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RESEARCH ARTICLE

Sleeve Gastrectomy—A "Food Limiting" Operation

John Melissas · Markos Daskalakis · Sophia Koukouraki · Ioannis Askoxylakis · Maria Metaxari · Efstathios Dimitriadis · Maria Stathaki · John A. Papadakis

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Abstract
Background Sleeve gastrectomy (SG), which, thus far, is showing good resolution of comorbidities and good weight loss, shows increasing popularity among bariatric surgeons. The aim of this study was to evaluate clinical outcome and the gastric emptying of solid foods, 24 months after SG.
Methods Fourteen morbidly obese patients, four males and ten females, median age 41 years (range 29–65), median body mass index (BMI) 49.46 kg/m^2 (range 41.14–55.63), who underwent SG for weight loss, were studied prospectively. Nine patients underwent gastric emptying studies, using radioisotopic technique before, 6 months and 24 months after the operation. The remaining five patients underwent gastric emptying studies, 6 months and 24 months after the operation.
Results A significant reduction in patients' weight and BMI was evident at 6, 12 and 24 months postoperatively. In the nine patients who underwent gastric emptying studies pre-, 6 and 24 months postoperatively, the *T*-lag phase duration significantly decreased, following the SG, from 17.30 (range 15.50–20.90) min, to 12.50 (range 9.20–18.00) min at 6 months and 12.16 (range 10.90–20.00) min at 24 months postoperatively ($P<0.05$). The gastric emptying half time (*T*1/2) accelerated significantly postoperatively from 86.50 (range 77.50–104.60) min, to 62.50 (range 46.30–80.00) min at 6 months and 60.80 (range 54.80–100.00) min at 24 months after SG ($P<0.05$). The percentage of gastric emptying (%GE) increased significantly postoperatively, from 52 (range 43–58) % to 72 (range 57–97) % at 6 months and 74 (range 45–82) % at 24 months, following SG ($P<0.05$). No differences in gastric emptying were observed, when values at 24 months were compared to those at 6 months postoperatively. When the whole group of 14 patients was studied, there were also no significant changes in *T*-lag, *T*1/2 and %GE between 6 and 24 months postoperatively.
Conclusions Our study indicates the constant effect of SG in the acceleration of gastric emptying of solids, which occurs faster, not only in short but also in long-term postoperatively. Such effects on gastric motility, in combination with the reported alterations in gut hormones, may explain how this 'food limiting' operation results in weight loss.

Keywords Sleeve gastrectomy · Morbid obesity · Bariatric surgery · Gastric emptying · Scintigraphy

J. Melissas (✉) · M. Daskalakis · I. Askoxylakis · E. Dimitriadis
Bariatric Unit Department of Surgical Oncology, Heraklion University Hospital, Medical School, University of Crete,
15 Delaporta St., Herarklion 71409,
Crete, Greece
e-mail: melissas@med.uoc.gr

S. Koukouraki · M. Stathaki
Department of Nuclear Medicine, Heraklion University Hospital, Medical School, University of Crete,
Crete, Greece

M. Metaxari
Department of Anaesthesiology, Heraklion University Hospital, Medical School, University of Crete,
Crete, Greece

J. A. Papadakis
Department of Internal Medicine, Heraklion University Hospital, Medical School, University of Crete,
Crete, Greece

Introduction

The World Health Organization projects that by 2015, approximately 2.3 billion adults will be overweight and more than 700 million will be obese [1]. As the epidemic of obesity continues, the problem, once considered, only in high-income countries, is now dramatically on the rise in low- and middle-income countries, particularly in urban settings [1, 2].

Surgery has been the only effective treatment for morbid obesity, with long-term sustained weight loss and postoperative complete resolution or significant improvement in the obesity comorbidities [3–5]. Bariatric surgery is feasible and safe, when carried out in specialized medical institutions properly equipped to care for the obese in a multidisciplinary setting [6].

Sleeve gastrectomy (SG) was introduced as a multipurpose bariatric operation [7]. SG involves removing the fundus and greater curvature portion of the stomach, leaving only a lesser curvature tube [8]. SG was initially described as a first-step procedure followed by either biliopancreatic diversion with duodenal switch (BPD-DS) or Roux-en-Y gastric bypass (RYGBP) in super-super obese patients, body mass index (BMI) >60 kg/m^2 or in high-risk patients [9, 10]. More recently, SG has been indicated as a definitive treatment in patients with BMI >40 kg/m^2 or BMI >35 kg/m^2 associated with comorbidities, and it has also been proposed for patients with moderate obesity BMI <35 kg/m^2 and metabolic syndrome [7, 8, 11].

Historically, surgical strategies for weight loss have focused on volume restriction, malabsorption, or both. However, recent studies have questioned the real contribution of restrictive or malabsorptive mechanisms, in part, due to an increased understanding of body weight control pathways involving multiple peptides [12, 13]. These regulatory pathways and their interactions remain incompletely understood.

The sensation of the stomach is determined, in part, by its motor functions such as tone, compliance and gastric emptying, but is also regulated by multiple neurohormonal mechanisms. Thus, changes in gastric emptying and sensory functions which occur in morbidly obese patients after surgical treatment, may alter these regulatory mechanisms and contribute to the weight loss [14]. The aim of the present study was to evaluate clinical outcome and the gastric emptying of solid foods up to 24 months after SG.

Patients and Methods

Fourteen morbidly obese patients (four male, ten female), who underwent laparoscopic SG for weight loss, were studied prospectively. The patients' demographic characteristics and BMI changes are shown in Table 1. Weight, BMI, meal size, and frequency using a quantitative food-frequency questionnaire [15], postprandial feeling of fullness and satiety, the presence of dumping syndrome and symptoms such as nausea, vomiting, heartburn, dysphagia, and indigestion were all recorded pre- and postoperatively during regular follow-up visits. The percentage of excess BMI lost (%EBL) was calculated using the formula %EBL=[(preoperative BMI−current BMI)/(preoperative BMI−25)]×100 [16]. Gastric emptying studies for solids were performed in 9 patients preoperatively and in all of them at 6 and 24 months postoperatively. Written consent was obtained from each patient. Permission was given by the local ethics committee.

Gastric Emptying Study

Acceleration of gastric emptying, following SG, has been found in our previous study, where preliminary results at 6 months from 11 patients were reported [14]. From this group of patients, nine returned for gastric emptying studies at 24 months postoperatively (from the remaining two patients, one underwent BPD-DS due to inadequate weight loss 1 year postoperatively and the second did not volunteer to come back for gastric emptying studies). Five more patients underwent gastric emptying studies only postoperatively at 6 and 24 months after SG.

After an overnight fast, each patient ingested a standard solid food meal consisting of a hamburger labeled with 74 MBq 99mTc-sulfur colloid and 140 g of fresh tomato. The hamburger contained 100 g of minced beef meat, 20 g of toasted bread, 10 ml of olive oil, and half an egg. The total calorie content of the meal was 390 kcal (52% fat-derived, 32% protein-derived, 16% carbohydrate-derived) and was consumed within 10 min.

Data acquisition Scintigraphic imaging was performed with a γ-camera (Millennium, GE Medical Systems,

Table 1 Demographic characteristics, postoperative weight and BMI alterations

	Patients (*n*=14)	6th month	12th month	24th month
Age (years)	41 (29–65)			
Weight (kg)	140 (104–167)	101 (79–132)	91 (75–112)	89 (75–110)
BMI (kg/m^2)	49.46 (41.14–55.63)	35.97* (31.25–43.72)	33.04* (28.93–38.95)	32.51* (27.72–38.95)
%EBL		54.19** (35.69–74.00)	66.08** (48.47–81.50)	71.16** (51.47–87.25)

Values expressed as median (range)
*P=0.001; **P<0.05

Milwaukee, WI) equipped with a LEGP collimator. The passage of the meal was evaluated by a digital computer. Immediately after completion of the meal, the subjects were positioned sitting in front of the γ-camera. Anterior static images of the abdominal field were acquired (60 s for each frame) at regular time intervals, every 10 min for a total of 90 min. The camera captured frames and transmitted them to a computer for analysis and storage.

Qualitative and quantitative analysis was performed on every image by drawing regions of interest enclosing the stomach. Time 0 was considered the time of meal completion. The retention of the meal in the stomach at time 0 was defined as 100%. Time activity curves were generated using a gastric region of interest for each of the views. Quantitative parameters were determined as percentage gastric emptying (%GE) at 90 min, half time (min) based on an exponential fit. The counted radioactivity over the gastric area was corrected for isotope physical decay. *T*-lag is the period of time in which gastric emptying is <10% of the initial count and the *T*1/2 is the time interval between the completion of the meal and the point at which half of the meal has left the stomach [17].

Statistical Analysis

Statistical analysis of data was performed using the SyStat v 10.0 program (SPSS Inc, Chicago, IL). Continuous variables were expressed as median values (range). Differences in clinical and laboratory parameters, before and after surgical treatment, were examined using paired Wilcoxon signed rank test. The level of significance was set at $P < 0.05$.

Results

All patients tolerated the operation well and recovered within a short time period. Postoperative %EBL changes are shown in Fig. 1. After the SG procedure, all patients noted a feeling of fullness with very little food (e.g. 100 ml of yoghurt), while postprandial satiety was provoked with significantly less food than preoperatively; these findings were evident also at 2 years after the operation. All patients were consuming significantly smaller-sized meals at 6 and 24 months postoperatively. Their appetite was significantly reduced 6 months after SG, compared to preoperative status. Only one patient reported an increased in appetite at 2 years postoperatively. Daily meal frequency was increased postoperatively from 2–3 (range 1–4) before sleeve gastrectomy, to 5–6 (range 3–8) much smaller meals at 6 months postoperatively, in half of the patients. These patients reported a similar meal frequency compared to preoperative status, at 2 years following SG. The remaining seven patients (50%) were constantly snacking preoperatively (daily meals >8). The number of their daily meals was reduced postoperatively to 2–3 (range 2–4) small regular meals daily and had not changed at follow-up at 24 months.

Five patients (35.7%) reported occasional vomiting after a larger than usual meal consumption at 6 months postoperatively, but only one patient continued to report such symptoms 2 years after the operation. The remaining nine patients (64.3%) did not experience vomiting postoperatively and reported that they had quickly become accustomed to the appropriate meal size in order to avoid nausea or vomiting.

Gastroesophageal reflux (GER) or symptoms indicative of GER, such as heartburn or acid regurgitation, were evident in two patients preoperatively. In both patients, these symptoms disappeared completely postoperatively. Five patients, who were GER symptom-free preoperatively, reported evidence of reflux disease at 6 months following the operation. All but one had complete remission of their symptoms at 24 months postoperatively.

No patient developed dumping syndrome, diarrhea, or a peptic ulcer postoperatively. Seven patients experienced

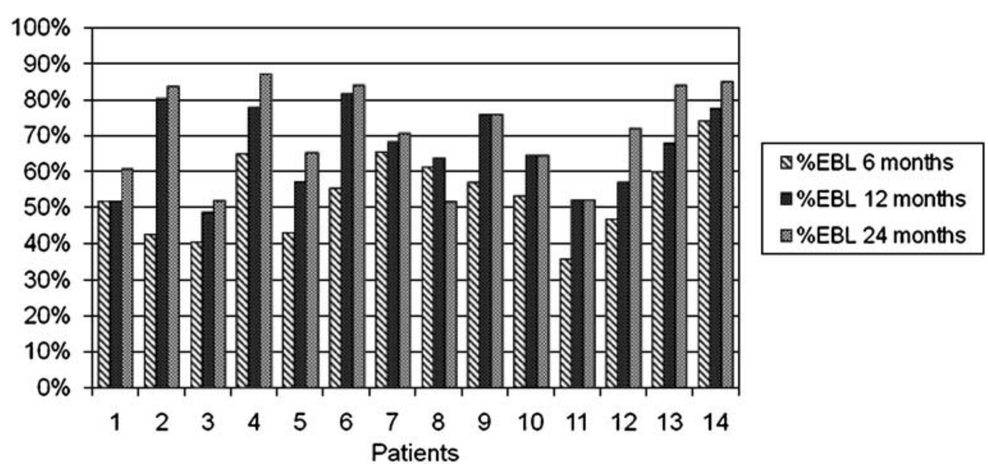

Fig. 1 Percent of excess BMI lost

Table 2 Gastric emptying studies, patients=9

	Preoperatively	6th month postoperatively	24th month postoperatively
%GE	52 (43–58)	72* (57–97)	74* (45–82)
T-lag (min)	17.30 (15.50–20.90)	12.50* (9.20–18.00)	12.16* (10.90–20.00)
*T*1/2 (min)	86.50 (77.50–104.60)	62.50* (46.30–80.00)	60.80* (54.80–100.00)

Values expressed as median (range)
*$P<0.05$

temporary hair loss during the first six postoperative months. Quality of life was excellent in all patients, and there were no major complaints. All patients in this series were absolutely positive that they would again undergo the same bariatric procedure.

Solid Gastric Emptying

In each patient, solid emptying was characterized by a lag phase followed by a linear emptying. In the nine patients who underwent gastric emptying studies (Table 2) before, 6 months and 24 months after SG, the lag phase (which represents the time from the end of the meal to the beginning of the emptying into the duodenum and small intestine) was significantly decreased from 17.30 min preoperatively to 12.50 min at 6 months and 12.16 min at 24 months postoperatively ($P<0.05$). The *T*1/2 (the time elapsed from completion of the meal to the point at which half of the meal had left the stomach) accelerated significantly postoperatively—from 86.50 min before, to 62.50 min at 6 months and 60.80 min at 24 months after SG, respectively ($P<0.05$). The percentage of gastric emptying (%GE), which indicates the portion of the meal that left the stomach at the end of the observation period of 90 min, was increased significantly postoperatively—from 52% preoperatively, to 72% at 6 months and 74% at 24 months following SG ($P<0.05$). Comparing the postoperative findings at 24 months with those at 6 months, no significant changes in gastric emptying were observed. There was also no significant change in *T*-lag, *T*1/2 and %GE, when the whole group of patients ($n=14$) was studied at 6 and 24 months after SG (Table 3).

Discussion

A number of studies have been conducted regarding gastric emptying in obese subjects, but the results have been inconsistent [18–20]. The difference in the obtained results could be attributed to the complexity and heterogeneity of obesity's pathophysiology.

It is generally believed that after restrictive-type surgery, a small amount of food can be consumed and accommodated in the tiny gastric pouch, which is constructed in continuation with the esophagus, and through this mechanical restriction, a significant weight reduction is accomplished [21].

Laparoscopic SG has recently been introduced as a very promising bariatric procedure. Patient selection criteria for SG are now becoming wider and include morbidly obese patients with BMI <50 kg/m^2 [7, 8, 22]. This novel procedure is generally considered restrictive; it was assumed that SG achieves weight loss by restricting the amount of food that can be consumed, with no malabsorption. However, there are differences between SG and the traditional representatives of the restrictive procedures (vertical banded gastroplasty and adjustable gastric banding), as we have previously reported [14]. In order to achieve energy intake reduction, which will result in acceptable weight loss, the pouch volume for both restrictive procedures has to be tiny and not exceed 15 cm^3 [23]. In SG, food intake is not restricted by the introduction of foreign material. The volume of the remaining stomach is larger by far (up to 150–200 cm^3) [7, 24]. The gastric fundus, the major food storage compartment and upper part of the body of the stomach, including the "gastric pacemaker", are removed.

As far as gastric emptying is concerned, our results indicate that gastric emptying for solids occurs faster at 6 months following SG and this is a persistent finding 2 years thereafter. The time, from the termination of a meal to the beginning of emptying into the duodenum, was significantly shorter, following the partial resection of the stomach, indicating an alteration in gastroduodenal coordination. Excision of the fundus and absence of receptive relaxation, as well as alterations in the contractile activity in the proximal stomach are possible

Table 3 Postoperative gastric emptying studies, patients=14

	6th month	24th month	*P*
%GE	70 (56–97)	68.5 (42–98)	0.123
T-lag (min)	12.75 (9.20–18.00)	13.13 (9.18–21.40)	0.109
*T*1/2 (min)	64.20 (46.30–80.30)	65.68 (45.90–105.00)	0.109

Values expressed as median (range)

explanations for the decreased *T*-lag phase found in this study. The time required for half of the solid meal to leave the stomach (*T*1/2) and the percentage of the meal emptied into the small intestine at the end of the 90-min observation period (%GE), were also significantly altered following SG, indicating that the stomach empties solid foods rapidly and possibly incompletely processed, into the duodenum. These effects on gastric motility were also evident at 2 years after SG and possibly are correlated with the significant continuation of weight loss observed in our patients (Table 1).

Previous studies of gastric emptying after restrictive procedures have shown conflicting results [21, 24, 25]. None of these studies has, however, found evidence of faster gastric emptying neither in short nor in long-term after restrictive surgery, as recorded in this present study at 2 years following SG.

Weiner et al. demonstrated that a more restrictive SG is important for better long-term weight-loss results [26], but data also strongly suggest that bariatric surgery anatomically affects not only gastric capacity and the area of absorption of the nutrients but also the pattern of secretion of many gut hormones. Ghrelin, a potent orexigenic hormone, is mainly synthesized in the gastric fundus [27, 28]. With sleeve gastrectomy, almost the whole of the gastric fundus is surgically removed, which suggests that after the operation, the levels of ghrelin should be altered. Lager et al. reported significantly reduced levels of ghrelin in ten obese patients undergoing SG at 1 and 6 months after surgery [29]. Furthermore, when the biliopancreatic diversion is associated with the pylorus preserving sleeve gastrectomy (duodenal switch), the circulating levels of ghrelin are markedly suppressed [30]. Increases in the response of other gastrointestinal hormones, such as glucagon-like peptide-1 (GLP-1), a meal-related satiation factor, have been reported after BPD and RYGBP [31]. This type of response may be caused by the intestinal bolus quickly reaching the level of the small intestine.

In our series, only one patient reported vomiting after the small meals, which they are now, at 2 years following SG, able to consume. Their appetite has been reduced, pre-existing bulimia is only notable by its absence and postprandial satiety is provoked with significantly less food than preoperatively. The rapid gastric emptying, which may produce an increase in GLP-1 action and the resection of the ghrelin-producing gastric fundus may partly explain these phenomena. Thus, SG appears to be more than just a gastric restrictive operation. SG is not only a multi-purpose operation, but also a multifactorial one with a restrictive aspect and a complex neurohormonal aspect not yet fully elucidated. Hence, “food limiting” operation appears to be a more appropriate term to define SG.

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