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Surgeon-specific technical variation during laparoscopic sleeve gastrectomy and its association with weight loss and erosive esophagitis: a single-center cohort study

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Abstract

Background

Despite the widespread adoption of laparoscopic sleeve gastrectomy (LSG), considerable variation exists in operative technique. The influence of surgeon-specific technical variation on postoperative weight loss and erosive esophagitis (EE) remains incompletely understood.

Methods

A retrospective single-centre cohort study was conducted at a high-volume bariatric centre including patients who underwent primary LSG between 2008 and 2022. Six fellowship-trained bariatric surgeons were evaluated. Representative procedures were independently reviewed to characterize surgeon-specific operative techniques, including antrectomy distance, fundal mobilisation, sleeve calibre, distance from the incisura angularis, sleeve fixation and staple-line reinforcement. Multivariable logistic regression identified factors associated with achieving ≥ 20% total weight loss (%TWL) and postoperative EE at 12 months.

Results

Among 815 patients undergoing LSG, 725 with complete 12-month follow-up were included. Mean age was 41.2 ± 10.3 years, mean preoperative BMI was 42.7 ± 6.9 kg/m², and 67.4% were female. At 12 months, 577 patients (79.6%) achieved ≥ 20% TWL, while EE was identified in 119 patients (23.1%). Younger age (adjusted OR 0.94, 95% CI 0.92–0.97), absence of type 2 diabetes mellitus (adjusted OR 2.99, 95% CI 1.74–5.16), greater early postoperative weight loss (adjusted OR 1.25, 95% CI 1.17–1.34), and sleeve calibre (adjusted OR 1.69, 95% CI 1.01–2.82) were independently associated with achieving ≥ 20% TWL. Tighter sleeve calibre was the strongest technical factor associated with postoperative EE (adjusted OR 5.21, 95% CI 2.73–9.94), together with increasing age and greater early postoperative weight loss.

Conclusions

Within a standardized high-volume bariatric programme, both patient characteristics and surgeon-specific technical variation were associated with postoperative outcomes following LSG. Moderate sleeve calibration was associated with favourable weight-loss outcomes, whereas tighter sleeve construction was associated with an increased risk of postoperative EE. These findings support careful attention to sleeve geometry to optimise the balance between weight loss and reflux-related complications.

Introduction

Metabolic bariatric surgery (MBS) remains the most effective and durable treatment for severe obesity and obesity-related metabolic disease, with current international guidelines recommending surgery for patients with a body mass index (BMI) ≥ 37.5 kg/m², or ≥ 32.5 kg/m² in the presence of obesity-associated comorbidities in Asian populations [1]. Among the available bariatric procedures, laparoscopic sleeve gastrectomy (LSG) has become the most frequently performed operation worldwide, accounting for more than 40% of all bariatric procedures because of its technical simplicity, reproducibility, and favourable safety profile [2]. Despite these advantages, considerable variation persists in the operative technique used to construct the gastric sleeve [3].

LSG comprises several critical technical steps that may influence postoperative outcomes, including the distance of gastric transection from the pylorus, the extent of fundal mobilisation and resection, sleeve calibration, management of the incisura angularis, and the use of staple-line reinforcement or sleeve fixation. Although expert consensus statements have proposed recommendations to standardize these operative steps, many of these recommendations are based on expert opinion rather than high-quality comparative evidence [4]. Consequently, substantial differences in surgical practice continue to exist even among experienced bariatric surgeons.

Technical variation during LSG has been proposed as a potential contributor to differences in postoperative weight loss and gastroesophageal reflux disease (GERD). Previous studies evaluating operative technique have primarily relied on retrospective video review or multicentre registry data [5, 6]. While these investigations have provided valuable insights, they are limited by heterogeneity in patient selection, perioperative pathways, postoperative follow-up, and surgeon-specific practices. Furthermore, assessment based on a single operative video may not accurately represent a surgeon's habitual technique, and many studies have relied on patient-reported reflux symptoms rather than objective endoscopic findings. These factors make it challenging to distinguish the influence of operative technique from other clinical variables that affect postoperative outcomes.

The relationship between sleeve construction and postoperative reflux remains particularly controversial. Technical factors such as antral preservation, sleeve calibre, complete fundal resection, and the configuration of the sleeve at the incisura have all been implicated in the development of GERD after LSG, yet published findings remain inconsistent. Because reflux symptoms correlate poorly with endoscopic findings following LSG, studies using objective endoscopic assessment may provide a more accurate evaluation of reflux-related complications than symptom-based questionnaires alone.

To better characterize technical variation in routine clinical practice, we evaluated LSG procedures performed by six experienced bariatric surgeons within a single high-volume tertiary referral centre using standardized multidisciplinary perioperative care and follow-up protocols. Rather than analysing isolated operative videos, representative procedures were directly observed to characterize each surgeon's habitual operative technique across the pre-stapling, stapling, and post-stapling phases of LSG. These technical characteristics were subsequently examined in relation to clinically meaningful weight loss and

endoscopically confirmed erosive esophagitis (EE) at 12 months after surgery while accounting for important patient-related factors.

We hypothesized that specific aspects of sleeve construction would be associated with both postoperative weight-loss outcomes and the development of EE. The primary objective of this study was therefore to identify surgeon-related technical factors associated with achieving clinically meaningful total weight loss (≥ 20% TWL) at 12 months after LSG. The secondary objective was to determine which operative characteristics were associated with postoperative EE, thereby providing practical insights into technical factors that may help optimize the balance between effective weight loss and reflux-related complications following LSG.

Methods

Study design

This retrospective single-centre cohort study evaluated the association between surgeon-specific technical variations during LSG and postoperative weight loss and EE at 12 months. All procedures were performed at a high-volume tertiary referral bariatric centre between 1 January 2008 and 31 December 2022. The centre performs approximately 250–350 bariatric procedures annually and fulfils the American Society for Metabolic and Bariatric Surgery (ASMBS) criteria for a Bariatric Surgery Centre of Excellence, performing well above the minimum annual case volume required for accreditation. Although the centre performs a broad spectrum of bariatric procedures, including Roux-en-Y gastric bypass, one-anastomosis gastric bypass, sleeve-plus procedures and revisional bariatric surgery, the present study was restricted to patients undergoing primary LSG.

Perioperative care was standardized throughout the study period using a multidisciplinary programme comprising bariatric surgeons, endocrinologists, dietitians, psychologists, specialist nurses and physiotherapists. Standardized protocols were used for patient selection, perioperative management, nutritional counselling and postoperative follow-up, thereby minimizing variability unrelated to surgical technique.

Six fellowship-trained bariatric surgeons were included in the study. All had completed formal upper gastrointestinal or bariatric fellowship training, possessed more than seven years of independent consultant experience at the commencement of the study, and routinely performed complex upper gastrointestinal surgery.

The study was approved by the institutional review board, and the requirement for individual informed consent was waived because of the retrospective analysis of de-identified data.

Assessment of surgical technique

The principal objective of this study was to characterize habitual differences in operative technique between experienced bariatric surgeons rather than evaluate individual operations.

Representative LSG procedures performed by each surgeon were independently observed by two bariatric surgery fellows (FKL and LJQ), both of whom had completed advanced bariatric surgical training in Australia and the United Kingdom. The observers were not involved in patient care or postoperative outcome assessment.

Operative technique was evaluated according to predefined domains representing the major phases of sleeve gastrectomy (Table 1):

Table 1
Variation in LSG techniques between surgeons in Singapore's tertiary referral centre

Stages	Surgical Techniques	Surgeon 1	Surgeon 2	Surgeon 3	Surgeon 4	Surgeon 5	Surgeon 6
Pre-stapling	Complete visualization of fundus (fat pad removal)	·	√	√	√	·	·
Stapling	Distance from pylorus	2-3cm	4-6cm	2-3cm	4cm	4cm	4cm
	Distance from incisura	> 2cm	> 2cm	2cm	> 2cm	> 2cm	> 2cm
	Sleeve tightness	Very loose	Tight	Very tight	Tight	Loose	Loose
	Complete resection of fundus	·	√	√	·	√	√
Post-stapling	Sleeve fixation	·	·	√	·	·	·
	Oversewing of staple line	√	·	·	·	·	√

Pre-stapling

distance of gastric transection from the pylorus (antral preservation), gastric fat pad dissection and fundal mobilisation.

Stapling

sleeve calibre, distance from the incisura angularis and completeness of fundal resection.

Post-stapling

sleeve fixation and staple-line oversewing.

A minimum of three representative procedures was assessed for each surgeon. Rather than assigning technical characteristics to individual patients, these observations were used to characterize each surgeon's routine operative practice. This approach was adopted because the participating surgeons used highly standardized techniques that remained consistent throughout the study period.

Assessment of sleeve calibre

Because no validated intraoperative method exists to quantify sleeve tightness, sleeve calibre was assessed qualitatively. All surgeons used a 40Fr bougie for gastric calibration. Overall sleeve calibre was evaluated according to the relationship between the stapled gastric tube and the bougie, staple-line trajectory, residual gastric redundancy, and tissue tension along the greater curvature. Based on these features, each surgeon's habitual sleeve construction was categorized into an ordinal scale ranging from relatively loose to very tight.

Both observers independently reviewed the operative procedures and subsequently reached consensus. When disagreement occurred, the recordings were reviewed jointly until consensus was achieved. As the assessment reflected surgeon-level operative style rather than patient-level measurements, sleeve calibre was analysed as an ordinal surgeon-specific characteristic.

The technical characteristics of each participating surgeon are summarized in Table 1.

Study population

Consecutive patients undergoing primary LSG during the study period were identified from a prospectively maintained institutional bariatric database. Baseline variables included age, sex, ethnicity, body weight, body mass index (BMI), and presence of type 2 diabetes mellitus (T2D). Operative outcomes included hospital length of stay and early postoperative complications, including staple-line leak and postoperative haemorrhage.

Patients were routinely reviewed 30 days after surgery and subsequently at 3, 6, 9 and 12 months within the multidisciplinary bariatric programme. Patients with missing 12-month weight data were excluded from the primary analysis. Figure 1 illustrates patient selection.

Outcome measures

The primary outcome was percentage total weight loss (%TWL) at 12 months following LSG.

Percentage TWL was calculated as:

$$\%TWL = [(\text{preoperative weight} - \text{postoperative weight})/\text{preoperative weight}] \times 100$$

A clinically meaningful weight-loss response was predefined as ≥ 20% TWL, consistent with previously published bariatric outcome recommendations [7].

The secondary outcome was postoperative erosive esophagitis (EE).

EE was diagnosed by upper gastrointestinal endoscopy performed during routine postoperative surveillance and classified according to endoscopic findings. Because previous work from our institution demonstrated poor agreement between reflux symptoms and endoscopic esophagitis after LSG, objective endoscopic findings were used rather than symptom-based GERD questionnaires [8].

Missing data and assessment of attrition bias

To evaluate potential selection bias arising from loss to follow-up, baseline characteristics of included and excluded patients were compared.

Age, sex, ethnicity, baseline BMI and T2D prevalence were compared using Pearson's chi-square test for categorical variables and Student's t-test or Kruskal-Wallis test for continuous variables, as appropriate.

Statistical analysis

Continuous variables are presented as mean ± standard deviation or median (interquartile range), depending on data distribution. Categorical variables are reported as frequencies and percentages. Comparisons between groups were performed using Student's t-test or Kruskal-Wallis test for continuous variables and Pearson's chi-square test for categorical variables.

Variables associated with achieving ≥ 20% TWL at 12 months were first evaluated using univariable logistic regression. Clinically relevant variables together with those demonstrating statistical significance in univariable analysis were entered into multivariable logistic regression models to estimate adjusted odds ratios (ORs) with corresponding 95% confidence intervals (CIs). Separate multivariable logistic regression models were constructed for postoperative EE.

Because surgical practice evolved during the 14-year study period, operative year was included as a covariate to account for temporal changes. Sensitivity analyses were performed using both three operative periods (2008–2012, 2013–2017 and 2018–2022) and two operative periods (2008–2016 and 2017–2022).

Sleeve calibre and pyloric transection distance were analysed as ordinal variables. Linear trends were evaluated using the Jonckheere-Terpstra test and Spearman rank correlation where appropriate. Model discrimination was assessed using the area under the receiver operating characteristic curve (AUC). Statistical analyses were performed using RStudio (version 2023.06.0 Build 421) and R version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria). Two-sided P values < 0.05 were considered statistically significant.

Sample size considerations

Model adequacy was assessed using the events-per-variable (EPV) criterion. Simulation-based power analyses (1,000 replications) were performed to estimate the statistical power of each predictor included in the final multivariable logistic regression models for both weight-loss and EE outcomes.

Results

Patient characteristics

Between January 2008 and December 2022, 815 patients underwent primary LSG. Of these, 725 patients (89%) had complete 12-month follow-up data and were included in the primary analysis (Fig. 1). Baseline characteristics are summarized in Table 2. The study cohort comprised 489 women (67.4%) and 236 men (32.6%), with a mean age of 41.2 ± 10.3 years (range, 18–68 years). Mean preoperative body weight was 114.4 ± 22.2 kg, corresponding to a mean body mass index (BMI) of 42.7 ± 6.9 kg/m². T2D was present in 219 patients (30.6%).

Table 2
Patient's characteristics.

Characteristics	Findings (n = 725)
Age, median(IQR)	41(16)
Gender	
Male	236 (32.6)
Female	489 (67.4)
Race	
Chinese	238 (32.8)
Malay	260 (35.9)
Indian	181 (25.0)
Eurasian	6 (0.828)
Caucasian	2 (0.276)
Others	38 (5.24)
Pre-operative body weight, mean (SD)	114.4. (22.2)
Pre-operative BMI, mean (SD)	42.7 (6.9)
T2D status	219 (30.6)
Outcomes	
Post-operative body weight, mean (SD)	83.2 (17.3)
Post-operative BMI, mean (SD)	31.1 (5.7)
Total weight loss ≥ 20%, mean (SD)	577 (79.6)
Erosive Esophagitis	119 (23.1)
Surgical complication (leak & haemorrhage)	7 (0.86)
Hospital stay duration, mean (SD), median, min, max	2.8 (2.16), 2, 1, 28
Data presented as number (percentage).	

Mean hospital stay was 2.8 ± 2.2 days (range, 1–28 days). Early postoperative complications occurred in seven patients (0.86%), including staple-line leak and postoperative haemorrhage. There was no postoperative mortality.

At 12 months, mean BMI had decreased to 31.1 ± 5.7 kg/m² and mean body weight to 83.2 ± 17.3 kg. Overall, 577 patients (79.6%) achieved the predefined threshold of ≥ 20% total weight loss (%TWL). Patients who did not achieve ≥ 20% TWL were significantly older than responders (44.9 vs. 40.2 years, $P < 0.001$) and had a marginally longer hospital stay (2.91 vs. 2.77 days, $P < 0.001$). Patients with T2D achieved lower mean %TWL than those without diabetes (24.4% vs. 28.1%, $P < 0.001$). No significant differences were observed with respect to sex or ethnicity (Tables 3 **and Supplementary Table 1**).

Table 3

Comparison between %TWL < 20% and %TWL≥20% across variables.

Variables	%TWL < 20%	%TWL≥20%	p value
Age, median(IQR)	45	40	< 0.001*
Gender			
Female	106 (21.6)	383 (78.4)	0.264
Male	42 (17.7)	194 (82.3)	
Race			
Chinese	56 (23.5)	182 (76.5)	0.175
Malay	51 (19.6)	209 (80.4)	0.762
Indian	34 (18.8)	147 (81.2)	0.602
Eurasian	3 (50)	3 (50)	0.195
Caucasian	0 (0.0)	2 (100)	1
Others	4 (10.5)	34 (89.5)	0.178
T2D status			
No	75 (15.1)	422 (84.9)	< 0.0001*
Yes	70 (32.0)	149 (68.0)	
Pre-stapling - complete visualization of fundus			
No	55 (19.1)	233 (80.9)	0.535
Yes	93 (21.3)	344 (78.7)	
Stapling - distance from pylorus			
2-3cm	31 (15.7)	166 (84.3)	0.071
4-6cm	46 (21.0)	173 (79.0)	0.873
4cm	71 (23.0)	238 (77.0)	0.167
Stapling - distance from incisura			
> 2cm	127 (21.5)	464 (78.5)	0.165
2cm	21 (15.7)	113 (84.3)	
Stapling - sleeve tightness			

Variables	%TWL < 20%	%TWL≥20%	p value
Loose	55 (19.1)	233 (81.9)	0.535
Tight	72 (23.8)	231 (76.2)	0.072
Very tight	21 (15.7)	113 (84.3)	0.165
Stapling - complete resection of fundus			
No	36 (24.5)	111 (75,5)	0.208
Yes	112 (19.4)	466 (80.6)	
Post-stapling - sleeve fixation			
No	127 (21.5)	464 (78.5)	0.165
Yes	21 (15.7)	113 (84.3)	
Post-stapling - oversew			
Negative	104 (20.1)	414 (79.9)	0.800
Positive	44 (21.3)	163 (78.7)	
Surgeon			
1	10 (15.9)	53 (84.1)	0.440
2	46 (21.0)	173 (79.0)	0.873
3	21 (15.7)	113 (84.3)	0.165
4	26 (31.0)	58 (69.0)	0.016*
5	11 (13.6)	70 (86.4)	0.141
6	34 (23.6)	110 (76.4)	0.343
Erosive Esophagitis			
No	88 (22.2)	308 (77.8)	0.121
Yes	18 (15.1)	101 (84.9)	

Comparison of included and excluded patients

Among the 815 eligible patients, 90 (11%) lacked complete 12-month follow-up data and were excluded from the primary analysis. Compared with the study cohort, excluded patients were younger, had a higher preoperative BMI, were less likely to have T2D and were more frequently operated on during the earlier study period. These findings suggest the possibility of attrition bias.

Surgical characteristics

Six fellowship-trained bariatric surgeons performed a mean of 201.3 ± 91.8 LSG procedures each (range, 118–364). Mean operative duration was 127.2 ± 77.0 minutes. Although all surgeons used a standardized 40Fr bougie, variations were observed in several technical aspects of sleeve construction, including antrectomy distance (2–6 cm from the pylorus), degree of fundal mobilisation and resection, sleeve calibre, distance from the incisura angularis, sleeve fixation and staple-line reinforcement (Table 1).

Representative operative observations demonstrated that these technical characteristics were consistent within individual surgeons throughout the study period.

Predictors of clinically meaningful weight loss

Results of the univariable logistic regression analysis are presented in **Supplementary Table 2**. Increasing age was associated with lower odds of achieving ≥ 20% TWL at 12 months (OR 0.96, 95% CI 0.94–0.98; P < 0.001), whereas patients without T2D were significantly more likely to achieve successful weight loss than those with T2D (OR 2.57, 95% CI 1.69–3.89; P < 0.001).

Early postoperative weight loss was strongly associated with subsequent success. Each 1% increase in %TWL at 1 month increased the odds of achieving ≥ 20% TWL at 12 months by 21% (OR 1.21, 95% CI 1.14–1.28; P < 0.001).

Sleeve calibre demonstrated a significant quadratic association with weight-loss outcome (OR 1.47, 95% CI 1.04–2.08; P = 0.03), suggesting that both relatively loose and excessively tight sleeves were associated with lower rates of successful weight loss, whereas moderate sleeve calibration was associated with the highest likelihood of achieving ≥ 20% TWL. Other operative variables, including antrectomy distance, distance from the incisura angularis, complete fundal resection and staple-line reinforcement, were not significantly associated with the primary outcome in univariable analyses.

Multivariable logistic regression confirmed that younger age, absence of T2D, greater early postoperative weight loss and sleeve calibre remained independently associated with achieving ≥ 20% TWL (**Table 4**). Increasing age reduced the likelihood of successful weight loss (adjusted OR 0.94, 95% CI 0.92–0.97; P < 0.001), whereas the absence of T2D increased the odds almost threefold (adjusted OR 2.99, 95% CI 1.74–5.16; P < 0.001). Early postoperative weight loss remained the strongest predictor (adjusted OR 1.25 per 1% increase in %TWL, 95% CI 1.17–1.34; P < 0.001). The quadratic association between sleeve calibre and weight-loss outcome also remained significant after adjustment (adjusted OR 1.69, 95% CI 1.01–2.82; P = 0.044).

Operative period was not independently associated with the primary outcome.

The multivariable model demonstrated good discrimination, with an area under the receiver operating characteristic curve (AUC) of 0.80 (95% CI 0.70–0.89) (**Supplementary Table 3**).

Predictors of postoperative erosive esophagitis

Postoperative EE was identified in 119 patients (23.1%). EE demonstrated a weak positive correlation with %TWL at 12 months (Spearman r = 0.131, P = 0.003). In univariable analysis (**Supplementary Table 4**), male sex (OR 1.80, 95% CI 1.10–2.95; P = 0.019), complete fundal mobilisation (OR 2.81, 95% CI 1.46–5.40; P = 0.002), shorter antrectomy distance, narrower sleeve calibre, sleeve fixation and stapling closer to the incisura angularis were associated with postoperative EE.

In the multivariable model (Table 5), increasing age (adjusted OR 1.04, 95% CI 1.01–1.08; P = 0.014), greater %TWL at 3 months (adjusted OR 1.11, 95% CI 1.05–1.19; P < 0.001) and sleeve calibre remained independently associated with EE. Sleeve calibre demonstrated the strongest association, with tighter sleeves associated with substantially greater odds of postoperative EE (adjusted OR 5.21, 95% CI 2.73–9.94; P < 0.001). Male sex and T2DM were not independently associated with EE after adjustment. The multivariable EE model demonstrated acceptable discrimination (AUC 0.71, 95% CI 0.59–0.82).

Table 4
Predictors for TWL ≥ 20%.

Independent variables	**OR**	**95% CI**	**p value**
	Adjusted		
	Multivariable (AUC = 0.80, 95% CI 0.70–0.89)		
Age (years)	0.943	(0.918, 0.969)	< 0.001*
T2D status			
Yes (reference)			
No	2.99	(1.74, 5.16)	< 0.001*
Operative period			
2008–2012	0.485	(0.178, 1.32)	0.157
2013–2017	1.21	(0.632, 2.31)	0.567
2018–2022 (reference)			
Early percent total weight loss at 1 month	1.25	(1.17, 1.34)	< 0.001*
Stapling - sleeve tightness (quadratic trend) across ordinal levels:	1.69	(1.01, 2.82)	0.044*
Loose			
Tight			
Very tight			

Table 5: Predictors for erosive esophagitis post-LSG.

Independent variables	OR	95% CI	p value
	Adjusted		
	Multivariable (AUC = 0.71, 95% CI 0.59–0.82)		
Age (years)	1.04	(1.01, 1.08)	0.014*
Gender			
Female (reference)			
Male	1.9	(0.987, 3.66)	0.055
T2D status			
Yes (reference)			
No	1.92	(0.938, 3.93)	0.074
Operative period			
2008–2016	0.772	(0.31, 1.92)	0.577
2017–2022 (reference)			
Early percent total weight loss at 3 months	1.11	(1.05, 1.19)	< 0.001*
Stapling - sleeve tightness (linear trend) across ordinal levels:	5.21	(2.73, 9.94)	< 0.001*
Loose			
Tight			
Very tight			

Model performance and statistical power

The multivariable model predicting successful weight loss included five predictors and 577 outcome events, yielding an events-per-variable (EPV) ratio of 115. Simulation-based power analysis (1,000 replications) demonstrated excellent statistical power (> 98%) for age, T2D status and early postoperative %TWL. Power for operative variables, including sleeve calibre and operative period, ranged from 26% to 55%, reflecting their comparatively smaller effect sizes.

The multivariable model for postoperative EE included 119 events (EPV 23.8). Simulation analyses demonstrated excellent power (> 95%) for sleeve calibre and early postoperative %TWL, moderate power for age (73%), and lower power for sex, T2D, operative period and the quadratic sleeve-calibre term.

Discussion

In this single-centre cohort study, both patient-related and surgeon-specific technical factors were associated with clinically meaningful weight loss and postoperative EE following LSG. Younger age, absence of type 2 diabetes mellitus, greater early postoperative weight loss, and surgeon-specific sleeve calibre were independently associated with achieving ≥ 20% TWL at 12 months. Conversely, tighter sleeve construction, shorter antrectomy distance and stapling closer to the incisura angularis were associated with an increased risk of postoperative EE. Together, these findings suggest that although technical variation influences postoperative outcomes, achieving an appropriate balance between effective gastric restriction and preservation of normal gastric physiology is equally important.

Patient factors remain important determinants of weight-loss success after LSG. Increasing age and the presence of T2D were independently associated with a lower likelihood of achieving clinically meaningful weight loss, consistent with previous studies demonstrating reduced metabolic response in older individuals and patients with longstanding diabetes [9]. These findings reinforce the importance of appropriate patient counselling and optimisation of metabolic control before surgery. In contrast, early postoperative weight loss emerged as the strongest predictor of long-term success, supporting its role as an early clinical marker for identifying patients who may benefit from intensified dietary, behavioural or pharmacological intervention.

Among the operative variables evaluated, sleeve calibre demonstrated the strongest association with both weight-loss efficacy and postoperative EE. Interestingly, our analysis identified a quadratic relationship between sleeve calibre and weight-loss outcomes, suggesting that both relatively loose and excessively tight sleeves were associated with less favourable results, whereas an intermediate sleeve calibre produced the highest likelihood of achieving successful weight loss. These findings support the concept that optimal sleeve construction extends beyond simple bougie size and is influenced by the overall geometry of the gastric sleeve.

Previous studies have similarly reported improved weight loss with more aggressive gastric resection and shorter antrectomy distance [10–12]. A smaller residual gastric reservoir may reduce gastric compliance and caloric intake, while excessive antral preservation has been associated with subsequent gastric dilatation and weight regain [13, 14]. However, our findings also demonstrate the potential trade-off between maximizing restriction and increasing reflux-related complications.

Postoperative EE occurred in almost one-quarter of patients and was independently associated with tighter sleeve calibre, shorter antrectomy distance and stapling closer to the incisura angularis. These observations are biologically plausible. Excessive narrowing of the gastric sleeve may increase intragastric pressure, impair gastric emptying and disrupt the normal anti-reflux barrier, thereby predisposing patients to reflux and oesophageal mucosal injury. Likewise, excessive narrowing near the incisura angularis may contribute to functional obstruction and proximal gastric pressurisation. Importantly, sleeve calibre demonstrated a substantially stronger association with EE than any patient-

related factor, suggesting that meticulous sleeve construction may represent one of the few modifiable determinants of postoperative reflux.

These findings have several practical implications for bariatric surgeons. First, they support careful attention to sleeve geometry rather than focusing solely on bougie size during LSG. Second, they suggest that constructing an excessively tight sleeve to maximise weight loss may not be desirable because any incremental improvement in weight reduction may be offset by a considerably greater risk of postoperative reflux and erosive esophagitis. Instead, our data support the concept of balanced sleeve construction that achieves adequate restriction while preserving favourable gastric emptying and reducing reflux-related complications.

The present study has several strengths. All procedures were performed within a single high-volume bariatric centre using standardized multidisciplinary perioperative care, thereby minimizing variability in patient selection, postoperative management and follow-up. Unlike previous video-based studies that evaluated isolated operations, surgeon-specific technical characteristics were derived from multiple representative procedures, providing a more comprehensive assessment of habitual operative practice. Furthermore, postoperative reflux was evaluated using objective endoscopic evidence of erosive esophagitis rather than symptom-based questionnaires, which have previously been shown to correlate poorly with endoscopic findings after LSG.

Several limitations should be acknowledged. First, the retrospective observational design precludes causal inference, and the identified associations should be interpreted as hypothesis-generating rather than evidence of direct cause-and-effect relationships. Second, surgeon-specific technical assessment was based on qualitative evaluation of representative procedures rather than patient-level quantitative measurements. Although this approach was designed to characterize each surgeon's habitual operative technique and consensus was reached between two independent bariatric surgery fellows, sleeve calibre remains a subjective assessment without a validated intraoperative measurement. Third, the participating surgeons were evaluated using representative procedures, which may not capture every technical variation over the 14-year study period, although all surgeons maintained a highly standardized operative approach within a high-volume bariatric programme. Finally, despite adjustment for operative period in the multivariable analyses, subtle temporal changes in surgical instrumentation, perioperative management and operative experience over time cannot be completely excluded.

Future prospective multicentre studies incorporating objective intraoperative measurements of sleeve geometry, three-dimensional imaging or artificial intelligence-assisted video analysis may provide a more reproducible method for evaluating technical variation and further refine the optimal balance between weight-loss efficacy and reflux prevention following LSG.

In conclusion, within a standardized high-volume bariatric programme, both patient characteristics and surgeon-specific technical variation were associated with postoperative outcomes following LSG. Younger age, absence of T2D, greater early postoperative weight loss and balanced sleeve calibre were associated with successful weight loss, whereas tighter sleeve construction and shorter antrectomy

distance were associated with a higher risk of postoperative erosive esophagitis. These findings suggest that meticulous sleeve construction should aim to balance adequate gastric restriction with preservation of normal gastric physiology, thereby optimising weight-loss outcomes while minimising reflux-related complications. Prospective studies using objective assessment of sleeve geometry are required to validate these observations and establish evidence-based recommendations for sleeve construction.

Declarations

Competing Interests

The authors declare no competing financial interests

Contributions

W.K.W., E.C., K.L.F., J.Q.L., C.L., T.L., Z.J.L., A.E., E.L., W.H.C., J.T., O.G., H.C.T., P.C.L., J.S., and C.H.L. contributed to the conception and design of the study, and/or acquisition, analysis, and interpretation of data. W.K.W. and C.H.L. were responsible for the overall study conceptualisation and supervision. E.C., K.L.F., and J.Q.L. contributed to study design and data acquisition. C.L., T.L., Z.J.L., A.E., E.L., W.H.C., and J.T. contributed to data acquisition, clinical interpretation, and manuscript drafting. O.G. and S.T. contributed to study interpretation and methodological oversight. H.C.T., P.C.L., and J.S. provided critical revision of the manuscript for important intellectual content. All authors reviewed the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

Conflict of Interest

Wai Kit Wong, Ellis Cheong, Kang Ler Fong, Jie Qi Lim, Ciaran Lim, Tiffany Lye, Zhen Jin Lee, Alvin Eng, Eugene Lim, Weng Hoong Chan, Jeremy Tan, Orlanda Goh, Sarah Tan, Hong Chang Tan, Phong Ching Lee, Jacqueline Sim and Chin Hong Lim declare that they have no competing interests related to this work.

Ethical Approval

The study was approved by the SingHealth Centralised Institutional Review Board (CIRB). The requirement for informed consent was waived because of the retrospective analysis of de-identified clinical data.

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Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

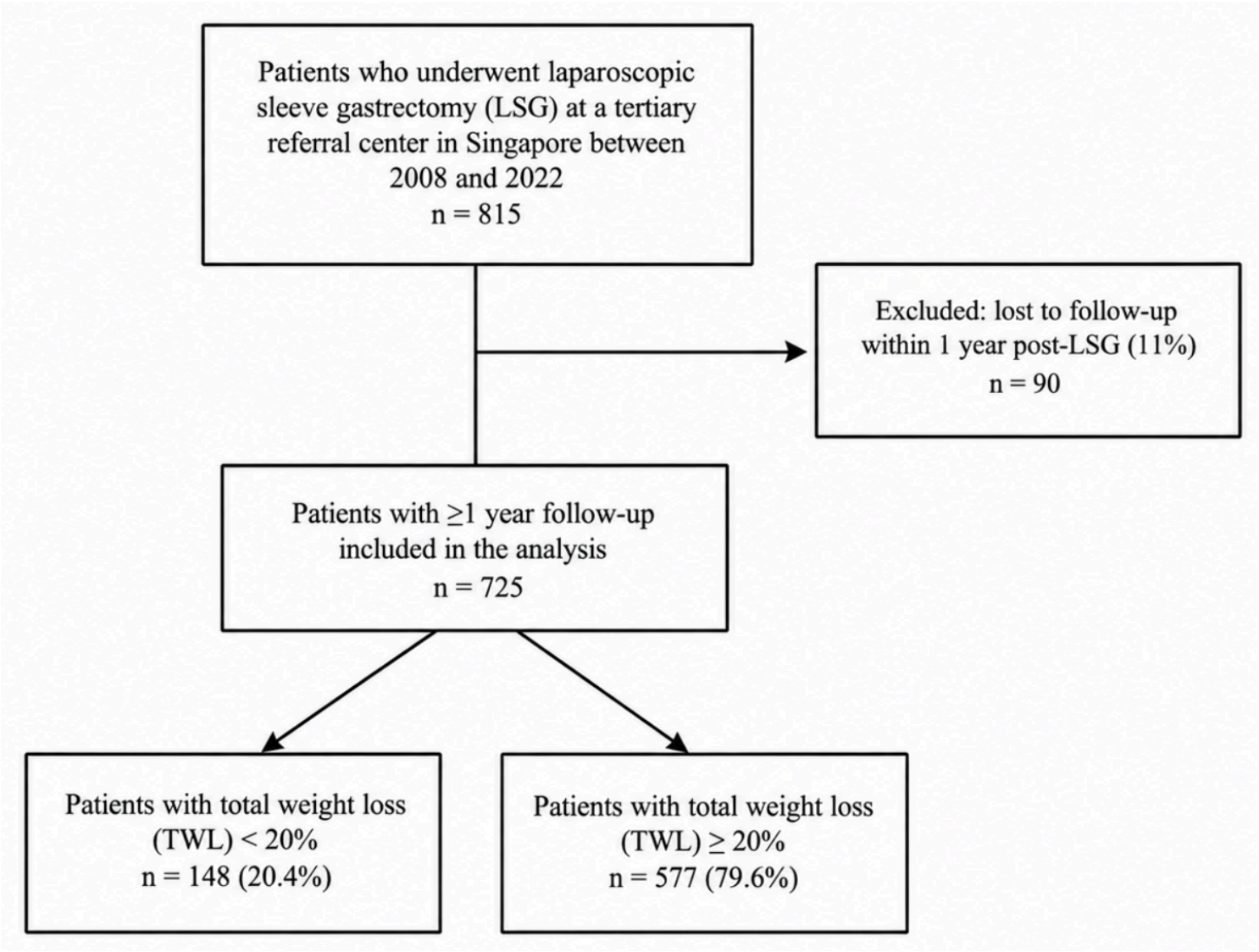


Figure 1

Flow diagram of patient’s inclusion and exclusion criteria.

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