



Control of Eating Attributes and Weight Loss Outcomes over One Year After Sleeve Gastrectomy

Ellina Lytvyak¹  · Amir Zarrinpar^{2,3} · Cecilia Dalle Ore³ · Euyhyun Lee⁴ · Keila Yazdani-Boset⁵ · Santiago Horgan⁷ · Eduardo Grunvald^{3,6,7}

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Abstract

Purpose Sleeve gastrectomy (SG) is a commonly performed metabolic-bariatric surgery, but its effectiveness is variable and difficult to predict. Our study aimed to compare control of eating (CoE) attributes pre- and post-SG depending on the achievement of optimal weight loss target at 1 year post-SG.

Materials and Methods A prospective longitudinal cohort study using the CoE Questionnaire, pre-SG, and postoperatively at 3, 6, and 12 months was conducted. Total weight loss (TWL) $\geq 25\%$ at 12 months post-SG was set as an optimal weight loss target.

Results Forty-one patients (80.5% females, mean age 41.7 ± 10.6) were included. Sex, age, baseline weight, BMI, and smoking status were all comparable. At 3 months post-SG, “difficulty to control eating” score became significantly different between $\geq 25\%$ TWL and $< 25\%$ TWL groups (7 [0–50] vs. 17 [5–63], $p = 0.042$). At 6 months, it was followed by “feeling of fullness,” “frequency of food cravings,” and “difficulty to resist cravings” demonstrating significant differences between $\geq 25\%$ TWL and $< 25\%$ TWL groups. At 12 months, significant differences between groups were observed in “feeling hungry,” “difficulty to resist cravings,” “eating in response to cravings,” and difficulty to control eating scores.

Conclusion Individuals with obesity who achieved a target of $\geq 25\%$ TWL at 1 year post-SG have an early improvement in overall eating control at 3 months that steadily persists at 6 and 12 months. Improvements in other aspects tend to follow later, at 6 and 12 months. These findings may assist in identifying individuals with inadequate response to help attain optimal weight loss targets and developing a prognostic model to identify predictors of successful weight loss.

Keywords Control of eating · Obesity · Sleeve gastrectomy · Weight loss

Introduction

Metabolic bariatric surgery (MBS) is the most potent therapeutic option for obesity, providing durable and long-term weight loss effects [1–3]. Currently, sleeve gastrectomy (SG) is a commonly performed bariatric

procedure with a greater than a fivefold increase in its frequency in the USA from 2011 to 2021 [4, 5].

A complex interplay of different factors results in a great degree of variability in weight loss response to SG and prevents an accurate approximation of its effectiveness. Gastrointestinal hormonal signals are known to exert effects on satiety, satiation, and hedonic ingestive behaviors [6]. Moreover, neural circuits are differentially altered after bariatric surgery, promoting homeostatic regulation to a lower weight [7–9]. Other factors that potentially predict both effectiveness and risk of weight recurrence after surgical intervention likely involve behavioral, lifestyle, psychosocial, and environmental influences [10–13].

Various psychometric measures have been used to correlate post-surgical weight loss with changes in hedonic eating behaviors, but those changes after bariatric surgery have not been fully elucidated [14, 15]. A better understanding of

Key Points

- Individuals achieving $\geq 25\%$ total weight loss at 1 year after sleeve gastrectomy have improved overall eating control as early as at 3 months.
- Improvements in other aspects of eating control follow later, at 6 and 12 months.
- Our findings may assist in identifying poor responders early and helping them attain optimal weight loss targets.
- Our findings may also assist in identifying predictors of successful weight loss after sleeve gastrectomy.

Extended author information available on the last page of the article

post-surgical dynamics of various aspects of hedonic eating behaviors would be helpful for identifying poor responders and offering them additional weight loss support and tools to improve SG effectiveness and, hopefully, prevent significant weight recurrence.

The aim of our study was to assess and compare various serial control of eating (CoE) attributes pre- and post-SG depending on the achievement of optimal weight loss target at 1 year post-SG and explore the utility of validated Control of Eating Questionnaire (CoEQ) in the post-SG patient population.

Methods

Study Design

A prospective longitudinal pre-post cohort study using the CoEQ at the pre-SG visit (baseline) and then at 3, 6, and 12 months post-SG [16] was conducted. Efforts were made to extend the study period beyond 12 months post-SG. The high attrition rate, however, resulting in only 9% of participants who completed the baseline questionnaire remaining in the study by a 12-month timepoint, did not allow this. Total weight loss (TWL) of $\geq 25\%$ at 12 months post-SG was set as an optimal weight loss target [17–22]. Individuals who achieved this magnitude of weight loss were deemed to be good responders (GRs) and those who did not, poor responders (PRs). Differences in sex, age, obesity-associated diseases, baseline weight, baseline body mass index (BMI), smoking status, and selected CoEQ scores between those who achieved the target and those who did not were assessed.

Participants

Patients were screened for potential participation in the study from the obesity and bariatric surgery program at the Bariatric and Metabolic Institute at University of California San Diego Health consecutively from June 2016 to August 2019. The institute is a fully accredited academic medical and bariatric surgery center by the American College of Surgeons Bariatric Surgery Center Network (ACS BSCN). Our center offers a range of services for sustained weight loss, from nonsurgical programs to bariatric surgery. The multi-disciplinary team includes bariatric surgeons, obesity medicine specialists, nurses, psychologists, nurse practitioners, registered dietitians, and health coaches specializing in the treatment of obesity. Bariatric surgeons are certified by the American Board of Surgery, and obesity medicine specialists by the American Board of Obesity Medicine. Our center performs over 150 bariatric and metabolic surgeries per year.

Inclusion criteria were BMI ≥ 40 kg/m² or 35.0–39.9 kg/m² with major obesity-associated disease(s) and planned SG. Exclusion criteria included age younger than 18 years, planned procedures other than SG, previous history of any other bariatric procedure(s), use of anti-obesity medications within the 3 months prior to screening, weight loss $\geq 5\%$ prior to the initial visit, infection with human immunodeficiency virus, active eating disorders, adult attention-deficit/hyperactivity disorder treated with psychostimulant medications, substance use disorder not in remission, significant intellectual disability, malignancy not in remission (except for non-melanoma skin cancer), and lack of proficiency in English.

Survey

The CoEQ is a 21-item validated comprehensive questionnaire designed to measure various aspects of hedonic eating, satiety, and satiation, including but not limited to the intensity, severity, and type of food cravings, and overall control of eating over the previous 7 days. Except for one question requiring a narrative response, the items are assessed using a 100-mm visual analog scale (VAS). The score for each of the selected CoE attributes was determined based on the location marked by a patient on the VAS with a minimum of 0 and a maximum of 100. Nine of the CoEQ items were selected for analysis based on expert opinion as the most direct measures of CoE attributes [16].

Statistical Analysis

Descriptive statistics to determine patients' characteristics at baseline and at the specified subsequent timepoints were applied. Nonparametric statistical methods were applied for baseline characteristic analysis and over time comparison for all continuous variables, except for weight where parametric statistical techniques were applied. Data were presented as the mean \pm standard deviation (SD), median (min–max), and count (%).

Changes in CoEQ measures were calculated by comparing the score on the VAS at each postoperative timepoint to the baseline value. Percent total weight loss (%TWL) was defined as TWL at each defined timepoint divided by initial weight.

Proportions were compared using Fisher's exact test. One-way repeated measure ANOVA and Friedman's two-way analysis of variance by ranks were utilized to assess the trends in parameters over time. Means were compared using two-tailed paired and independent *t* tests; Wilcoxon matched-pair signed-rank and Mann–Whitney were used to compare medians. All analyses and data visualization were performed using SPSS 21.0 and GraphPad 6.0 with a *p* value ≤ 0.05 indicating statistical significance [23].

Results

Characteristics of Participants, Weight Status, and Control of Eating Attributes at Baseline

Figure 1 shows the study flow for subject participation. Out of 767 screened, 461 completed the baseline CoEQ. Forty-one patients with the completed CoEQs at all four consecutive timepoints were included.

The mean age was 41.7 ± 10.6 years; the vast majority were females ($n = 33$, 80.5%), and over half of the participants were Hispanic ($n = 21$, 51.2%) (Table 1). About one-third of the patients were current or former smokers at baseline ($n = 13$, 31.7%) but non-smokers at the time of surgery. All patients had at least one obesity-associated disease, with the most common being dyslipidemia ($n = 32$, 78.0%), followed by obstructive sleep apnea ($n = 23$, 56.1%) and hypertension ($n = 17$, 41.5%). The abovementioned characteristics and prevalences of comorbidities were

comparable between GRs and PRs, except for the prevalence of metabolic dysfunction-associated steatotic liver disease, which was highly prevalent among PRs ($n = 9$, 39.1%) and not identified among GRs ($n = 0$). No significant differences were identified with respect to treatment for mood disorders and diabetes between GRs and PRs. All patients had class II or class III obesity. The median BMI was 43.6 [35.2–66.3] kg/m^2 at baseline and 39.7 [31.9–58.8] kg/m^2 at the time of surgery. There were no meaningful differences in weight (122.4 ± 15.6 kg vs. 129.6 ± 21.2 kg; $p > 0.05$) and BMI (42.8 [37.4–66.3] kg/m^2 vs. 44.9 [35.2–64.2] kg/m^2 ; $p > 0.05$) at baseline. Both GR and PR groups also had comparable weights at the time of surgery ($p > 0.05$) (Table 1).

Changes in Weight Status over One Year Post-SG

Dynamics of weight status (weight, BMI, and TWL) over the course of the study are presented in Table 2 and Fig. 2 for all patients in the study, and GRs compared to PRs. Overall, all

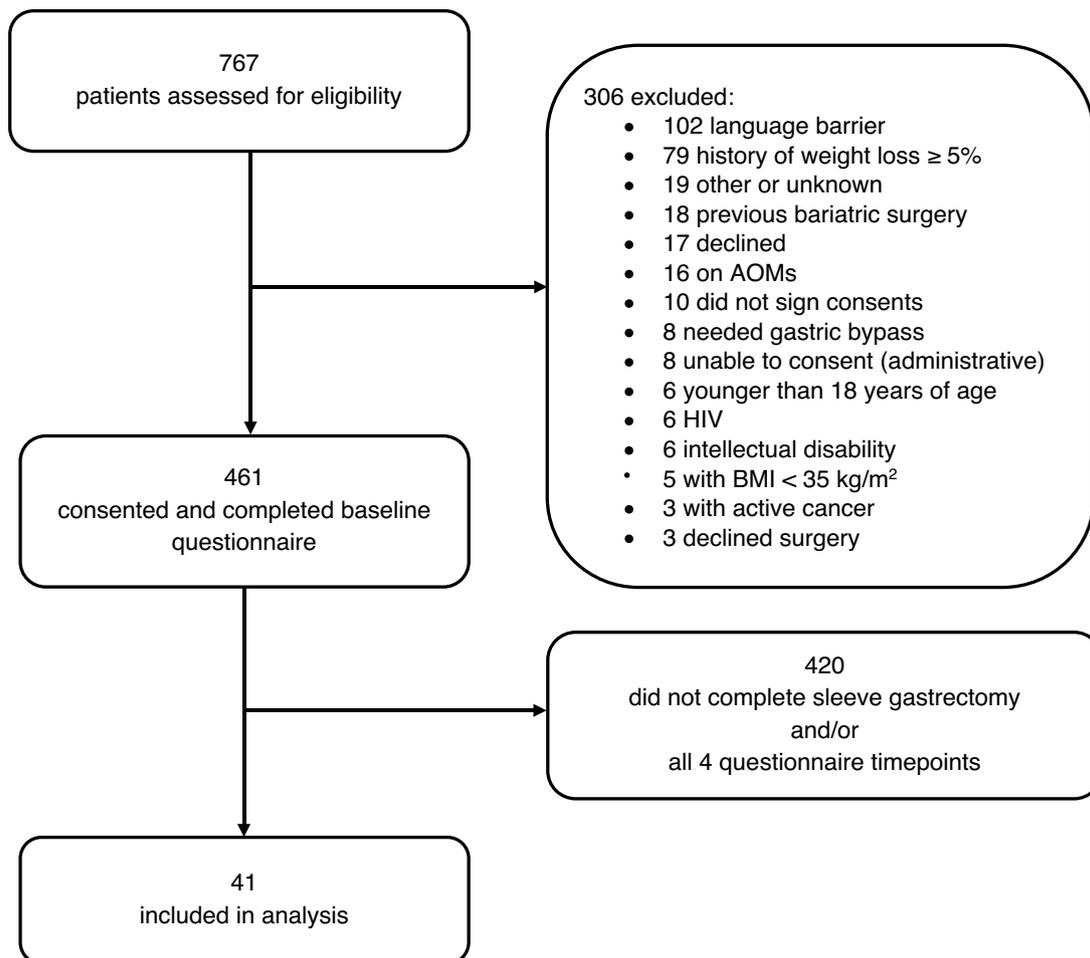


Fig. 1 Flow diagram of the process of participants' selection for the study

Table 1 Patient baseline characteristics

Parameter	All patients $n=41$	TWL at 12 months	
		$\geq 25\%$ Good Responders	$< 25\%$ Poor Responders
Age (years)	41.7 \pm 10.6	39.4 \pm 10.5	43.4 \pm 10.6
Sex, female	33 (80.5%)	15 (78.3%)	18 (83.3%)
Race/ethnicity			
Hispanic	21 (51.2%)	8 (44.4%)	13 (56.5%)
Caucasian	15 (36.6%)	8 (44.4%)	7 (30.4%)
Middle Eastern	3 (7.3%)	2 (11.1%)	1 (4.3%)
African American	1 (2.4%)	0	1 (4.3%)
Native American	1 (2.4%)	0	1 (4.3%)
Weight status			
Weight at baseline (kg)	126.4 \pm 19.0	122.4 \pm 15.6	129.6 \pm 21.2
BMI at baseline (kg/m ²)	43.6 (35.2–66.3)	42.8 (37.4–66.3)	44.9 (35.2–64.2)
Weight at surgery (kg)	115.1 \pm 17.9	109.5 \pm 12.6	119.4 \pm 20.5
BMI at surgery (kg/m ²)	39.7 (31.9–58.8)	39.4 (3.8–54.9)	41.3 (31.9–58.8)
Smoking status			
Never or former	39 (95.1%)	0	23 (100%)
Current	2 (4.9%)	2 (11.1%)	16 (88.9%)
Obesity-associated diseases			
Pre-diabetes	12 (29.3%)	5 (27.8%)	7 (30.4%)
Diabetes	7 (17.1%)	2 (11.1%)	5 (21.7%)
Hypertension	17 (41.5%)	7 (38.9%)	10 (43.5%)
Dyslipidemia	32 (78.0%)	13 (72.2%)	19 (82.3%)
MASLD (formerly, NAFLD)	9 (22.0%)	0 ^{##}	9 (39.1%)
Obstructive sleep apnea	23 (56.1%)	9 (50.0%)	14 (60.9%)
Cardiovascular diseases	1 (2.4%)	1 (5.6%)	0
Osteoarthritis	7 (17.1%)	2 (11.1%)	5 (21.7%)
GERD	7 (17.1%)	3 (16.7%)	4 (17.4%)
PCOS ^a	1 (3.0%)	0	1 (5.6%)
Depression	16 (39.0%)	7 (38.9%)	9 (39.1%)
Bipolar disorder	1 (2.4%)	0	1 (4.3%)

Values are expressed as n (%) for categorical variables, $\mu \pm SD$ for normally distributed, and median (min–max) for not normally distributed continuous variables. Analyses are based on independent t test (two-sided), Mann–Whitney test, and Fisher’s exact test (two-sided). Asterisks denote statistically significant differences between groups

BMI, body mass index; *MASLD*, metabolic dysfunction-associated steatotic liver disease, *NAFLD*, nonalcoholic fatty liver disease; *GERD*, gastroesophageal reflux disease; *PCOS*, Polycystic Ovary Syndrome

^aProportions calculated for females’ cohort

^{##} $p \leq 0.01$

patients in the cohort had a substantial total weight loss, more pronounced over the first 3 months post-SG, compared to baseline (100.8 \pm 17.5 kg vs. 126.4 \pm 19.0 kg; $p \leq 0.001$), followed by modest additional weight loss at 6 months (97.5 \pm 19.2 kg) and weight stability up to 12 months (97.5 \pm 19.7 kg). A similar trend was observed for BMI and TWL. GR cohort demonstrated a rapid decline in weight in the first 3 months (from 122.4 \pm 15.6 to 92.6 \pm 12.6 kg; $p \leq 0.001$), followed by another profound decrease by 6 months (86.3 \pm 13.3 kg; $p \leq 0.001$ compared to baseline) and a modest decline to 83.9 \pm 12.1 kg by 12 months

($p \leq 0.001$ when compared to baseline). The most intense weight loss among PRs was observed in the first 3 months post-SG (from 129.6 \pm 21.2 to 107.2 \pm 18.3 kg; $p \leq 0.001$), followed by a small decrease to 106.2 \pm 18.8 kg by month 6 ($p \leq 0.001$ compared to baseline) and some recurrence in weight by month 12 (108.1 \pm 18.0 kg), which remained significantly different from the baseline ($p \leq 0.001$). In addition, in all patients along with GRs and PRs separately, BMI and weight were markedly lower in comparison to baseline ($p \leq 0.001$). While GRs and PRs had comparable weight status at baseline, meaningful differences

Table 2 Changes in weight, body mass index (BMI), and total weight loss (TWL) over the course of the study, for all study subjects ($n=41$) and those who achieve optimal weight loss target of $\geq 25\%$ TWL ($n=18$, good responders) compared to those who did not ($n=23$, poor responders)

Parameter	<i>n</i>	Baseline	3 months	6 months	12 months	<i>p</i> value (over time comparison)
Weight (kg)						
All patients	41	126.4 ± 19.0	100.8 ± 17.5 ^{###}	97.5 ± 19.2 ^{###}	97.5 ± 19.7 ^{###}	<0.001
Patients with TWL ≥ 25%	18	122.4 ± 15.6	92.6 ± 12.6 ^{####*}	86.3 ± 13.3 ^{####*}	83.9 ± 12.1 ^{###**}	<0.001
Patients with TWL < 25%	23	129.6 ± 21.2	107.2 ± 18.3 ^{###}	106.2 ± 18.8 ^{###}	108.1 ± 18.0 ^{###}	<0.001
BMI (kg/m²)						
All patients	41	43.6 (35.2–66.3)	35.0 (26.8–54.2) ^{###}	34.3 (24.0–52.7) ^{###}	36.1 (22.4–52.8) ^{###}	<0.001
Patients with TWL ≥ 25%	18	42.8 (37.4–66.3)	32.9 (26.8–48.7) ^{###**}	30.4 (24.0–47.0) ^{###**}	29.8 (22.4–45.2) ^{###***}	<0.001
Patients with TWL < 25%	23	44.9 (35.2–64.2)	36.6 (27.6–54.2) ^{###}	36.9 (27.8–52.7) ^{###}	38.1 (29.2–52.8) ^{###}	<0.001
Total weight loss (TWL) (%)						
All patients	41	-	19.3 (9.3–41.3) ^{###}	22.5 (6.2–46.7) ^{###}	22.9 (4.7–46.5) ^{###}	<0.001
Patients with TWL ≥ 25%	18	-	22.8 (17.3–41.3) ^{###***}	28.3 (19.8–46.7) ^{###***}	30.0 (25.0–46.5) ^{###***}	<0.001
Patients with TWL < 25%	23	-	17.0 (9.3–26.6) ^{###}	17.4 (6.2–26.2) ^{###}	18.1 (4.7–24.8) ^{###}	<0.001

Values are expressed as $\mu \pm$ SD for normally distributed and median (min–max) for not normally distributed continuous variables. Analyses for changes over time are based on one-way repeated measures ANOVA (for normally distributed continuous variables) and Friedman's two-way analysis of variance by ranks (for not normally distributed continuous variables). Differences in weight status and scores between each of the subsequent timepoints (3, 6, or 12 months) in comparison to the baseline were analyzed using paired two-sided *t* test (for normally distributed continuous variables) and Wilcoxon matched-pair signed-rank test (for not normally distributed continuous variables). Asterisks denote statistically significant differences:

[#] $p \leq 0.05$

^{##} $p \leq 0.01$

^{###} $p \leq 0.001$

Differences in weight status between groups with TWL $\geq 25\%$ vs. TWL < 25% at each of the timepoints (baseline, 3, 6, or 12 months) were analyzed using an independent two-sided *t* test (for normally distributed continuous variables) and two-tailed Mann–Whitney test (for not normally distributed continuous variables), with statistical significance denoted as:

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

between groups in weight, BMI, and TWL started to be evident at month 3 and persisted through months 6 and 12.

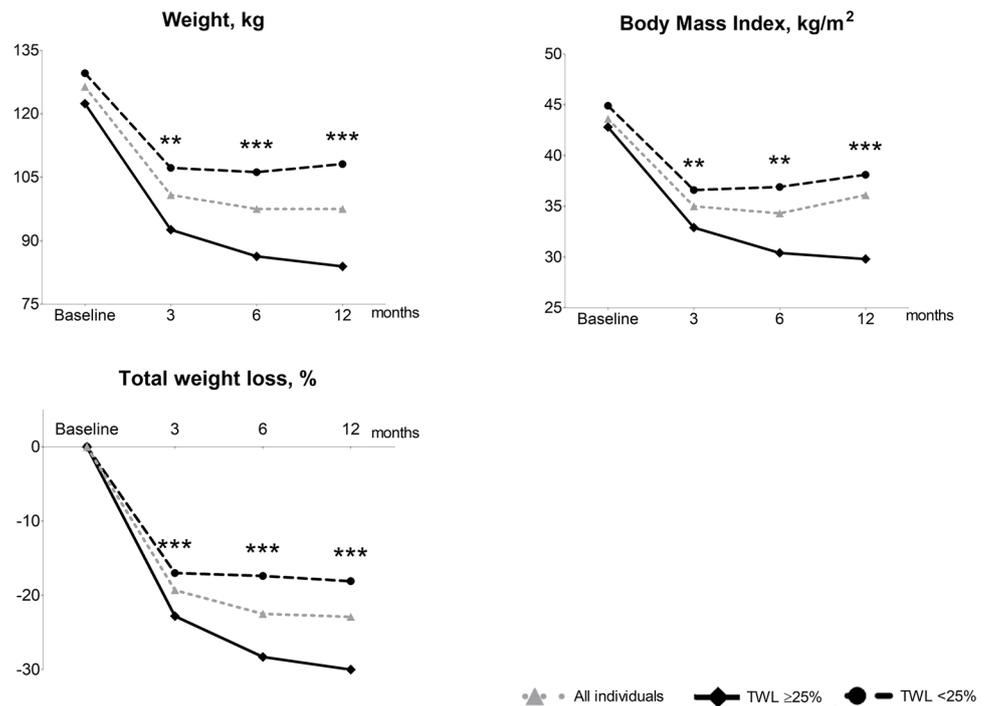
Changes in Overall Eating Control, Satiety, and Fullness over One Year Post-SG

There were no differences in overall eating control and feelings of hunger or fullness between GRs and PRs at baseline (Table 3, Fig. 3). At 3 months post-SG difficulty to control eating score fell dramatically and, moreover, became significantly different between the GR and PR groups (7 [0–50] vs. 17 [5–63], $p = 0.042$). The gap in this score continued increasing by 6 months, and by 12 months became even wider with statistically significant difference between groups (23 [0–53] vs. 46 [13–95]; $p = 0.006$). The feeling

fullness score rose similarly in both GR and PR groups in the first 3 months post-SG ($p < 0.001$ compared to baseline). At 6 months, however, there was a split in direction that led to significant differences between GRs and PRs (79 [42–95] vs. 62 [14–93], $p = 0.026$). The feeling hungry score fell more profoundly among GRs compared to PRs by 3 months, reaching almost the same level (36 [4–100] and 35 [6–64], respectively).

By 12 months, the feeling hungry score among GRs continued to remain stable while among PRs, a considerable rebound was observed that contributed to a significant difference in scores between those patients' cohorts (37 [1–70] in comparison to 55 [11–90]; $p = 0.014$). Interestingly, while the difficulty to control eating score decreased by more than a half by 12 months compared to baseline among GRs (23 [0–53]

Fig. 2 Changes in weight, BMI, and TWL from baseline to 3, 6, and 12 months post-sleeve gastectomy, for all individuals (grey-dotted line), those who achieved optimal weight loss target of $\geq 25\%$ TWL at 12 months (good responders, solid blackline), and those who did not (poor responders, dashed black line). Weight, BMI, and TWL are statistically significantly different between good and poor responders at each of the subsequent time points. Differences in values analyzed using a two-tailed Mann–Whitney test. Statistical significance denoted as $**p \leq 0.01$, $***p \leq 0.001$



vs. 51 [4–98]; $p=0.011$), it did not demonstrate a significant difference among PRs (46 [13–95] vs. 56 [12–92]; $p=0.594$).

Changes in Desire to Eat Sweet or Savory Foods over One Year Post-SG

The desire to eat sweet foods score was the only one among other selected CoE attributes that at baseline was significantly lower among GRs compared to PRs (44 [0–90] vs. 75 [9–100]; $p=0.026$) (Table 3; Fig. 4). Moving forward into the post-surgical period, considerable differences between GR and PR groups were observed in the pattern, where dynamics of desire for sweet foods was much more pronounced than changes in desire for savory foods. The desire to eat sweet foods score fell dramatically by 3 months post-SG timepoint among GRs and PRs ($p < 0.001$ in comparison to baseline in both groups). By 6 months, it rebounded in both groups, followed by a relative stabilization of this score among GRs and a continuous rebound among PRs. The desire to eat savory foods score fell substantially in the first 3 months post-SG among GRs (48 [1–75] vs. 57 [0–90]; 0.042) and then continued trending down by 12 months; however, even at that point, it did not demonstrate significant difference compared to baseline (42 [7–88] vs. 57 [0–90]; 0.113). Among PRs, a desire for savory foods had a tendency to decline in the first 3 months but was not significantly different from baseline (40 [6–93] vs. 51 [11–99]; $p=0.188$). By 6 months, the score stabilized and at the end of the observation period rebounded back, almost reaching the pre-SG level (50 [12–91] vs. 51 [11–99]; $p=0.770$).

Changes in Cravings’ Frequency, Strength, and Control over One Year Post-SG

Table 3 and Fig. 5 demonstrate changes in craving domains over the period of observation. At baseline, PRs tended to have stronger and more frequent food cravings compared to GRs, though the difference was not significant. Surprisingly, from baseline to 3 months, compared to GRs, PRs also had more pronounced and statistically significant decline in the strength and frequency of cravings (68 [4–100] vs. 26 [7–76]; $p=0.004$ and 69 [11–100] vs. 28 [9–91]; $p=0.001$, respectively) and in food intake in response to them (31 [0–98] vs. 16 [1–74] $p=0.038$). Of note, GRs’ decline in these scores was not significant. The difficulty to resist cravings score fell markedly and significantly in both GR (from 40 [0–96] to 13 [0–66]; $p=0.008$) and PR (from 51 [4–99] to 17 [0–72]; $p=0.001$) groups over the first 3 months. Proceeding further in their post-SG period, PRs had a profound rebound in all studied aspects of cravings, while GRs’ scores continued trending down or rebounded just slightly. It resulted in “frequency of food cravings” and difficulty to resist food cravings scores becoming significantly lower among GRs in comparison to PRs (29 [2–100] vs. 56 [7–85]; $p=0.01$ and 21 [0–86] vs. 33 [5–83]; $p=0.05$, respectively) at 6 months. A gap in scores reflecting control over cravings between GRs and PRs continued to become wider and at 12 months; difficulty to resist food cravings and “eating in response to food cravings” scores in GRs were significantly lower compared to PRs (15 [0–65] vs. 47 [8–100]; $p=0.002$ and 20 [0–89] vs. 41 [12–96]; $p=0.004$, respectively).

Table 3 Changes in control of eating attributes over the course of the study, depending on %TWL at 12 months

Parameter	<i>n</i>	Baseline	3 months	6 months	12 months	<i>p</i> value (over time comparison)
Generally, how difficult has it been to control your eating? (score)						
All patients	41	54 (4–98)	13 (0–63) ###	22 (0–85) ###	37 (0–95) #	< 0.001
Patients with TWL ≥ 25%	18	51 (4–98)	7 (0–50) ## *	19 (0–70) ##	23 (0–53) # **	0.001
Patients with TWL < 25%	23	56 (12–92)	17 (5–63) ###	37 (4–85) ##	46 (13–95)	< 0.001
How hungry have you felt? (score)						
All patients	41	60 (16–96)	35 (4–100) ###	41 (6–93) ###	49 (1–90) ##	< 0.001
Patients with TWL ≥ 25%	18	68 (17–90)	36 (4–100) ###	38 (9–93) ###	37 (1–70) ### *	0.004
Patients with TWL < 25%	23	57 (16–96)	35 (6–64) ###	42 (6–74) ###	55 (11–90) ###	< 0.001
How full have you felt? (score)						
All patients	41	60 (4–98)	74 (9–99) #	70 (14–95)	67 (16–98)	0.046
Patients with TWL ≥ 25%	18	57 (14–95)	75 (42–99) ###	79 (42–95) ### *	73 (16–98) ###	0.029
Patients with TWL < 25%	23	61 (4–98)	74 (9–99) ###	62 (14–93) ###	62 (32–90) ###	0.519
How strong was your desire to eat sweet foods? (score)						
All patients	41	61 (0–100)	21 (0–95) ###	27 (0–95) ##	47 (0–100)	< 0.001
Patients with TWL ≥ 25%	18	44 (0–90) *	15 (0–72) ###	27 (0–95) ###	31 (0–93) ###	0.018
Patients with TWL < 25%	22	75 (9–100)	26 (3–95) ###	36 (5–93) ###	62 (10–100) ###	0.001
How strong was your desire to eat savory foods? (score)						
All patients	41	54 (0–99)	48 (1–93) #	44 (7–87) #	46 (7–91)	0.012
Patients with TWL ≥ 25%	18	57 (0–90)	48 (1–75) #	46 (7–77)	38 (7–87)	0.058
Patients with TWL < 25%	23	51 (11–99)	40 (6–93)	39 (8–87)	50 (12–91)	0.169
During the last 7 days how often have you had food cravings? (score)						
All patients	41	59 (4–100)	28 (2–100) ###	41 (2–100) #	45 (0–100) #	0.001
Patients with TWL ≥ 25%	18	52 (4–97)	30 (2–100)	29 (2–100) **	42 (0–79)	0.264
Patients with TWL < 25%	23	69 (11–100)	28 (9–91) ###	56 (7–85) #	47 (17–100)	< 0.001
How strong have any food cravings been? (score)						
All patients	41	64 (3–100)	26 (0–100) ###	40 (5–100) #	46 (0–100)	< 0.001
Patients with TWL ≥ 25%	18	51 (3–96)	30 (0–100)	29 (5–100) *	34 (0–76)	0.171
Patients with TWL < 25%	22	68 (4–100)	26 (7–76) ##	49 (8–89) #	50 (16–100)	< 0.001
How difficult has it been to resist any food cravings? (score)						
All patients	41	51 (0–99)	16 (0–72) ###	28 (0–86) ##	40 (0–100)	< 0.001
Patients with TWL ≥ 25%	18	40 (0–96)	13 (0–66) ##	21 (0–86) *	15 (0–65) # **	0.016
Patients with TWL < 25%	23	51 (4–99)	17 (0–72) ###	33 (5–83)–	47 (8–100)	< 0.001
How often have you eaten in response to food cravings? (score)						
All patients	41	35 (0–98)	16 (0–81) ##	21 (3–86) ##	27 (0–96)	0.033
Patients with TWL ≥ 25%	18	45 (0–96)	8 (0–81)	16 (3–51) #	20 (0–89) # **	0.301
Patients with TWL < 25%	21	31 (0–98)	16 (1–74) #	23 (12–86)	41 (12–96)	0.074

Values are expressed as $\mu \pm$ SD for normally distributed and median (min–max) for not normally distributed continuous variables. Analyses for changes over time are based on one-way repeated measures ANOVA (for normally distributed continuous variables) and Friedman's two-way analysis of variance by ranks (for not normally distributed continuous variables). Differences in weight status and scores between each of the subsequent timepoints (3, 6, or 12 months) in comparison to the baseline were analyzed using paired two-sided *t* test (for normally distributed continuous variables) and Wilcoxon matched-pair signed-rank test (for not normally distributed continuous variables). Asterisks denote statistically significant differences:

$p \leq 0.05$

$p \leq 0.01$

$p \leq 0.001$

Differences in weight status and scores between groups with TWL ≥ 25% vs. TWL < 25% at each of the timepoints (baseline, 3, 6, or 12 months) were analyzed using an independent two-sided *t* test (for normally distributed continuous variables) and two-tailed Mann–Whitney test (for not normally distributed continuous variables), with statistical significance denoted as:

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

Fig. 3 Changes in overall eating control, satiety, and fullness from baseline to 3, 6, and 12 months post-sleeve gastrectomy, for all individuals (grey dotted line), those who achieved optimal weight loss target of $\geq 25\%$ TWL at 12 months (good responders, solid blackline), and those who did not (poor responders, dashed black line). Differences in scores between good and poor responders analyzed using a two-tailed Mann–Whitney test. Statistical significance denoted as $*p \leq 0.05$, $**p \leq 0.01$

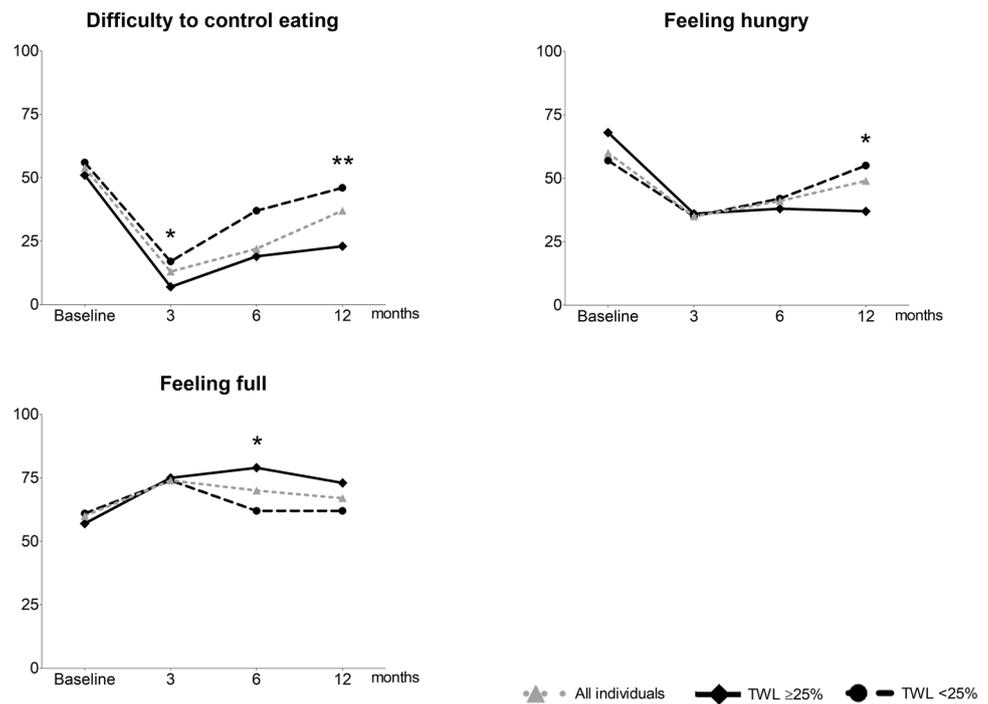
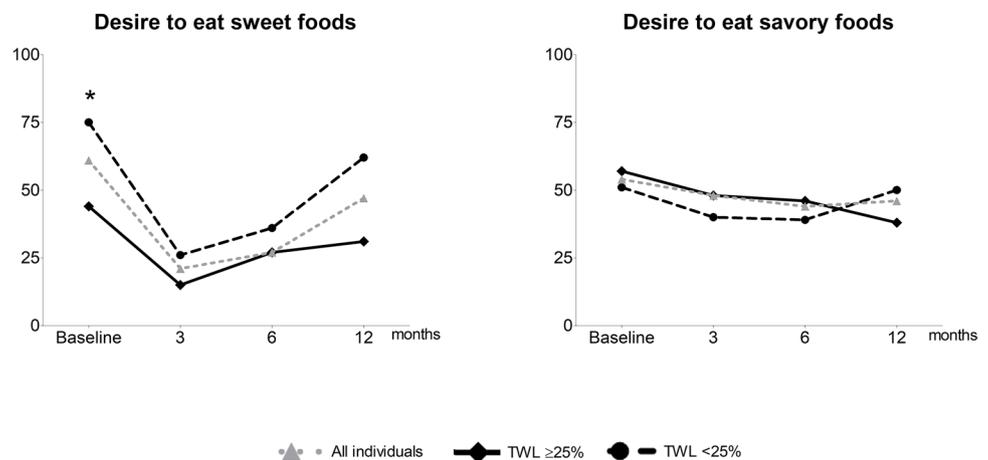


Fig. 4 Changes in desire to eat sweet or savory foods from baseline to 3, 6, and 12 months post-sleeve gastrectomy, for all individuals (grey-dotted line), those who achieved optimal weight loss target of $\geq 25\%$ TWL at 12 months (good responders, solid black line), and those who did not (poor responders, dashed black line). Differences in scores between good and poor responders analyzed using a two-tailed Mann–Whitney test. Statistical significance denoted as $*p \leq 0.05$



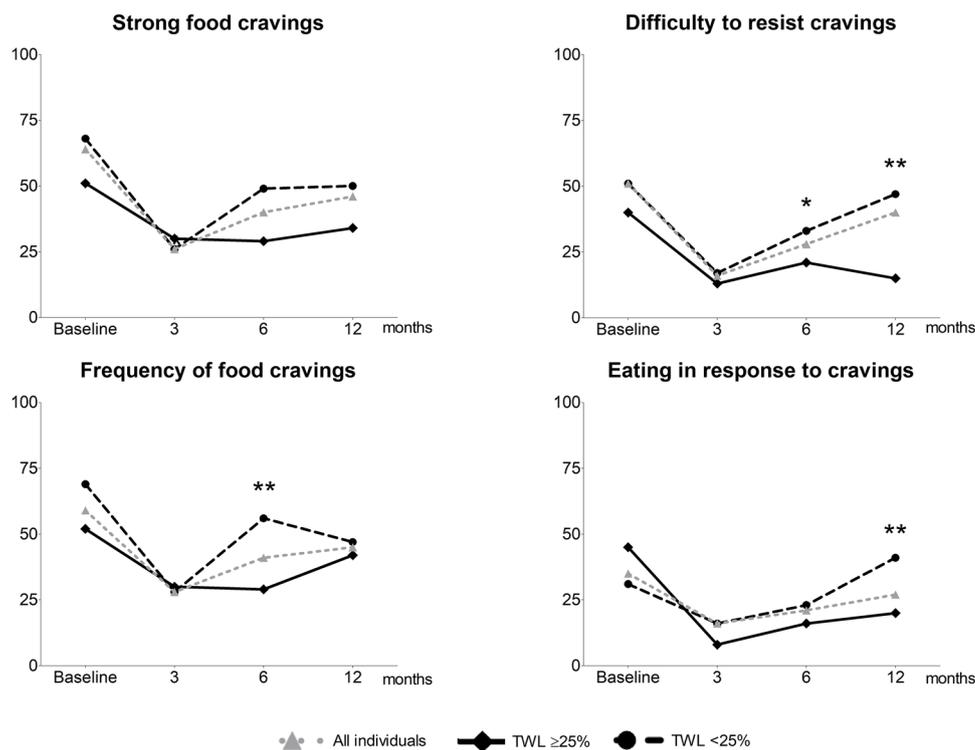
Discussion

The aim of our study was to compare various serial CoE attributes pre- and post-SG depending on the achievement of optimal weight loss target at 1 year post-SG using a validated CoEQ questionnaire with VAS. Focusing on the measures capturing eating behaviors, GRs (subjects who lost $\geq 25\%$ TWL at 1 year post-surgery) reported earlier improvement in overall eating control that remained as such at 6 and 12 months. There were also greater differences between subsequent and baseline scores measuring the intensity, severity, and type of food cravings, and overall control of eating compared to PRs (subjects who

lost $< 25\%$ TWL at 1 year post-SG). To our knowledge, we are the first who explored the utility of the CoEQ in the post-SG patient population and demonstrated various aspects of heterogeneity in eating behaviour in relation to the weight loss outcomes at one year post-SG.

The validated CoEQ questionnaire with VAS we utilized in our study has been widely used as a tool to assess the effectiveness of anti-obesity medications in several clinical trials and cohort studies in different patient populations for over a decade [24–29]. However, to our knowledge, our study is the first prospective longitudinal study to explore the utility of CoEQ in a post-SG population. The CoEQ encompasses a few domains (satiety, satiation, and hedonic eating). It is a comprehensive

Fig. 5 Changes in cravings domain from baseline to 3, 6, and 12 months post-sleeve gastrectomy, for all individuals (grey-dotted line), those who achieved optimal weight loss target of $\geq 25\%$ TWL at 12 months (good responders, solid black line), and those who did not (poor responders, dashed black line). Differences in scores between good and poor responders analyzed using a two-tailed Mann–Whitney test. Statistical significance denoted as $**p \leq 0.01$



tool that covers a variety of relevant psychometric parameters, including but not limited to cravings (frequency, intensity, and difficulty in resisting them, cravings as they pertain to specific foods) as well as feeling hungry or full, general appetite, and overall control of eating. From a practical perspective, CoEQ has only 21 questions and is easy to use in clinical settings as it utilizes VAS which improves response rate. In our study, we demonstrated that CoEQ is a comprehensive psychometric tool for the measurement of eating behavior that has the potential for use in post-SG patients. It opens avenues for its further utilization in routine clinical practice (in the office and via web-based platforms) and also in clinical trials in the postoperative period.

Many reports have demonstrated both improved CoE and elevated post-prandial gut hormones after bariatric surgery [30–33]. Work by others investigating changes in the CoE and gut peptides has resulted in mixed findings. Scholtz et al. reported that when compared to a weight-matched control group and subjects treated with a laparoscopic adjustable gastric band, those with RYGB showed higher eating restraint, and both surgical groups exhibited less hunger and hedonic food value compared to the non-operative group, with analyses performed on average 8 or 9 months after surgery [31]. In line with these findings, the RYGB group exhibited higher post-prandial levels of GLP-1 and PYY compared to the gastric band group, consistent with RYGB characterized as a “metabolic procedure” [31].

Although there were differences in the magnitude of measure dynamics between the two groups (GRs vs. PRs)

in our study, various domains of eating control were affected after SG, supporting a well-recognized concept of a great degree of heterogeneity in the postoperative period. Other researchers have also shown the effect of MBS on changes in energy consumption, food sensations and preferences, hedonic eating, and other domains of ingestive behaviors [34–40]. Postoperative aversions to specific foods or tastes have also been noted [41]. At 1 year, both SG and RYGB induce reductions in both hedonic eating behaviors and binge eating patterns [42]. In contrast to nonsurgical calorie restriction, both procedures have also demonstrated increased satiety and satiation and diminished reward-driven food intake [43, 44].

In contrast, other groups have shown that overall energy consumption decreases after MBS without changes in macronutrient or food-type selection. There may be a discordance between subjective individual reporting of desire for certain foods and actual consumption of those foods [45]. Reduction in portion sizes as the main driver of post-surgical weight loss was also reported [46]. However, there likely is the variability of reported changes in food desirability and selection, and some of this heterogeneity, similar to our findings, may in part explain disparate weight loss outcomes [47, 48].

To the best of our knowledge, the heterogeneity of eating behavior after SG has not been systematically evaluated yet in a longitudinal prospective study and correlated with the weight loss outcomes in a post-SG period. In addition to measuring heterogeneity, the CoEQ also allowed us to methodically assess a composite measure, the difficulty to control eating score.

In our analysis, we found that GRs (patients who lost $\geq 25\%$ TWL at 1 year post-SG) had early-occurring improvement in overall eating control (at 3 months post-SG) that remained consistent at 6 and 12 months. There were also substantial differences between subsequent and baseline scores measuring the intensity, severity, and type of food cravings, and overall control of eating among GRs compared to PRs (subjects who lost $< 25\%$ TWL at 1 year post-SG). Specifically, at 6 months, significant differences between GRs and PRs were observed in the feeling of fullness, frequency of food cravings, and difficulty to resist cravings scores, suggesting the imperative role of overall eating control and, particularly, craving control in the early postoperative period that reflects low disinhibition and supports success in weight loss outcomes at 1 year. It remains the case at a later stage as at 12 months, GRs demonstrate significantly lower feeling hungry, difficulty to resist cravings, eating in response to cravings, and difficulty to control eating scores compared to PRs, which again reflects the high importance of craving control and highlights the critical role of overall control of eating. These findings are novel and have not been previously described in the literature.

While different aspects of eating behavior were described in patients undergoing MBS, studies appraising its changes through the lens of weight loss are limited. Graham et al. and, separately, Zerrweck et al. reported that post-RYGB patients with food aversion exhibited a larger reduction in weight compared to those without [38, 41]. Makaronidis et al. reported an association of post-SG weight loss with postoperative appetite changes. However, appetite was measured in a cross-sectional manner only once, and the timing of the measurement varied from 6 months to 5 years following the surgery [36]. The study conducted by Cushing et al., based on adolescent's data, suggested that cravings were not associated with changes in BMI following RYGB [49]. As the abovementioned studies assessed only specific aspects of eating behavior and utilized measurement tools other than CoEQ, it is challenging to provide any comparison with our findings.

The results of our study provide a clear comprehensive picture of longitudinal changes in eating control, appetite, intensity, frequency, and difficulty in resisting food cravings over the first year post-SG in relation to weight loss outcomes, outlining a great degree of heterogeneity in eating behaviour and highlighting the importance of close monitoring and attention to the control of eating and food cravings control. It may assist in identifying individuals with an inadequate response early in the postoperative course and choosing tailored interventions to help attain optimal weight loss targets. It may also assist in developing a prognostic model and identifying predictors of successful weight loss early in the postoperative period and exploring performance characteristics of those predictors.

Study Limitations

Some limitations of our study need to be discussed. First, our sample size was relatively small. Second, we did not consider the education and socio-economic status of responders which may potentially influence their eating patterns and food choices. Finally, our particular instrument was applied only to patients undergoing sleeve gastrectomy, and it is unknown if similar findings would be noted after other metabolic surgical procedures.

Future Steps

As a future step, it would be beneficial to measure the association of our selected CoE attributes with weight loss outcomes beyond 1 year after bariatric surgery and also assess how those attributes change after other metabolic surgical procedures.

Conclusion

Individuals with obesity who achieved $\geq 25\%$ total weight loss at 1 year post-sleeve gastrectomy have an early occurring improvement in overall eating control at 3 months that steadily persists at 6 and 12 months. Improvements in other aspects of eating control tend to follow later, at 6 and 12 months after the procedure, and are mainly observed in the craving domain. It highlights the importance of close monitoring and attention to the control of eating and food craving control among post-SG patients. Our findings may assist in identifying individuals with an inadequate response early in the postoperative course and choosing tailored interventions to help them attain optimal weight loss targets. It may also assist in developing a prognostic model and identifying predictors of successful weight loss early in the postoperative period and exploring performance characteristics of those predictors. Further investigations, specifically examining larger and mixed samples, effects of RYGB, and correlation with gut hormone and/or neurobiological changes, may shed more light on the physiologic effects of MBS and clinical features of different responders.

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Data Availability Data available on request from the authors.

Declarations

Ethics Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Institutional Review Board.

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

Conflict of Interest The authors declare no competing interests.

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Authors and Affiliations

Ellina Lytyyak¹  · Amir Zarrinpar^{2,3} · Cecilia Dalle Ore³ · Euyhyun Lee⁴ · Keila Yazdani-Boset⁵ · Santiago Horgan⁷ · Eduardo Grunvald^{3,6,7}

✉ Ellina Lytyyak
lytyyak@ualberta.ca

¹ Division of Preventive Medicine, Department of Medicine, University of Alberta, 5-30 University Terrace, 8303 112 Street, Edmonton, AB T6G 2T4, Canada

² Division of Gastroenterology, University of California San Diego, 9500 Gilman Dr, La Jolla, San Diego, CA 92093, USA

³ School of Medicine, University of California San Diego, 9500 Gilman Dr, La Jolla, San Diego, CA 92093, USA

⁴ Altman Clinical and Translational Research Institute, University of California San Diego, 9452 Medical Ctr Dr, La Jolla, San Diego, CA 92037, USA

⁵ University of California San Diego, 9500 Gilman Dr, La Jolla, San Diego, CA 92093, USA

⁶ Division of General Internal Medicine, University of California San Diego, 9500 Gilman Dr, La Jolla, San Diego, CA 92093, USA

⁷ Division of Minimally Invasive Surgery, Bariatric and Metabolic Institute, University of California San Diego, 4303 La Jolla Village Drive, Suite 2110, San Diego, CA 92122, USA