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ORIGINAL SCIENTIFIC REPORT

Geometry of Sleeve Gastrectomy Measured by 3D CT Versus Weight Loss: Preliminary Analysis

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Abstract

Background The size of the remnant stomach with respect to weight loss failure after laparoscopic sleeve gastrectomy (LSG) remains controversial. This study aimed to evaluate the impact of the actual size and volume of the remnant stomach, as measured by three-dimensional computed tomography (3D-CT) volumetry, on weight loss after LSG.
Methods The clinical outcomes of 52 patients who underwent LSG between October 2008 and February 2019 were assessed. Weight metrics were recorded at 1, 3, and 6 months and 1 year postoperatively. 3D-CT volumetry was performed 1 year postoperatively, and the total remnant stomach volume (TSV), proximal stomach volume (PSV), antral stomach volume (ASV), and the distance between the pylorus and the distal edge of staple line (DPS) were measured. The relationship between the weight metrics and aforementioned factors was analyzed.
Results Of the 52 patients who underwent LSG, 40 patients participated in this study. The average body mass index preoperatively was 38.3 ± 5.1 kg/m^2, and the average percentage of total weight loss (%TWL) 1 year after LSG was 26.6 ± 9.3%. The average TSV, PSV, ASV, and DPS were 123.2 ± 60.3 ml, 73.4 ± 37.2 ml, 49.8 ± 30.3 ml, and 59.9 ± 18.5 mm, respectively. The DPS ($r = -0.394$, $p = 0.012$) and ASV ($r = -0.356$, $p = 0.024$) were correlated with %TWL 1 year postoperatively.
Conclusions The actual DPS and ASV measured by 3D-CT affected weight loss after LSG. 3D-CT may be useful for the immediate identification of factors affecting insufficient weight loss in patients; this may, in turn, aid in the implementation of early intervention treatments.

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Introduction

Laparoscopic sleeve gastrectomy (LSG) has become the most popular bariatric/metabolic surgical procedure worldwide [1]. The average percentage of excess weight loss (%EWL) 5 years postoperatively was reported to be 60.5% based on a survey from the fifth international consensus conference that included 120 expert surgeons and was based on more than 1000 cases [2]. LSG has also been known to improve obesity-associated diseases such as type-2 diabetes mellitus (T2DM) [3–7], hypertension [7, 8], and dyslipidemia [7–9].

Conversely, several patients fail to achieve satisfactory weight loss after LSG. The rate of suboptimal weight loss or weight loss failure, which is defined as %EWL < 50–55% 1 year postoperatively or percentage of total weight loss (%TWL) <20%, was 10.9–25.1% [10–12]. Furthermore, weight loss failure leads to weight regain, and the rate of revisional surgery at more than 10 years after LSG due to significant weight regain ranged from 20.6 to 21.5% [13, 14]. However, the factors affecting weight loss after LSG have not been clearly identified. Early weight loss after LSG correlated with the mid-term weight loss effect after LSG [10, 11, 15]. Although several studies reported that the %EWL at 1 [10, 11], 3 [11], and 4 months [15] after LSG were postoperative predictors of weight loss, it remains unclear why weight loss during the early period affects mid-term weight loss after LSG [11].

There is controversy regarding the distance between the pylorus and the distal edge of the staple line (DPS) and antrectomy, which contributes to weight loss after LSG. In a randomized study, the LSG group in which the division was started 2 cm from the pylorus had a higher %EWL at 6, 12, and 24 months compared with the LSG group in which the division was started 6 cm from the pylorus [16]. On the other hand, it was reported that LSG with antral resection did not significantly contribute to a decrease in body mass index (BMI) at 12 months and 24 months compared with antral preservation [17].

A limited number of studies have investigated whether the actual anthropometric parameters of the remnant stomach, including the DPS, affect weight loss after LSG. This study aimed to investigate the impact of actual DPS and volume of the remnant stomach, as measured by 3D computed tomography (CT) volumetry, on weight loss after LSG.

Materials and methods

Patients

Fifty-two patients who underwent LSG at Shiga University of Medical Science (SUMS) Hospital in Japan between October 2008 and February 2019 were assessed for inclusion eligibility. Patients were followed-up by CT scan more than 1 year after LSG. The institutional ethical review board of SUMS hospital approved the study (Approval Number: 18-77-4, R2019-116), and all patients provided written informed consent. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The criteria for LSG were the same as that for bariatric surgery in Japan [18], which includes a BMI $\geq$ 35 kg/m^2, BMI $\geq$ 32 kg/m^2 with T2DM, or BMI $\geq$ 32 kg/m^2 with more than 2 comorbidities other than T2DM. Although this study is a retrospective one, demographic characteristics, weight metrics, laboratory tests, and comorbidities were prospectively recorded after informed consent was obtained.

All patients were enrolled in a preoperative educational program, which included an interview with the bariatric team comprising bariatric surgeons, endocrinologists, bariatric nurses, a national registered dietitian, and clinical psychologists. Patients received nutritional guidance by a national registered dietitian. Resting energy expenditure (REE) was measured using indirect calorimetry preoperatively (AE-310S, MINATO MEDICAL SCIENCE CO., LTD., Osaka, Japan).

Clinical data (including demographic characteristics, weight metrics, laboratory tests, and comorbidities) were collected and prospectively recorded on the day of the first visit, on the day of the surgery and at 1, 3, and 6 months and 1 year after LSG. Body weight before LSG was defined as the body weight measured just before the surgery on the day of the surgery. %TWL, for which the baseline was the body weight just before the surgery, was recorded.

Patients underwent a routine preoperative upper gastrointestinal contrast study, upper gastrointestinal endoscopy, abdominal CT, and dual-energy X-ray absorptiometry (DEXA, GE Healthcare, Madison, WI, USA). Fat mass and lean body mass were measured using DEXA. The length (L) and width (W) of the resected stomach portion were measured in the resected organ. The resected stomach was regarded as 2 circular cones; the volume of the resected stomach (V) was calculated as follows: V = L $\pi(W/2)^2/3$ (Fig. 1). 3D-CT was performed 1 year after LSG by our Department of Radiology as part of routine follow-up in the absence of any adverse events. The remnant stomach volumes and DPS were assessed after multiplanar reconstruction and 3D volume rendering reconstruction using the Aquarius Workstation iNtuition Edition (TeraRecon, San Mateo, CA, USA; Fig. 2a, b). All gastric CT data were analyzed by the same radiologist, who was blinded to the body weight and %TWL of the patients. The following parameters of the remnant stomach were assessed: total remnant stomach volume (TSV) and proximal stomach volume (PSV) (corresponding to the volume of the stomach from the gastroesophageal junction to the distal end of the staple line), antral stomach volume (ASV) (corresponding to the volume of the stomach from the distal end of the staple line to the pylorus), and DPS (corresponding to the distance between the pylorus and the distal edge of staple line).

Surgical technique

Two surgeons performed all LSG procedures as follows: 5 laparoscopic trocars were placed in the upper abdomen, establishing pneumoperitoneum at 10–12 mmHg. The greater omentum was dissected along the greater curvature of the stomach with an ultrasonic energy device (SonoSurg™: Olympus, Tokyo, Japan) or a vessel sealing device (Liga Sure™: Medtronic; Minneapolis, USA). After mobilizing the fundus and exposing the angle of His, the stomach wall was dissected using a 45-Fr. bougie with 60 mm endoscopic linear staplers (Echelon Flex™; Ethicon Endosurgery, USA). The dissection was started 5 cm from the oral side of the pylorus up to 1 cm on the distal side of the gastroesophageal junction (GEJ) using forceps that were 2.5 cm wide when fully opened in each case. The staple line was routinely reinforced by suturing using 2–0 nonabsorbable sutures.

Statistical analysis

Data distribution was tested for normality using the Shapiro–Wilk test. Descriptive results for the continuous variables were reported as mean ± standard deviation, as appropriate. Pearson's correlation coefficient (r) was calculated for the continuous variables to assess the association of the measured factors with weight loss after LSG. A p value <0.05 was deemed to be statistically significant. Statistical analysis was performed using SPSS version 25.0 for Windows (IBM Corp., Armonk, New York, USA).

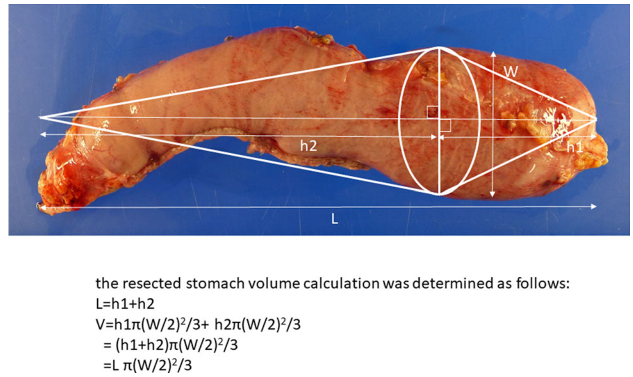

Fig. 1 The resected stomach was regarded as two circular cones; the volume of the resected stomach (V) was calculated as follows: V = L $\pi(W/2)^2/3$; L: length, W: width

Results and discussion

Fifty-two patients underwent LSG at SUMS hospital between October 2008 and February 2019. Forty of the 52 patients completed the study, and 12 patients were lost to follow-up 1 year after LSG (follow-up rate: 77%). Patient characteristics at baseline are presented in Table 1. The mean age was 43.1 ± 10.1 years; preoperative mean body weight, 105.1 ± 21.7 kg; and preoperative mean BMI, 38.3 ± 5.1 kg/m^2. Changes in BMI and %TWL are described in Fig. 3a, b. The %TWL at 1, 3, 6, and 12 months was 8.0 ± 3.6, 17.2 ± 5.8, 22.9 ± 8.3, and 26.6 ± 9.3%, respectively (Fig. 3b). The TSV, PSV, ASV, and DPS, as measured by 3D-CT volumetry, were 123.2 ± 60.3 ml, 73.4 ± 37.2 ml, 49.8 ± 30.3 ml, and 59.9 ± 18.5 mm, respectively (Table 2). The TSV and PSV did not correlate with the %TWL 1 year postoperatively (Fig. 4a, b); however, the ASV ($r = -0.356$, $p = 0.024$) and DPS ($r = -0.394$, $p = 0.012$) correlated with the %TWL 1 year postoperatively (Fig. 4c, d). Other factors, such as preoperative REE, preoperative HbA1c and C-peptide levels, and size of the resected stomach did not correlate with the %TWL 1 year postoperatively. The %TWL values at 1 month ($r = 0.451$, $p < 0.004$) and 3 months ($r = 0.656$, $p < 0.001$) after LSG also positively correlated with the %TWL 1 year postoperatively (Table 2). Frequency of vomiting at 1 year after LSG was 2.8 ± 4.0 times/week (Table 2), which did not correlate with remnant stomach measurements by 3D-CT volumetry, such as TSV, PSV, ASV, and DPS (Table 3).

Identifying factors that affect weight loss after LSG is important for the prevention of insufficient weight loss and the progression of treatment strategies for patients with weight loss failure after LSG. In this study, we showed that the actual DPS and ASV, as measured by 3D-CT volumetry, were associated with weight loss in the short to mid-term period after LSG.

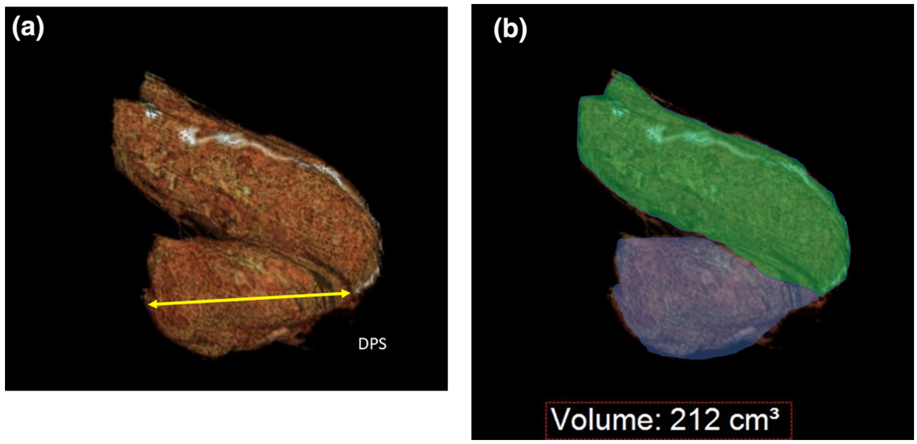

Fig. 2 **a** Measurement of the DPS (indicated by the yellow arrow) after 3D volume reconstruction; **b** sleeve volumes after 3D volume reconstruction *DPS* distance between the pylorus and distal edge of the staple line; *TSV* total remnant stomach volume, stomach volume indicated in green and blue; *PSV* proximal stomach volume, stomach volume indicated in green; *ASV* antral stomach volume, stomach volume indicated in blue; *3D* three-dimensional

Antrectomy, in which the staple is placed at a shorter distance from the pylorus, is often discussed with respect to weight loss in the mid-term after LSG. Abdalla et al. reported that patients with antrectomy showed greater weight loss than patients without antrectomy after LSG in a prospective randomized study [16]. In another prospective randomized study, patients in whom the initial section was 3 cm from the pylorus had better %EWL and %TWL at 3, 6, and 12 months postoperatively than patients with an initial Sect. 8 cm from the pylorus [19]. Although 3 other prospective randomized studies reported that LSG with and without antrectomy showed no difference in the %EWL at 1–2 years [17, 20, 21], a systematic review and meta-analysis reported that antral resection (< 2–3 cm) resulted in a higher %EWL at 24 months compared with antral preservation (>5 cm) (70% vs 61%) [22]. However, the volume and the relative parameters of the sleeve change with time after the surgery, and this may play an important role in weight loss after LSG.

Table 1 Patient characteristics

	N = 40
Age[a], years	43.1 ± 10.1
Female[b], %	24(60.0%)
Height, cm	165 ± 9
Body weight before surgery[a], kg	105.1 ± 20.7
BMI before surgery[a], kg/m^2	38.3 ± 5.1
Preoperative somatic fat volume[a], %	44.6 ± 5.8
Type 2 diabetes mellitus [b], %	25(62.5%)
Hypertension[b], %	23(57.5%)
Dyslipidemia[b], %	32(80.0%)
1-year %EWL[a], %	81.9 ± 34.1
1-year %TWL[a], %	26.6 ± 9.3
Leakage[b], %	1(2.5%)
Stricture[b], %	2(5.0%)
Mortality[b], %	0(0.0%)

SD standard deviation; *BMI* body mass index; *%EWL* % excess weight loss; *%TWL* % total weight loss

[a]Values are mean ± SD, [b]Values are number (%)

In the current study, 3D-CT volumetry was found to be a useful tool to assess the anthropometric measurements, such as the TSV, PSV, ASV, and DPS of the remnant stomach, and to investigate their association with weight loss after LSG. Our results were consistent with a previous report, which showed that a radical antrectomy with a small sleeve volume, evaluated using 3D-CT volumetry, improved weight loss after LSG [23]. To the best of our knowledge, there is no report that describes the correlation between the actual DPS (which is an important factor for dissection of the stomach during surgery), measured by 3D-CT volumetry and weight loss after LSG. Our preliminary results indicate that the %TWL 1 year postoperatively was significantly correlated with DPS and ASV. This fact indicates that the actual DPS and ASV measured by 3D-CT volumetry contribute to weight loss in the short to mid-term period after LSG.

Possible mechanisms underlying the effect of DPS on early and mid-term weight loss include a similar mechanism to that of the effect of antrectomy on early and mid-term weight loss. A previous report showed that gastric emptying was accelerated after LSG with antrectomy [24]. In addition, another report showed that the speed of gastric emptying was greater in the antrectomy group (with a DPS of 3 cm) than in the group without antrectomy (with a DPS of 8 cm) [25]. The greater speed of gastric emptying is

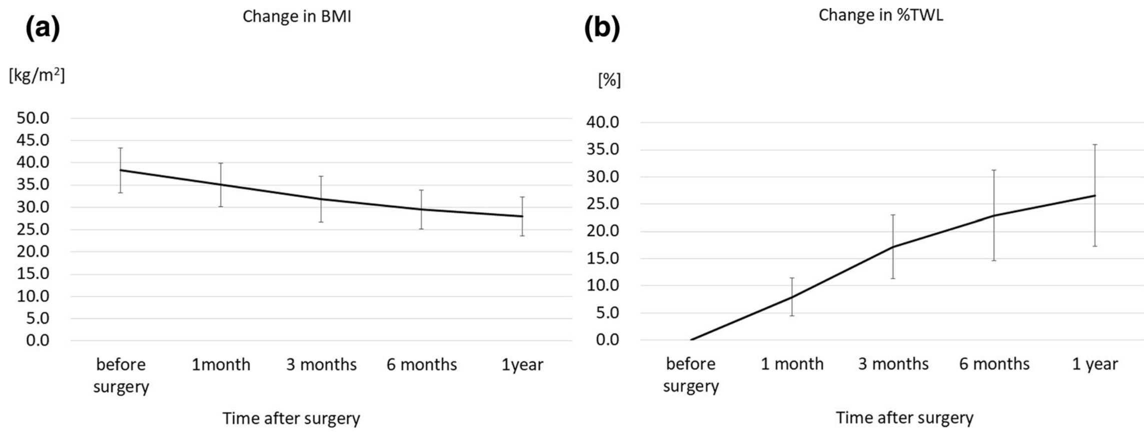

Fig. 3 **a** Change in the BMI; **b** Change in the %TWL, *BMI* body mass index; *%TWL* percentage of total weight loss

Table 2 Correlation between continuous variables and 1-year %TWL

	Value	1-year %TWL	
		r	*P* value
Age[a], years	43.1 ± 10.1	−0.311	0.051
Height[a], cm	165 ± 9	0.057	0.727
Body weight before surgery[a], kg	105 ± 21	0.249	0.121
BMI before surgery[a], kg/m^2	38.3 ± 5.1	0.305	0.055
Preoperative HbA1c[a], %	7.1 ± 1.9	−0.162	0.317
Preoperative C-peptide[a], (ng/ml)	2.7 ± 1.1	0.118	0.473
Preoperative somatic fat volume[a], %	44.6 ± 5.8	0.228	0.187
Preoperative REE[a]	1728 ± 354	−0.017	0.918
Resected stomach measurements			
Resected stomach, length, mm[a]	267.6 ± 33.9	−0.042	0.812
Resected Stomach, width, mm[a]	54.6 ± 8.4	−0.260	0.138
Resected stomach, volume, cm^3[a]	216.1 ± 77.2	−0.260	0.138
Remnant stomach measurements			
Total remnant stomach volume (TSV)[a], ml	123.2 ± 60.3	−0.240	0.136
Proximal stomach volume (PSV), ml	73.4 ± 37.2	−0.053	0.745
Antral stomach volume (ASV)[a], ml	49.8 ± 30.3	−0.356	0.024
Distance between pylorus and distal edge of staple line (DPS)[a], mm	59.9 ± 18.5	−0.394	0.012
Body weight metrics			
1-month %TWL[a], %	8.0 ± 3.6	0.451	0.004
3-month %TWL[a], %	17.2 ± 5.8	0.656	<0.001
6-month %TWL[a], %	22.9 ± 8.3	0.770	<0.001
Frequency of vomiting at 1 year after LSG[a], times/week	2.8 ± 4.0	−0.041	0.813

%TWL % total weight loss; *BMI* body mass index; *REE* resting energy expenditure; *LSG* laparoscopic sleeve gastrectomy, *r*, Pearson's correlation coefficient

[a]Values are mean ± SD

considered to result in earlier satiety and as such, increased weight loss [26].

Our results indicated that the volume of the resected stomach did not correlate with weight loss after LSG. These results were consistent with those of previous reports [27–29]. The resected gastric volume, which was measured by filling with tap water, was not a predictor of the %EWL 6 and 12 months postoperatively [27]. The size of the

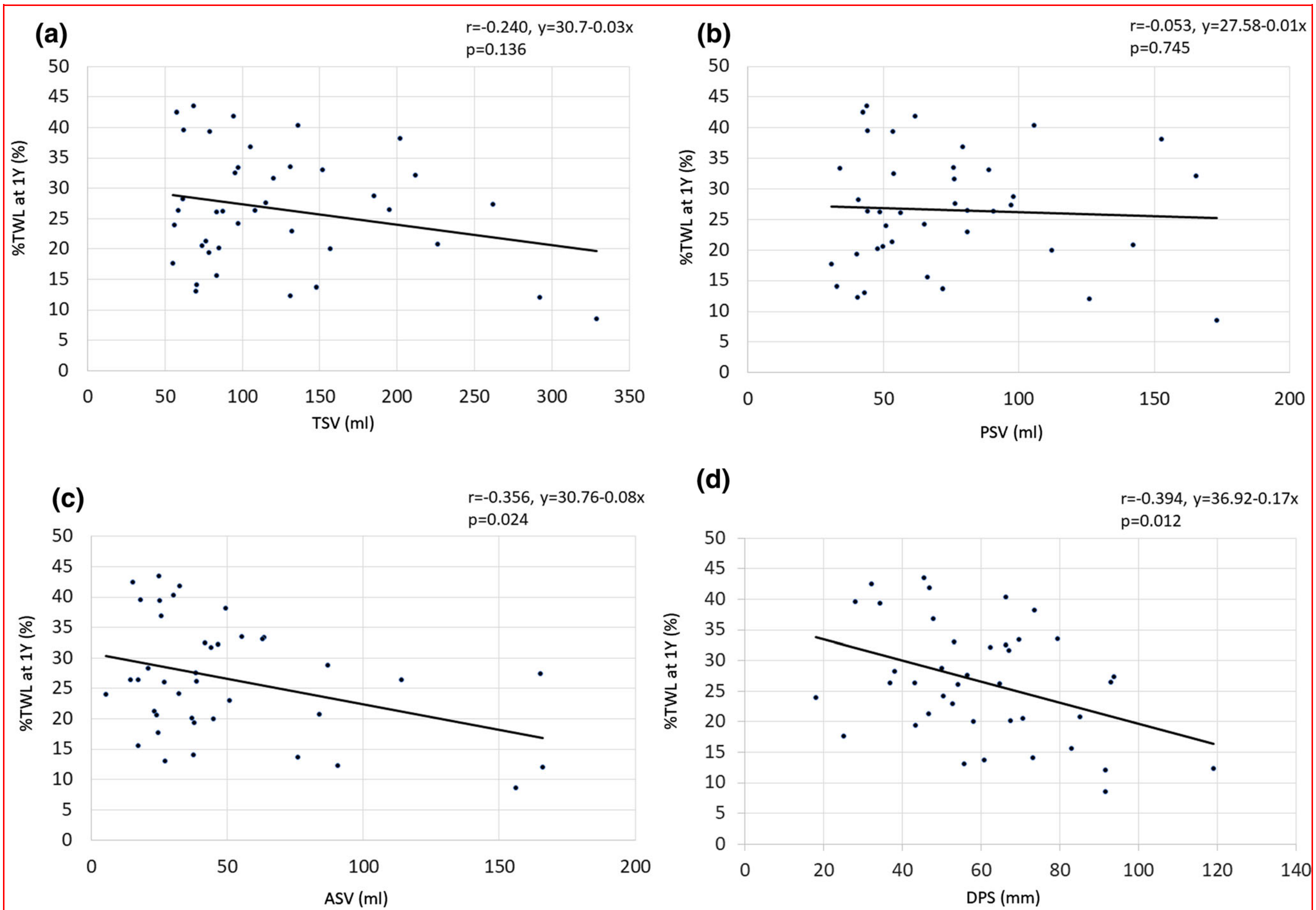

Fig. 4 **a** Correlation between the TSV and %TWL at 1 year postoperatively; **b** Correlation between the PSV and %TWL at 1 year postoperatively; **c** Correlation between the ASV and %TWL at 1 year postoperatively; **d** Correlation between the DPS and %TWL at 1 year postoperatively, *TSV* total remnant stomach volume; *%TWL* percentage of total weight loss; *PSV* proximal stomach volume; *ASV* antral stomach volume; DPS: distance between the pylorus and distal edge of the staple line

Table 3 Correlation between measurements of 3D-CT volumetry and frequency of vomiting

	Frequency of vomiting at 1 year after LSG	
	r	*P* value
Remnant stomach measurements		
Total remnant stomach volume (TSV)	0.152	0.377
Proximal stomach volume (PSV)	0.137	0.424
Antral stomach volume (ASV)	0.130	0.450
Distance between pylorus and distal edge of staple line (DPS)	−0.065	0.706

LSG laparoscopic sleeve gastrectomy; *r* Pearson's correlation coefficient

resected stomach, which was calculated by CT-volumetry, was not associated with the %EWL 6 months postoperatively [28].

Despite our surgical protocol, which indicates that the DPS was 5 cm, the actual DPS varied. Two factors may account for this variability. First, it is possible that the incision of the greater curvature started from different distances in individual cases, and as such, the DPS would not have been precisely 5 cm. However, we measured 5 cm in every case and started stapling the stomach from that point. Second, although the DPS was precisely 5 cm in the surgery, the DPS changed with time. This may account for the different outcomes reported in randomized studies on antrectomy. Further studies are needed to clarify the variability in the DPS postoperatively.

There is a concern that shorter DPS induces vomiting and leakage after LSG. In the literature, although LSG with shorter DPS is reported to worsen food tolerance at 3 and 6 months postoperatively [20], LSG with shorter DPS did not increase the frequency of leakage [17, 22]. In this study, frequency of vomiting at 1 year did not correlate with any of the measurements of 3D-CT volumetry, including DPS and ASV. Leak occurred (at the proximal side of the remnant stomach) in only 1 case, in which actual DPS was 46.7 mm. In this case, stricture developed after leak. There was another case of stricture, with an actual DPS of 32.3 mm. In both cases, endoscopic balloon dilatation was successfully performed within 6 months after LSG. Although shorter DPS did not lead to vomiting at 1 year postoperatively, we cannot conclude that shorter DPS induces adverse events such as leak and stricture, since the number of cases studied was less.

From our results, the actual DPS and ASV appear to play an important role in limiting weight loss after LSG. 3D-CT was found to be useful for the immediate identification of factors resulting in poor weight loss after bariatric surgery, which can help surgeons and other team members consider medical or surgical interventions. Re-sleeve gastrectomy with shorter DPS may be one of the potential surgical interventions for patients who fail to lose enough weight after LSG. It has been reported that resection of residual fundus or "neo-fundus," not antrum, is important for re-sleeve gastrectomy [30, 31]. Our findings indicate that we should focus on actual DPS and ASV for revisional surgery, and not just residual fundus or "neo-fundus." Actual remnant stomach size and volume measured by 3D-CT volumetry might help select the appropriate intervention treatment, such as re-sleeve gastrectomy or bypass surgery, for patients with insufficient weight loss after LSG.

Limitations

The present study has some limitations that include a small sample size, the single-center nature of the study, the short follow-up duration, and lack of a control group with the first staple at a shorter distance from pylorus. Further studies are necessary to demonstrate that the actual DPS and ASV are factors that have a significant influence on weight loss for longer periods after LSG.

Conclusion

The actual DPS and ASV, as measured by 3D-CT, impacted on weight loss after LSG. 3D-CT would be useful for the immediate identification of factors affecting insufficient weight loss, which can aid the planning of intervention treatments. In addition, it is expected that the procedure for forming a remnant stomach will be developed further with time, and as such, will be more efficacious for a longer period of time after the surgery.

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Compliance with ethical standards

Conflict of interest None of the authors has any conflict of interest or any financial ties to disclose.

Informed consent Written informed consent was obtained from all individual participants included in the study.

Human and Animal Rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The institutional ethical review board of Shiga University of Medical Science Hospital approved the study (Approval Number: 18-77-4, R2019-116).

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