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ORIGINAL CONTRIBUTIONS

Sleeve Gastrectomy: Correlation of Long-Term Results with Remnant Morphology and Eating Disorders

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Abstract

Background Remnant dimension is considered one of the crucial elements determining the success of sleeve gastrectomy (SG), and dilation of the gastric fundus is often believed to be the main cause of failure.

Objectives The main outcome of this study is to find correlations between remnant morphology in the immediate post-operative stage, its dilation in years, and the long-term results. The second purpose aims to correlate preoperative eating disorders, taste alteration, hunger perception, and early satiety with post-SG results.

Materials and Methods Remnant morphology was evaluated, in the immediate post-operative stage and over the years (≥2 years), through X-ray of the oesophagus-stomach-duodenum calculating the surface in anteroposterior (AP) and right anterior oblique projection (RAO). Presurgery diagnosis of eating disorders and their evaluation through "Eating Disorder Inventory-3" (EDI3) during follow-up were performed. Change in taste perception, sense of appetite, and early satiety were evaluated. Patients were divided into two groups: "failed SGs (EWL<50%) and "efficient SGs" (EWL >50%).

Results There were a total of 50 patients (37 F, 13 M), with mean age 52 years, preoperative weight 131 ± 21.8 kg, and BMI 47.4 ± 6.8 kg/m^2. Post-operative remnant mean dimensions overlapped between the two groups. On a long-term basis, an increase of 57.2 and 48.4% was documented in the AP and RAO areas respectively. In "failed" SGs, dilation was significantly superior to "efficient" SGs (AP area 70.2 vs 46.1%; RAO area 59.3 vs 39%; body width 102% vs 41.7%). Preoperative eating disorders were more present in efficient SGs than in failed SGs with the exception of sweet eating. There were no significant changes to taste perception during follow-up. Fifty-two percent of efficient SGs vs 26% of failed SGs reported a persistent lack of sense of hunger; similarly, 92.5 vs 78% declared the persistence of a sense of early satiety. The two groups did not statistically differ as far as all the variables of the EDI3 are concerned.

Conclusion On a long-term basis, the remnant mean dilation is around 50% compared to the immediate post-operative stage but failed SGs showed larger remnant dilation than efficient SGs and, in percentage, the more dilated portion is the body of the stomach. As far as all the EDI3 variables obtained

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are concerned, the two groups did not statistically differ. Of all eating disorders, sweet eating seems to be weakly connected to SG failure.

Keywords Sleeve gastrectomy · Remnant morphology · Eating disorders · Mechanisms of action · Sleeve failure · Long-term follow-up

Introduction

The continuous growth of the prevalence of obesity and overweight cases in the general population represents a real, authentic threat for public health. Bariatric surgery is considered the most efficient treatment for pathological obesity as far as it allows, whatever the type of surgical procedure used, a larger amount of weight loss and a better control of comorbidities correlated with obesity in contrast with non-surgical remedies, even long-term [1]. Among the various types of bariatric surgery, sleeve gastrectomy (SG) has in the last few years shown a continuous increase in popularity which has made it the second most performed bariatric/metabolic surgical operation in the world [2]. Although it is still considered a restrictive operation, SG's greater efficiency in contrast with other purely restrictive procedures such as AGB proves the fact that the action mechanisms responsible for the results of SG are not only mechanical but also involve other different elements such as the modification of gastrointestinal motility [3–5], of some hormonal (GLP-1, PYY, ghrelin, leptin) [6–11] or neural [12, 13] signalling pathways, changes at the central nervous system level [14–16] and alteration of bile acids [17] and intestinal microbiota [18]. In fact, in the last 15 years, SG has become renowned as a safe, efficient operation for the treatment of pathological obesity and its comorbidities. However, up to 30% of patients who underwent SG require revisional surgery due to insufficient weight loss, weight regain or complications in general. According to literature, 10–25% of SGs are encumbered by insufficient weight loss or weight regain, especially 2–3 years post surgery [19–21].

In literature, the size of the remnant continues to be considered one of the crucial elements determining the success of SG in the treatment of obesity and the dilation of the gastric fundus is believed to be one of the main elements responsible for its failure. There are many other factors involved such as the dilation of the remnant, the use of a bougie that is too big for the calibration of the remnant during surgery, incomplete fundus resection, the greater or lesser marked preservation of the antrum and the consequences that these technical features have on gastric emptying.

A recent review of literature has reached the conclusion that neither binge eating nor other eating disorders diagnosed in the preoperative stage can be predictors of post-operative results in terms of weight loss [22]. Patients who undergo bariatric surgery generally obtain a reduction of symptoms for depression, anxiety and eating disorders as well as a significant improvement in their quality of life [23]. However, to date, the relationship between the preoperative psychological state and the results reached in the post-operative stage is not clear. Some studies have suggested that the psychopathology and eating disorders present in the preoperative stage are associated to non-optimal weight loss after bariatric surgery and sometimes even to adverse psychosocial outcomes. Currently, there is still no adequate level of evidence that allows us to conclude, with any degree of certainty, that preoperative psychological characteristics can be used to foresee post-operative results, be it in terms of weight loss or psychosocial adaptation.

With the conviction that there are multifactor reasons behind possible SG failure, the first purpose of the study is the long-term evaluation of the morphological change of the gastric pouch, especially its dilation, and how this can be related to post-SG results; the second purpose is to search for correlations between remnant morphology and dimensions of the gastric pouch in the immediate post-operative stage, long-term weight loss and resolution of comorbidities; the third objective is to correlate preoperative eating disorders, taste alteration, hunger perception and early sense of satiety with long-term weight loss and resolution of comorbidities.

Materials and Methods

Study Design

Following the approval of the internal ethical committee and the participation of patients, with previous undersigned informed consent, we conducted a study that aimed to correlate long-term post-SG results (minimum 24 months of follow-up) with remnant morphology, evaluated through X-ray of the oesophagus-stomach-duodenum with hydro-soluble contrast (XRESD), and eating disorders diagnosed in the preoperative stage and evaluated in correspondence with the study in question through self-administration of the Italian version of the "Eating Disorder Inventory-3" (EDI3) [24]. Research was also carried out, via direct interview, by using an Italian adjusted version of the European Prospective Investigation into Cancer and Nutrition (EPIC) food frequency questionnaire [25], regarding changes in the perception of taste, the presence/absence of a subjective sense of appetite, the sensation of post-SG early satiety and their possible variations in time. A detailed pathological and pharmacological anamnesis was carried out through psychiatric, endocrinological, diabetes and nutritional evaluation, and haematochemical tests were examined and reported. Preoperative evaluation and post-operative follow-up were carried out by the same medical team, which has vast experience in the bariatric field and constantly collaborated with our surgical team.

XRESD with hydro-soluble contrast in the immediate post-operative stage and during the follow-up was carried out with the same instruments and by the same radiologist.

Post-SG results have been described in terms of weight loss and resolution of comorbidities such as type 2 diabetes mellitus (T2DM), hypertension (HTN) and sleep apnoea (OSAS).

Patient Selection

Availability to participate in this study was requested via an initial phone call, which was made to the patients who underwent SG at the Department of Clinical and Experimental Medicine and Bariatric Surgery of the University Hospital of Pisa (AOUP) before May 2014 (24 months minimum follow-up required).

During the selection, the following *exclusion criteria* were applied:

– Allergy to hydro-soluble contrast
– Previous bariatric surgery (SG as redo-surgery)
– Appearance of "major" complications during the post-operative stage (according to LABS [26] classification)
– Medical conditions requiring acute hospitalisation, blindness, severe medical conditions (liver cirrhosis, end-stage renal failure, malignancy, connective tissue diseases, endocrine diseases such as hypothyroidism or hyperthyroidism) or illnesses, such as chronic congestive heart failure, recent myocardial infarction or stroke, unstable angina pectoris, and treatment with pharmacologic agents known to affect carbohydrate homeostasis

Fifty volunteers were enrolled and accepted to take part in the current study.

Surgical Technique

Every operation was carried out using a laparoscopic technique by the same operating team. Five trocars were used, and occasionally, an additional sixth trocar was placed. The gastro-splenic omentum dissection from the great curvature was carried out using a Harmonic Ultrasonic® (Ethicon) or Sonicision® (Covidien) at approximately 5–6 cm from the pylorus to a complete dissection and exposition of the left diaphragmatic pillar. The His angle was totally mobilised, and the adhesions between the posterior wall of the stomach and the pancreas were freed. The gastric tubule was created with a 36F bougie using mechanical staplers (Endo-GIA Ultra/iDrive Ultra® Covidien or Echelon Flex/Echelon Flex Powered® Ethicon) with reinforced cartridges (SEAMGUARD® staple line reinforcement material, W.L. Gore & Associates) preserving 5–6 cm of antrum. The methylene blue test was carried out during all procedures to exclude the presence of leakage. Easy flow type drainage was placed in correspondence with the stapler line at the end of the operation.

X-ray Oesophagus-Stomach-Duodenum

The morphological study of the remnant post SG was carried out through digital fluoroscopy with targeted X-rays with specific standard projections: anteroposterior (AP) and right anterior oblique (RAO) positions (at approximately 45°–50°) with patient in an upright position on clinostat "Clinodigit Compact X-Frame Italray". The entire test was video recorded with a rate of four frames per second and a resolution of 3001 × 3001 × 14 bit. The use of the same iodinated water-soluble radiological contrast in the immediate post-operative and monitoring stages allowed us to compare the obtained images (Fig. 1). The test was carried out by the same radiologist using the same radiological equipment to reduce bias. Digital fluoroscopy allowed a global morphological and dynamical evaluation of the gastric remnant, making possible to evaluate peristalsis and estimate emptying time. The presence of contrast in the duodenum soon after the first deglutition, or no longer than 30 s after it, has been defined as "rapid gastric emptying". During the study, the remnant areas post SG were digitally calculated and expressed in square millimetres with AP and RAO projections in the immediate post-operative stage (1–2 post-operative days) and during the follow-up (24–66 months). Once these values were acquired, it was possible to calculate the effective long-term dilation of the remnant, expressing it in absolute values (mm^2) or in percentages with respect to the immediate post-operative stage. The widths of the upper part of the remnant (ex-fundus), body and antrum were measured on the AP projection. The body width was measured in correspondence with the gastric incisura, the width of the ex-fundus and the antrum in correspondence with the point of greater amplitude. These values made it possible to calculate the effective dilation of the single components of

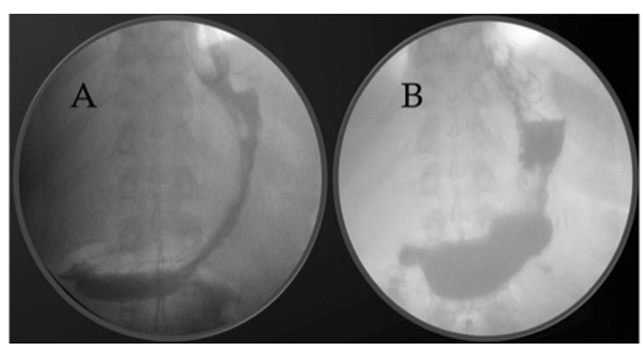

Fig. 1 X-ray oesophagus-stomach-duodenum, anteroposterior projection. Morphological study of the remnant in the immediate post-operative stage (**a**) and during follow-up (**b**)

the remnant in absolute values (mm) as well as in percentages with respect to the immediate post-operative stage. In the end, each SG was schematically illustrated with the use of the XRESD in AP projection, taken in the immediate post-operative stage, to be able to see if there were any correlations between the shape of the remnant and the long-term results of SG. Three shapes were found: golf club shape, angular shape (≤90°) and inverted C shape (Fig. 2).

Psychiatric Evaluation and Self-Administration of the Eating Disorder Inventory-3

The patients who were candidates for bariatric surgery were referred, within a multidisciplinary context for obesity diagnosis and therapy, to the counselling service at the Psychiatric Operative Unit of the Hospital of Pisa. The aim of the psychiatric evaluation was, together with the exclusion of specific contraindications to obesity surgery, to evaluate comorbidities according to the diagnostic criteria of the DSM-IV-TR (axes I and II) through the application of dimensional psychopathological models that are able to highlight subthreshold symptomatology. Following bariatric surgery, simultaneously to the radiological evaluation, the patients were administered a psychometric evaluation comprising the Italian adaptation of EDI-3[24] and a structured collection of information regarding the single alterations of eating behaviour. The current study has used data regarding the presence of preoperative eating disorder diagnosis and the dimensional psychopathological evaluation at the time of the radiological follow-up, with the aim of identifying the associations between psychopathological and radiological clinical indexes in response to obesity surgery.

EDI-3, compared to the original EDI which was already widely used at a clinical and experimental level in the treatment of eating disorders, is the third version and has expanded and improved psychometric characteristics. The questionnaire, which was self-administered, reveals psychological traits and symptoms associated with the development and maintenance of eating disorders defined according to the criteria of the DSM-IV-TR. Although, originally, the instrument was validated on normal-weight or underweight individuals (female subject samples with anorexia nervosa and bulimia and healthy controls), its validity was later confirmed in the case of obese subject samples [27–29].

Definitions

The success and failure of SG have been defined according to the percentages of excess weight lost (EWL %) post surgery, assessed at the time of the current study. The EWL% was calculated using the following formula: EWL% = 100% × [weight lost ÷ (preoperative weight − ideal weight)]. EWL <50% was used to define failure of the procedure.

The excess body weight (EW) was defined as the weight in kilos exceeding the ideal body weight (IBW), which was calculated on an index of body mass (BMI) of 25 kg/m^2.

To evaluate the efficiency of SG as treatment for metabolic syndrome and its single components, "remission of diabetes" was defined, in agreement with the American Diabetes Association (ADA) [30], as reaching glycaemic values that are below the diabetic range without pharmacological treatment for at least a year (*partial remission*: glycated haemoglobin <6.5%, fasting glycaemia 100–125 mg/dl; *complete remission*: glycated haemoglobin <6%, fasting glycaemia <100 mg/dl), "hypertension in remission" as reaching maintained systolic pressure values below 140 mmHg and diastolic values below 90 mmHg without antihypertensive treatment and "OSAS remission" as absence of sleep apnoeas without positive pressure ventilation, documented by polysomnography.

Data Collection and Statistical Analysis

The data obtained during the study in question was integrated with the data, prospectively collected, already present in the computerised database regarding patients who underwent surgery at the Bariatric and Metabolic Surgery Department of the University of Pisa. The results were expressed as mean SD or interquartile range, for variables with normal or skewed distribution, respectively. The differences among groups were compared with the χ^2 test for categorical variables, the Mann-Whitney *U* test for continuous variables and the Wilcoxon signed-rank test for paired data. The variations in time (presurgery vs post-surgery) were evaluated with

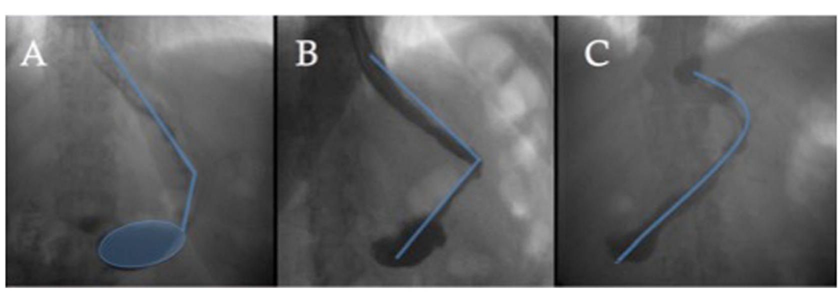

Fig. 2 X-ray oesophagus-stomach-duodenum, anteroposterior projection in the immediate post-operative stage. Three different shapes were found: golf club shape (**a**), angular shape (≤90°) (**b**) and inverted C shape (**c**)

ANOVA for repeated measures; for this test, the parameters with a distribution which was not normal were transformed into logarithms. The result of the ANOVA model was a *p* value for the time factor, a *p* value for the difference among the groups and *p* for interaction time × group. A multiple regression model was used to analyse the correlations between variables. A value of $p < 0.05$ was considered significant.

Results

The 50 patients included in our study had a mean follow-up of 35 months (range 24–66); 23 were included in the "failed" SG group (EWL below 50%) and 27 in the "efficient" SG group (EWL above 50%).

The majority were women (F 37/M 13), the mean age on the day of surgery was 52 years (range 25–74), the mean preoperative weight was 131 ± 21.8 kg (range 90–199.5), the mean BMI was 47.4 ± 6.8 kg/m^2 (range 35.3–62) and EW was 61.9 ± 20.7 kg (range 27.9–110.3). Before surgery, among the sample of 50 patients under study, 19 (38%) had T2DM, 36 (72%) had HTN on pharmacological treatment and 12 (24%) patients had polysomnographic diagnoses of varying degrees of OSAS (from moderate to severe). On average, the follow-up months for the sample under study amounted to 35 (range 24–66). The preoperative differences in anagraphical and anthropometric values between the two groups were not statistically significant, and they are reported in Table 1.

The post-operative results, described in terms of weight loss (WL), EWL%, TWL%, EBMIL% and weight regain (WR), are reported in Table 1. At the time of the study, 7 patients (36.8%) had a complete remission of T2DM and 1 (5.3%) a partial remission; 14 patients (38.8%) were in remission of HTN and 5 (41.7%) resulted as no longer suffering from OSAS. The differences between the two groups in terms of remission of comorbidities are summarised in Table 1. Changes, in terms of haematochemical values, are reported in Table 1. Between the two groups, there was no statistical difference related to nutritional markers such as total protein, albumin and transferrin.

Dimensions, shape and degree of dilation of the SGs evaluated by using XRESD are reported in Table 2. In AP projection of the immediate post-operative stage in the SG group with EWL <50%, there was a slight prevalence towards the "golf club" shape (52.2%) followed by the "inverted C" shape (47.8%). In SGs with EWL >50%, the prevailing shape was the inverted C (42%) followed by the golf club (36%) and an amount of not inconsiderable "angular" shapes (22%) were not present in the failed SG group. The differences between the two groups are statistically significant ($p = 0.0007$). Rapid remnant emptying was observed in 22.2% of the efficient SGs (six patients) against 4.3% of failed SGs (one patient).

Preoperative eating disorders were diagnosed: 8.5% binge eating, 59.5% grazing, 66% emotional eating, 25.5% craving and 62.5% sweet eating. Analysis of the EDI results showed that the two groups do not differ significantly when considering all the variables provided by the EDI (Table 3). Subjective change in taste perception can almost be overlapped in both groups. Eighty-nine percent of patients with SG failure had not noticed any change in sweet taste perception; 11% reported to perceive sweet tastes with greater intensity after surgery. In patients with efficient SG, 86.5% did not report any change in sweet perception; 4.5% reported a reduction in intensity and 9% an increase. The change in salty perception is similar: 95% of patients with EWL <50% did not report changes, and 5% declared an increase in intensity; patients with EWL >50% did not report changes in 91% of cases, while 4.5% reported an increase in intensity and in 4.5% cases a reduction in intensity. Similar trends occur in fat perception: in failed SGs, 95% report no change while 5% report greater intensity; in efficient SGs, 82% indicate no change, while 4.5% report a reduction in intensity and 3.5% an increase. Seventy-eight percent of the failed SG group still perceived, even years later, the sense of early satiety; 22% on the contrary reported to have lost it around 14 months after surgery (range 3–18 months). Twenty-six reported that they still did not feel the sense of hunger while 74% have reacquired appetite after an average of 12 months (range 2–36 months). Of patients in the efficient SG group, 92.5% continue to have, even years later, a sense of early satiety; 7.5% who have lost it, lost it on average after 19 months (range 18–20 months). Fifty-two percent reported that they still did not have a sense of hunger while 48% reacquired appetite after an average stage of 14 months (range 2–36 months). The differences between the two groups lie within the limits of significance ($p = 0.06$) for a sense of appetite and non-significant for the sense of early satiety.

Alimentary vomiting with a frequency superior to two episodes per month (range 3–10) was reported by three (11.1%) patients in the efficient SG group and by two (8.7%) patients in the failed SG group. The difference is not statistically significant.

Discussion

An RXESD carried out in the immediate post-operative stage and in later stages allowed us to evaluate the dimensions, the shape and the degree of dilation of the SG under examination. From a technical-surgical point of view, it is interesting to point out that in the immediate post-operative stage the mean dimensions of the remnant in the two groups overlap (Table 2), which indicates that in both groups surgery was carried out in the same way as obtaining, on average, the same degree of restriction. What emerged was that on a long-term

Table 1 Results

	Failed	Efficient	All	*p* pre-post	*p* inter
Gender	M 9, F 14	M 4, F 23	M 13, F 37		ns
Age	54 (27–74)	50.5 (25–66)	52 (25–74)		ns
Preoperative W (kg)	133 ± 19 (90–180)	129 ± 27 (95–199.5)	131 ± 21.8 (90–199.5)		ns
Preoperative BMI (kg/m^2)	47.6 ± 6.2 (36.6–58.8)	47.2 ± 7.4 (35.3–62)	47.4 ± 6.8 (35.3–62)		ns
EW (kg)	63.3 ± 18.4 (32.3–102.6)	60.7 ± 22.7 (27.9–110.3)	61.9 ± 20.7 (27.9–110.3)		ns
Follow-up (months)	36.5 ± 13.4 (24–66)	34 ± 11 (24–61)	35.1 ± 12.1 (24–66)		ns
WL (k)	21.2 ± 10 (2–41)	41.7 ± 17.2 (19–98)	32.3 ± 17.6 (2–98)		<0.0001
EWL%	33.7 ± 13.2 (3.6–49.5)	70.3 ± 4.3 (50.1–109.2)	53.5 ± 24.6 (3.6–109.2)	<0.0001	<0.0001
TWL%	15.6 ± 6.3 (1.5–25)	31.7 ± 8.5 (17.3–49.1)	24.31 ± 11 (1.5–49.1)	<0.0001	<0.0001
WR	7.8 ± 7.3 (0–30)	4.3 ± 4.4 (0–18)	5.9 ± 6.1 (0–30)		0.018
Preoperative T2DM	10 (43.5%)	9 (33.3%)	19 (38%)		ns
Follow-up T2DM	5 (21.7%)	6 (22.2%)	11 (22%)		ns
T2DM remission	5 (50%)	3 (33.3%)	8 (42.1%)		ns
Preoperative HTN	18 (78.3%)	18 (66.7%)	36 (72%)		ns
Follow-up HTN	13 (56.5%)	9 (33.3%)	22 (44%)		ns
HTN remission	5 (27.8%)	9 (50%)	14 (38.8%)		ns
Preoperative OSAS	7 (30.4%)	5 (18.5%)	12 (24%)		ns
Follow-up OSAS	5 (21.7%)	2 (7.4%)	7 (14%)		ns
OSAS remission	2 (28.6%)	3 (60%)	5 (41.7%)		ns
Preoperative FPG (mg/dl)	113 ± 48	98 ± 28	110 ± 49		ns
Follow-up FPG (mg/dl)	102 ± 39	88 ± 10	96 ± 27	0.032	ns
Preoperative HbAc1 (%)	7.03 ± 1.74 *(only diabetics 8.35 ± 1.77)*	6.34 ± 1.06 *(only diabetics 7.41 ± 1.25)*	6.77 ± 1.52		ns
Follow-up HbAc1 (%)	6.16 ± 1.44 *(only diabetics 6.9 ± 1.83)*	5.5 ± 0.45 *(solo diabetics 5.69 ± 0.6)*	5.77 ± 1	<0.0001	ns
Preoperative TOT-Ch (mg/dl)	179 ± 42	201 ± 37	191 ± 40		ns
Follow-up TOT-Ch (mg/dl)	198 ± 45	204 ± 38	103 ± 40	ns	ns
Preoperative TG (mg/dl)	106 ± 83	168 ± 70	168 ± 77		ns
Follow-up TG (mg/dl)	116 ± 50	96 ± 43	109 ± 52	<0,0001	ns

FPG fasting plasma glucose, *TOT-Ch* total cholesterol, *TG* triglycerides, *p pre-post* statistic analysis between preoperative stage and follow-up, *p inter* statistic analysis between "failed" and "efficient" sleeve gastrectomies

basis, patients who underwent SG demonstrate a mean dilation of the remnant quantifiable in approximately 50% with respect to dimensions in the immediate post-operative stage and that there is a statistically significant difference in the entity of the mean dilation between the two groups. Different authors have studied the morphology of the remnant and its degree of dilation in patients whose SG had been identified as failure, but, as far as we are aware, only a few have studied these morphological characteristics, comparing the immediate post-operative stage with the long-term follow-up, either in SGs with scarce effects in terms of weight loss or in SGs which were efficient regarding the treatment of obesity and its comorbidities. Through a gastric CT with volumetric reconstructions, 3 days and 2 years after SG, Braghetto et al. [31] studied the volumes of the remnant, in a group of 15 patients, describing a significant increase in gastric volume but without finding, probably due to the small dimension of the sample, a significant correlation between remnant dilation and weight loss. In a recent study, Deguines et al. [32], also with the use of a gastric CT, confirmed Braghetto's volumetric findings describing the mean volume of the remnant at 2 years of SG equal to 255 cm^3, but unlike Braghetto, they reported significant correlations between the dimensions of the remnant and success or failure of the SG defined

Table 2 Dimensions and degrees of dilation of the SGs evaluated by using X-ray oesophagus-stomach-duodenum in the immediate post-operative stage (post-op) and during follow-up

	Failed	Efficient	All	*p* pre-post	*p* inter
Area AP post-op (mm^2)	4010 ± 914	3958 ± 792	3982 ± 841		ns
Area AP follow-up (mm^2)	6620 ± 1589	5668 ± 1347	6106 ± 1525	<0.0001	0.019
Area AP dilation (mm^2)	2610 ± 1359	1710 ± 1276	2124 ± 1378		0.019
Area RAO post-op (mm^2)	4781 ± 1392	4540 ± 1178	4651 ± 1273		ns
Area RAO follow-up (mm^2)	7328 ± 2020	6093 ± 1417	6661 ± 1812	<0.0001	0.024
Area RAO dilation (mm^2)	2546 ± 1674	1552 ± 1347	2010 ± 1772		0.024
Ex-fundus post-op (mm)	25.6 ± 5.9	23.3 ± 7.1	24.4 ± 6.6		ns
Ex-fundus follow-up (mm)	37.4 ± 9.6	35.1 ± 8.1	36.2 ± 8.8	<0.0001	ns
Ex-fundus dilation (mm)	11.9 ± 9.2	11.8 ± 10.1	11.8 ± 9.6		ns
Body post op (mm)	12.7 ± 5.1	11 ± 3.3	11.8 ± 4.3		ns
Body follow-up (mm)	23.4 ± 9.8	13.3 ± 5.3	19 ± 8.6	<0.0001	0.002
Body dilation (mm)	10.7 ± 9.4	4.4 ± 3.9	7.3 ± 7.6		0.0025
Antrus post-op (mm)	39 ± 8.8	35.3 ± 8.7	37 ± 8.9		ns
Antrus follow-up (mm)	49 ± 10.1	43 ± 8.7	45.8 ± 9.8	<0.0001	ns
Antrus dilation (mm)	10 ± 10.6	7.7 ± 9.3	8.8 ± 9.8		ns

AP anteroposterior projection, *RAO* right anterior oblique projection, *p pre-post* statistic analysis between preoperative stage and follow-up, *p inter* statistic analysis between "failed" and "efficient" sleeve gastrectomies

by EWL <50%. A recent investigation by Fahmy et al. [33], conducted on a small group of patients who have gained weight post SG, reports a significant correlation between the quantity of weight gained and the volume of the remnant, calculated using gastric CT with volumetric reconstructions at 2 years of surgery.

Vidal et al. [34], in a recent study in which remnant volume was measured using a geometrical approximation after

Table 3 Variables provided by self-administration of the Eating Disorder Inventory-3 during follow-up (*p inter* statistic analysis between "failed" and "efficient" sleeve gastrectomies)

	Failed		Efficient		
	Mean	Standard. deviation	Mean	Standard. deviation	*p* inter
Drive for thinness	12.41	7.19	12.95	7.05	0.79
Bulimia	5.63	6.33	4.55	4.79	0.51
Body dissatisfaction	17.67	8.81	20.50	8.80	0.27
Composite risk of eating disorder	35.70	16.95	38.00	14.67	0.62
Low self-esteem	4.48	4.14	4.23	3.75	0.82
Personal alienation	6.15	6.05	6.55	4.27	0.80
Interpersonal insecurities	7.26	6.27	5.55	4.53	0.29
Interpersonal alienation	7.81	5.09	7.14	4.19	0.62
Interoceptive deficits	7.11	6.26	7.95	7.24	0.66
Emotional dysregulation	6.30	5.18	6.64	5.52	0.83
Perfectionism	7.15	4.98	8.50	5.22	0.36
Asceticism	6.59	4.35	9.00	6.15	0.12
Maturity fears	11.26	6.49	10.95	7.35	0.88
Inadequacy	10.63	9.24	10.77	7.30	0.95
Interpersonal problems	15.07	10.58	12.68	7.81	0.38
Affective problems	13.41	10.77	14.59	11.30	0.71
Over control	13.74	8.03	17.50	9.78	0.15
General psychological maladjustment	64.11	32.35	66.50	33.57	0.80

XRESD at 1 month and at 12 months of SG surgery, documented a mean volumetric increase of the remnant of 50% at 1 year and EWL% at 18 months inversely correlated with the volumetric increase of the remnant at 12 months.

Our data, although not obtained with CT study and not expressed in volumes, perfectly agree with the data of the studies mentioned by demonstrating a dilation of the remnant, with a mean 35 months of follow-up, of about 50% with respect to the immediate post-operative stage. Our study also agrees with the abovementioned studies by affirming that there is a correlation between the degree of SG dilation and long-term weight loss. Even though the morphological/dimensional description of the remnant using an XRESD is probably more approximate than using gastric CT with volumetric reconstructions, our study with respect to Deguines' has the advantage that it was carried out in both the immediate post-operative stage and years after surgery allowing us to evaluate the morphological change that the remnant underwent in each patient throughout the years. With respect to Fahmy's study, ours has the advantage that it demonstrated the degree of remnant dilation not only in patients with insufficient weight loss or weight regain but also in patients whose SG was efficient. The added value with respect to Braghetto's study lies instead in the sample dimension being studied (50 vs 15). Regarding Vidal's study, which has a very similar design, ours examines a group of patients with more long-term follow-up (mean of 35 vs 18 months).

Possible explanations to justify a dilated remnant are multiple: a technical error during surgery, the use of a bougie that is too big, the interindividual differences in the elastic properties of the gastric wall and the incorrect post-operative eating habits. It has been hypothesised that the failure of patients to comply with assigned diets could lead to a continued, progressive, mechanical enlargement of the remnant causing such dilation that they are able to introduce an ever greater volume of calories with a reduced sense of satiety. In our study, the standardisation of the technique (using a 36F bougie) and the overlapping morphological results between the two groups with XRESD carried out in the immediate post-operative stage allow us to exclude the two first hypotheses. However, it is clear that excessive dilation of the remnant, undermining the restrictive component, leads to weight loss which is not optimal.

Another interesting factor which emerged from our study is that, despite the fact that all the remnant parts (ex-fundus, body and antrum) dilated, the body in failed SG is the portion with a greater degree of dilation (ex-fundus 51.7%, body 102%, antrum 30.2%) (Table 2). When analysing the dilation differences of the single parts between the two groups, the only one that is statistically significant is, once again, the body (failed vs efficient, 102 vs 41.7%) ($p = 0.0025$). This data differs from most of the results reported in literature [35] which describe a greater dilation of the upper portion of the remnant pouch (ex-fundus) compared to other portions, which, in most cases, is held responsible for possible SG failure. Dilation of the "ex-fundus" represents, in fact, one of the most frequent long-term complications reported in literature needing revision surgery in approximately 4.5% of patients [36, 37]. On the other hand, recent studies demonstrated that the cranial dilation ("fundal") of the remnant does not significantly influence weight loss and the volume of the new fundus does not correlate with EWL and BMI post SG, concluding that the new fundus does not act as functional reservoir [38]. In our study, the upper portion of the remnant was dilated by an average of 51.7% in failed SGs and 60.1% in efficient SGs with post-operative dimensions that can be overlapped. This data, in association with recent evidence reported in literature, leads us to presume that failures, which in the past were attributed to dilation of the upper portion of the remnant, are in reality due to an incomplete gastric fundus resection ab initio and that, in these cases, the mechanism determining failure is more of a hormonal nature than a mechanical one.

Some studies [39, 40] have suggested that gastric receptors defined as "tension" or "stretch" receptors have a role in the control of satiety by sending signals to the central nervous system through vagal afferents. SG efficiency in the first months post surgery and in the long term for those whose restriction remains could be due to stimulation of stretch receptors even after ingesting modest amounts of food, with the consequent sense of early satiety. Moreover, the interstitial cells of Cajal, which are above all grouped at the middle region level of the gastric body, are responsible for the natural gastric pacemaker and they determine the peristaltic movements of the stomach. In contrast, the gastric fundus is electrically silent. These elements would explain the reason why, in our study, patients who had gastric restriction that remained, even long-term, at body level, had better results in terms of EWL. These deductions would also be coherent with the evidence found in the efficient SG group which reported a greater persistence in time of a sense of early satiety compared to the failed SG group (92.5 vs 78%) and a similar result was observed for lack of appetite (52 vs 26%).

The analysis of the remnant shapes in the immediate post-operative stage (Fig. 2) showed a statistically significant difference between the two groups ($p = 0.0007$). This data, which is not distorted by significant vomiting or "food intolerance", suggests greater success in those patients with a narrow remnant pouch, subject to greater mechanical stimulation, with radical resection of the gastric fundus and minor antral reservoir.

There does not seem to be an agreement among authors regarding the dimensions of the antrum to be preserved during SG [41–49]. Our study has not shown significant differences between the two groups, neither in the immediate post-operative dimensions of the antrum nor in those measured in the follow-up. Although data analyses related with SG shapes suggest the propensity towards an antrum with a narrower reservoir, data in our possession does not allow us to draw conclusions to this respect.

As far as all the variables provided by the EDI are concerned, the two groups of patients did not statistically differ.

This, together with the absence of frank differences in psychiatric comorbidity diagnosed in the preoperative evaluations, suggests that the instruments used do not allow us to grasp elements able to explain the different responses between the groups nor even the different degrees of dilation of the remnant post SG. Although literature has documented an improvement of variables evaluated with EDI pre and post SG [50], a significant difference between failed and efficient SGs cannot be demonstrated with the data in our possession.

As far as comorbidities are concerned, analysing the two groups, it is interesting that T2DM remission in the failed SG group occurred in 50% of patients vs 33.3% in the efficient SG group, in which it is like suggesting that the resolution of this comorbidity is, at least in part, independent of weight loss and mediated by other hormonal/neuronal mechanisms. HbA1c values of diabetic patients examined improved after SG without a significant statistical difference between the two groups (Table 1).

A greater tendency towards remission was observed in the efficient SG group compared to the failed SG group regarding HTN (50 vs 27.8%) and OSAS (60 vs 28.6%). This data, although not statistically significant, suggests a possible, more direct cause-effect relationship between weight loss and HTN and OSAS remission than with T2DM.

Changes in terms of plasma value reduction, FPG, HbA1c, TG and total cholesterolaemia (Table 1) did not statistically differ between the two groups suggesting that the improvement of the metabolic/laboratory profile obtained post SG is not to be attributed to just weight loss.

Our study presents some limitations:

- The morphological study of the gastric remnant was carried out through XRESD with hydro-soluble contrast in the absence of gaseous distension. This has not allowed us to measure the effective volume of the remnant but to evaluate its dimension (area and width) on planar images. We chose this radiological investigation because it was possible to carry out in the immediate post-operative stage (a fistula risk moment) and easily repeatable in the follow-up. For a more accurate measurement of the remnant, some studies [51, 52] used complex techniques, among which there are nuclear medicine investigations and CT with 3D multiplanar reconstructions. However, these studies entail an increased exposition to radiation for patients and an increase in costs for the hospital.
- The EDI-3 was only administered in the follow-up and not in the post-operative stage. This has not allowed us to confirm or contradict post-SG improvements of some variables of the EDI described in literature.
- For some variables, for example rapid emptying of the remnant, the sample of 50 patients was too small to establish statistically significant differences between the two groups.

Conclusions

The long-term mean dilation of the remnant post SG of the population examined was approximately 50% with respect to the immediate post-operative stage. Patients with EWL <50% showed greater remnant dilation than those with EWL >50% despite having had overlapping post-operative dimensions. The portion, in percentage, with greater dilation was the gastric body in failed SGs. With regards to the comorbidities associated with obesity, T2DM remission does not seem to be strictly correlated with weight loss. As far as all the variables provided by the EDI are concerned, the two groups of patients have not shown statistically significant differences. Lastly, among all eating disorders, sweet eating seems to be connected, although weakly, with SG failure.

Compliance with Ethical Standards

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

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