



# Sleeve Volume and Preoperative Gastric Volume Assessment Using Three-dimensional MDCT Gastrography and Their Correlation to Short-term Post-Sleeve Gastrectomy Weight Loss

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## Abstract

**Purpose** Several factors including preoperative stomach capacity and sleeve volume impact weight loss after laparoscopic sleeve gastrectomy (LSG). We aimed at measuring these volumes using multidetector computed tomography (MDCT) gastrography and correlating them with postoperative weight losses.

**Materials and Methods** Morbidly obese patients prepared for LSG during 2018 were included in the study. MDCT gastrography was performed 1 week before, 6 and 12 months after LSG. Preoperative gastric volume and postoperative sleeve volumes were measured. Correlation with preoperative BMI and postoperative %TWL was performed. The change in sleeve volume at 6 and 12 months was assessed.

**Results** A total of 98 patients (62 F) were included. Mean preoperative BMI was  $47 \pm 7$  kg/m<sup>2</sup>. Follow-up was achieved in 89 patients (91%) and 82 patients (83%) at 6 and 12 months, respectively. Mean %TWL was  $24 \pm 3$  and  $32.8 \pm 3$  at 6 and 12 months, respectively ( $p < 0.05$ ). Preoperative gastric volume ranged from 800 to 1800 ml (mean  $\pm$  SD,  $1310 \pm 307$ ) and dropped significantly to range from 140 to 170 ml ( $158 \pm 9$ ) and from 165 to 210 ml ( $181 \pm 12$ ) at 6 and 12 months postoperatively, respectively. Pouch was not significantly dilated at 12 vs. 6 months postoperatively. Preoperative gastric volume was significantly correlated with preoperative BMI ( $p = 0.006^*$ ) but not with postoperative weight losses. Correlation between postoperative pouch volumes and weight losses at 6 and 12 months postoperatively showed no significance.

**Conclusion** Sleeve pouch is significantly smaller than preoperative stomach, but not significantly correlated to weight loss. Restriction is an important, but not the only factor controlling weight loss after LSG.

**Keywords** MDCT gastrography · Sleeve gastrectomy · Sleeve volume

## Introduction

Laparoscopic sleeve gastrectomy (LSG) is currently the most commonly performed bariatric procedure worldwide [1–3]. In a recent report, sleeve gastrectomy represented almost 60% of the worldwide bariatric practice in the time period from 2015 to 2018 [1]. This is mainly attributed to its excellent outcomes

in terms of weight loss and resolution of comorbidities [1, 2] with lower complication rates and nutritional deficiencies compared with other malabsorptive procedures [2, 4]. Accordingly, factors behind its mechanism of action are always being assessed. Of those, preoperative stomach capacity and sleeve volume have been a matter of concern, and a sleeve pouch volume of around 100 ml has been proposed by many authors as being adequate for a satisfactory outcome [5–7]. Langer et al. proposed sleeve dilatation as a major factor behind weight regain after LSG [8]. However, dilatation is not always associated with weight regain and it was not proved whether dilatation is a true cause of weight regain or a normal postoperative physiological process [9, 10]. Neurohormonal as well as other changes have been described to contribute also in postoperative weight loss [7, 11, 12]. Accordingly, we aimed in this study at assessing preoperative and

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postoperative stomach volumes using multidetector computed tomography (MDCT) gastrography and correlating these data with weight losses at 6 and 12 months.

## Patients and Methods

### Study Design and Patient Selection

From January to December 2018, all morbidly obese patients prepared for elective LSG at the research institute in Alexandria, Egypt, and willing to be included in this prospective observational study signed an informed consent explaining the operative procedure and the study protocol. The study protocol was approved by the IRB of Alexandria University, Egypt. All included patients conformed to the INH consensus criteria [13]. All patients were thoroughly prepared and investigated before the procedure. MDCT gastrography was performed 1 week before LSG. Prophylactic low-molecular-weight heparin was injected subcutaneously the night before the procedure. Patients with prior bariatric interventions were excluded from the study. All patients who developed during the study any conditions necessitating radiological assessment were excluded from further MDCT evaluation and accordingly from the study to avoid additional radiation exposure.

### Operative Technique

All procedures were performed by one surgeon. Dissection of the gastric greater curvature started 5 cm proximal to the pylorus up to the angle of His. Gastric pouch was calibrated over a 36-Fr orogastric bougie. Gastric stapling was started about 4 cm proximal to the pylorus and sparing 1 cm lateral to the angle of His.

### Postoperative Regimen

All patients were discharged on the first postoperative day in absence of complications. Postoperative follow-up was routinely scheduled after 1, 3, 6, 9, 12 months, and then once yearly. At each visit, weight loss was expressed in terms of % total weight loss (%TWL, defined as the percentage of the total weight that was lost postoperatively) and % excess weight loss (%EWL, defined as the percentage of the excess weight that was lost postoperatively). At 6 and 12 months postoperatively, follow-up MDCT gastrography was performed.

### Technique of MDCT Gastrography

MDCT gastrography was performed on 64 detectors, multi-detector CT scanner (Siemens SOMATOM® Perspective, Siemens Medical Solutions, Malvern, PA). Patients were instructed to fast for at least 4 h before examination and given

intravenous injection of 40 mg butylscopolamine then asked to swallow 2 to 4 packs of effervescent granules (sodium bicarbonate) as tolerated on table with no water. Image acquisition was performed in spine position and limited to the stomach which is adequately inflated with gas on the topogram. Scans were acquired using the least radiation dose with the following parameters: 80 KV, 125 mA,  $32 \times 0.6$  mm collimation, with 1 mm slice thickness reconstruction using SAFIRE iterative reconstruction. Data were transferred to a dedicated 3D workstation. Three-dimensional volume-rendering images were created by a combination of manual and semi-automatic segmentation tools. Different masks were created to represent the various relevant structures in different colors. The volume of the stomach (in preoperative series) and the sleeve pouch was measured on multiplanar reformations. Volume of the resected stomach was estimated by subtracting the pouch volume at 6 months postoperatively from the preoperative stomach volume, putting in consideration that intraoperative sleeve pouch construction was standardized throughout the study. The whole procedure was performed and interpreted in all patients by one radiologist.

### Outcome of the Study

The primary outcome of the study was the correlation between the volume of the sleeve pouch (measured in ml by MDCT) and weight loss (expressed as %TWL and %EWL) at 6 and 12 months postoperatively. Other outcomes were (1) correlation of preoperative gastric volume (measured in ml by MDCT) with height and preoperative BMI, (2) correlation between preoperative gastric volume and postoperative weight loss at 6 and 12 months, (3) correlation between resected stomach volume and postoperative weight loss at 6 and 12 months, (4) the change in pouch volume measured in milliliter at 6 and 12 months postoperatively.

### Statistical Analysis

Data was collected and fed into the personal computer. Statistical analysis was done using Statistical Package for Social Sciences (SPSS/version 20) software. Arithmetic mean, standard deviation, to compare between two group Student's *t*-test was used, while for more than two groups, ANOVA test was used. Pearson correlation coefficient (*r*) was used to find the association between two variables. The level of significance was 0.05.

## Results

The study included 98 patients (62 F, 63%). Mean age ( $\pm$  SD) in years at the time of LSG was  $41.8 \pm 8.5$  (range, 27–56). Associated co-morbidities included diabetes mellitus (41

patients, 42%), hypertension (39 patients, 40%), COPD (29 patients, 30%), and osteoarthritis (19 patients, 20%). Table 1 shows the anthropometric measurements of the study cohort at baseline, as well as at 6 and 12 months postoperatively. No significant gender differences were noticed as regards %TWL throughout the study. At 6 months, %TWL ranged from 19 to 27% ( $23.5 \pm 3.1$ ) in male patients and from 20 to 28% ( $23.8 \pm 2.7$ ) in female patients ( $p = 0.472$ ). At 12 months, %TWL ranged from 26.3 to 38.8% ( $32.7 \pm 2.9$ ) in male patients and from 27 to 38% ( $32 \pm 3$ ) in female patients ( $p = 0.285$ ).

Eighty-nine patients (91%) and 82 patients (83%) completed the study follow-up protocol at 6 and 12 months, respectively. Nine patients did not complete the follow-up protocol at 6 months (4 patients did not attend follow-up visits and 5 patients developed complications necessitating CT abdominal assessment (early postoperative leakage in 3 patients and postoperative bleeding in 2 patients)). Those 9 patients were excluded from the study. Further, 7 patients did not complete the follow-up protocol at 12 months (6 patients did not attend follow-up visits and 1 patient developed trocar site hernia necessitating CT abdominal assessment before management). Those 7 patients were also excluded from the study. Preoperative gastric volume measured by MDCT ranged from 800 to 1800 ml (mean  $\pm$  SD,  $1310 \pm 307$ ). Resected stomach volume ranged from 650 to 1649 ml (mean  $\pm$  SD,  $1171 \pm 295$ ). Postoperative pouch volume measured by MDCT ranged from 140 to 170 ml (mean  $\pm$  SD,  $158 \pm 9$ ) and from 165 to 210 ml (mean  $\pm$  SD,  $181 \pm 12$ ) at 6 and 12 months postoperatively, respectively. Volumes measured at both 6 and 12 months postoperatively were significantly lower compared with baseline volume (ANOVA,  $p < 0.05$ ). However, there was no significant dilatation of pouch volume at 12 months vs. 6 months postoperatively.

Correlating preoperative gastric volume with preoperative BMI (Fig. 1) as well as with patient's height (Fig. 2) was significant. No significant correlation was shown between preoperative gastric volume and weight loss at 6 (Fig. 3) and 12 (Fig. 4) months postoperatively. Similarly, no significant correlation was shown between resected gastric volume and weight loss at 6 (Fig. 5) and 12 (Fig. 6) months postoperatively. Correlation between postoperative pouch volumes and weight losses at 6 (Fig. 7) and 12 (Fig. 8) months postoperatively showed no significance.

## Discussion

Over the last years, LSG proved to be an efficient bariatric procedure, in terms of weight loss and resolution of obesity-related comorbidities. Gagner et al [14] reported %EWL results of 59.3%, 59%, 54.7%, 52.3%, 52.4%, and 50.6% after 1, 2, 3, 4, 5, and 6 years, respectively. Toro et al. showed that %EWL outcomes at 1, 3, 6, and 12 months reached 17%, 33%, 43%, and 54%, respectively. Our short-term results are consistent with those, with a mean %EWL of 56% and 66% (mean %TWL of 24% and 32%) at 6 and 12 months post-LSG, respectively. Mean BMI dropped significantly at 6 and 12 months compared with baseline value. Mean BMI, %TWL, and %EWL were significantly different at 12 vs. 6 months. Similar to other reports, no significant gender differences were noticed as regards %TWL [15].

The induced restrictive effect is one of the main mechanisms leading to weight loss [16]. However, other factors have been proposed. The primary aim in this study was to investigate whether the volume effect of the stomach before the

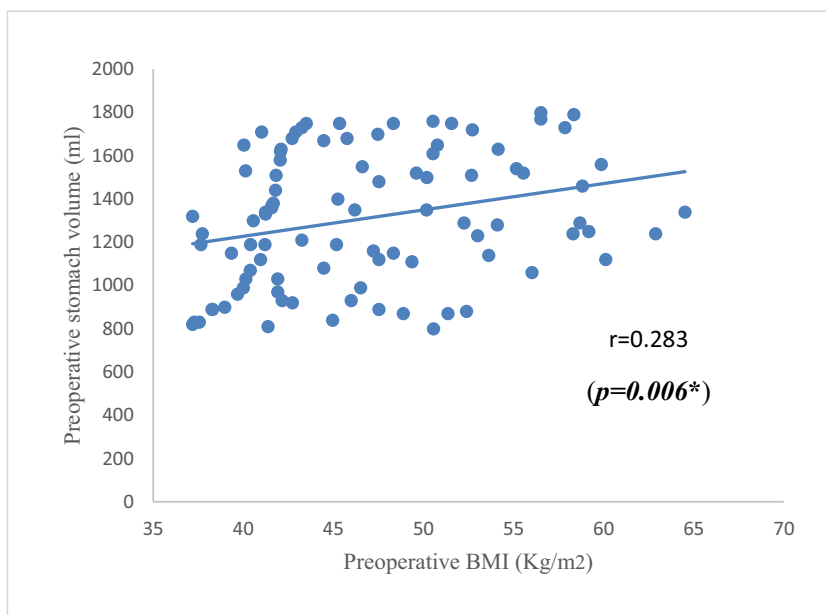
**Table 1** Anthropometric measurements of the study cohort at baseline, at 6, and 12 months postoperatively

	Preoperative ( $n = 98$ )	At 6 months postoperatively ( $n = 89$ )	At 12 months postoperatively ( $n = 82$ )
Weight (kg)			
Mean $\pm$ SD	131 $\pm$ 16.8*	100 $\pm$ 13* <sup>§</sup>	88 $\pm$ 12* <sup>§</sup>
Range	99–165	77–134	68–122
BMI (kg/m <sup>2</sup> )			
Mean $\pm$ SD	47 $\pm$ 6.9*	36 $\pm$ 5.2* <sup>§</sup>	31.8 $\pm$ 4.8* <sup>§</sup>
Range	37–62.5	27.5–47	24.5–43
%TWL			
Mean $\pm$ SD		24 $\pm$ 2.9**	32.8 $\pm$ 3***
Range		19–28	26.3–38.8
%EWL			
Mean $\pm$ SD		56 $\pm$ 8.8**	66.5 $\pm$ 7.5***
Range		39–65	54–79

\*<sup>§</sup>  $p < 0.05$  for ANOVA test

\*\* $p < 0.05$  for  $t$  test

**Fig. 1** Correlation between preoperative gastric volume with preoperative BMI



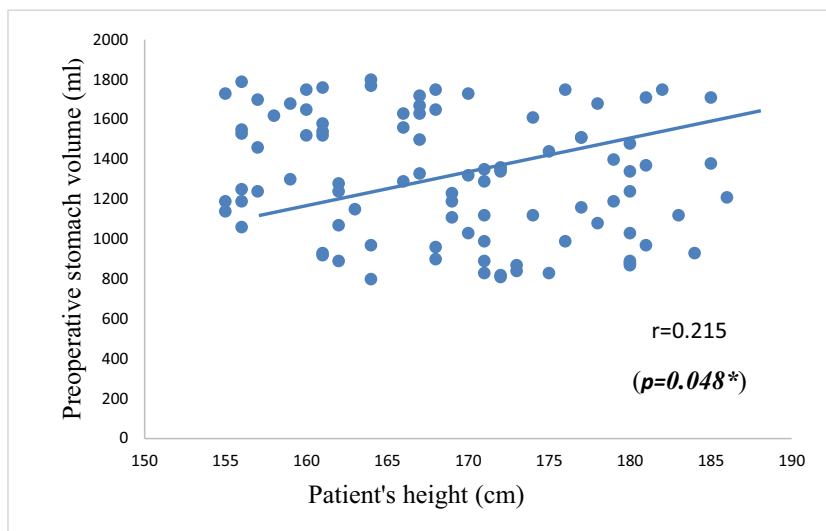
operation and of the narrow remaining pouch is simply the only factor responsible for weight loss.

As regards the preoperative gastric volume, Csendes et al. reported that morbidly obese individuals do not have larger stomach volumes [17]. Similarly, Delgado-Aros et al. found no correlation between preoperative BMI and the gastric volume [18]. Conversely, Kim et al. revealed that obesity is linked to a larger antral volume [19]. Similarly, Pawanindra et al [20] used MDCT to assess gastric volume and found a statistically significant correlation with preoperative BMI. The same technique and outcome were reported by Elbanna [21] whose cohort had a mean volume of 920 ml. Similar outcomes were noticed in our cohort, with a slightly higher mean preoperative gastric volume of  $1310 \pm 307$  ml (800–1800 ml) and a significant correlation with preoperative BMI (Fig. 1).

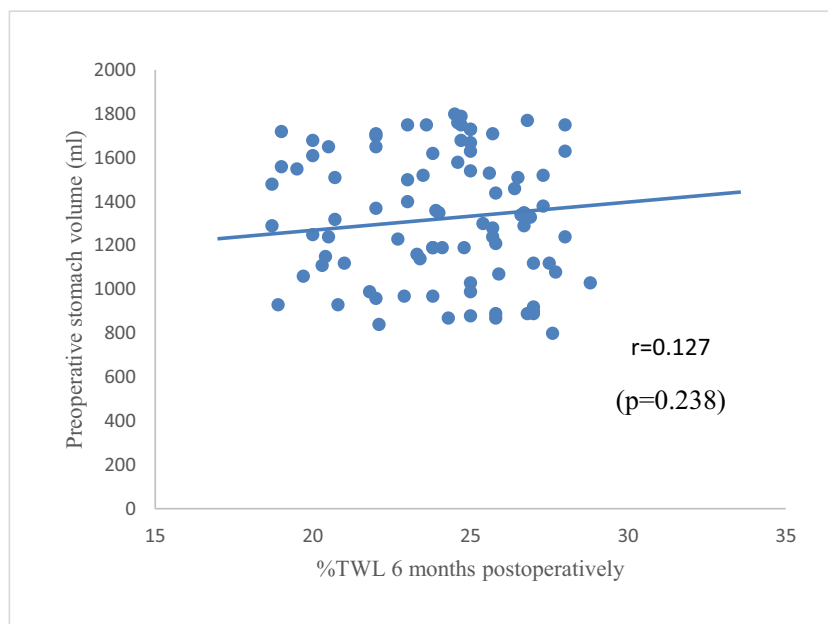
Elbanna et al. reported no correlation between the preoperative gastric volume and postoperative weight loss [21]. This corresponds to our results at 6 and 12 months (Figs. 3 and 4). Correlating volume of the resected stomach to postoperative weight loss did not seem to have significance in some trials [22, 23]. Similar outcomes were reported in our study at 6 and 12 months (Figs. 5 and 6).

As regards assessment of sleeve pouch volume, several modalities have been reported for this purpose which represents a relative difficulty when compared with the small ovoid pouches after gastric bypass readily measurable on plain films or under fluoroscopy [10, 24]. Endoscopic trials have been used to measure the oral-aboral pouch extension while the transverse diameter was only estimated. This affected the quantitative accuracy of this modality [24]. Dogan et al.

**Fig. 2** Correlation between preoperative gastric volume with patient's height



**Fig. 3** Correlation between preoperative gastric volumes and %TWL at 6 months postoperatively



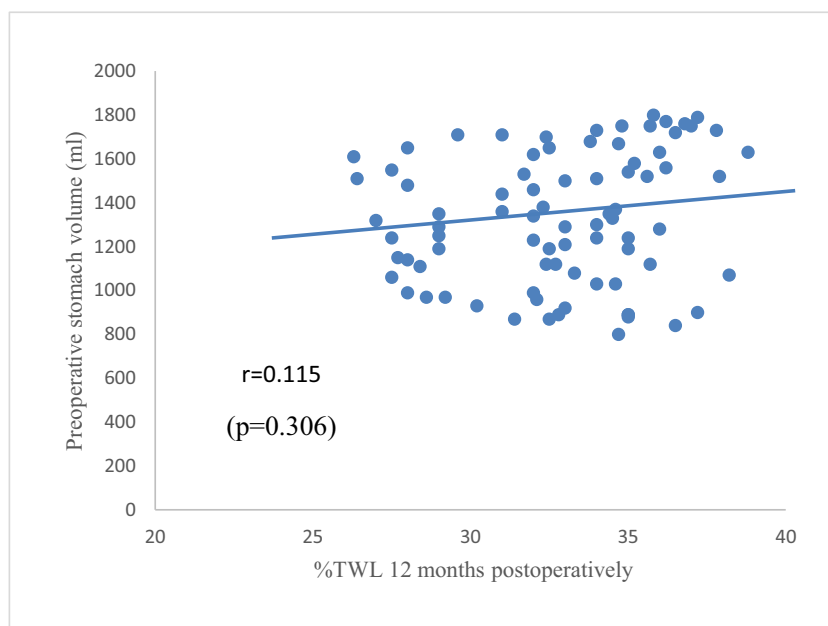
estimated the pouch volume intraoperatively by infusing methylene blue and saline through a nasogastric tube after clamping the pylorus and esophagogastric junction, and the amount infused was noted [25]. Upper GIT series have also been implemented, but technical difficulties and inaccurate results have led to aborting the procedure [7]. A more complex assessment through upper GIT series was reported by Vidal who measured the volume of 2 components; a cylindrical part for the gastric body and a truncated cone for the antrum [26]. A disadvantage here is the radiation exposure.

We adopted MDCT gastrography which proved to be more feasible and accurate [10, 21, 24]. Our main concern was the

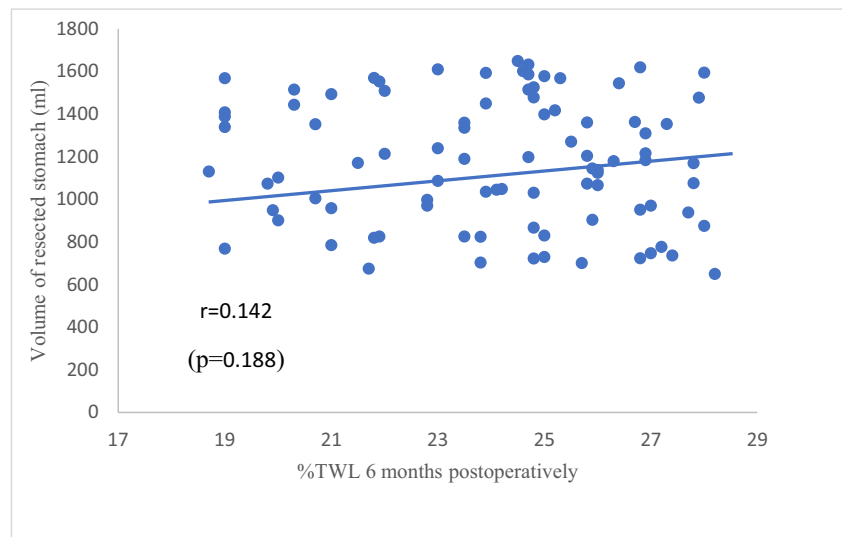
radiation exposure, although there are previous reports for similar exposure [9, 21, 26]. This concern was addressed through using low-dose CT with iterative reconstruction and limiting the scan range to the stomach. This significantly decreased the exposure compared with previous reports in literature [9, 21, 26].

To accurately assess the effect of volume restriction on weight loss, the best design was through preoperative and serial postoperative volume measurements and correlating them to weight losses at same points of time. Vidal [26] measured pouch volume at 1 and 12 months postoperatively and correlated them to weight losses up to 18 months

**Fig. 4** Correlation between preoperative gastric volumes and %TWL at 12 months postoperatively



**Fig. 5** Correlation between resected stomach volumes and %TWL at 6 months postoperatively



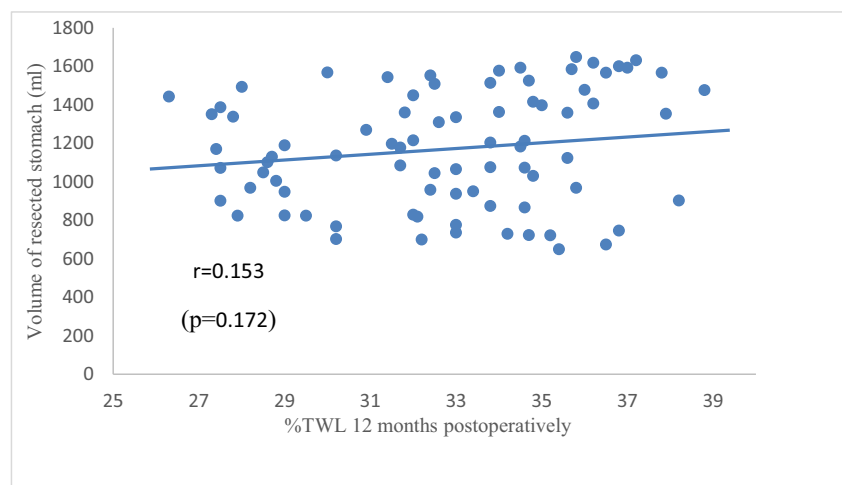
postoperatively which affected the accuracy of his results. Preoperative volume assessment was also missed. Braghetto [9] measured pouch volume on the third postoperative day using barium series and CT abdomen. Both procedures were repeated 2 years later. Again, preoperative estimation was missed. Additionally, barium assessment added unnecessary radiation exposure with a possible risk of barium peritonitis if leak was encountered in this early setting. Elbanna [21] used MDCT for preoperative and immediate postoperative volume assessment. Values were correlated for weight losses after 6 months. The disadvantage here is that very early MDCT can lead to inadvertent pouch distension with its sequelae. Second, postoperative gastric wall edema can affect pouch volume assessment. Third, results should be cautiously interpreted due to correlating immediate postoperative pouch volumes with weight losses 6 months later and lack of serial postoperative volume assessment. In contrary, we measured the gastric volume preoperatively then at 6 and at 12 months postoperatively. In addition, we correlated weight loss with

pouch volume at corresponding points of time. To the best of our knowledge, this correlation was not previously reported in literature.

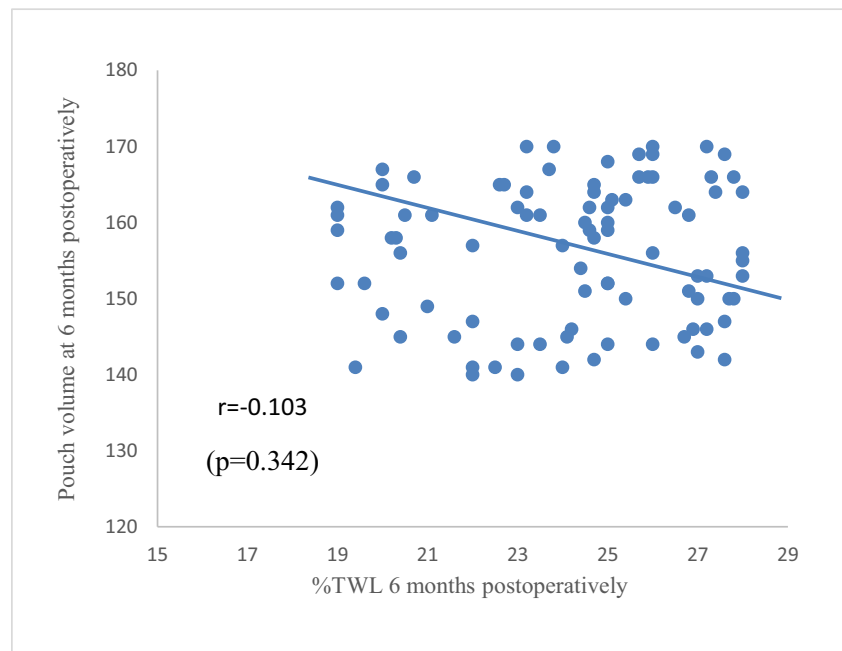
Interestingly, pouch volumes showed no significant correlation with %TWL at both 6 and 12 months post-LSG (Figs. 7 and 8). Similar outcomes were shown by Pawanindra at 3 months postoperatively [20]. Corresponding results at 12 months [10] and up to 3 years postoperatively [9] have also been published. In contrary, other reports showed significant positive correlations implying that larger volumes are associated significantly with weight regain [21, 27].

Assessing pouch volume at 6 and 12 months revealed a non-significant increase from a mean of  $158 \pm 9$  ml to  $181 \pm 12$  ml, respectively. In contrary, Baumann [10] revealed a significant increase in the mean pouch volume at 6 vs. 2 months (196 ml vs. 105 ml, respectively). Vidal noted also a significant increase in the mean pouch volume at 12 months vs. 1 month postoperatively (188 ml vs. 125 ml, respectively) [28].

**Fig. 6** Correlation between resected stomach volumes and %TWL at 12 months postoperatively



**Fig. 7** Correlation between postoperative pouch volumes and %TWL at 6 months postoperatively



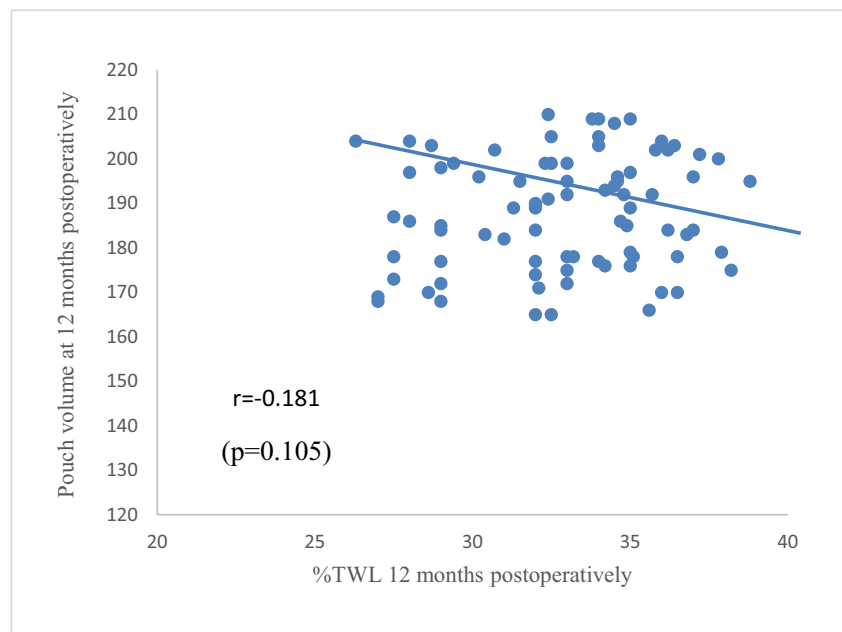
The significant increase in %TWL and %EWL throughout our study, which was not significantly correlated with smaller pouch volumes and was even surprisingly associated with an increase in pouch volume signifies that restriction is an important, but not the only factor controlling weight loss after LSG.

Other factors have been proved to impact weight loss. LSG results in early satiety by reducing the plasma Ghrelin level and increasing Glucagon-like peptide-1 and peptide YY levels [29–31]. Postoperative accelerated gastric emptying contributes also to weight loss [32]. Gender, preoperative weight loss, nutritional pattern, and smoking have also been involved [8,

29, 30]. A cutoff limit of the weight of the resected stomach that allows adequate weight loss has been proposed to be 120 g in females and 160 g in males [33]. Others showed that the low distensibility of the sleeve which is at least one-tenth that of the resected stomach in addition to the increased intraluminal pressure play a significant role in weight loss [7].

Our study has several limitations; first, radiation exposure raises an ethical concern. Second, we estimated the volume of the resected stomach by subtracting the pouch volume at 6 months postoperatively from preoperative gastric volume instead of directly measuring the volume of the resected part.

**Fig. 8** Correlation between postoperative pouch volumes and %TWL at 12 months postoperatively



Results should therefore be interpreted with caution. Third, we did not measure the volume of the remaining pouch intraoperatively. However, we standardized the bougie caliber (36-Fr) throughout the study to keep the pouch volume constant [22]. Fourth, a longer follow-up duration would have been more informative.

However, our study has several advantages. We performed a prospective intraindividual evaluation, unlike Baumann [10] who assessed patients retrospectively with no intraindividual comparison in most of them. We correlated volume and weight simultaneously at both 6 and 12 months. This was missed in the study by Dogan [16] who correlated intraoperative pouch volume with postoperative weight losses up to 2 years later and Elbanna [21] who correlated very early (1 week) postoperative pouch volume with weight loss 6 months later. Additionally, very early pouch distension [21] during MDCT is a risky procedure and postponing it to 6 months in our study would be safer.

In conclusion, LSG results in significant weight losses, at least on short-term scale. Preoperative gastric volume shows a significant correlation with preoperative BMI but not with short-term postoperative weight losses. Pouch volume shows no significant correlation to weight loss at 6 and 12 months. Pouch volume shows a non-significant increase at 12 vs. 6 months. That is to say; restriction is an important, but not the only factor controlling weight loss after LSG. Prospective studies with long-term follow-up assessment are needed to confirm these findings.

## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

**Informed Consent** An informed consent was obtained from all individual participants included in this study.

All procedures performed in the study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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