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Original article

Computed tomography assessment of postoperative gastric vascular supply and staple-line leak development after sleeve gastrectomy

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Abstract

Background: Residual arterial supply of the gastric tube after sleeve gastrectomy (SG) can be damaged by surgery, which can reduce gastric tube perfusion and could promote postoperative leakage.
Objective: To compare the postoperative vascularization of the gastric tube using early computed tomography (CT) scanning after SG in patients with or without postoperative staple-line leak.
Setting: University hospital.
Methods: A retrospective analysis of a prospective database was performed in consecutive patients undergoing SG. Patients who presented with a staple-line leak were matched (1:3) with a control group of patients who underwent surgery without postoperative morbidity during the same period. Gastric tube vascularization was studied on a postoperative day 2 CT scan in both groups of patients.
Results: During the study period, 1826 patients underwent SG, including 42 patients (2.3%) who presented with a staple-line leak. Those 42 patients were successfully matched to 126 control patients. Global identification of residual gastric arterial supply in early postoperative CT scans was similar in patients with or without staple-line leak after SG. However, residual vascular supply of the gastroesophageal junction (i.e., terminal and anterior cardiotuberosity branches of the left gastric artery or left inferior phrenic artery) was more frequently interrupted by the staple line in the group of patients who developed a gastric leak.
Conclusion: This study suggests a correlation between interruption of the main arteries supplying the gastroesophageal junction by the staple line on early postoperative CT scans and the development of gastric leak after SG. These results support the vascular theory as one of the causes of leak after SG. (Surg Obes Relat Dis 2022;■:1–8.) © 2022 American Society for Bariatric Surgery. Published by Elsevier Inc. All rights reserved.

Keywords: Obesity; Bariatric surgery; Sleeve gastrectomy; Gastric vascular supply; Computed tomography

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Sleeve gastrectomy (SG) is the most frequently performed bariatric procedure throughout the world [1]. Staple-line leak remains the most feared postoperative complication, with an incidence rate of approximately 1% in experienced centers [2]. Different predictive factors of staple-line leak have been described, including super obesity (body mass index [BMI] >50 kg/m^2) [3], sarcopenia [4], visceral obesity [5], use of a small bougie calibration diameter <40F [3], lack of surgical experience [6], and absence of staple-line reinforcement [7]. The exact mechanism explaining staple-line leak is still unclear, but 2 main theories have been proposed. The vascular theory associates staple-line leak with reduced perfusion at the upper third of the gastric tube [8–10]. The mechanical theory suggests that gastric tube hyperpressure due to reduced gastric volume, pyloric conservation, and a potential decrease in gastric emptying could explain the appearance of gastric leakage at the upper part of the sleeve [11,12]. However, several authors consider that both mechanisms could be involved in an intricate way in staple-line leak development [13].

The gastric arterial vascularization, which can be subject to several anatomic variations, consists of 4 main arteries: the left and right gastric arteries and the left and right gastroepiploic arteries. These main arteries form 2 arterial circles in the lesser and greater curvatures. Specifically, the vascular supply of the gastroesophageal junction is provided by the cardiotuberosity branch along with the other upper branches of the left gastric artery (LGA). Recurrent branches from the left inferior phrenic artery (LIPA) also contribute to the vascularization of this region. Finally, short gastric arteries and branches from the upper part of the left gastroepiploic artery complete this arterial supply (Fig. 1). However, these latter branches are systematically sectioned during standard SG.

After standard SG, gastric vascularization is theoretically provided by the arterial circle of the lesser curvature and a branch arising from the LIPA. However, the residual arterial supply of the gastric tube can be damaged by surgery, which can reduce gastric tube perfusion and could promote postoperative leakage. The remnant vascularization after SG has been poorly studied. An anatomic study demonstrated that vascularization of the upper third of the gastric tube can be altered by an SG procedure, mainly by damage to branches arising from the LGA [13]. Furthermore, intraoperative gastric microperfusion using visible light spectroscopy showed a zone of reduced microperfusion at the upper part of the stomach with significant drop of tissue oxygenation after SG [8]. Finally, indocyanine green fluorescent angiography was used after SG to evaluate the persistent blood supply without any conclusive results [14]. Paradoxically, no study assessed postoperative gastric tube vascularization using standard radiologic examinations. In our department, computed tomography (CT) is routinely performed after SG on postoperative day 2 [15]. We therefore

Fig. 1. Representation of the anatomic gastric arterial vascularization focusing on the gastroesophageal junction supply. (1) Left inferior phrenic artery and recurrent branches. (2) Anterior cardiotuberosity branch of the left gastric artery. (3) Left gastric artery terminal branches. (4) Right gastric artery terminal branches.

decided to retrospectively analyze these CT scans to assess postoperative gastric tube vascularization.

The aim of this study was to evaluate and compare the postoperative residual vascularization of the gastric tube using early CT scans after SG in patients with or without postoperative staple-line leak.

Materials and Methods

Between January 2011 and December 2017, data from all consecutive patients who underwent laparoscopic SG in our department were prospectively collected and retrospectively analyzed after institutional review board approval. Patients who presented with a staple-line leak were identified and matched (1:3) with a comparable control group of patients who underwent surgery without postoperative morbidity during the same period. Gastric tube vascularization was studied on postoperative day 2 CT scans in both groups of patients. Patients with an upper gastrointestinal surgical history (except cholecystectomy) were excluded from the analysis, as were patients without an available good-quality arterial phase CT scan. Matching criteria were baseline characteristics (i.e., sex, age, and BMI), co-morbidities (i.e., diabetes, obstructive sleep apnea syndrome, hypertension, dyslipidemia, and cardiovascular disease), tobacco use, and antiplatelet and/or anticoagulant therapy.

A second analysis was performed to compare remnant gastric tube vascularization after SG with normal gastric vascularization in a group of patients without obesity. This latter group consisted of all consecutive patients without cirrhosis and obesity and with no surgical abdominal history who underwent enhanced abdominal CT scan with arterial phase for the exploration of pancreatic or liver cancer in our department between January 2018 and December 2019. Patients with vascular modifications related to tumoral compression or thrombosis were excluded.

Perioperative management

All patients were informed about perioperative and intraoperative management, and informed consent was obtained before surgery for prospective data collection. Preoperative evaluation by a multidisciplinary team was conducted with standard investigations by esophagogastroduodenoscopy, upper gastrointestinal series, and, if needed, preoperative CT scan (particularly in patients with symptomatic gastroesophageal reflux disease and/or presenting endoscopic findings of reflux to rule out any hiatal hernia), polysomnography and endocrinology, and nutritional evaluations. Patients were eligible for surgery according to French guidelines [16]. The surgical indication was validated during a multidisciplinary staff meeting. In patients with hiatal hernia, a gastric bypass was performed rather than SG with concomitant hiatal hernia repair.

SG was routinely performed in our department, as reported previously [17,18]. Briefly, gastrocolic ligament and gastroepiploic vessel dissection along the greater curvature was completed with a thermofusion device. This dissection started at the level of the antrum, 5 cm before the pylorus, heading upward, sectioning the gastrosplenic ligament until reaching the left diaphragmatic crus. Care was taken not to extensively dissect the medial part of the left crus to avoid future mediastinal ascension of the remaining stomach. Then, dissection of adhesions of the posterior wall of the stomach was performed. Transection of the stomach was done using a 60-mm endoscopic stapler (Endo-GIA Tri-Staple with purple cartridge [3, 3.5, and 4 mm; Medtronic, Paris, France] or Echelon Flex powered with a gold cartridge [3.8 mm; Ethicon, Issy-les-Moulineaux, France]) after placement of a 36F orogastric calibration tube along the lesser curvature. The same height of staples was used for all parts of the stomach. Careful hemostasis of the mucosa on the staple line was performed using bipolar coagulation. Staple-line reinforcement and drainage were not routinely used.

A multidetector abdominal CT scan with and without intravenous enhancement (arterial and portal phases) and with oral contrast material (Gastrografin; Bayer, La Garenne-Colombes, France) using a General Electric CT Light Speed VCT 64 4.3 (GE Healthcare, Vélizy-Villacoublay, France) with a slice thickness of 1 mm was routinely performed 2 days after surgery, as reported previously [15]. Intravenous enhancement (Iomeron 400; Iomeprol, Bracco Imaging, Massy, France) was obtained by intravenous injection of 90 mL of a contrast agent infused at 3.5 mL/s. This abdominal CT scan is part of our department's protocol to rule out essentially hemorrhage/hematoma but also staple-line leak [15]. After the CT scan, patients were allowed free liquid intake and placed on a semiliquid diet, and solid intake was allowed gradually during the first 3 weeks after SG. When a surgical complication was identified on CT scan, management was promptly determined according to the gravity of each complication. Subclinical hematomas smaller than 5 cm not applying pressure on the staple-line or in contact with <2 cm of the staple line were conservatively treated by close monitoring of arterial blood pressure to avoid hypertension, discontinuation of anticoagulation, delay in oral intake, antibiotic treatment, and early postoperative consultation and blood test. Larger hematomas (>5 cm) compressing or in contact with >2 cm of the staple line were actively treated with relaparoscopy and external drainage. In cases of diffuse peritonitis due to gastric staple-line leakage, laparoscopy was undertaken with lavage and drainage of the peritoneal cavity. A combined approach of laparoscopy and endoscopic internal treatment (pigtail stents and enteral nutrition via nasojejunal feeding tube) also was used. Exclusive endoscopic treatment was used in cases of limited perigastric collection. Patients were monitored with a standard follow-up program supervised by a multidisciplinary team (a surgeon, a nutritionist, a dietitian, and a psychologist) consisting of 4 visits to the outpatient clinic during the first postoperative year, biannual consultation for the next 4 years, and yearly consultation afterward.

CT scan analysis

The arterial phase of each CT scan was reinterpreted using maximum-intensity projection gastric vascularization reconstruction by 3 radiologists blinded to patient global postoperative course using Carestream Vue PACS Software (Carestream Health, Noisy-le-Grand, France). The staple line was initially identified in the CT scan performed without intravenous enhancement in order to differentiate it from the arteries. In each patient, identification of the following arteries was evaluated: LGA terminal branches, anterior cardiotuberosity branch of the LGA, LIPA, and right gastric artery terminal branches (Fig. 2). Interruption of the latter arteries by the staple line was evaluated. Arterial interruption was defined as a complete stop of the arterial branch on the staple line without visualization of any persistent downstream arterial flow.

Data collection and statistical analysis

Demographic data were obtained from a prospective electronic database, with additional retrospective medical records reviewed when necessary. Data recorded included patients' characteristics, perioperative course, and follow-up details. Co-morbidities were regarded as significant when medication was used or when continuous positive airway pressure was employed in patients with obstructive sleep apnea syndrome. Staple-line leak was regarded as a

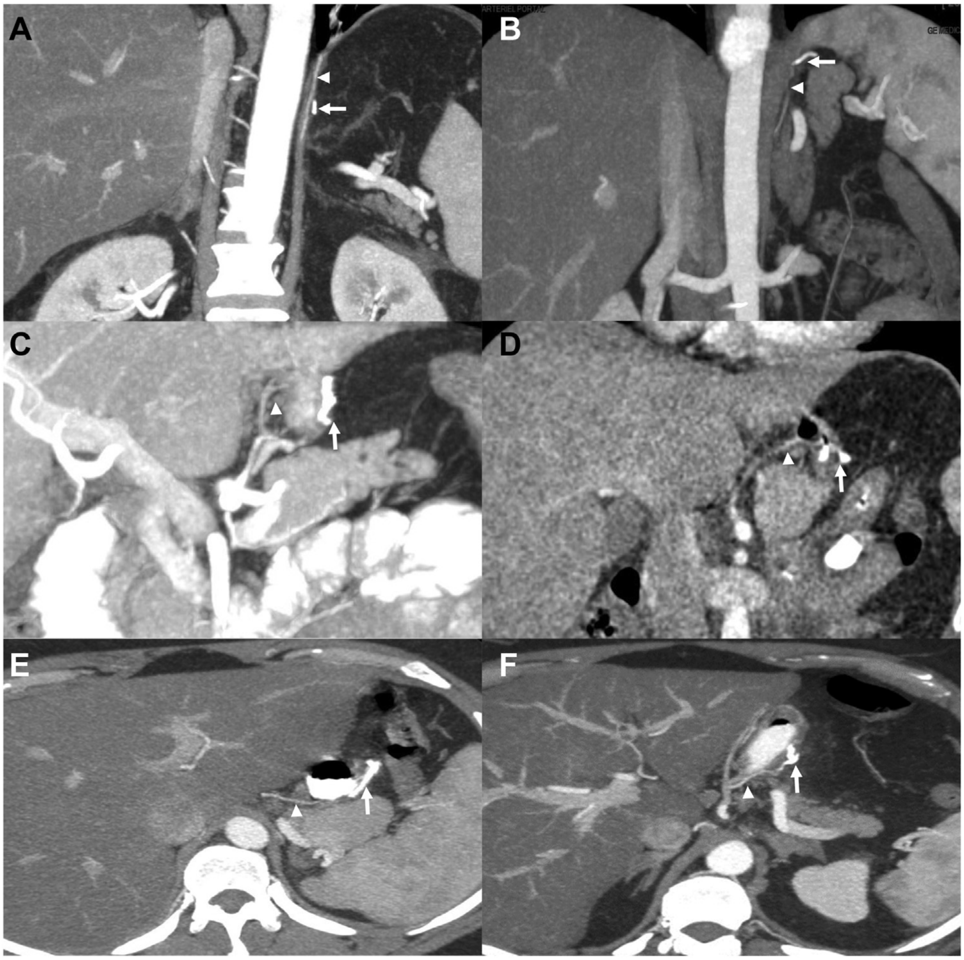

Fig. 2. Arterial phase computed tomography scan 2 days after sleeve gastrectomy. (A) Normal aspect of left inferior phrenic artery at distance from the staple line. (B) Left inferior phrenic arterial flow interruption on staple line. (C) Normal aspect of anterior cardiotuberosity branch of the left gastric artery at distance from the staple line. (D) Anterior cardiotuberosity branch arterial flow interruption on the staple line. (E) Normal aspect of left gastric artery terminal branches at distance from the staple line. (F) Interruption of arterial flow of the left gastric artery terminal branches on the staple line. Arrows indicate the staple line. Arrowheads indicate the artery.

complication when an intra-abdominal abscess requiring drainage or antibiotic treatment was found on a CT scan or during relaparoscopy. Complication severity was stratified according to the Dindo-Clavien classification [19]. Postoperative mortality was considered to be any death occurring within 90 days of surgery or at any time during the postoperative hospital stay. Percentage excess weight loss (%EWL) was calculated using the following formula: %EWL = [weight loss (kg)/excess weight (kg)] × 100. Excess weight was based on the patient's ideal weight, with a BMI of 25 kg/m^2. Discontinuation of all medication for the treatment of a co-morbidity (or end of continuous positive airway pressure use) was regarded as remission.

Continuous variables were expressed as median and interquartile range (IQR) and were compared using the Mann-Whitney test. Categorical variables were expressed as frequencies (percentages) and were compared using the χ^2 test or Fisher exact test as appropriate. P values $<.05$ were considered statistically significant. Matching and statistical analysis were carried out with SPSS software (IBM, Armonk, NY, USA).

Results

Characteristics of patients, intraoperative data, and postoperative course

During the study period, 1826 patients without upper gastrointestinal surgical history (except cholecystectomy) underwent laparoscopic SG in our department, including 42 patients (2.3%) who presented with a staple-line leak. The global median postoperative time to appearance of the gastric leak was 7 days (IQR: 2–14 days). Those 42 patients were compared with 126 patients matched (1:3) who underwent SG without postoperative morbidity during the same period. All these patients had an available arterial phase

CT scan. There were 34 men (20.2%) and 134 women (79.8%). The median age was 40 years (IQR: 32–49 years), and the median BMI was 39.8 kg/m^2 (IQR: 36.8–43.4 kg/m^2). As expected, baseline characteristics of patients were similar in both groups. Conversion to open surgery was required in 1 patient, who finally presented with a gastric leak due to an inability to control bleeding from a short gastric vessel. A non–statistically significant superior operative duration was observed in the gastric leak group (96 minutes [IQR: 82–120 minutes] versus 86 minutes [IQR: 71–105 minutes]; P = .054). In 23 of the 42 patients (54.8%) who presented with a gastric leak, a reintervention was required for surgical drainage. One of these patients died of septic shock on postoperative day 10. The other 19 patients who presented with a gastric leak were managed exclusively by endoscopy ± radiology. Dindo-Clavien classification grade was IIIb, IVa, IVb, and V, respectively, in 18, 18, 5, and 1 patient(s). Median hospital stay was superior in the gastric leak group (7 days [IQR: 5–22 days] versus 3 days [IQR: 2–4 days]; $P < .0001$), as expected. Characteristics of patients, intraoperative data, and postoperative course in relation to gastric leak are summarized in Table 1.

Weight loss and co-morbidity resolution

Of the 168 patients included in the study, 149 (88.7%) reached 12-month postoperative follow-up, including 35 patients (83.3%) who presented with a gastric leak and 114 patients (90.5%) who did not. Median %EWL at 1 year was 72% (IQR: 53%–90%). Median percentage of total weight loss at 1 year was 26% (IQR: 21%–33%). Weight loss and co-morbidity resolution 12 months following the procedure were globally similar in the 2 groups. Weight loss and co-morbidity resolution 12 months postoperatively in relation to gastric leak are summarized in Table 2.

CT scan findings

Twenty of 42 patients who presented with a gastric leak had signs suggesting the development of the gastric leak on the postoperative day 2 CT scan. The diagnosis of leak was certain in 15 patients. Identification of the LGA terminal branches, the anterior cardiotuberosity branch of the LGA, the LIPA, and the right gastric artery terminal branches was similar in patients with or without staple-line leak after SG. However, interruption of the LGA terminal branches, the anterior cardiotuberosity branch of the LGA, or the LIPA was observed more frequently at the level of the staple line in the group of patients who subsequently developed a gastric leak. CT scan findings in relation to gastric leak are summarized in Table 3. Besides, no difference was observed concerning the identification of studied branches in the whole group of patients who underwent

Table 1
Baseline characteristics of patients, intraoperative data, and postoperative course in relation to gastric leak

Characteristic	Gastric leak (n = 42)	No gastric leak (n = 126)	P value
Sex (female), n (%)	33 (78.6)	101 (80.1)	.826
Age (y), median (IQR)	41 (34–50)	39 (32–48)	.421
Height (cm), median (IQR)	1.66 (1.59–1.72)	1.66 (1.6–1.72)	.716
Weight (kg), median (IQR)	111 (102–129)	110 (98–126)	.574
BMI (kg/m^2), median (IQR)	40.0 (37.6–44.4)	39.7 (36.5–43.2)	.440
Previous abdominal surgery, n (%)	12 (28.6)	44 (34.9)	.571
Co-morbidity, n (%)			
OSAS	17 (40.5)	58 (46.0)	.592
Diabetes	7 (16.7)	20 (15.9)	>.999
Hypertension	12 (28.6)	36 (28.6)	>.999
Dyslipidemia	6 (14.3)	20 (15.9)	>.999
Fatty liver disease	11 (26.2)	20 (15.9)	.168
Cardiovascular disease	2 (4.7)	12 (9.5)	.521
Tobacco use, n (%)	2 (4.7)	4 (3.2)	.640
Antiplatelet and/or anticoagulant therapy, n (%)	1 (2.4)	5 (4.0)	>.999
Intraoperative data			
Blood loss ≥50 mL, n (%)	3 (7.1)	2 (1.6)	.100
Additional trocar, n (%)	1 (2.4)	3 (2.4)	>.999
Conversion, n (%)	1 (2.4)	0	.250
Operative duration (min), median (IQR)	96 (82–120)	86 (71–105)	.054
Abdominal drainage, n (%)	2 (4.7)	2 (1.6)	.260
Postoperative course			
Hospital stay (d), median (IQR)	7 (5–22)	3 (2–4)	<.0001*
Mortality, n (%)	1 (2.4)	0	.250

IQR = interquartile range; BMI = body mass index; OSAS = obstructive sleep apnea syndrome.
* Statistically significant.

Table 2
Weight loss and co-morbidity resolution 12 months postoperatively in relation to gastric leak

Characteristic	Gastric leak (n = 35)	No gastric leak (n = 114)	*P* value
Weight loss (kg), median (IQR)	32 (24–44)	29 (21–37)	.120
BMI reduction (kg/m^2), median (IQR)	12 (8–14)	10 (8–13)	.234
%TWL, median (IQR)	29 (22–35)	26 (21–33)	.123
%EWL, median (IQR)	75 (61–93)	67 (52–90)	.284
Co-morbidity resolution 12 months postoperatively			
OSAS resolution, n (%)	10 (62.5)	37 (71.1)	.546
Diabetes resolution, n (%)	5 (71.4)	12 (63.1)	>.999
Hypertension resolution, n (%)	5 (50)	16 (47.0)	>.999
Dyslipidemia resolution, n (%)	6 (100)	12 (66.7)	.277

IQR = interquartile range; BMI = body mass index; %TWL = percentage total weight loss; %EWL = percentage excess weight loss; OSAS = obstructive sleep apnea syndrome.

SG and in the control group of patients without obesity (Table 4).

Discussion

The upper third of the gastric tube after SG seems to be an area particularly exposed to high pressure and ischemic constraints. Several approaches have been used to study gastric tube vascularization modifications, including anatomic study [13], light spectroscopy [8], and indocyanine green fluorescent angiography [14]. To our knowledge, this study is the first to precisely assess remnant gastric tube arterial supply after SG using arterial phase CT scan.

Arterial CT scan is a high-performance imaging technique designed to study gastric vascularization. In our study, arterial branches (LGA terminal branches, anterior cardiotuberosity branch of the LGA, LIPA, and right gastric artery terminal branches) were clearly identified in more than 95% of patients. It was initially planned to study the recurrent branches of the LIPA, but these thin branches were only visible in 56% of patients after SG and in and 67% of the control group (data not shown), and therefore, we decided to specifically focus on the LIPA. The prevalence of recurrent branches of the LIPA to the gastroesophageal junction is not precisely known. In angiography and arterial CT studies, these recurrent branches are described by authors without comment on their prevalence [20]. In a limited series of 23 patients, Kim et al. [21] noted these recurrent branches in 78% of cases, but in the specific context of patients with hepatocellular carcinoma presenting a blood supply from the LIPA. Besides, in anatomic studies, prevalence rates of these branches vastly range from 11% to 100% [22–24].

Our results suggest a correlation between interruption of the main arteries supplying the gastroesophageal junction (i.e., LGA terminal branches, anterior cardiotuberosity branch of the LGA, and LIPA) by the staple line during SG and the development of a staple-line gastric leak. Perez et al. [13] already demonstrated in a cadaveric study that vascularization of the upper third of the gastric tube could be altered by SG, but they focused on branches arising from the LGA without studying the LIPA. Furthermore, their ex vivo study was not designed to assess any correlation with the development of a gastric leak. To our

Table 3
Computed tomography findings* in relation to gastric leak

Characteristic	Gastric leak (n = 42)	No gastric leak (n = 126)	*P* value
Identification of left gastric artery terminal branches, n (%)	42 (100)	126 (100)	>.999
Arterial interruption on staple line, n (%)	3 (7.1)	1 (.8)	.048†
Identification of anterior cardiotuberosity branch of left gastric artery, n (%)	42 (100)	120 (95.2)	.338
Arterial flow interruption on staple line, n (%)	8 (19.0)	6 (5)	.0009†
Identification of left inferior phrenic artery, n (%)	41 (97.6)	126 (100)	.250
Arterial flow interruption on staple line, n (%)	14 (34.1)	7 (5.5)	<.0001†
Identification of right gastric artery terminal branches, n (%)	42 (100)	126 (100)	>.999
Arterial flow interruption on staple line, n (%)	1 (2.3)	0	.250

* Visible on arterial phase of contrast-enhanced abdominal computed tomography scan.
† Statistically significant.

Table 4
Computed tomography findings* in the sleeve gastrectomy and control groups

Characteristic	Sleeve gastrectomy (n = 168)	Control (n = 74)	*P* value
Identification of left gastric artery terminal branches, n (%)	168 (100)	74 (100)	>.999
Identification of anterior cardiotuberosity branch of left gastric artery, n (%)	162 (96.4)	74 (100)	.181
Identification of left inferior phrenic artery, n (%)	167 (99.4)	71 (95.9)	.086
Identification of recurrent branch of left inferior phrenic artery, n (%)	94 (56.3)	45 (67.2)	.142
Identification of right gastric artery terminal branches, n (%)	168 (100)	74 (100)	>.999

* Visible on arterial phase of contrast-enhanced abdominal computed tomography scan.

knowledge, this clinical study is the first to demonstrate a possible correlation between postoperative vascular modifications and staple-line leak development after SG. In addition, identification of the studied arteries 2 days after SG was equivalent between patients who developed a gastric leak and those who did not. It was also similar in the whole group of patients who underwent SG and in the control group. These findings reinforce the idea that modifications of tissue vascularization of the upper third of the gastric tube after SG are not due to primary anatomic variations but could be a direct consequence of stapling and possibly dissection.

Practically, avoiding intensive dissection of the left crus and/or stapling on close contact with the calibration tube might help to decrease the staple-line leak rates by preserving the vascular supply of the upper third of the gastric tube. Similarly, avoiding accidental or intentional application of the distal end of the last stapler cartridge on the left crus could have an important impact on vascularization preservation. Using a large calibration tube also could help to move the staple line away from the main gastroesophageal junction vessels. The literature suggests that the use of large calibration tubes (≥40F) could decrease the risk of staple-line leak after SG [25]. Our team is currently conducting a prospective randomized study [26] to validate this hypothesis. Likewise, large oversewing or intensive mono- or bipolar coagulation of the upper part of the staple line could increase the risk of ischemia in this part of the gastric sleeve. However, in this series, no staple-line oversewing was used, and when required, only limited low-intensity bipolar coagulation was applied on the staple-line mucosa. One could argue that visualization of the LGA, anterior cardiotuberosity terminal branches, and recurrent branches of the LIPA is the better way to avoid any arterial damage, but practically, these small arteries are generally difficult to identify during surgery.

This study has several limits that should be underlined. First of all, despite the use of a prospective electronic database, our analysis is exposed to inherent classical bias because of its retrospective nature. Matching allowed us to study comparable patients, but these results should be confirmed by a larger cohort including all patients who underwent SG during the same period of time to avoid selection bias. Preoperative CT scans (which are not part of our preoperative workout) are also missing in the analysis and would have been the best control group. All CT scans included an arterial phase, but they were not specifically performed for prospective arterial study, which might have biased our analysis. Radiologists reinterpreted CT scans blinded to patient global postoperative course, but in several cases, radiologic signs already suggested or revealed the presence of a leak, which might have influenced the interpretation. Finally, it is important to specify that the aim of this study was not to recommend routine use of postoperative CT scans. This postoperative protocol was applied until 2017 to assess the interest of the postoperative day 2 CT scan. Previous results demonstrated that the routine use of postoperative CT scans is not required [15]. The global postoperative management has evolved in our department since 2017, and most patients currently receive a liquid meal on day 1.

Conclusion

This retrospective comparative study suggests a correlation between interruption by the staple line of the main arteries supplying the gastroesophageal junction (LGA terminal branches, anterior cardiotuberosity branch of the LGA, and LIPA) on early postoperative CT scans and the development of a staple-line gastric leak after SG. These results support the vascular theory as one of the causes of leak after SG. Avoiding intensive dissection of the left crus and/or stapling with close contact with the gastroesophageal junction may help to decrease staple-line leak rates by preserving the vascular supply of the upper third of the gastric tube.

Disclosures

The authors have no commercial associations that might be a conflict of interest in relation to this article.

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