JMBS
Journal of Metabolic and Bariatric Surgery

J Metab Bariatr Surg 2020;9(2):42-51
https://doi.org/10.17476/jmbs.2020.9.2.42

ORIGINAL ARTICLE

Morphologic Study of Gastric Sleeves by CT Volumetry at One Year after Laparoscopic Sleeve Gastrectomy

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Purpose: Laparoscopic sleeve gastrectomy (SG) is now frequently performed as a definitive bariatric procedure. The aim of the study was to evaluate the detailed morphology of remnant stomachs after SG with respect to volume and sleeve migration. **Materials and Methods:** We performed a retrospective review of prospectively collected data on patients that completed a 12-month postop examination, which included CT volumetry of sleeve, and a questionnaire that addressed postop food tolerance. CT volumetry study included total sleeve volume (TSV), tube volume (TV), antral volume (AV), tube/antral volume ratio (TAVR), and the presence of intrathoracic sleeve migration (ITSM). **Results:** Fifty-five patients were included in this retrospective study. Mean %TWL (% total weight loss) at 12 months postop was 32.8% (14.3-55.5), and mean TSV, TV, AV, and TAVR were 166.6±63.3 ml, 68.9±35.4 ml, 97.7±42.9 ml, and 0.8±0.6 respectively. TSV was not correlated significantly with %TWL at 12 months postop (r=−0.069, P=0.619). Fourteen patients (14/55, 25.5%) showed ITSM by CT. Patients with ITSM had a significantly lower mean GER score (5.1±2.0 vs. 7.3±2.0, P=0.001), a lower total food tolerance score (21.6±3.8 vs. 24.4±4.6, P=0.048), and a higher proportion showed suboptimal weight loss (35.7% vs. 9.8%, P=0.023). **Conclusion:** Mean TSV was not found to be significantly correlated with %TWL at 12 months postop. Patients with suboptimal weight loss had higher mean TAVR, and the presence of ITSM indicated more frequent GER symptoms, lower food tolerance, and a higher probability of suboptimal weight loss.

Key Words: Sleeve gastrectomy, CT volumetry, Weight loss, Hiatal hernia

INTRODUCTION

Laparoscopic sleeve gastrectomy (SG) is now frequently performed as a definitive bariatric procedure. In 2014, SG became the most widely performed types of bariatric surgery worldwide, and in 2016, it maintained its predominance by accounting for more than 50% of all primary bariatric interventions [1,2]. This increase in the popularity of SG appears to be due to its technical simplicity and lower morbidity and mortality rates than Roux-en-Y gastric bypass or adjustable gastric band surgery. However, SG has the potential drawbacks of weight regain and gastroesophageal reflux disease (GERD), which may develop de novo or be aggravated postoperatively in those with preoperative GERD. Rates of weight regain and unsuccessful weight loss after SG at mid/long-term follow-up are relatively high [3], and rates of *de novo* GERD after SG of between 5 and 69% have been reported [4]. We hypothesized these two issues are related to morphologic changes of the gastric sleeve,

Received: October 7, 2020, Revised: November 2, 2020, Accepted: November 3, 2020
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and thus, we undertook a CT volumetry study at 12 months after SG. The aim of the study was to evaluate detailed morphologies of remnant stomachs after SG with respect to residual volume and hiatal hernia as represented by intra thoracic sleeve migration (ITSM). In addition, we compared patient groups in terms of GI quality of life as assessed using food tolerance scores determined using a questionnaire.

MATERIALS AND METHODS

This single-center study was conducted by reviewing the prospectively collected data of patients who completed a 12-month postop examination after SG. Surgery was performed by a single surgeon (S.M.K) at the Gil Medical Center (Gachon University, Incheon, South Korea) from Jan 1 2019 to Jun 30 2019. All study procedures were in accord with the ethical standards of our institutional committee and with the 1964 Declaration of Helsinki and its later amendments. The guidelines issued by the Asian Consensus Meeting on Metabolic Surgery (ACMOM 2008, Trivandrum, India) for BMI restriction using bariatric surgery (http://www.acmoms.com/acmom_2008.html) were followed throughout. Postoperative examinations included measurement of anthropometric change (Body Fat Index), comprehensive metabolic panels, upper GI endoscopy, CT volumetry of gastric sleeve, and completion of a questionnaire about postoperative food tolerance and GER.

1. Surgical techniques for SG

After gastrolysis of the greater omentum from the greater curvature, a Bougie (36 Fr) was inserted to guide gastric resection, which was performed using five to seven 60 mm staples (green load in initial firing and blue loads for subsequent applications). First firing of the stapler was started at 6 cm from pylorus, and final firing saved about 1 cm lateral to the angle of His. We did not perform seromuscular reinforcement along the staple line. If present, hiatal defects were closed anteriorly and posteriorly using several non-absorbable sutures (2-0 Ethibond®; Ethicon, Somerville, NJ, USA).

2. CT volumetry study

All CT scans were interpreted by the same radiologist (S.J.C). Stomach volumes were measured by CT volumetry with 3D reconstruction after fasting for at least 4 hours. CT examinations were performed after administering effervescent granules (Top®; Taejoon Pharmaceuticals, South Korea) to distend the remnant stomach. CT images were acquired using a 128-detector CT scanner (Somatom Definition Flash, Siemens Healthcare, Germany) and reconstructed with 3D-volume rendering to calculate remnant gastric volumes from cardia to pylorus using dedicated software (Syngo.via, VA 30A®; Siemens Healthineers) in transverse images of slice thickness 5 mm. Variables measured included total sleeve volume (TSV), tube volume (TV), antral volume (AV), and tube/antral

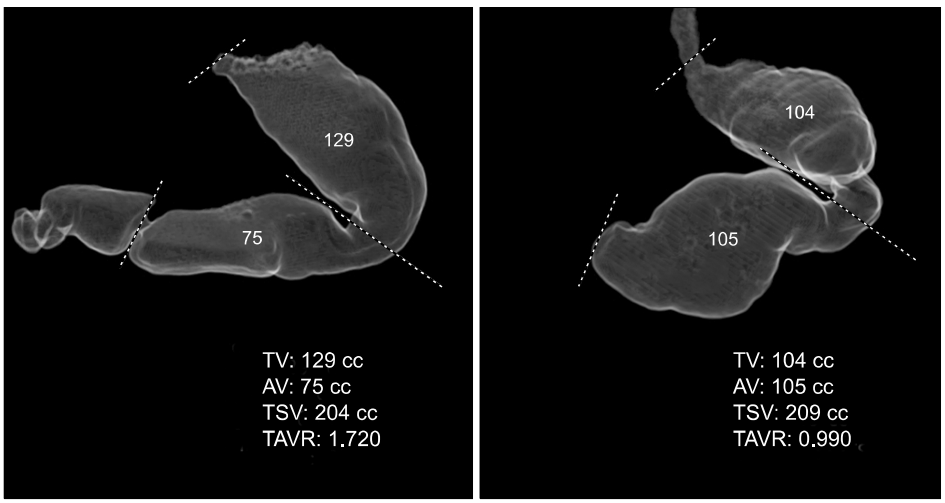

Fig. 1. Stomach volumes were measured by CT volumetry with 3D reconstruction. CT examinations were performed after administering effervescent granules. Variables measured included total sleeve volume (TSV), tube volume (TV), antral volume (AV), and tube/antral volume ratio (TAVR). TSV was defined as total sleeve volume from the top of a staple line to the pylorus; TV as the volume of the sleeve portion from the top of the staple line to incisura angularis; AV as the volume of the sleeve portion from incisura angularis to pylorus; and TAVR was defined as TV/AV.

volume ratio (TAVR), and the presence of intrathoracic sleeve migration (ITSM) was also noted. TSV was defined as total sleeve volume from the top of a staple line to the pylorus; TV as the volume of the sleeve portion from the top of the staple line to incisura angularis; AV as the volume of the sleeve portion from incisura angularis to pylorus; and TAVR was defined as TV/AV (Fig. 1). ITSM was defined as the presence of a staple line above the diaphragmatic crus in coronal CT view (Fig. 2).

3. Food tolerance/GER questionnaire

Food tolerance and HVR (heartburn, vomiting, and regurgitation) scores were calculated using a questionnaire, as previously described [5,6]. Three sections of this tool provide a total score for food tolerance, which was measured as follows:

1) Patient satisfaction with quality of current eating (scored between 1 (very poor) and 5 (excellent)).

2) Degree of tolerance for eight food types (i.e., red meat, white meat, salad, vegetables, bread, rice, pasta, and fish). Scores for food types ranged from 0–2, where 0 means the food could not be eaten at all, 1 means eaten with some difficulty, and 2 means eaten without difficulty. Scores for this section were then summed, and thus, ranged from a minimum of 0 to 16.

3) HVR frequency scores ranging from 0 to 9, where 0 means "on medication", 1 means "often" (>2×/week), 2 means "rarely" (≤2×/week), and 3 means "never."

Cumulatively, these scores ranged from 1 to 30, where a score of 1 indicated extremely poor quality of eating and a score of 30 indicated maximum food tolerance.

Data were analyzed using SPSS Ver. 11.5 (SPSS Inc., Chicago, IL, USA). Continuous variables are presented as means±standard deviations and were compared using T-test or one-way ANOVA for independent samples, whereas categorical variables are presented as percentages (%). Categorical variables were compared using Pearson's Chi-squared or Fisher's exact test, as appropriate. All tests were two-tailed, and statistical significance was accepted for P-values of <0.05. Results are presented as means± SDs or as numbers (percent), as indicated. The study was approved beforehand by our institutional review board (GFIRB2020-406).

RESULTS

From Jan 1 2019 to Jun 30 2019, 195 patients underwent primary or revisional (concurrent gastric band removal) laparoscopic SG, of these 195, 55 patients completed the

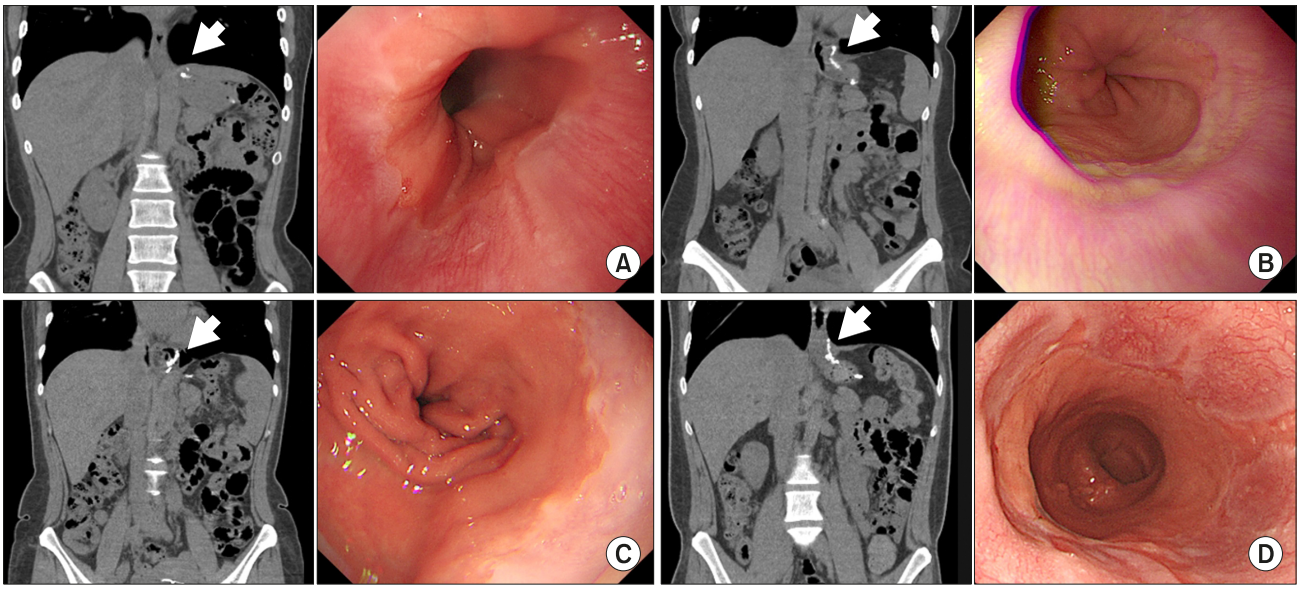

Fig. 2. ITSM was defined as the presence of staple line (arrows) above diaphragmatic crus in coronal CT view. (A) ITSM(−). (B–D) ITSM(+).

12-month postoperative examination, and these patients were enrolled in this study.

Table 1. Demographic/anthropometric data, CT volumetry results, and food tolerance scores of the 55 study subjects at 1 year after laparoscopic sleeve gastrectomy (n=55)

Demographic/anthropometric data	
Gender (F:M)	45 (81.8%):10 (18.2%)
Age (y)	35.0±7.5 (21-51)
Preoperative BMI (kg/m^2)	39.2±6.0 (30.1-56.1)
%TWL at postop 1 year	32.8±7.9 (14.3-55.5%)
n (TWL at 1 year <25%)	9/55 (16.4%)
CT volumetry	
TSV (cc)	166.6±63.3 (47-337)
TV (cc)	68.9±35.4 (12-183)
AV (cc)	97.7±42.9 (23-256)
TAVR	0.802±0.593 (0.207-4.276)
ITSM, n (%)	14/55 (25.5%)
Food tolerance and HVR	
Food satisfaction score (1-5)	3.9±1.0 (1-5)
Specific food tolerance score (0-16)	
Redmeat	1.7±0.5 (1-2)
Whitemeat	1.7±0.5 (1-2)
Salad	1.9±0.3 (1-2)
Vegetables	1.8±0.4 (1-2)
Bread	1.7±0.4 (1-2)
Rice	1.3±0.5 (0-2)
Noodles	1.4±0.7 (0-2)
Fish	1.8±0.4 (1-2)
HVR score (0-9)	
Heartburn	2.2±1.0 (0-3)
Regurgitation	2.2±1.0 (0-3)
Vomiting	2.3±0.8 (1-3)
Total Food tolerance score (0-30)	23.7±4.5 (10-30)

1. Demographic/anthropometric data, gastric morphology, and food tolerance

For all 55 study subjects, the female to male (F:M) ratio (%) was 45 (81.8%):10 (18.2%). Mean patient age was 35.0±7.5 years (21-51), and mean preoperative BMI (kg/m^2) was 39.2±6.0 kg/m^2 (30.1-56.1). Mean %TWL at 1 year postop was 32.8±7.9% (14.3-55.5%), and 9 patients (16.4%) showed suboptimal weight loss (TWL of <25%). CT volumetry at 12 months postop showed mean TSV (cc) was 166.6±63.3 cc (47-337), TV (cc) was 68.9±35.4 (12-183), AV (cc) was 97.7±42.9 (23-256), and mean TAVR was 0.802±0.593 (0.207-4.276), respectively. ITSM was present in 14 patients (25.5%). Mean food satisfaction score was 3.9±1.0 (1-5) and mean HVR scores were 2.2±1.0 (0-3) for heartburn, 2.2±1.0 (0-3) for regurgitation, and 2.3±0.8 (1-3) for vomiting, respectively. The mean total food tolerance score was 23.7±4.5 (10-30) (Table 1).

2. Correlation between residual stomach volume and weight loss/GER/food Tolerance at 12 months after LSG

%TWL at 12 months postop was poorly correlated with TV, AV, TSV, and TAVR (r= −0.067, −0.046, −0.069, and −0.126, respectively). When patients were divided into two %TWL groups (<25% or >25%), the only significant difference found was that TAVR was greater in

Table 2. Correlation between volume parameters (TV, AV, TSV, and TAVR) and weight loss (%TWL)/food tolerance (TFT)/GER (HRV) at 12 months after laparoscopic sleeve gastrectomy (n=55)

	TV	AV	TSV	TAVR
%TWL				
Correlation (r)	−0.067	−0.046	−0.069	−0.126
P	0.627	0.740	0.619	0.360
%TWL >25%	67.6±37.4	99.0±44.4	166.6±67.6	0.73±0.36
%TWL <25%	75.4±23.3	91.0±35.5	166.4±36.6	1.17±1.21
P	0.553	0.613	0.991	0.043
TFT				
Correlation (r)	0.270	0.185	0.277	0.052
P	0.046	0.176	0.041	0.708
HRV				
Correlation (r)	0.139	0.068	0.124	0.011
P	0.311	0.621	0.367	0.934

TV = Tube volume, AV = Antral volume, TSV = Total sleeve volume, TAVR = Tube antral volume ratio, %TWL = Total weight loss, TFT = Total food tolerance score, HRV = Total HRV (heartburn, regurgitation, vomiting) score.

patients with a %TWL of <25% (1.17±1.21 vs. 0.73±0.36, P =0.043) (Table 2, Figs. 3, 4). We also looked at the correlation between food tolerance/ gastroesophageal reflux and TSV, TV, AV, TAVR, and found positive correlation between total food tolerance score and tube volume (r=0.271, P=0.046) (Table 2).

3. Correlation between the presence of ITSM and food tolerance/gastroesophageal reflux

Fourteen (25.5%) of the study subjects were diagnosed with ITSM at 12 months postop. We compared patients with or without ITSM (ITSM (−) (n=41) vs. ITSM (+) (n=14)) in terms of perioperative clinical features, weight loss, CT volumetry and endoscopic findings, and food tolerance scores. Mean age (years) (34.2±7.4 vs. 37.4±7.7, respectively), female to male ratio (34:7 vs 11:3), mean preoperative BMI (kg/m^2) (40.1±6.3 vs 36.5±4.0), numbers of concurrent LSG+AGB removals (5/41 (12.2%) vs. 3/14 (21.4%)), numbers of HH repairs (4/41 (9.75%) vs 4/14 (28.6%)), and %TWLs (33.7±7.5 vs 0.1±9.0, respectively, P=0.149) were not significantly different in the ITSM (−) and (+) groups. However, the percentage of patients with suboptimal weight loss (TWL at 1 year <25%) [7] was significantly higher in the ITSM (+) group (4/41 (9.8%) vs 5/14 (35.7%), P=0.023). Means TSVs (cc), as determined by CT volumetric analysis, were not significantly different (173.5±64.5 vs. 146.5±57.1, P=0.170), and neither were mean TVs (cc), AVs (cc), or mean TAVRs (72.1±37.6 vs. 59.5±27.3, P=0.255, 101.4±43.4 vs. 87.0±41.1, P=0.281, and 0.81±0.66 vs. 0.78±0.37, P=0.872, respectively). Endoscopic findings revealed higher grade reflux esophagitis in the ITSM (+)

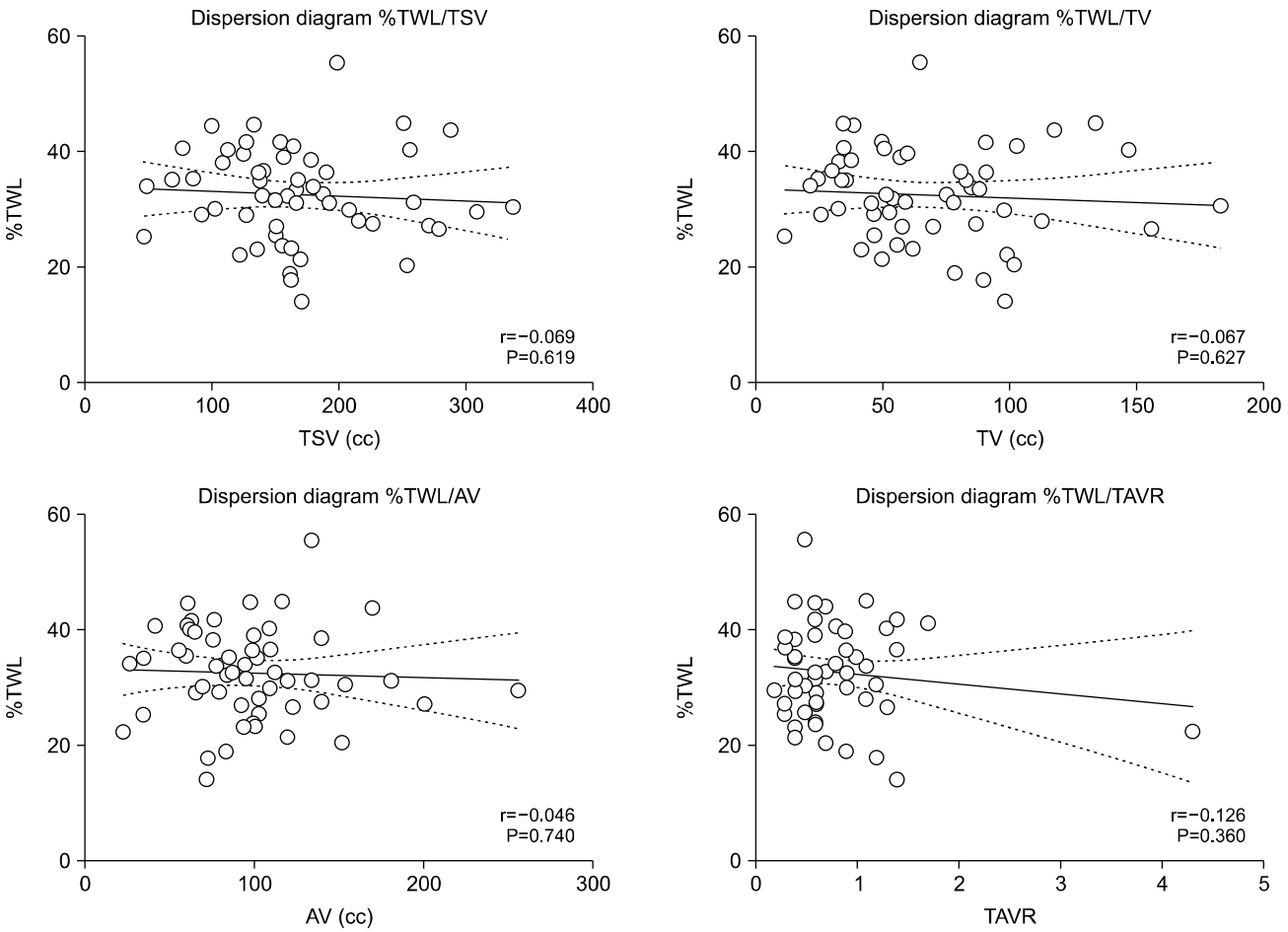

Fig. 3. Dispersion diagrams of %TWL associated with TSV (total sleeve volume), TV (tube volume), AV (antral volume), and TAVR (tube antral volume ratio).

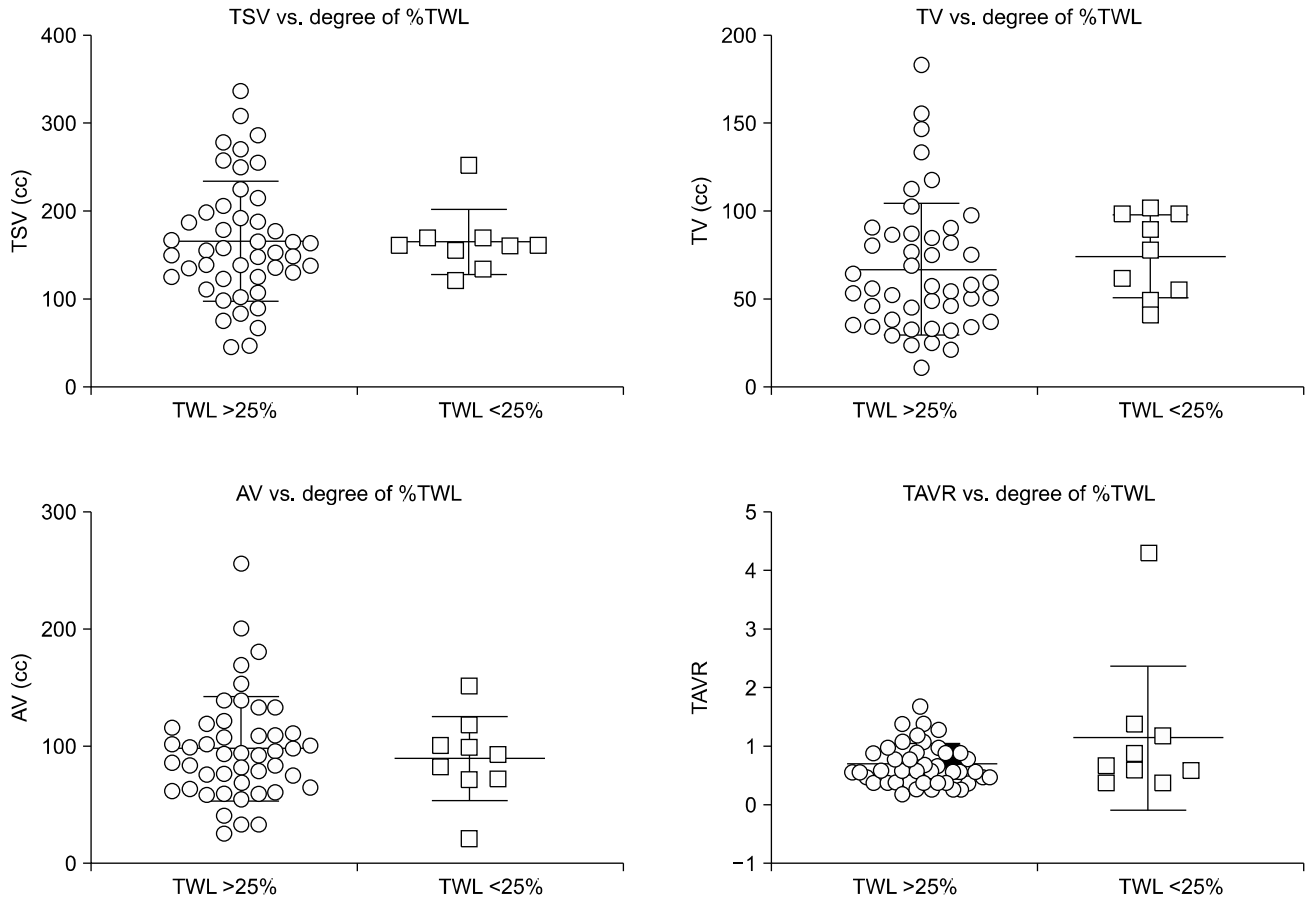

Fig. 4. When patients were divided into two %TWL groups (>25% or <25%) at 12 months postop, the only significant difference found was that TAVR was significantly higher in patients with a TWL of <25% (1.17±1.21 vs. 0.73±0.36, P=0.043).

group (LA grade (M/A/B/C) numbers were 34/9/1/0 in the ITSM (−) group and 3/5/6/0 in the ITSM (+) group, P=0.000). Group general food satisfaction scores were not significantly different (4.0±0.9 vs. 3.6±1.0, P=0.132). Group specific food tolerance scores were similar, but summed HRV scores (H+R+V) were significantly different (7.3±2.0 vs. 5.1±2.0, P=0.001). Heartburn (2.5±0.9 vs 1.4±0.9, P=0.000), regurgitation (2.4±0.9 vs.1.7±1.1, P=0.032), and vomiting (2.5±0.7 vs. 2.0±0.9, P=0.060) were more frequent in the ITSM (+) group. In addition, the mean total food tolerance score was significantly higher in the ITSM (−) group (24.4±4.6 vs. 21.6±3.8, P=0.048) (Table 3).

DISCUSSION

The most important mechanism for effecting weight loss after SG is to reduce stomach volume, and thus, the correlation between stomach volume and weight loss has received much research attention. In this study, we found RGV after laparoscopic SG measured at 12 months postoperatively was not significantly correlated with %TWL, but that intrathoracic gastric sleeve migration was significantly associated with suboptimal weight loss (defined as %TWL <25 at 1 year) and food tolerance as determined by symptoms (heartburn, vomiting, reflux) associated with GER.

Some contradictory short-term results have been published about the correlation between RGV as measured by CT volumetry and weight loss after SG. Hanssen et al. [8] observed a significant relationship

Table 3. Perioperative clinical features, weight losses, CT volumetry results, endoscopic findings, and food tolerance scores according to the presence of intrathoracic sleeve migration

	ITSM(−) (n=41)	ITSM(+) (n=14)	P-value
Age (yr)	34.2±7.4	37.4±7.7	0.168
F:M, n	34:7	11:3	0.715
Preopertive BMI (kg/m^2)	40.1±6.3	36.5±4.0	0.057
LSG+AGB removal	5/41 (12.2%)	3/14 (21.4%)	0.396
Repair of HH	4/41 (9.75%)	4/14 (28.6%)	0.085
%TWL 1 year	33.7±7.5	30.1±9.0	0.149
n (TWL <25%)	4/41 (9.8%)	5/14 (35.7%)	0.023
CT volumetry			
TSV (cc)	173.5±64.5	146.5±57.1	0.170
TV (cc)	72.1±37.6	59.5±27.3	0.255
AV (cc)	101.4±43.4	87.0±41.1	0.281
TAVR	0.81±0.66	0.78±0.37	0.872
Endoscopy			
LA-M/A/B/C	31/9/1/0	3/5/6/0	0.000
Food satisfaction	4.0±0.9	3.6±1.0	0.132
Specific food tolerance			
Redmeat	1.7±0.5	1.6±0.5	0.787
Whitemeat	1.7±0.5	1.7±0.5	0.707
Salad	1.9±0.3	1.7±0.5	0.040
Veggie	1.9±0.4	1.7±0.5	0.251
Bread	1.8±0.4	1.6±0.5	0.134
Rice	1.2±0.5	1.3±0.5	0.797
Noodle	1.4±0.7	1.4±0.6	0.946
Fish	1.8±0.4	1.9±0.3	0.222
HRV score (H+R+V)	7.3±2.0	5.1±2.0	0.001
Heartburn (H)	2.5±0.9	1.4±0.9	0.000
Regurgitation (R)	2.4±0.9	1.7±1.1	0.032
Vomiting (V)	2.5±0.7	2.0±0.9	0.060
Total food tolerance score	24.4±4.6	21.6±3.8	0.048

between RGV and %EWL at 6 months after SG and reported that a RGV of ≥100 ml at 6 months after SG was associated with poor %EWL. Elbanna et al. [9] also observed that RGV was negatively correlated with %EWL at 6 months postoperatively (r=−0.7495, P< 0.00001), thus had a significant impact on %EWL after SG. On the contrary, Pawanindra et al. [10] suggested early post-operative weight loss (at 3 months) correlated well with the volume of the excised stomach but not with that of the RGV. Disse et al. [11] in a CT volumetric study observed that dilatation of the gastric sleeve was not necessarily linked to an increase in daily caloric intake or insufficient weight loss during the first 18 months following surgery. In a longer-term study, it was concluded that RGV was probably correlated with weight loss. In another CT volumetric study, Bakr et al. [12] observed patients that experienced weight regain after SG had a median RGV of 515 ml (range 172-1066 ml), and that CT estimated RGV was negatively correlated with %EWL (r=−0.674, P=0.008). Others have suggested that RGV is the most important factor of long-term weight regain after LSG [13,14].

In the present study, we chose to use a 12-month outcome to evaluate gastric volumes and weight losses because; 1) maximal weight loss usually occurs during the year following SG and 2) it is known that incidence of reflux symptoms is greatest during the first year after SG [15-17]. Our observations suggest that degree of weight loss during the first postoperative year is correlated with intrathoracic sleeve migration rather than residual gastric volume *per se*. Furthermore, we believe our results are more reliable than other studies on the correlation between gastric volume and weight loss that used similar short-term outcomes because all operations in the present

study were performed by a single surgeon with experience of around 300 cases of LSG. Thus, the same surgical strategies were used for SG, including the use of 36 Fr bougies, gastric resection starting at 6 cm from pylorus, no imbrication of the staple line, and aggressive repair of hiatal defects. Furthermore, all operations were performed over a period of only 6 months and no complications such as stenosis or fistula occurred.

In this study, intrathoracic sleeve migration was frequently observed on 1 year CT scans (14/55 (25.5%)). ITSM is referred to as transhiatal herniation of the stomach during conventional endoscopy, and relatively few studies have addressed ITSM after LSG [18-20]. Patients with ITSM by CT in our study had a significantly lower mean GER score (5.1±2.0 vs. 7.3±2.0, P=0.001) and mean total food tolerance score (21.6±3.8 vs. 24.4±4.6, P=0.048), and a significantly higher proportion exhibited suboptimal weight loss (35.7% vs. 9.8%, P=0.023).

ITSM is essentially hiatal herniation (HH) of the gastric sleeve into the thorax. In the presence of HH, the LES (lower esophageal sphincter) is displaced proximally, which leads to spatial separation (splitting) of the intrinsic LES from the extrinsic compression by the diaphragm. Consequently, the resting LES pressure decreases in proportion to the size of the HH. The proximal displacement of the LES in the presence of an HH further compromises the competence of the gastrointestinal junction owing to the loss of the intra-abdominal segment of the LES, because the intra-abdominal location of the LES per se is considered to serve as a valve by being exposed to positive abdominal pressure [21,22]. In our cohort of patients having ITSM, this LES splitting phenomenon might result in significantly higher incidence of heartburn and regurgitation, but not vomiting, consequently significantly lower HRV scores (5.1±2.0 vs. 7.3±2.0, P=0.001, Table 3).

GER and suboptimal weight loss after LSG have also been reported. Chronic GERD often influences dietary intake and may increase the likelihood of maladaptive eating. Furthermore, some patients turn to eating or drinking as means of providing symptom relief, which can obviously lead to excess calorie intake and subsequent weight gain [23].

Given that ITSM is associated with suboptimal weight loss and GER after SG, it would seem gastroesophageal

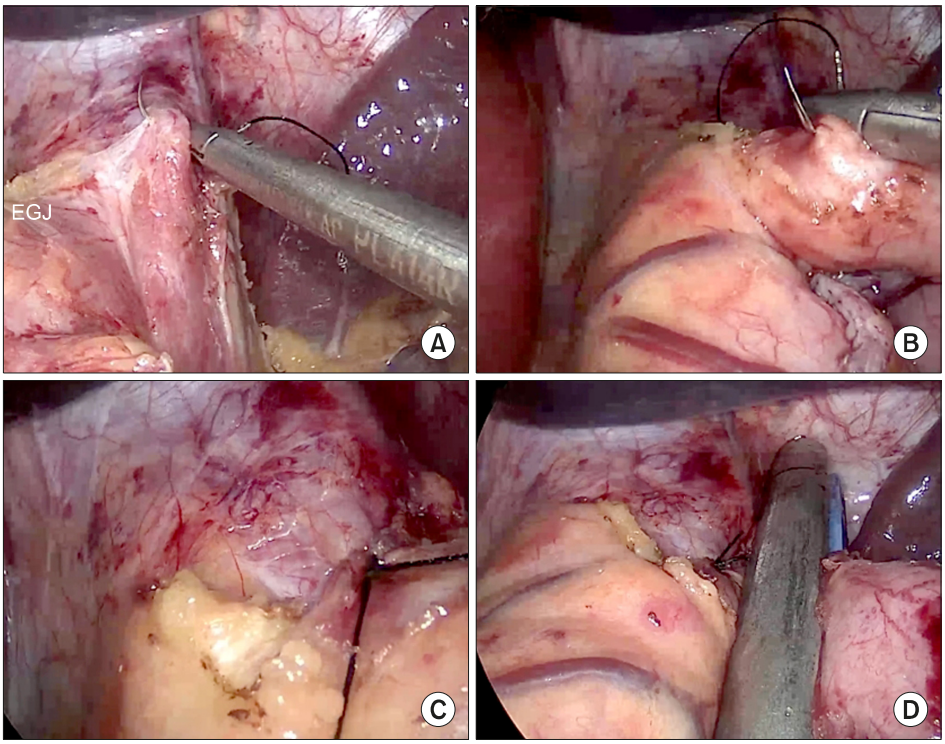

Fig. 5. Fundocrural fixation. After clearing the fat pad around the angle of His, the diaphragmatic crura is fixed with fundus (A-C), and then final closure is performed (D). Theoretically, FCF stabilizes the angle of His and prevents thoracic migration of the upper part of gastric sleeve. EGJ = esophagogastric junction.

reflux symptoms are a primary driver of patient satisfaction with SG [24], and thus it would be valuable to find a means of preventing ITSM after LSG. We speculate the cause of ITSM is multifactorial and that it is caused by functional disturbance of food passage and resulting proximal dilatation, which causes gastric elongation as well as dilatation. The upper part of an elongated gastric tube may migrate through weakened hiatus, as possibly facilitated by negative intrathoracic pressure and a diminished fat pad around the hiatus. A few studies have described the use of gastropexy for the prevention of gastric rotation after SG [25,26], and claimed this mitigates GER by achieving good staple line alignment in the gastric sleeve. Likewise, we suggest fundocrural fixation (FCF) for preventing sleeve migration though the hiatus (Fig. 5). Currently, we are performing a prospective study on the effect of SG with/without FCF on ITSM, and therefore, on the development of *de novo* GER after SG.

In conclusion, in the present study, mean total sleeve volume was not found to be significantly correlated with %TWL at 12 months postop. However, patients showing suboptimal weight loss had a significantly higher mean TAVR. Furthermore, the presence of ITSM indicated more frequent GER symptoms, lower food tolerance, and a higher probability of suboptimal weight loss at one year postop, during which maximal weight loss occurs after SG.

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