	48	(17.6)	0.158
PS ≥ 2	2	(2.4)	7	(2.6)	1.000
Current smoking	4	(4.7)	22	(8.1)	0.350
Histology					0.221
Adenocarcinoma	76	(89.4)	228	(83.5)	
SCC	8	(9.4)	25	(9.2)	
Other malignancy	0	(0.0)	2	(0.7)	
Benign	1	(1.2)	18	(6.6)	
Neoadjuvant CRT	64	(75.3)	197	(72.2)	0.675
Ischemic preconditioning	1	(1.2)	10	(3.7)	0.470
Procedure					1.000
Transhiatal	75	(88.2)	239	(87.5)	
McKeown	10	(11.8)	34	(12.5)	
Minimally invasive					0.767
No	33	(38.8)	118	(43.2)	
Yes, without robot	11	(12.9)	35	(12.8)	
Yes, robot-assisted	41	(48.2)	120	(44.0)	
Pyloromyotomy	**84**	**(98.8)**	**267**	**(97.8)**	**1.000**
Postoperative nasogastric tube	**85**	**(100.0)**	**273**	**(100.0)**	**1.000**
Operation time (min)	387	(243–638)	377	(203–801)	0.285
Pathological stage [b]					0.690
O, I, II	58	(69.0)	169	(66.3)	
III, IV	26	(31.0)	86	(33.7)	
Conduit width [c] (cm)	4.3	(2.9–6.2)	4.6	(2.9–7.6)	0.120
Short gastric length [d] (cm)	7.8	(0.0–15.4)	7.1	(−0.8 to 17.5)	0.037*
Perfusion variables					
Ingress index (%)	36.3	(0.8–94.3)	46.1	(0.4–99.1)	0.002**
Ingress time (s)	69.3	(9.6–155)	56.5	(7.5–160)	0.002**
Anastomotic stricture	**40**	**(47.1)**	**40**	**(14.7)**	**< 0.001*** **
Delayed conduit emptying	**2**	**(2.4)**	**3**	**(1.1)**	**0.341**

Data were presented as mean (range) or frequency (%)

[a]Coronary artery disease, cerebrovascular disease, major vascular disease, and peripheral vascular disease; [b]excluding benign diseases; [c]width at the middle of the conduit; [d]length from the last gastroepiploic branch to the perfusion assessment point (5 cm from the tip)

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

BMI, body mass index; *CRT*, chemoradiation therapy; *PS*, performance status; *SCC*, squamous cell carcinoma

Table 2 Incidence of anastomotic leak in each perfusion pattern

	Leak rate	
Good in & out flow	*7.5%	(5/67)
Good inflow, poor outflow	21.1%	(4/19)
Poor inflow, good outflow	17.7%	(11/62)
Poor in & out flow	*31.0%	(65/210)

Good inflow: ingress index ≥ 63.5; poor inflow: ingress index < 63.5

Good outflow: ingress time ≤ 37.5; poor outflow: ingress time > 37.5

*$p < 0.001$ with Bonferroni correction between "good in & out flow" and "poor in & out flow"

group (69.3 vs 56.5 s, $p = 0.002$). The conduit width did not significantly differ between the groups. Threshold values of INI and INT were obtained from the ROC curves, which were 63.5% (area under the curve = 0.610) and 37.5 s (0.610), respectively. Incidence of anastomotic leak for each perfusion pattern is shown in Table 2. The leak rate in the good inflow and outflow group was significantly lower than that in the poor inflow and outflow group with the Bonferroni correction (7.5 vs 31.0%, $p < 0.001$).

On multiple linear regression analysis for estimation of INI, older age and lower BMI were risk factors of lower ingress index, and gastric ischemic preconditioning was a factor significantly associated with better perfusion. Wider conduit and smaller distance from the last gastroepiploic branch were better for the gastric conduit perfusion (Table 3). Patients were divided into three groups (narrow, medium, and wide conduit groups) and patient characteristics in each group were obtained (Table 4). The relationship between conduit shape and perfusion pattern is shown in Fig. 3. After applying propensity score matching, 78 patients each from the narrow conduit group and the wide conduit group were selected (Table 5). There was no significant difference in the matching variables. All of the perfusion data (INI, INT, and perfusion pattern) were significantly better in the matched wide conduit group ($p < 0.001$, 0.004, and < 0.001, respectively). The short gastric length was longer in the matched narrow conduit group compared to the matched wide conduit group (8.1 vs 6.5 cm, $p = 0.005$). Anastomotic leaks, its severity, strictures, and delayed conduit emptying did not differ between the two matched groups. Since the short gastric length in the matched narrow conduit group was longer, multiple linear regression analysis including the short gastric length and "wide conduit" was performed to remove the effect of the short gastric length. This revealed that "wide conduit" was an independent factor for better INI considering the short gastric length ($p = 0.001$, Table 6), especially when the perfusion assessment point is 5 cm or more farther from the last gastroepiploic branch, which is visualized in Fig. 4. On the other hand, "wide conduit" was not a significant factor for better INT ($p = 0.054$).

Discussion

Esophagectomy and reconstruction is one of the most challenging procedures in gastrointestinal surgery and is still associated with high morbidity and mortality compared to other

Table 3 Multiple linear regression analysis for estimation of ingress index

	Coefficient	SE	*t*	*p*
(Intercept)	44.665	12.971	3.443	< 0.001***
Age (year)	− 0.354	0.117	− 3.024	0.003**
Sex (female)	3.300	2.955	1.117	0.265
BMI (kg/m^2)	0.570	0.199	2.869	0.004**
Diabetes (medication)	0.147	3.160	0.047	0.963
Chronic heart failure	− 3.948	8.070	− 0.489	0.625
Artery disease [a]	− 5.127	2.845	− 1.802	0.072
PS ≥ 2	− 7.990	7.500	− 1.065	0.287
Current smoking	− 7.701	4.482	− 1.718	0.087
Neoadjuvant CRT	− 0.856	2.639	− 0.334	0.746
Ischemic Preconditioning	25.95	6.814	3.808	< 0.001***
Conduit width [b] (cm)	5.885	1.330	4.423	< 0.001***
Short gastric length [c] (cm)	− 2.598	0.394	− 6.589	< 0.001***
Operation time	− 0.001	0.012	− 0.060	0.952

[a]Coronary artery disease, cerebrovascular disease, major vascular disease, and peripheral vascular disease; [b]width at the middle of the conduit; [c]length from the last gastroepiploic branch to the perfusion assessment point (5 cm from the tip)

BMI, body mass index; *CRT*, chemoradiation therapy; *PS*, performance status; *SE*, standard error

**$p < 0.01$, ***$p < 0.001$

Table 4 Patient characteristics and operative outcomes in each conduit shape

	Narrow ($n = 106$)		Medium ($n = 137$)		Wide ($n = 115$)	
Age (year)	67.7	(28–95)	64.5	(21–90)	62.8	(36–86)
Sex (male)	81	(76.4)	109	(79.6)	95	(82.6)
BMI (kg/m^2)	27.2	(17.9–46.2)	28.2	(16.2–51.2)	28.6	(17.8–50.4)
Diabetes (medication)	16	(15.1)	26	(19.0)	15	(13.0)
Chronic heart failure	5	(4.7)	2	(1.5)	1	(0.9)
Artery disease [a]	25	(23.6)	32	(23.4)	26	(22.6)
PS ≥ 2	1	(0.9)	5	(3.6)	3	(2.6)
Current smoking	4	(3.8)	12	(8.8)	10	(8.7)
Neoadjuvant CRT	79	(74.5)	97	(70.8)	85	(73.9)
Ischemic preconditioning	10	(9.4)	1	(0.7)	0	(0.0)
Procedure						
Transhiatal	90	(84.9)	116	(84.7)	108	(93.9)
McKeown	16	(15.1)	21	(15.3)	7	(6.1)
Robot-assisted	60	(56.6)	57	(41.6)	44	(38.3)
Pyloromyotomy	**102**	**(96.2)**	**136**	**(99.3)**	**113**	**(98.3)**
Nasogastric tube	**106**	**(100.0)**	**137**	**(100.0)**	**115**	**(100.0)**
Short gastric length [b] (cm)	7.9	(−0.8 to 17.5)	7.4	(−0.1 to 15.4)	6.7	(0.2–14.6)
Perfusion variables						
Ingress index (%)	36.2	(1.3–95.1)	44.1	(0.4–98.5)	50.5	(2.2–99.1)
Ingress time (sec)	61.5	(9.1–140)	63.8	(7.5–160)	52.8	(9.6–160)
Perfusion pattern						
Good in & out flow	14	(13.2)	23	(16.8)	30	(26.1)
Good inflow, poor outflow	2	(1.9)	9	(6.6)	8	(7.0)
Poor inflow, good outflow	16	(15.1)	19	(13.9)	27	(23.5)
Poor in & out flow	74	(69.8)	86	(62.8)	50	(43.5)
Anastomotic leak	29	(27.4)	34	(24.8)	22	(19.1)
Mild	3	(2.8)	4	(2.9)	1	(0.9)
Moderate	14	(13.2)	19	(13.9)	10	(8.7)
Severe	12	(11.3)	11	(8.0)	11	(9.6)
Anastomotic stricture	28	(26.4)	25	(18.2)	27	(23.5)
Delayed conduit emptying	**0**	**(0.0)**	**1**	**(0.7)**	**4**	**(3.5)**

Data were presented as mean (range) or frequency (%)

[a]Coronary artery disease, cerebrovascular disease, major vascular disease, and peripheral vascular disease; [b]length from the last gastroepiploic branch to the perfusion assessment point (5 cm from the tip)

BMI, body mass index; *CRT*, chemoradiation therapy; *PS*, performance status

surgeries.[8] An anastomotic leak is one of the most important complications following esophagectomy and leads to disability, prolonged hospitalization, increased costs, and higher mortality. Impaired conduit perfusion is a known risk factor of esophagogastric anastomotic leaks after esophagectomy.[9] Gastric conduit perfusion has been studied and assessed quantitatively recently with several methods including ICG fluorescence angiography,[4,10,11] tissue oxygen measurement,[12,13] and thermal imaging.[14] However, there are limited data on the relationship between conduit shapes and perfusion.

We addressed an important topic in identifying the ideal gastric conduit shape in terms of its perfusion. Conduit preparation is widely influenced by surgeon judgement, and it remains unclear whether conduit width is a significant confounding factor associated with anastomotic complications. We assessed conduit perfusion quantitatively with ICG fluorescence angiography and grouped patients into three groups according to the width of the conduit and showed that wide conduits have better perfusion than narrow conduits. It is generally felt that the gastric conduit perfusion greatly depends on its length, and it has been reported that poorer perfusion was detected at more peripheral assessment point of the gastric conduit.[15,16] Although wide conduits had higher ingress index and shorter ingress time in our study (Table 4 and Fig. 3),

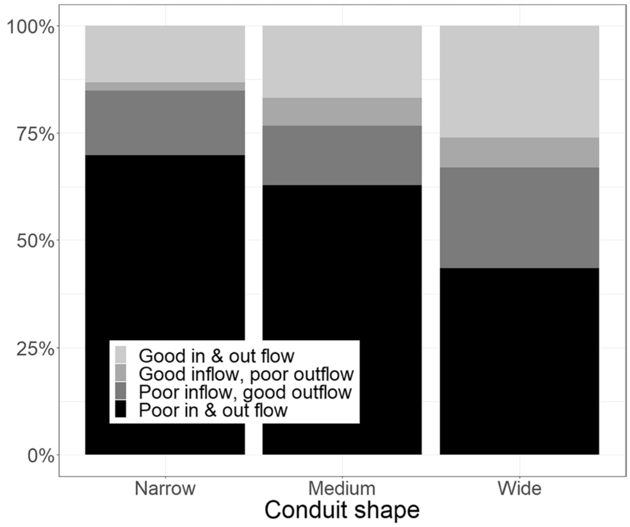

Fig. 3 Conduit shape and perfusion pattern. Conduits were divided into 3 patterns based on the width of the conduit in the middle. Narrow is < 4 cm, Medium is ≥ 4 cm and < 5 cm, while Wide is ≥ 5 cm. Wide conduits had a better conduit perfusion pattern than the other conduits with fewer subjects with poor in and outflow

these results were obtained without considering conduit length. Therefore, we measured the short gastric length in all the patients, which is a length from the last gastroepiploic branch to the perfusion assessment point (5 cm from the tip). Including short gastric length in multiple linear regression analysis, we removed the effect of length on perfusion and concluded that creating a wide conduit is an independent factor of improved conduit perfusion (Table 6 and Fig. 4). We also showed that the width of the conduit does not matter when the perfusion assessment point is within 5 cm from the last gastroepiploic branch, and that only ingress index depends on the width. Given these results, we propose that a wide conduit be created when the estimated anastomotic site is 5 cm or farther from the last gastroepiploic branch. Our study revealed that wide conduits have better perfusion than narrow conduits, but also revealed that the perfusion is also impacted by the distance from the last gastroepiploic branch.

While some previous studies concluded that wide conduits are superior as they have better perfusion and lower leak rates,[2,17] other studies have concluded that narrow conduits are superior as they have adequate length to perform a cervical anastomosis with lower incidence of bile acid reflux.[3,18,19] A novel conduit shape has been studied, which is narrow at antrum but is wide at the tip of the conduit to exploit the advantages of the narrow gastric tube and the subtotal gastric tube.[20,21] It also has been reported that the width of a gastric conduit has no impact on tissue blood flow and leak rates.[22] One of the drawbacks of wide conduits is delayed conduit emptying. We routinely perform a concomitant pyloromyotomy and place a nasogastric tube during esophagectomy to reduce delayed conduit emptying. Wide conduits had a higher rate of emptying than narrow conduit, although there was no significance probably due to a small number of cases.

This study has several limitations. First, the perfusion assessment was performed at 5 cm from the tip of the conduit, which might not be an exact anastomotic site. This could lead to inconsistent relationship between gastric conduit perfusion and anastomotic leaks. Additionally, the perfusion can be affected by other unlisted factors, such as blood loss, volume status, and blood pressure during perfusion assessment. The perfusion can also be impacted by being pulled up through the posterior mediastinal route. Since we have not established perfusion assessment in the neck, this could also be a limitation. Second, the total conduit length was not measured, although enough length to perform CEGA is an advantage of narrow conduits. Finally, this was a single-center study and, therefore, the study results may have lower external validity. Future prospective studies could mark the area of anastomosis and measure total conduit length.

Conclusions

Conduit width is a significant factor contributing to gastric conduit perfusion, especially when the estimated anastomotic site occurs > 5 cm from the last gastroepiploic branch. Wide conduits seem to have better inflow and outflow patterns and creating wider conduits might reduce anastomotic leaks. However, the relationships between conduit shape, conduit perfusion, and anastomotic leaks are not straight forward. More cases will be needed to determine the ideal conduit shape.

Author Contribution • Yoshitaka Ishikawa: conceptualization, methodology, investigation, formal analysis, resources, data curation, visualization, writing—original draft, writing—review and editing.

• Andrew C. Chang: methodology, investigation, data curation, writing—review and editing.

• Jules Lin: methodology, investigation, data curation, writing—review and editing.

• Mark B. Orringer: methodology, investigation, data curation, writing—review and editing.

• William R. Lynch: methodology, investigation, data curation, writing—review and editing.

• Kiran H. Lagisetty: investigation, resources, writing—review and editing.

• Elliot Wakeam: investigation, resources, writing—review and editing.

• Rishindra M. Reddy: conceptualization, methodology, investigation, supervision, writing—review and editing.

• All authors gave final approval of the submitted manuscript to be published.

Table 5 Comparison of the matched narrow and wide conduits

	Propensity score-matched				
	Narrow ($n=78$)		Wide ($n=78$)		p
Matching variables					
Age (year)	**66.4**	**(41–86)**	**65.9**	**(47–86)**	**0.613**
Sex (male)	**61**	**(78.2)**	**62**	**(79.5)**	**1.000**
BMI (kg/m^2)	**27.3**	**(17.9–46.2)**	**27.8**	**(17.8–49.5)**	**0.871**
Diabetes (medication)	**12**	**(15.4)**	**12**	**(15.4)**	**1.000**
Chronic heart failure	**1**	**(1.3)**	**1**	**(1.3)**	**1.000**
Artery disease [a]	**17**	**(21.8)**	**15**	**(19.2)**	**0.843**
PS ≥ 2	**0**	**(0.0)**	**0**	**(0.0)**	**1.000**
Current smoking	**3**	**(3.8)**	**3**	**(3.8)**	**1.000**
Neoadjuvant CRT	**58**	**(74.4)**	**57**	**(73.1)**	**1.000**
Ischemic preconditioning	**0**	**(0.0)**	**0**	**(0.0)**	**1.000**
Procedure					**1.000**
Transhiatal	**72**	**(92.3)**	**72**	**(92.3)**	
McKeown	**6**	**(7.7)**	**6**	**(7.7)**	
Robot-assisted	**44**	**(56.4)**	**35**	**(44.9)**	**0.200**
Comparative outcomes					
Pyloromyotomy	**75**	**(95.2)**	**77**	**(98.7)**	**0.620**
Nasogastric tube	**78**	**(100.0)**	**78**	**(100.0)**	**1.000**
Short gastric length [b] (cm)	**8.1**	**(− 0.8 to 14.6)**	**6.5**	**(0.2–12.6)**	**0.005****
Perfusion variables					
Ingress index (%)	**33.3**	**(2.3–79.1)**	**48.2**	**(2.2–95.2)**	**< 0.001*****
Ingress time (sec)	**66.3**	**(9.1–140)**	**51.2**	**(9.6–150)**	**0.004****
Perfusion pattern					**< 0.001*****
Good in & out flow	**7**	**(9.0)**	**18**	**(23.1)**	
Good inflow, poor outflow	**2**	**(2.6)**	**6**	**(7.7)**	
Poor inflow, good outflow	**9**	**(11.5)**	**21**	**(26.9)**	
Poor in & out flow	**60**	**(76.9)**	**33**	**(42.3)**	
Overall anastomotic leak	**24**	**(30.8)**	**16**	**(20.5)**	**0.199**
Leak severity					**0.163**
Mild	**3**	**(3.8)**	**1**	**(1.3)**	
Moderate	**11**	**(14.1)**	**8**	**(10.3)**	
Severe	**10**	**(12.8)**	**7**	**(9.0)**	
Anastomotic stricture	**25**	**(32.1)**	**18**	**(23.1)**	**0.282**
Delayed conduit emptying	**0**	**(0.0)**	**3**	**(3.8)**	**0.245**

Data were presented as mean (range) or frequency (%)

$^{**}p<0.01$, $^{***}p<0.001$

[a]Coronary artery disease, cerebrovascular disease, major vascular disease, and peripheral vascular disease; [b]length from the last gastroepiploic branch to the perfusion assessment point (5 cm from the tip)

CRT, chemoradiation therapy

Table 6 Multiple linear regression analysis for estimation of ingress index and time

Ingress index	Coefficient	SE	*t*	*p*
(Intercept)	49.921	5.119	9.752	< 0.001***
Short gastric length [a] (cm)	− 2.051	0.556	− 3.689	< 0.001***
Wide conduit	11.725	3.539	3.313	0.001**
Ingress time	Coefficient	SE	*t*	*p*
(Intercept)	39.081	7.339	5.325	< 0.001***
Short gastric length [a] (cm)	3.359	0.797	4.213	< 0.001***
Wide conduit	− 9.839	5.074	− 1.939	0.054

[a]Length from the last gastroepiploic branch to the perfusion assessment point (5 cm from the tip)

SE, standard error

$^{**}p < 0.01$, $^{***}p < 0.001$

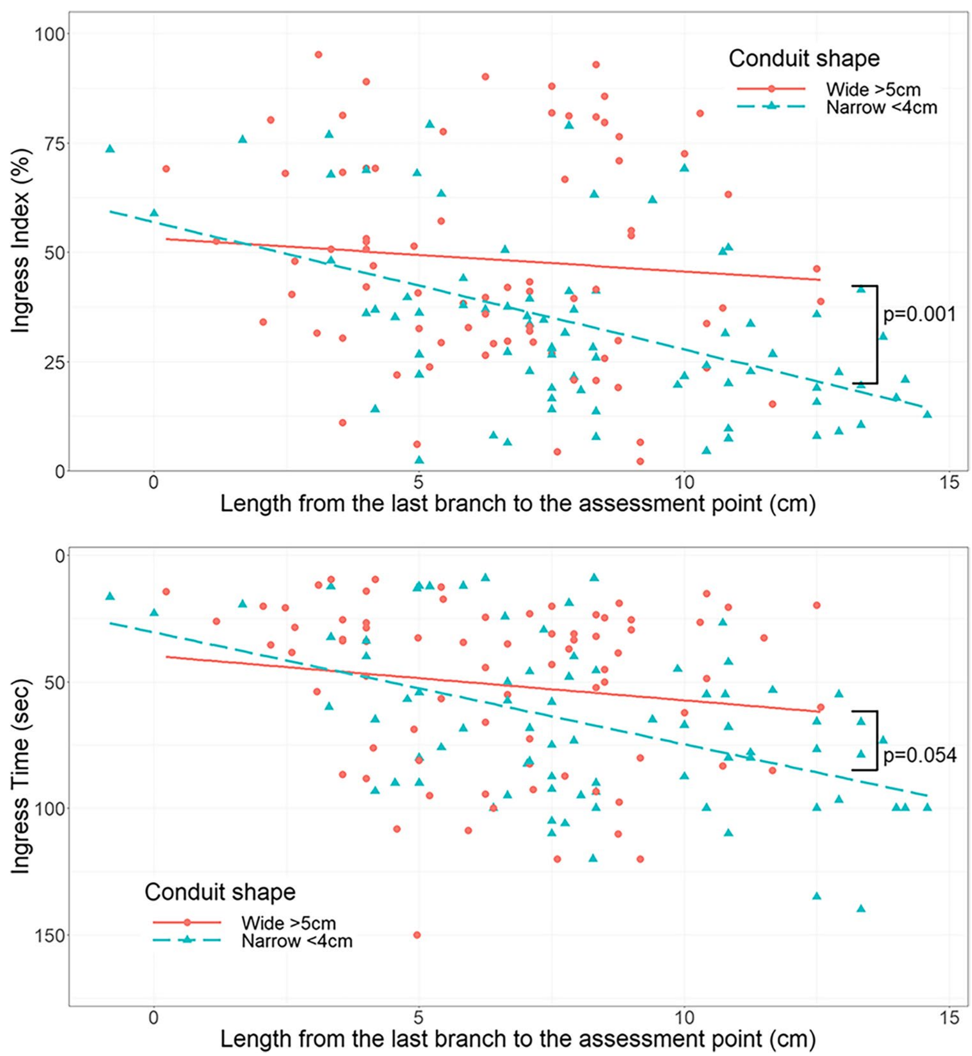

Fig. 4 Relationship between short gastric length and ingress index after matching. Wide conduits have significantly higher ingress index (top panel) than the other conduits ($p = 0.001$), with the separation occurring when the perfusion assessment point is 5 cm or more from the last gastroepiploic branch. The Ingress time (lower panel) does not differ between the conduit shapes

Declarations

Conflict of Interest The authors declare no competing interests.

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