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Effect of morbid obesity, gastric banding and gastric bypass on esophageal symptoms, mucosa and function

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Abstract
Background Obesity and gastroesophageal reflux disease (GERD) are commonly associated diseases. Bariatric surgery has been shown to have various impacts on esophageal function and GERD. Our aim was to evaluate changes in symptoms, endoscopic findings, bolus passage and esophageal function in patients after primary gastric bypass surgery as compared to patients converted from gastric banding to gastric bypass.
Methods Obese patients scheduled for laparoscopic Roux-en-Y gastric bypass (naïve-to-bypass) and patients who previously underwent gastric banding and were considered for conversion from gastric banding to gastric bypass (band-to-bypass) were included. Patients rated esophageal and epigastric symptoms (100 point VAS) and underwent upper endoscopy, impedance–manometry, and modified "timed barium swallow" before/after surgery.
Results Data from 66 naïve-to-bypass patients (51/66, 77 % females, mean age 41.2 ± 11.1 years) and 68 band-to-bypass patients (53/68, 78 % females, mean age 43.8 ± 10.0 years) were available for analysis. Esophageal symptoms, esophagitis, esophageal motility abnormalities and impaired esophageal bolus transit were more common in patients that underwent gastric banding compared to those that underwent gastric bypass. The majority of symptoms, lesions and abnormalities induced by gastric banding were decreased by conversion to gastric bypass. Esophagitis was present in 28/68 (41 %) and 13/47 (28 %) patients in the band-to-bypass group, pre- versus postoperatively, respectively, ($p < 0.05$). The percentage of swallows with normal bolus transit increased following transformation from gastric band to gastric bypass (57.9 ± 4.1 and 83.6 ± 3.4 %, respectively, $p < 0.01$).
Conclusions From an esophageal perspective, gastric bypass surgery induces less motility disorders and esophageal symptoms and should be therefore favored over gastric banding in difficult to treat obese patients at risk of repeated bariatric surgery.

Keywords Bariatric surgery · Impedance–manometry · Endoscopy · Obesity

Abbreviations

BMI	Body mass index
BTT	Bolus transit time
DEA	Distal esophageal amplitude
EFT	Esophageal function testing
GERD	Gastroesophageal reflux disease
GI	Gastrointestinal
HPZ	High-pressure zone
LA	Los Angeles classification
LASGB	Laparoscopic adjustable silicone gastric banding
LES	Lower esophageal sphincter

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LRYGBP	Laparoscopic Roux-en-Y gastric bypass
LVBG	Laparoscopic vertical banded gastroplasty
MII-EM	Combined impedance–manometry
PPIs	Proton pump inhibitors

Overweight and obesity are major concerns with regard to the health status of the adult and adolescent population. The prevalence of obesity more than doubled between 1980 and 2009 as indicated by a survey of the Centers for Disease Control. A recently published report of the US National Health and Education Survey (NHANES) found that approximately 66 % of the adult US population is either overweight [defined as body mass index (BMI) 25–30 kg/m^2] or obese (defined as BMI $>$ 30 kg/m^2) [1]. The prevalence of extremely obese (defined as BMI $>$ 40 kg/m^2) individuals was shown to reach 4.8–5.1 % of the general population. As many extremely obese patients fail conventional pharmacologic and dietary therapies, bariatric surgery remains their only option.

Currently employed bariatric procedures include laparoscopic adjustable gastric banding (gastric banding), laparoscopic vertical sleeve gastrectomy and laparoscopic Roux-en-Y gastric bypass (LRYGBP). These interventions lead to various degrees of weight loss and metabolic changes. In addition, modifying gastric anatomy leads to changes in esophageal motility and gastroesophageal reflux patterns. Since morbid obesity is associated with increased prevalence of esophageal erosions and reflux symptoms [2, 3], individual procedures can improve but also worsen gastroesophageal reflux disease (GERD) symptoms and findings [3]. So far, those changes induced by bariatric interventions have not been evaluated by impedance–manometry.

The aims of the present study were to evaluate the changes in esophageal and upper gastrointestinal (GI) symptoms, endoscopic findings, bolus passage and esophageal function in patients scheduled for gastric bypass (naïve-to-bypass) as compared to obese patients with a conversion from gastric banding to gastric bypass. Our hypotheses were that gastric bypass surgery would improve reflux symptoms, have no influence on esophageal motility and reverse changes in esophageal function induced by prior gastric banding surgery.

Materials and methods

This study received IRB approval by the Ethics Committee of the University Hospital Zurich and Kantonsspital St. Gallen. The study is registered in the Clinical Trial Registry (NCT00680030). All authors had access to the study data and had reviewed and approved the final manuscript.

Study population

The study included two groups of patients (Fig. 1): (1) patients who underwent gastric banding in the past and were now considered for conversion from gastric banding to gastric bypass (band-to-bypass) and (2) a control group of patients scheduled to undergo gastric bypass (naïve-to-bypass). All patients considered candidates for these operations were approached to participate in this prospective study. The rationale to include a "control group" was to evaluate if abnormalities after conversion from gastric banding to gastric bypass would have been encountered even if patients underwent direct gastric bypass. Since our centers did not perform "de novo" gastric band implantations starting 2006, we were not able to include patients naïve-to-banding. Patients were not included in the study if they had acute cardiac or pulmonary conditions, prior anti-reflux surgery or anti-reflux endoscopic procedures or if they were unable to provide informed consent. The reasons for conversion from gastric band to gastric bypass were either upper GI-tract symptoms or insufficient weight loss. Participants who fulfilled the inclusion/exclusion criteria underwent baseline symptom evaluation, upper GI endoscopy, an upper GI series (including modified "timed barium swallow") and esophageal function testing (EFT) using combined impedance–manometry (MII-EM) before and at least

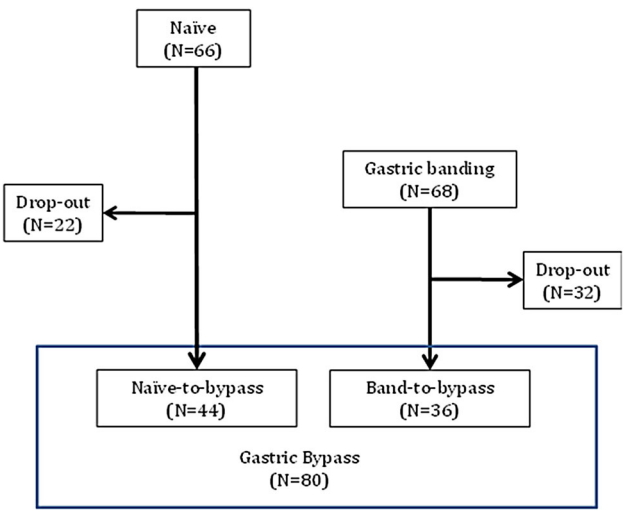

Fig. 1 A flowchart describes the patient groups in the study. Average duration between pre- and postoperative investigations was 165 ± 83 days in the naïve to bypass group and 177 ± 53 days in the band to bypass group (p = ns)

3 months after successful gastric bypass or conversion from gastric band to gastric bypass, respectively.

Operations: gastric bypass surgery and conversion from gastric band to gastric bypass

All operations were carried out by the same lead surgeon (MT). The LRYGBP procedure was performed using six abdominal ports. In all patients, a 15-20 ml gastric pouch was created as the restrictive component of the procedure. The gastrojejunostomy was performed end-to-side using a 25-mm-circular stapler (ECS 25 mm; Ethicon, Endo-Surgery, OH, USA). Limb lengths were systematically tailored according to patients' BMI, comorbidities, eating habits and psychosocial situation, thereby establishing a "proximal" and a "distal" variant of the LRYGBP procedure. Band-to-bypass patients always received a distal bypass, and the distribution of distal and proximal variants among the naïve patients was about equal. The biliopancreatic limb was 60-100 cm, according to tension of the mesentery. The alimentary limb in the proximal bypass was always 150 cm, thus leaving a long remainder of small bowel as the common channel. The common channel in the distal bypass was 10 % of total small bowel length (but always $\geq$60 and $\leq$100 cm), adding a marked malabsorptive element. The jejunojejunostomy or jejunoileostomy, respectively, was performed side-to-side, using a linear stapler.

The gastric banding patients had either a Lap-Band® (Allergan Inc., Irivne, CA, USA) or a Swedish Adjustable Gastric Band® (Ethicon Endo-Surgery, OH, USA) implanted in a high cardial position. The band was explanted at the beginning of the conversion procedure, along with adhesiolysis of the esophagogastric junction as necessary.

Symptom evaluation, endoscopy, upper GI series and esophageal function testing

As part of the clinical evaluation, patients were asked to rate esophageal symptoms (heartburn, chest pain, regurgitation and dysphagia), upper GI symptoms (nausea, abdominal pain, epigastric fullness and others) on a 7-point Likert scale (0—no discomfort to 7—maximal discomfort) and use of proton pump inhibitors (PPIs) (no PPI, PPI on demand, PPI qd or PPI bid). Sedated (propofol) upper endoscopy was performed by experienced gastroenterologists who paid particular attention to the integrity of esophageal mucosa, presence of hiatal hernia, the size of the gastric pouch above the band (in the band-to-bypass group), the size of the gastric pouch above the gastrojejunal anastomosis (postoperative examination) and the presence of ulcerations at the site of gastric banding/gastric bypass.

The radiologic examination consisted of a modified "timed barium swallow" (achalasia) protocol [4]. Patients drank 100-150 ml liquid barium, and PA images focused on the gastroesophageal junction were taken immediately after swallowing and at time intervals 30 s, 1 and 3 min. We assessed the height and width of the barium column at these times. Stasis was declared if the barium column was higher than 1 cm 30 s after oral ingestion of barium contrast.

Esophageal function testing (EFT) was performed using a solid-state Koenigsberg 9-channel (5-pressure 4-impedance) probe [Sandhill esophageal function testing (EFT) catheter; Sandhill Scientific Inc, Highlands Ranch, CO] and started by placing a combined impedance–manometry probe trans-nasally through the esophagus into the stomach. Subjects were placed in recumbent position, and the lower esophageal sphincter (LES) was located by station pull-through technique. The most distal circumferential pressure sensor was placed in the high-pressure zone (HPZ) of the LES. The LES resting pressure was measured as the 4-s average mid-respiratory pressure in the distal esophagus. Participants received 10 swallows (5 cc each) of liquid (0.9 % normal saline) and 10 swallows (5 cc each) of a standard viscous material (EFT viscous, Sandhill Scientific, Inc) and asked to refrain from swallowing for 20–30 s after each individual swallow. Analyzed parameters included: Bolus transit time (BTT): time interval (s) between bolus entry at the proximal measuring segment and bolus exit at the distal segment, contraction amplitude at 5, 10, 15 and 20 cm above the HPZ, distal esophageal amplitude (DEA): average amplitude of contraction at 5 and 10 cm above HPZ, contraction onset velocity of contractions: contraction velocity between 5 and 10 cm above the HPZ and LES mid-respiratory resting pressure measured during station pull-through.

Esophageal contractions were classified as (1) normal if the contraction amplitude at 5 and 10 cm above HPZ exceeded 30 mmHg and the distal onset velocity was less than 8 cm/s, (2) simultaneous if the contraction amplitude at 5 and 10 cm above HPZ exceeded 30 mmHg and the distal onset velocity exceeded 8 cm/s or contraction onset was retrograde and (3) ineffective if the contraction amplitude at 5 or 10 cm above HPZ was less than 30 mmHg. Esophageal motility abnormalities were classified according to conventional manometric criteria published by Spechler and Castell [5].

Swallows were classified as having (1) complete bolus transit if impedance detected bolus entry at 20 cm above the HPZ and bolus exit at all three distal sites (15, 10 and 5 cm above HPZ) and (2) incomplete bolus transit if bolus exit was not detected in any of the three distal sites (15, 10 and 5 cm above HPZ).

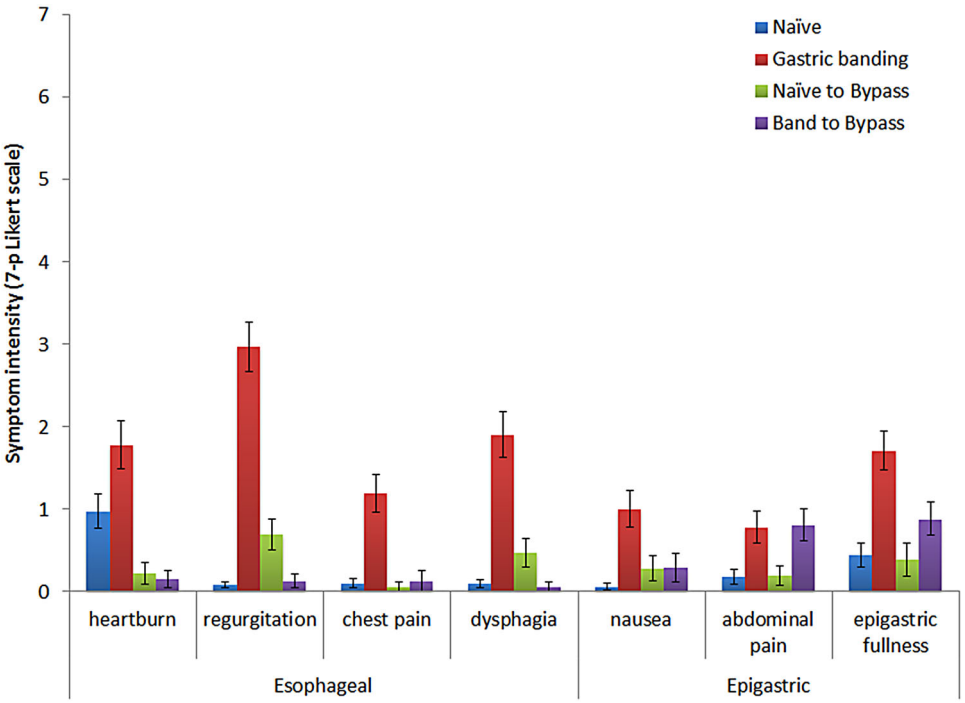

Fig. 2 Esophageal and epigastric symptoms before and after gastric bypass in the naïve to bypass group and band to bypass group of patients. Patients following gastric banding had more intense symptoms compared to the naïve patients. Symptom intensity either decreased or remained unchanged after gastric bypass. *Bars* indicate mean values, the error-bars standard error of the mean (SEM)

Data analysis and sample size calculation

Proportions were compared using McNemar test, and continuous parameters (i.e., symptom scores, esophageal manometry and bolus transit data) recorded prior and after the operation were compared using paired *T* tests or Wilcoxon Matched-Pair Signed-Rank test according to data distribution. Data from naïve, gastric banding and gastric bypass groups were compared using one-way ANOVA (with Bonferroni post hoc correction for comparison between groups) or Kruskal–Wallis H Test according to data distribution. For statistical significance, alpha was set at 0.05.

Assuming that esophageal motility abnormalities are present in 50 % of patients prior to the conversion of banding to bypass and that conversion reduces this proportion by 50 %, we calculated that 40 complete datasets would be required for an 85 % power to identify this change. Allowing a dropout rate of 20 %, we planned to enroll 48 patients in this arm. The number of patients going directly to gastric bypass (naïve-to-bypass) surgery was matched to the number of patients in the band-to-bypass group.

Results

The flowchart in Fig. 1 shows the different groups of patients and the number of dropouts. Patients were recruited between May 2006 and November 2009, and the follow-up examinations took place between October 2006 and May 2010.

The group of patients that underwent conversion from gastric band to gastric bypass (band-to-bypass) included 68 patients (53/68, 78 % females, mean age 43.8 ± 10.0 years). Preoperatively, 56 (83 %) band-to-bypass patients were off PPI therapy, and among patients on PPI therapy, 9 (13 %) were taking the medication once daily and 3 (4 %) patients were taking PPI bid. After a complete preoperative work-up, forty-seven (69 %) patients agreed to undergo postoperative upper GI endoscopy, 33 (48 %) patients modified barium swallow and 36 (53 %) patients esophageal function testing at an average of 101 ± 32 days following conversion from gastric band to gastric bypass (Fig. 1). Postoperatively, 3 (6 %) patients were on PPI therapy, whereas 44 (94 %) were not taking any acid suppressive medication.

The group of patients that directly underwent gastric bypass surgery (naïve-to-bypass) included 66 patients (51/66, 77 % females, mean age 41.2 ± 11.1 years) recruited between May 2006 and November 2009. Patients in this naïve-to-bypass group lost on average 7.0 ± 0.4 BMI points (preoperative 44.9 ± 0.9 kg/m^2 to postoperative 37.8 ± 0.8 kg/m^2; $p < 0.001$), whereas patients in the band-to-bypass group lost on average 5.4 ± 0.5 BMI points (preoperative 38.7 ± 0.8 kg/m^2 to postoperative 33.2 ± 0.7 kg/m^2; $p < 0.001$). Preoperatively, 54 (82 %) naïve-to-bypass patients were off PPI therapy, and among patients on PPI therapy, 8 (12 %) were taking the

Table 1 Symptoms, modified timed barium swallow and endoscopic findings in patients evaluated before and after gastric bypass assessed separately for naïve to bypass and gastric banding to bypass

	Before gastric bypass		After gastric bypass	
	Naïve ($N = 66$) Mean ± SEM	Gastric banding ($N = 68$) Mean ± SEM	Naïve→bypass ($N = 39$) Mean ± SEM	Band→bypass ($n = 47$) Mean ± SEM
Symptoms (0–7 point Likert scale)				
Esophageal				
Heartburn	$0.98 \pm 0.21^{a,b}$	$1.78 \pm 0.29^{a,b}$	0.22 ± 0.13^{a}	0.15 ± 0.10^{a}
Regurgitation	$0.08 \pm 0.04^{a,b}$	$2.97 \pm 0.30^{a,b}$	$0.69 \pm 0.19^{a,b}$	$0.13 \pm 0.08^{a,b}$
Chest pain	0.10 ± 0.06^{b}	$1.19 \pm 0.23^{a,b}$	0.06 ± 0.06	0.13 ± 0.13^{a}
Dysphagia	$0.10 \pm 0.05^{a,b}$	$1.91 \pm 0.28^{a,b}$	$0.47 \pm 0.17^{a,b}$	$0.06 \pm 0.06^{a,b}$
Epigastric				
Nausea	0.06 ± 0.04	1.00 ± 0.22^{a}	0.28 ± 0.15	0.29 ± 0.17^{a}
Abdominal pain	0.18 ± 0.09^{b}	0.78 ± 0.19^{b}	0.19 ± 0.12^{b}	0.81 ± 0.20^{b}
Epigastric fullness	0.44 ± 0.15^{b}	$1.71 \pm 0.24^{a,b}$	0.39 ± 0.20	0.88 ± 0.20^{a}
Modified timed barium swallow				
Retention in the distal esophagus	(7, 15 %)[b]	(38, 73 %)[a,b]	(3, 9 %)[b]	(9, 21 %)[a,b]
Column height 30 s	1.0 ± 0.4^{b}	$6.2 \pm 1.0^{a,b}$	0.7 ± 0.4	1.1 ± 0.4^{a}
Column height 1 min	0.5 ± 0.3^{b}	$6.4 \pm 1.0^{a,b}$	0.6 ± 0.3	0.7 ± 0.4^{a}
Column height 3 min	0.7 ± 0.4^{b}	$5.5 \pm 1.0^{a,b}$	0.0 ± 0.0	0.3 ± 0.3^{a}
Endoscopy				
No esophagitis	(46, 70 %)[b]	(40, 59 %)[b]	(38, 97 %)[b]	(34,72 %)[b]
Esophagitis				
LA A	(12, 18 %)	(11, 16 %)	(1, 3 %)	(4, 9 %)
LA B	(7, 11 %)	(16, 24 %)	(0, 0 %)	(7, 15 %)
LA C–D	(1, 1 %)	(1, 1 %)	(0, 0 %)	(2, 4 %)

Naïve: pre-op evaluation before gastric bypass; *gastric banding*: pre-op evaluation before conversion from gastric band to gastric bypass; *naïve→bypass*: post-op evaluation in patients who underwent direct gastric bypass; *band→bypass:* post-op evaluation in patients who underwent conversion from gastric band to gastric bypass

LA Los Angeles classification

[a] $p < 0.05$ pre-OP versus Post-OP

[b] $p < 0.05$ naive versus Banding

medication once daily, 1 (2 %) patient was taking PPI bid and 3 (4 %) patients were taking PPI on demand. The demographic data of the two groups were not different.

All naïve-to-bypass patients had a complete preoperative work-up including upper endoscopy, impedance–manometry and timed barium swallow. Postoperatively, thirty-nine (59 %) patients agreed to undergo upper GI endoscopy, 39 (59 %) patients underwent modified timed barium swallow and 44 (67 %) patients performed esophageal function testing at an average of 123 ± 83 days following gastric bypass surgery (Fig. 1). Postoperatively, 4 (10 %) patients were on PPI therapy, whereas 35 (90 %) were not taking any acid suppressive medication.

Given the high dropout rate, we explored potential differences between patients who completed the study and those who underwent only preoperative testing. We found no difference in age (43 vs. 42 years; $p = 0.55$), gender (females 80 vs. 76 %; $p = 0.67$), preoperative BMI (41 vs. 42; $p = 0.18$), presence/absence of esophagitis (esophagitis 35 vs. 36 %; $p = 0.91$) and initial intensity of symptoms between patients that came for follow-up and those who dropped-out of the study.

Symptom evaluation

Patients naïve to bariatric surgery reported minimal esophageal symptoms, much less compared to patients who had undergone gastric banding (Fig. 2). Patients who had previously undergone gastric banding reported moderately intense regurgitation and to a lesser degree dysphagia and heartburn. Postoperatively, esophageal and epigastric symptoms were minimal in patients who had undergone gastric bypass surgery. Symptom intensity scores are summarized in Table 1.

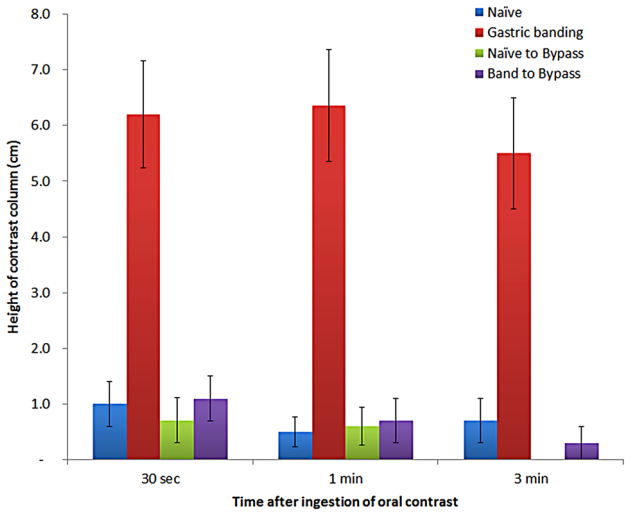

Fig. 3 Esophageal barium transit: height of the contrast column measured during a modified timed barium swallow with images taken 30 s, 1 and 3 min after ingestion of 100–150 ml barium. Contrast retention defined as a column greater than 1 cm at 30 s was observed in 7 (15 %) of naïve patients, in 38 (73 %) of patients following gastric banding, in 3 (9 %) of patient who underwent direct gastric bypass (naïve to bypass) and in 9 (21 %) of patients who underwent conversion from gastric banding to gastric bypass. *Bars* indicate mean values, the error-bars standard error of the mean (SEM)

Barium transit studies

Conversion from gastric band to gastric bypass improved esophageal emptying, only 21 % of patients in the band-to-bypass group having a measurable esophageal retention with a barium column higher than 1 cm above the LES in the 30 s image ($p < 0.05$ pre- vs. post-conversion). Abnormal esophageal transit was observed in only 15 % of patients naïve to bariatric surgery, whereas 73 % of patients who underwent gastric banding had esophageal retention 30 s after drinking 100–150 ml barium ($p < 0.01$). No changes in the incidence of esophageal retention were noticed in the naïve-to-bypass group. Details on the average height of esophageal columns at 30 s, 1 and 3 min are summarized in Table 1 and Fig. 3.

Endoscopic findings

Preoperatively, 28/68 (41 %) patients in the band-to-bypass group and 20/66 (30 %) patients in the naïve-to-bypass group had esophageal erosions ($p = 0.013$). Postoperatively, 13/47 (28 %) patients in the band-to-bypass group and 1/39 (3 %) patient in the naïve-to-bypass group had esophageal erosions ($p < 0.001$). The grading of esophageal erosions between groups is compared in Table 1 and Fig. 4.

Esophageal function testing

Patients with gastric banding had higher percentage of manometric ineffective contractions ($p < 0.05$) for liquid swallows and a lower percentage of swallows with complete bolus transit for both liquid ($p < 0.01$) and viscous ($p < 0.01$) swallows. Patients naïve to bariatric surgery had normal manometric patterns and bolus transit when compared to normal values in healthy volunteers from previously published works [6]. In the naïve-to-bypass group, the percentage of manometric normal contractions and percentage of liquid swallows with complete bolus transit declined postoperatively compared to preoperatively ($p < 0.05$). On the other hand, in the band-to-bypass group, the percentage of manometric normal/abnormal contractions did not change after the transformation from gastric band to gastric bypass and the percentage of swallows with normal bolus transit increased following transformation from gastric band to gastric bypass ($p < 0.01$).

Overall esophageal motility and bolus transit abnormalities were more severe in patients with gastric banding compared to gastric bypass. Esophageal manometry and impedance parameters are summarized in Table 2 and supplemental figure 1. In the band to bypass group, preoperative manometry found 40 (60 %) patients with normal esophageal motility, 16 (24 %) patients with IEM, 4 (6 %) patients with DES and 7 (10 %) patients with poorly relaxing LES. Postoperatively, we found 30 (68 %) patients with normal esophageal motility, 11 (25 %) patients with IEM, 2 (5 %) patients with DES and 1 (2 %) patient with poorly relaxing LES.

In the naïve-to-bypass group, preoperative manometry found 54 (82 %) patients with normal esophageal motility, 8 (12 %) patients with ineffective esophageal motility (IEM), 2 (3 %) patients with distal esophageal spasm (DES) and 2 (3 %) patients with nutcracker esophagus. Postoperatively, we found 20 (57 %) patients with normal esophageal motility, 14 (40 %) patients with IEM and 1 (3 %) patient with poorly relaxing LES.

Discussion

The present study provides a comprehensive review of esophageal/epigastric symptoms, endoscopic, bolus transit and esophageal function testing findings in patients undergoing gastric bypass surgery and transformation from gastric banding to gastric bypass surgery.

Current findings indicate that gastric banding is associated with a higher prevalence of esophageal symptoms (especially regurgitation), esophagitis, esophageal motility abnormalities (especially impaired LES relaxation) and impaired esophageal bolus transit (assessed by both

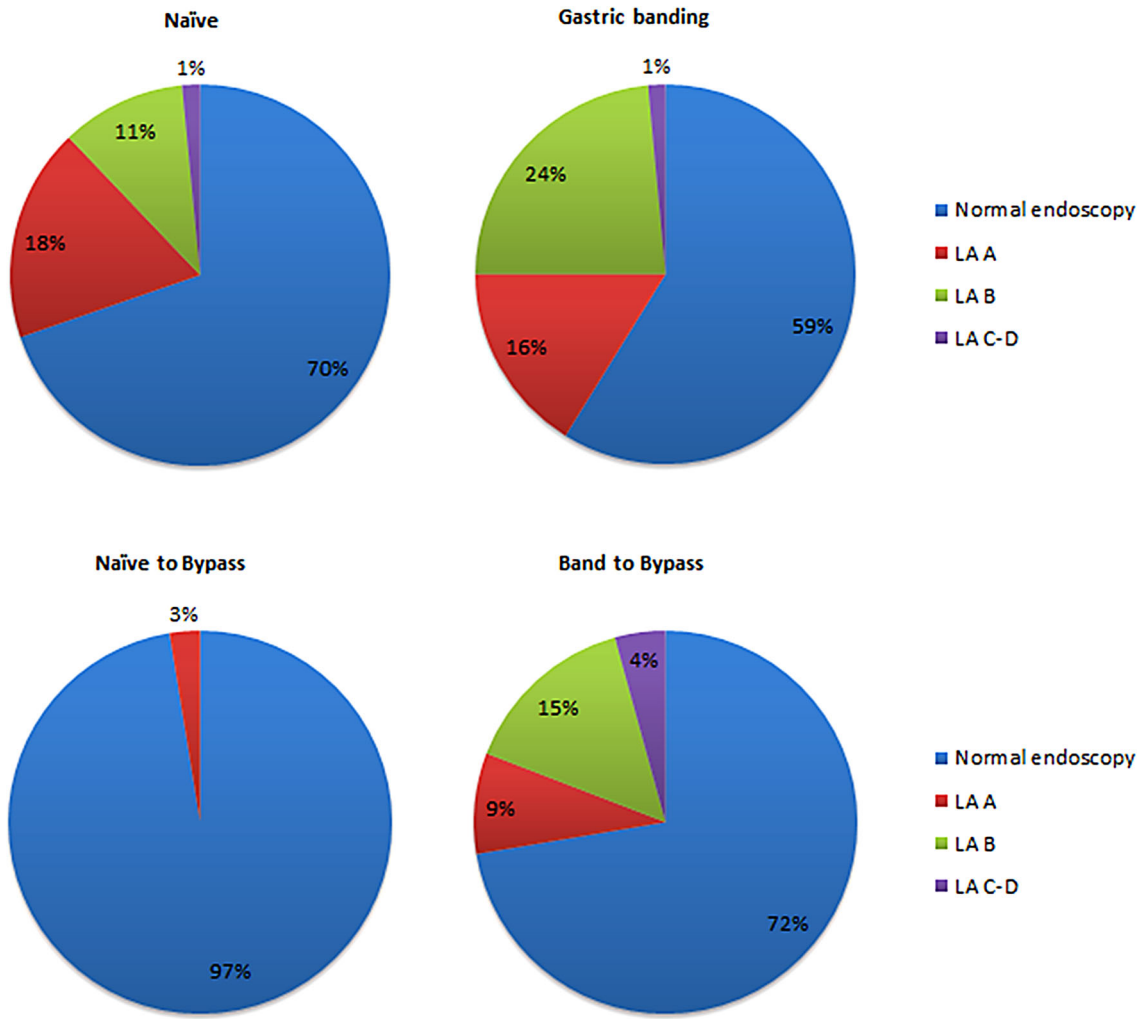

Fig. 4 Percentage of patients with normal esophageal findings and reflux esophagitis with erosions (classified according to the LA Criteria) in the naïve group ($N = 66$), postgastric banding ($N = 68$), after operation from naïve to bypass ($N = 44$) and after conversion from band to bypass ($N = 36$). Gastric bypass increased the proportion of normal esophageal findings in both groups of patients whether receiving direct and operation or undergoing conversion from gastric band to gastric bypass ($p < 0.05$ in both groups)

modified barium swallow and impedance recordings in this study). Conversely, primary gastric bypass surgery did not induce esophageal symptoms and erosions, but showed a measurable impairment of manometric properties and esophageal bolus transit, yet to a clinically insignificant extent. Moreover, the majority of symptoms, lesions and abnormalities induced by gastric banding were shown to be alleviated by conversion to gastric bypass. To our knowledge, this is the first study documenting the reversibility of gastric banding induced esophageal symptoms and motility abnormalities.

We found that ineffective motility is more frequent after gastric banding and to a lesser extent after gastric bypass surgery compared to naïve patients. The ineffective motility impacts bolus transit of liquid and viscous swallows as measured by impedance but does not become obvious during timed barium swallow, which prior studies concentrated on. Long-term follow-up after gastric banding has shown esophageal motility disorders in up to two-thirds of patients that may later lead to major complications as described in the paper by Naef et al. [7]. We believe that gastric bypass rather than gastric banding surgery should be considered in patients with motility disorders, albeit our finding only minor motility abnormalities in obese patients naïve to bariatric surgery.

Besides esophageal motility disorders, GERD is a controversial issue after bariatric surgery [8]. Our current findings with 41 % of reflux esophagitis after gastric banding versus 3 % after gastric bypass ($p < 0.01$) are different than those published by Dixon and O'Brien in 1999 [9]: Investigating the prevalence of esophageal erosions in patients undergoing gastric banding, the authors

Table 2 Esophageal function testing results evaluated before and after gastric bypass assessed separately for naïve to bypass and gastric banding to bypass patients

	Naïve ($N = 66$) Mean ± SEM	Gastric banding ($N = 68$) Mean ± SEM	Naïve→bypass ($N = 36$) Mean ± SEM	Band→bypass ($n = 44$) Mean ± SEM
Esophageal manometry				
Saline				
% Normal	82.2 ± 3.0 %[a,b]	70.3 ± 3.9 %[b]	63.2 ± 5.9 %[a]	70.2 ± 5.3 %
% Ineffective	14.7 ± 2.7 %[a,b]	25.0 ± 3.5 %[b]	36.2 ± 5.9 %[a]	28.1 ± 5.3 %
% Simultaneous	3.0 ± 1.4 %	4.8 ± 2.0 %	0.6 ± 0.4 %	1.7 ± 0.8 %
Distal esophageal amplitude (mmHg)	89.4 ± 4.9[a]	77.8 ± 5.1	68.1 ± 5.3[a]	73.3 ± 5.4
LESP residual pressure	1.2 ± 0.3[b]	4.3 ± 0.7[b]	1.6 ± 0.3	2.3 ± 0.8
Viscous				
% Normal	73.2 ± 3.4 %[a]	65.3 ± 4.4 %	59.4 ± 5.7 %[a]	61.8 ± 5.1 %
% Ineffective	23.3 ± 3.0 %[a]	29.0 ± 4.1 %	38.0 ± 5.5 %[a]	35.9 ± 5.1 %
% Simultaneous	3.5 ± 1.5 %	5.7 ± 1.6 %	2.6 ± 1.0 %	2.3 ± 1.1 %
Distal esophageal amplitude (mmHg)	76.5 ± 3.7[a]	77.8 ± 5.0	65.3 ± 6.2[a]	68.3 ± 5.4
LESP residual pressure	1.9 ± 0.4[b]	4.9 ± 0.6[b]	1.9 ± 0.4	3.4 ± 0.7
Impedance				
Saline				
% Complete bolus transit	91.7 ± 2.0 %[a,b]	57.9 ± 4.1 %[a,b]	80.7 ± 4.0 %[a]	83.6 ± 3.4 %[a]
% Incomplete bolus transit	8.4 ± 2.0 %[a,b]	42.1 ± 4.1 %[a,b]	19.3 ± 4.0 %[a]	16.5 ± 3.4 %[a]
Bolus transit time (s)	6.7 ± 0.2[a,b]	8.5 ± 0.3[a,b]	7.4 ± 0.3[a]	7.5 ± 0.3[a]
Viscous				
% Complete bolus transit	77.8 ± 2.8 %[b]	52.8 ± 3.9 %[b]	72.7 ± 4.5 %	68.7 ± 4.1 %
% Incomplete bolus transit	22.2 ± 2.8 %[b]	47.2 ± 3.9 %[b]	27.3 ± 4.5 %	31.3 ± 4.1 %
Bolus transit time (s)	7.8 ± 0.2[b]	9.0 ± 0.3[b]	8.7 ± 0.4	7.8 ± 0.3

Naïve: pre-op evaluation before gastric bypass; *gastric banding*: pre-op evaluation before conversion from gastric band to gastric bypass; *naïve→bypass*: post-op evaluation in patients who underwent direct gastric bypass; *band→bypass:* post-op evaluation in patients who underwent conversion from gastric band to gastric bypass

[a] $p < 0.05$ pre-OP versus post-OP

[b] $p < 0.05$ naive versus banding

found that 48/274 (16 %) of patients had reflux esophagitis requiring proton pump inhibitor (PPI) therapy. Two years after band placement, 36 (76 %) reported complete resolution of reflux symptoms and 7 (14 %) reported marked improvement. In a more recent trial, Rebecchi et al. [10] compared the incidence of GERD in 100 patients randomly assigned to either laparoscopic adjustable silicone gastric banding (LASGB) or laparoscopic vertical banded gastroplasty (LVBG). At the one-year follow-up, 13 (26 %) LASGB and 11 (21.6 %) LVBG patients developed GERD. In most cases, GERD was attributed to pouch dilation or poor compliance and required either re-operation (10 LASGB patients and 3 LVBG patients) or endoscopic dilation of the neo-pylorus (4 LVBG patients).

The low prevalence (3 %) of esophageal erosions in patients undergoing direct gastric bypass and the reduction after conversion from gastric banding to gastric bypass (from 41 to 28 %) are similar to previously published data. Perry et al. [11] reported on the effects of Roux-en-Y gastric bypass on recalcitrant GERD in morbidly obese patients. Their study included 57 patients with refractory GERD and BMI > 35 kg/m^2 scheduled to undergo laparoscopic gastric bypass. Postoperatively, only 3/57 (5 vs. 54 % preoperatively) patients used PPI bid and all 17/57 patients who had used high-dose H2-RA were now using low-dose ranitidine (ranitidine 150 mg daily), demonstrating the effect of surgery and weight loss on GERD symptomatology.

The present study has some limitations. The high dropout rate and limited compliance to individual investigations did not allow us to fully reach the targeted number patients. Nevertheless, most observed differences were statistically significant due to the larger than expected effect of gastric bypass on corresponding parameters. The group of patients with gastric banding included patients who either had an insufficient weight loss, did not tolerate

the inflated gastric band or both. An additional control group of patients without symptoms and successful weight loss would have offered a less biased estimate on the prevalence of symptoms and findings after gastric banding. Furthermore, this study investigated patients with thorough management of their symptoms and esophageal function after gastric banding by adjusting their bands regularly and performing transformation surgery if necessary, thus patients with achalasia-like distension of the esophagus after long-term gastric banding were excluded from functional testing. Also, the improvement in esophageal symptoms and findings in the band-to-bypass group might have been the result of "only" removing the gastric band device.

In conclusion, our findings indicate that laparoscopic Roux-en-Y gastric bypass surgery is associated with less esophageal symptoms, lesions and function abnormalities compared to gastric banding. Furthermore, gastric banding induced esophageal motility abnormalities can be significantly improved by conversion to gastric bypass. Thus, from an esophageal perspective, gastric bypass should be favored over gastric banding in difficult to treat obese patients at risk of repeated bariatric surgery.

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Author's contribution Jan Borovicka and Radu Tutuian equally contributed to the study design, planned the study protocol. Both of them also performed data analysis and wrote the manuscript. Radu Tutuian obtained funding from the study from the Research Foundation of the University Hospital of Zurich/University of Zurich. Claudia Krieger-Gruebel, Boudewijn van der Weg, Michael Christian Sulz, and Philipp Bisang performed the procedures and analyzed the data. Martin Thurnheer performed all gastric bypass surgeries. Bernd Schultes and Jean-Pierre Gutzwiler performed data analysis and approved the final draft. Daniel Pohl wrote the study protocol. Michael Fried and Christa Meyenberger critically reviewed the analysis and approved the final draft. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

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