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# Food Intake Following Gastric Bypass Surgery: Patients Eat Less but Do Not Eat Differently

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## ABSTRACT

**Background:** Lack of robust research methodology for assessing ingestive behavior has impeded clarification of the mediators of food intake following gastric bypass (GBP) surgery.

**Objectives:** To evaluate changes in directly measured 24-h energy intake (EI), energy density (ED) (primary outcomes), eating patterns, and food preferences (secondary outcomes) in patients and time-matched weight-stable comparator participants.

**Methods:** Patients [$n = 31$, 77% female, BMI (in kg/m$^2$) 45.5 ± 1.3] and comparators ($n = 32$, 47% female, BMI 27.2 ± 0.8) were assessed for 36 h under fully residential conditions at baseline (1 mo presurgery) and at 3 and 12 mo postsurgery. Participants had ad libitum access to a personalized menu ($n = 54$ foods) based on a 6-macronutrient mix paradigm. Food preferences were assessed by the Leeds Food Preference Questionnaire. Body composition was measured by whole-body DXA.

**Results:** In the comparator group, there was an increase in relative fat intake at 3 mo postsurgery; otherwise, no changes were observed in food intake or body composition. At 12 mo postsurgery, patients lost 27.7 ± 1.6% of initial body weight ($P < 0.001$). The decline in EI at 3 mo postsurgery (–44% from baseline, $P < 0.001$) was followed by a partial rebound at 12 mo (–18% from baseline), but at both times, dietary ED and relative macronutrient intake remained constant. The decline in EI was due to eating the same foods as consumed presurgery and by decreasing the size (g, MJ), but not the number, of eating occasions. In patients, reduction in explicit liking at 3 mo (–11.56 ± 4.67, $P = 0.007$) and implicit wanting at 3 (–15.75 ± 7.76, $P = 0.01$) and 12 mo (–15.18 ± 6.52, $P = 0.022$) for sweet foods were not matched by reduced intake of these foods. Patients with the greatest reduction in ED postsurgery reduced both EI and preference for sweet foods.

**Conclusions:** After GBP, patients continue to eat the same foods but in smaller amounts. These findings challenge prevailing views about the dynamics of food intake following GBP surgery. This trial was registered as clinicaltrials.gov as NCT03113305. *J Nutr* 2022;152:2319–2332.

**Keywords:** gastric bypass, energy intake, energy density, eating patterns, food preferences

## Introduction

Currently, manipulations of gastrointestinal anatomy, such as gastric bypass (GBP) surgery, represent the most effective treatment for obesity (1). However, the mechanisms underlying sustained weight loss following surgery are complex and equivocal (1). Although a decrease in energy intake (EI) is the main driver of weight loss (2), the literature presents an inconsistent picture of the impact of GBP on macronutrient intake (3), food selection, taste sensitivity, and food reward processes, all of which have been implicated in the diminution of EI.

From a methodologic standpoint, there are two plausible explanations for this ongoing confusion. First, food intake behavior is likely to transition over time between when patients are losing weight during a steep negative energy balance and when they are stabilizing or rebounding during weight-loss maintenance. Unfortunately, there has been a paucity of


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follow-up studies of sufficient duration to document these changes in eating behavior. Second, GBP surgery can serve as a model for investigating the role of gastrointestinal physiology in modulating EI but only if those EI data are valid. However, most studies have relied on the purported validity of subjective self-reported food intake data even though objective validation studies have consistently demonstrated that most EI data in people with obesity are systematically flawed by underreporting (4–7). Underreporting of EI implies misreporting of dietary factors, which may be food and/or macronutrient specific, leading to the possibility of dual bias of unpredictable magnitude and direction, and with unknown consequences for data interpretation (8–10).

The objective measurement of food preferences is also particularly challenging. Intuitively, any changes in food preferences following bariatric surgery would be expected to affect food selection and hence both EI and relative macronutrient intake, with much of the supporting evidence being inferred from changes in subjectively assessed (but probably biased) food intake data (11, 12). Furthermore, many of the available tools for assessing food preference assess only explicit (conscious) preference. However, implicit preference is thought to have a greater influence on EI (13) but is more challenging to measure given that it is a subconscious, spontaneous reaction to a stimulus (14, 15). To date, only one study has evaluated the relation between changes in subjectively assessed food preferences and objective measures of ad libitum intake (16, 17) following bariatric surgery and concluded that the observed reduction in EI was not caused by a shift in preference toward less energy-dense food (18–22). However, these findings were based on one eating event, which limits their extrapolation.

Consequently, the overall aim of this study was to apply fit-for-purpose techniques to evaluate changes in 24-h ad libitum EI, food preferences, and associated eating behaviors in patients at 1 mo presurgery and at 3 and 12 mo post-GBP surgery compared with time-matched weight-stable comparator participants. To ensure the highest degree of sensitivity and control over outcome variables, all measurements were made under fully residential conditions. The specific hypotheses were as follows: *1*) total EI and relative (percent energy) intake from fat and sugar will decrease in patients after GBP surgery compared with weight-stable comparators, and *2*) implicit and explicit preferences for high-fat, high-sugar foods will decrease in patients following GBP surgery compared with weight-stable comparators and will be associated with corresponding changes in relative (percent energy) macronutrient intake and decline in overall dietary energy density (ED).

## Methods

The design and full protocol for this study are described in detail elsewhere (23). The change in ED and associated EI and macronutrient intake, of food consumed (primary outcome), eating behaviors, food preferences, and body composition (secondary outcomes) up to 12 mo postsurgery, are reported here.

### Sample size

As this study protocol was both novel and intensive, there was no existing literature to inform a power calculation and so sample size was estimated using a randomized controlled trial (RCT) by le Roux et al. (20). This RCT, which assigned participants to undergo either Roux-en-Y gastric bypass (RYGB) or vertical banded gastrectomy (VBG) and assessed dietary intake by self-report measures, detected significant differences in EI in 16 (VBG, $n = 7$; RYGB, $n = 9$) participants at 6 y postsurgery. The sample size was calculated using the standard deviation associated with the change in dietary fat (percent energy) intake from pre- to postsurgery (1.9) and a 95% CI that indicated that 14 participants were required. Applying a 14% attrition rate as reported by Kenler et al. (18) in which changes in self-reported dietary intake were reported at 2 y postsurgery, it was estimated that a minimum of 16 patients should be recruited in the present study. However, given the intensity of the proposed protocol, possible participant attrition was accounted for by recruiting 32 patients scheduled to undergo GBP surgery and 32 weight-stable comparator participants.

### Study population

Patients ($n = 34$, 77% female) scheduled to undergo GBP surgery [either RYGB or one-anastomosis gastric bypass (OAGB)] were recruited. Inclusion criteria were ≥18 y of age and scheduled to undergo a GBP procedure. Exclusion criteria were pregnancy/lactation, medications known to affect food preferences or appetite, food allergies/dietary restrictions, and/or gastrointestinal conditions that may affect dietary intake or food preferences.

Using similar exclusion criteria, weight-stable, time-matched comparator participants ($n = 32$, 47% female) were recruited by e-mail, poster, and word of mouth. Inclusion criteria for comparator participants were ≥18 y of age and with no planned weight change.

### Study design

Participants were studied on 3 occasions, at baseline (1 mo presurgery before the start of the prerequisite energy-restricted diet) and at 2 postsurgery (3 and 12 mo) time points. At each time point, participants completed a 36-h fully residential period starting late afternoon on day 1 and ending at lunchtime on day 3 in the Human Intervention Studies Unit (HISU), Nutrition Innovation Centre for Food and Health, Coleraine campus, Ulster University. On arrival, a preset dinner (spaghetti bolognese) was provided if requested, followed by fasting from 22:00 h in advance of the measurement period on day 2 (07:00–23:00 h).

This unit consists of 9 en suite bedrooms, communal living and dining areas for participants, and a closed-access (to participants) kitchen. Closed-circuit television (CCTV) cameras in all communal

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Abbreviations used: BW, body weight; CCTV, closed-circuit television; ED, energy density; EI, energy intake; GBP, gastric bypass; HISU, Human Intervention Studies Unit; LFPQ, Leeds Food Preference Questionnaire; OAGB, one-anastomosis gastric bypass; RCT, randomized controlled trial; RYGB, Roux-en-Y gastric bypass; T, tertile; TWL, total weight loss; VBG, vertical banded gastrectomy.

| Day1 | Day 2 | Day 3 |
|---|---|---|
| ▪ Arrive late afternoon/evening<br>▪ Standardised dinner provided if requested<br>▪ Doubly labelled water (DLW) measurement of total energy expenditure. Baseline urine sample collected from subset of patients (n=7)<br>▪ Fast from 22:00h | ▪ Participant-defined wake-up time; ~06:00h-08:00h.<br>▪ Basal metabolic rate measured on waking<br>▪ Buffet breakfast (menu determined by individual participant preferences, kept the same at each visit)<br>▪ 24h *ad-libitum* access to food throughout measurement period<br>▪ Body composition measurements<br>▪ DLW administered to subset of patients (n=7)<br>▪ Questionnaires assessing medication use/gastrointestinal symptoms<br>▪ Fast from 23:00h | ▪ Fasted blood draw (28mL)<br>▪ 60 min allocated to eat standardised breakfast<br>▪ 90 min postprandial (8mL) blood draw<br>▪ Leeds Food Preference Questionnaire<br>▪ 24h post-DLW urine sample collected from a subset of patients (n=7)<br>▪ End of visit (~1pm)<br>▪ 7d activity assessment using Actigraph monitors from a subset of patients (n=7) |

**FIGURE 1** An overview of the full study protocol outlining scheduled measurements.

areas were employed to verify food intake and eating behaviors (timing/duration/size/frequency of eating occasions, food selection, eating speed). Participants remained in the HISU for the duration of each study period but had access to a range of sedentary activities, including reading and crafts, with televisions in communal areas and bedrooms. Figure 1 provides an overview of the protocol and scheduled measurements at each study time point.

### Food provision

To ensure that the foods/beverages served were compatible with usual food intake, each participant completed a 96-item food choice questionnaire based on a 9-point Likert scale (1 = dislike extremely, 9 = like extremely) in advance of the first study period. Foods were listed in no particular order and were representative of 6 macronutrient (expressed as percent energy) mix groups (high fat/low fat, high complex carbohydrate/low complex carbohydrate, high simple sugar/low simple sugar, high protein/low protein) (Table 1) (adapted from 24). Food choices were used to design individualized participant menus, based on 9 food options from each of the 6 macronutrient groups for which participants had given the highest hedonic response.

Each participant was presented with the same personalized menu of foods ($n$ = 54) at each study visit. In addition, drinks (sugar-sweetened/sugar-free beverages, tea, coffee, milk, and water) and condiments (salt/pepper, sugar/sweetener, butter/low-fat spread, jams, and sauces) were available. All food and snack items were prepared according to the manufacturer's instructions.

Foods were presented in different formats; hot and cold traditional "breakfast" foods ($n$ = 6) were presented as a buffet, whereas lunch/snack foods ($n$ = 36) were available ad libitum from each participant's assigned refrigerator and cupboard for storing nonperishable foods. Evening meals ($n$ = 12 dishes) were selected from individually tailored menus featuring hot savory dishes ($n$ = 6) and desserts ($n$ = 6), with no restriction on the number of choices that could be made.

Participants were advised to consume only the foods provided to them and not to share. Researchers were not present while participants were eating and meal snack times were not researcher prescribed in advance; rather, participants could select to eat at time(s) of their choosing.

### Outcome measures

#### *Dietary intake.*

The ad libitum food intake of each participant was directly and covertly measured by weighing all foods before serving together with leftovers from ~06:00–08:00 h to 23:00 h on day 2 of each study visit and verified by CCTV data. The main outcome measures were total EI (MJ/d, kcal/d), intake of macronutrients (g, kJ, %EI), ED (kJ/g; calculated based on the intake of foods and energy-containing beverages) (25), intake

**TABLE 1** Macronutrient paradigm of foods presented to study participants with examples of foods presented in each category[1]

| Characteristic | High simple sugar | High complex carbohydrate | High protein |
|---|---|---|---|
| High fat | $n$ = 9 foods<br>Fat >40% energy<br>Sugar >30% energy<br>e.g., chocolate muffin, chocolate bar, ice cream | $n$ = 9 foods<br>Fat >40% energy<br>CCHO >30% energy<br>e.g., croissant, steak pies, apple pies | $n$ = 9 foods<br>Fat >40% energy<br>Protein >13% energy<br>e.g., peanuts, bacon, cheese |
| Low fat | $n$ = 9 foods<br>Fat <20% energy<br>Sugar >30% energy<br>e.g., banana, grapes, sugar-free meringues | $n$ = 9 foods<br>Fat <20% energy<br>CCHO >30%<br>e.g., sesame bagel, white bread, sugar-free jelly | $n$ = 9 foods<br>Fat <20% energy<br>Protein >13% energy<br>e.g., ham, Quorn, fat-free cottage cheese |

[1]Macronutrient mix groups adapted from Geiselman et al. (24). CCHO, complex carbohydrate.

from macronutrient mix groups (g, kJ, %EI), and intake from sugar-sweetened beverages.

### *Eating patterns.*

By design, this protocol did not impose researcher- or participant-defined "meals" and "snacks" but instead applied the term *eating occasion*. An eating occasion has been defined as "an event which provides at least 210 kJ with a separation in time from a preceding or following eating event of at least 15 min" (26), but this arbitrary definition has not been subjected to independent evaluation. Using the CCTV data from the baseline time point to determine both pause duration between eating occasions and their energy content, it was established that a pause duration of 5 min was more applicable to this study (23). Accordingly, an eating occasion was defined as the consumption of at least 210 kJ separated in time by at least 5 min from a preceding or subsequent eating occasion.

The distribution of EI across the measurement period was divided into 4 eating epochs: wake-up to 11:00 h, 11:01–15:00 h, 15:01–19:00 h, and 19:01–23:00 h. These eating epochs were used to determine the circadian pattern of eating occasions, EI, relative macronutrient intake, and associated ED.

CCTV data were used to evaluate the frequency, duration, and size of eating occasions as well as eating rate and calculated as follows:

$$\text{Eating occasion amount (g)} = \frac{\text{total daily food intake (g)}}{\text{number of eating occasions}} \quad (1)$$

$$\text{Eating occasion energy content (MJ)} = \frac{\text{total daily EI (MJ)}}{\text{number of eating occasions}} \quad (2)$$

$$\text{Eating occasion duration (min)} = \frac{\text{total daily duration of eating}}{\text{number of eating occasions}} \quad (3)$$

$$\text{Eating occasion rate} = \frac{\text{total daily food (g) or EI (kJ)}}{\text{total daily eating occasion duration}} \quad (4)$$

Where the start or the end of an eating occasion could not be observed by CCTV, the eating occasion was recorded but omitted from subsequent analyses. Participant data were included only if CCTV data were available for all time points.

### *Food preferences.*

Prior to leaving the HISU on day 3, 2 h after breakfast and after all other dietary measurements had been completed, each participant completed the self-administered Leeds Food Preference Questionnaire (LFPQ) (14).

The LFPQ is a computer-based measurement of explicit and implicit components ("liking" and "wanting") of food reward. Participants were presented with prevalidated pictures of food items ($n = 16$) that were either high fat (>50% energy) or low fat (<20% energy) but similar in familiarity, palatability, and sweet/savory taste. The same 16 foods were used to assess both explicit and implicit measures of food preference (27). Prior to completing the LFPQ, participants were advised of the procedure, encouraged to answer based on preference rather than dietary advice, and given the opportunity to practice prior to beginning the test.

Explicit measures of food reward were determined by presenting participants with an image of a food item that is either high/low fat and sweet/savory and requiring them to rate on a visual analog scale either "How pleasant would it be to taste some of this food now?" or "How much do you want some of this food now?" Average responses to each category ($n = 4$) were calculated, with a higher score representing higher explicit preference for that food category. Examples of the food pictures included chocolate (high fat/sweet), cheese (high fat/savory), fruit salad (low fat sweet), and bread roll (low fat/savory).

Implicit wanting for food was measured by presenting participants with a forced-choice paradigm that required them to choose between a high-fat compared with a low-fat food and a sweet compared with a savory food. Participants were asked to respond quickly to the question "Which food do you most want to eat now?" Responses and reaction times were subsequently used to calculate an implicit wanting score, where selection and speed positively contribute to the score. Data were analyzed using a frequency-weighted algorithm that has been developed to assess which foods have been avoided or selected, with nonselection negatively contributing to the implicit wanting score (27).

### *Body composition.*

Body weight (BW) was measured in light indoor clothing to the nearest 0.1 kg in the late afternoon/early evening of day 2 on each study visit. Height was measured under standardized conditions to the nearest 0.1 cm using a standing stadiometer on day 2 of the first study visit only. BMI was calculated as weight (kg)/height (m$^2$) and categorized using WHO cutoffs (28). Percent total weight loss (TWL) was calculated using the following equation:

$$\%\text{TWL} = \left[\frac{(\text{BW at baseline (kg)} - \text{BW at time point (kg)})}{\text{BW at baseline (kg)}}\right] \times 100 \quad (5)$$

A whole-body DXA (GE Lunar iDXA; GE Healthcare) scan across multiple regions (trunk, android, gynoid) was conducted on day 2 at each time point to assess fat mass (kg), lean mass (kg), and visceral fat (g). If participant body width exceeded the scanner area, a half-body scan was used as a valid substitute for a whole-body scan (29). A qualified practitioner performed scans with outputs assessed by a radiographer.

## Ethics

This study was approved by the West of Scotland Research Ethics Service (REC 16/WS/0056, IRAS 200567) and registered at clinicaltrials.gov as NCT03113305. The procedures followed were in accordance with the Declaration of Helsinki of 1975 as revised in 1983. All participants provided written, informed consent to take part in this study. To deflect attention from the main purpose of the study, participants were informed that the primary purpose of the study was to measure changes in basal metabolic rate following GBP surgery.

## Statistics

Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) for Windows (version 25; IBM). Continuous variables are reported as mean ± SEM, whereas categorical variables are presented as a $n$ and percentage [$n$ (%)] unless otherwise stated. Where participants had missed an interim study assessment, missing-value regression imputation was used where possible to predict results. Data were imputed only where the adjusted $R^2$ value was >0.5, which is indicative of a good predictive value. Imputed values were only valid and used within weight and body composition data.

At baseline, independent $t$ tests were used to determine differences between groups, with the exception of epoch data [2-factor mixed ANOVA (group × epoch)] and the data set split by change in ED [1-factor ANOVA (tertile)]. A 2-factor mixed ANOVA (group × time) was used to determine differences in $\log_{10}$ ratios of change [$\log_{10}$ (3 mo/baseline) and $\log_{10}$ (12 mo/baseline)] between groups (patients compared with weight-stable comparator participants and RYGB compared with OAGB) following GBP surgery. In the case of mixed ANOVAs, time and epoch were treated as repeated measures, and group was treated as a between-subjects factor. The $\log_{10}$ (ratio) was used to standardize postoperative values to each participant's baseline values. The log transformation allows factor increases and decreases to be symmetrical around zero change. Bonferroni-corrected 1-sample $t$ tests were conducted to explore within-group pairwise comparisons between baseline (zero) and postsurgery $\log_{10}$ ratios of change. Post hoc tests were carried out regardless of a significant group or time effect being achieved, and therefore some caution should be exercised when applying these findings.

Where calculation of $\log_{10}$ ratios was not possible (i.e., in macronutrient mix group, food preference and epoch data sets where zero or negative values were obtained), 2-factor mixed ANOVA (group × time), 3-factor mixed ANOVA (group × time × epoch), or 1-factor ANOVA (tertiles) was used on raw values with time-point 3- and 12-mo values only. Within-group changes from baseline at a given postoperative time point were performed with Bonferroni-corrected

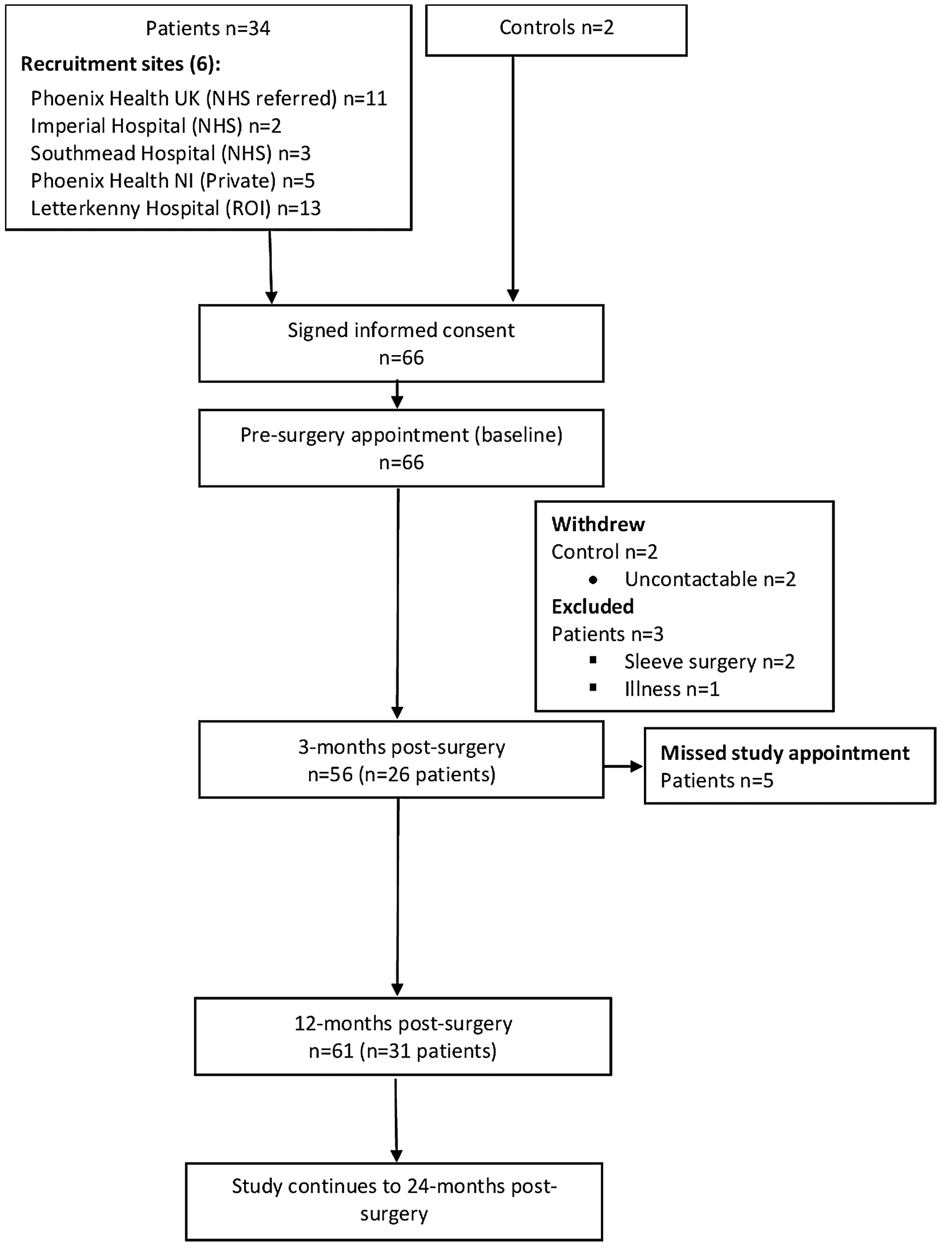


**FIGURE 2** Overview of participant recruitment, progression, and retention. NHS, National Health Service; ROI, Republic of Ireland.

paired *t* tests and between-group differences by Bonferroni-corrected independent *t* tests with the Levene test for equality of variance to test assumptions of variance.

Pearson correlation analysis was used to evaluate associations between variables and Pearson $\chi^2$ test to determine differences between categorical data.

The food group intake data were merged into high-sugar (>30% energy) and high-fat (>50% energy) foods comparable to the preference categories in the LFPQ, with the variables "high-fat food" and "high-sugar food" calculated by adding the 3 high-fat (high fat/high protein, high fat/high simple sugar, high fat/high complex carbohydrate) and 2 high-sugar (high fat/high simple sugar) food groups together (Table 1).

$$\text{Change variable} = (3\text{ or }12\text{ mo variable}) - (\text{baseline variable}) \quad (6)$$

$$\%\text{ change variable} = \frac{[(3\text{ or }12\text{ mo variable}) - (\text{baseline variable})]]}{\text{baseline}} \times 100 \quad (7)$$

Food preference variables were measured as bias for sweet and/or high-fat foods, with scores >0 indicating a preference for sweet/high-fat foods and a higher score indicating a greater preference. These were calculated as follows:

$$\text{Sweet bias variable} = \frac{(\text{mean sweet variable} - \text{mean savory variable})}{2} \quad (8)$$

$$\text{Fat bias variable} = \frac{(\text{mean high fat variable} - \text{mean low fat variable})}{2} \quad (9)$$

Within-group analyses were undertaken to determine if those who decreased their dietary ED also experienced the greatest decrease in food preferences for high-fat or high-sugar foods. Comparisons were made between tertiles of change in dietary ED (kJ/g) at 3 and 12 mo postsurgery. Significance was set at the $P < 0.05$ level.

**TABLE 2** Baseline characteristics of the participants[1]

| Characteristic | Patients ($n = 31$) | Comparators ($n = 32$) | $P$ value, $t(df)$[2] |
|---|---|---|---|
| Female, $n$ (%) | 24 (77.4) | 15 (46.9) | 0.026*, $\chi^2(1) = 4.97$ |
| Age, y | 47.3 ± 2.1 | 41.1 ± 2.5 | 0.09, $t(59) = (-1.71)$ |
| BW, kg | 125.7 ± 4.7 | 79.0 ± 2.7 | <0.001*, $t(52.2) = (-9.09)$ |
| Fat mass, kg | 63.7 ± 3.3 | 26.6 ± 1.7 | <0.001*, $t(48.4) = (-10.7)$ |
| Lean mass, kg | 59.1 ± 2.0 | 49.6 ± 1.9 | <0.001*, $t(59) = (-3.46)$ |
| Visceral fat, kg | 3.28 ± 0.34 | 1.02 ± 0.16 | <0.001*, $t(45.2) = (-6.23)$ |
| Height, cm | 165.2 ± 1.7 | 170.2 ± 1.6 | 0.033*, $t(59) = 2.18$ |
| BMI, kg/m[2] | 45.5 ± 1.3 | 27.2 ± 0.8 | <0.001*, $t(52.0) = (-12.0)$ |
| BMI category, $n$(%) | — | — | <0.001[3],* |
| Normal/underweight | 0 | 8 (25.0) | — |
| Overweight | 0 | 17 (53.1) | — |
| Obese | 31 (100) | 7 (21.9) | — |
| Type 1 diabetes mellitus, $n$ (%) | 2 (6.5) | 0 | — |
| Type 2 diabetes mellitus, $n$ (%) | 16 (51.6) | 0 | — |

[1]Data presented as mean ± SEM unless otherwise stated. BMI (in kg/$m^2$): normal/underweight, <25; overweight, 25–30; and obese, >30.
[2]Differences between groups for continuous variables assessed using independent samples $t$ tests.
[3]Differences between groups assessed using $\chi^2$, $\chi^2$ ($df$).
*Significant at $P = 0.05$ level.

## Results

### Participants

Sixty-six participants were recruited to the study, and 3 were excluded and removed from the database (alternative surgery, $n = 2$; surgery cancelled due to illness, $n = 1$), leaving 63 (31 patients, 32 comparators) eligible participants (**Figure 2**). However, 2 comparator participants were uncontactable after the first appointment and five patients missed the 3-mo appointment due to illness. Baseline characteristics are summarized in **Table 2**. The patient group had a greater proportion of females, had a higher BMI (>50% higher than the comparator group with all patients having a BMI >35 kg/$m^2$) and were more likely to have type 1 or type 2 diabetes mellitus. More patients underwent RYGB ($n = 22$, 71%) than OAGB ($n = 9$, 29%) surgery.

### Body composition and total weight loss

Following surgery, BW decreased relative to baseline in the GBP group at 3 mo [17.4 ± 1.2%; $t(30) = (-35.4)$, $P < 0.001$] and 12 mo [27.7 ± 1.6%; $t(30) = (-17.8)$, $P < 0.001$] but did not change in the comparator group ($P > 0.30$, at either time point) (**Figure 3**). There was no difference in weight loss between surgery type (RYGB compared with OAGB) over time [surgery type: $F(1, 53) = 0.04$, $P = 0.84$; time: $F(1, 53) = 53.03$, $P < 0.001$; surgery type × time: $F(1, 53) = 0.23$, $P = 0.63$].

At baseline, the absolute amounts (kg) of fat mass, lean mass, and visceral fat in the GBP group were all higher than in the comparator group (all $P < 0.001$, Table 2). There were significant main effects of group (all $P < 0.001$, Figure 3) and time (all $P < 0.020$, Figure 3) and group × time interactions (all $P < 0.001$, Figure 3) for all measures of body composition, with ratios of change in patients after surgery different from baseline (zero) at all time points for all body composition variables (all $P < 0.001$). TWL in patients reflected a fat mass loss: lean mass loss ratio of 3.0 and 4.3 at 3 and 12 mo, respectively. There were no changes in body composition variables in the comparator group at any time point ($P > 0.05$).

### Energy intake

Full dietary intake data were available for 20 patients and 25 comparator participants at all time points (**Figure 4**). Prior to surgery, the mean EI of the GBP group was 26% higher than the comparator group [20.8 ± 1.7 compared with 16.5 ± 1.3 MJ/d (4982 ± 409 compared with 3940 ± 303 kcal/d); $t(43) = (-2.06)$, $P = 0.45$]. There was an overall difference in ratios of change in EI between groups ($P < 0.001$) as well as a main effect of time ($P = 0.006$). The group × time interaction for EI fell just short of the criterion for statistical significance ($P = 0.06$). However, although at 3 mo postsurgery, EI in the GBP group was 44% lower than presurgery values [$t(19) = (-6.17)$, $P < 0.001$], by 12 mo postsurgery, their EI had partially rebounded with intake no longer statistically different compared with presurgery values [$t(19) = (-2.66)$, $P = 0.06$]. A greater reduction in EI was observed in patients who underwent OAGB surgery ($n = 7$) than those who underwent RYGB surgery ($n = 13$) [surgery type: $F(1, 36) = 4.61$, $P = 0.039$; time: $F(1, 36) = 8.22$, $P = 0.007$; group × time: $F(1, 36) = 4.61$, $P = 0.04$]. Moreover, although EI was lower than baseline at 3 mo after both surgical procedures [–56.0% EI, $t(6) = (-7.06)$, $P < 0.001$, compared with –35.2% EI, $t(12) = (-3.80)$, $P = 0.003$], by 12 mo, EI remained lower than presurgery values in the OAGB group [–32.5% EI, $t(6) = (-3.33)$, $P = 0.016$] but not in the RYGB group [–7.1% EI, $t(12) = (-1.19)$, $P = 0.26$].

### Macronutrient and food group intake and dietary ED

At baseline, there were no differences between the comparator and the GBP groups, respectively, in the relative intake (%EI) of macronutrients (protein, 13.5 ± 0.5% compared with 14.3 ± 0.9%; total carbohydrate, 47.2 ± 1.6% compared with 43.4 ± 1.7%; sugar, 22.8 ± 1.3% compared with 22.3 ± 1.4%; fat, 35.0 ± 1.3% compared with 38.4 ± 2.2%; saturated fat, 15.1 ± 0.6% compared with 16.0 ± 0.9%; $P > 0.09$), macronutrient mix food groups ($P > 0.15$; data not shown), or dietary ED [7.1 ± 0.4 compared with 6.9 ± 0.4 kJ/d; $t(40) = 0.39$, $P = 0.70$]. After surgery, there was a small overall difference between groups in relative sugar intake ($P = 0.047$); however, the ratio of change in the GBP group at 3 mo [$t(19) = (-2.33)$, $P = 0.123$] and 12 mo [$t(19) = (-1.57)$, $P = 0.53$] was

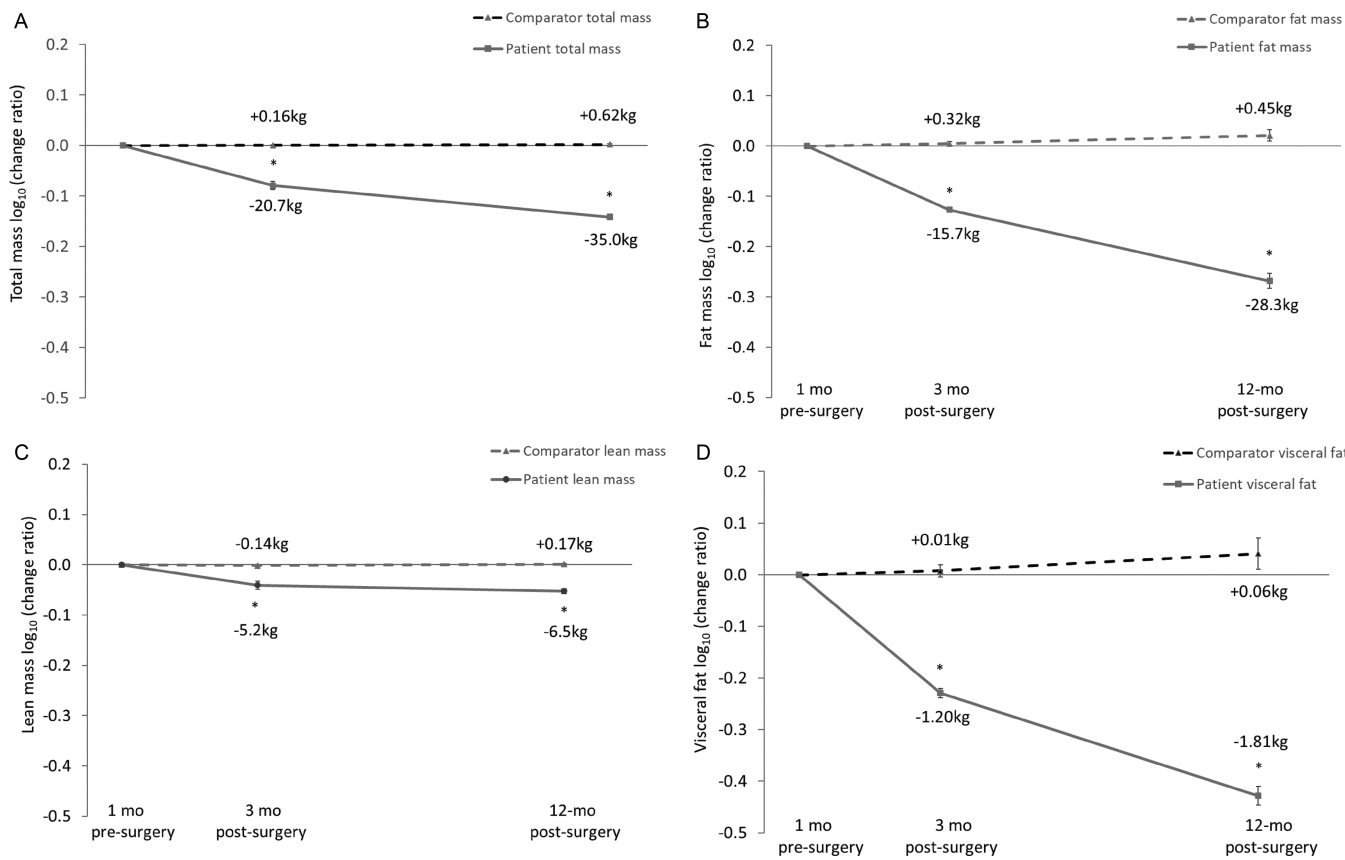


**FIGURE 3** Change [$\log_{10}$ (change ratios)] from baseline (1 mo presurgery) in (A) body weight, (B) fat mass, (C) lean mass, and (D) visceral fat (kg) at 3 and 12 mo postsurgery in patients (solid line, $n = 31$) and weight-stable comparator participants (broken line, $n = 30$). Data presented as mean $\log_{10}$ change ratio ± SEM. $\text{Log}_{10}$ change ratio 2-factor ANOVA (group × time). Total weight loss, group: $F(1, 112) = 833.5$, $P < 0.001$; time: $F(1, 112) = 62.2$, $P < 0.001$; group × time: $F(1, 112) = 68.5$, $P < 0.001$. Fat mass, group: $F(1, 112) = 514.3$, $P < 0.001$; time: $F(1, 112) = 43.8$, $P < 0.001$; group × time: $F(1, 112) = 70.2$, $P < 0.001$. Lean mass, group: $F(1, 112) = 243.1$, $P < 0.001$; time: $F(1, 112) = 2.45$, $P = 0.12$; group × time: $F(1, 112) = 5.57$, $P = 0.20$. Visceral fat, group: $F(1, 112) = 366.7$, $P < 0.001$; time: $F(1, 112) = 19.9$, $P < 0.001$; group × time: $F(1, 112) = 39.9$, $P < 0.001$. *Significant change from baseline at the $P < 0.05$ level. Datapoint labels indicate the actual measured change from baseline (kg).

similar to presurgery. There were no other differences in ratios of change between groups (Figure 4; $P > 0.07$). No differences were observed in the ratios of change in relative macronutrient intake between surgery type ($P > 0.23$).

At 12 mo after surgery, patients increased their intake of high-fat/high-protein-containing foods from 15.7 ± 1.9% EI at baseline to 25.7 ± 4.3% EI [$t(19) = 3.04$, $P = 0.028$]. Additionally, after surgery, the first foods selected at the breakfast buffet shifted from low-fat/high-complex carbohydrate-containing foods (e.g., Cornflakes, Weetabix) presurgery (45% of patients) to high-fat/high-protein-containing foods (e.g., bacon, eggs) at 12 mo after surgery (55% patients, $P = 0.002$). However, these dietary changes were not reflected in a change in relative protein intake at 12 mo [$t(19) = 1.56$, $P = 0.54$]. In the comparator group, with the exception of an increase in relative fat intake at the 3-mo time point [+2.8%; $t(10) = 3.01$, $P = 0.025$], no other changes were observed.

### Eating patterns: time, number, duration, size of eating occasions, and eating rate

Figure 5 shows the circadian distribution of EI (expressed as percentage of total daily EI across eating epochs) in patients following surgery. The hourly distribution of EI (data not shown) indicated that although mealtimes were not researcher prescribed, the spread of EI was broadly in line with a traditional UK meal pattern (breakfast, lunch, dinner plus snacks) and remained consistent from pre- to postsurgery (data not shown).

Presurgery, there were no differences between the groups in the distribution of EI [group: $F(1, 168) = 0.12$, $P = 0.73$; Figure 5], relative macronutrient intake, or ED (data not shown) across eating epochs, and there was no main effect of group postsurgery [3-factor ANOVA (time × group × epoch), $P > 0.10$].

Within-group comparisons showed that at 3 and 12 mo postsurgery, patients were consuming less energy in the first eating epoch (07:00–11:00 h) [$t(18) = 0.01$, $P = 0.038$, and $t(18) = 0.004$, $P = 0.016$, respectively] compared with baseline values. No changes were observed in any other epoch. The distribution of EI, ED, and relative macronutrient intake within epochs remained consistent across all time points in the comparator group.

EI and eating behavior data were calculated on a subgroup of participants where CCTV footage was available at all time points and accurate assessments of eating behavior could be monitored ($n = 12$ comparators, $n = 17$ patients; Figure 6). At baseline, there were no differences in EI [16.8 ± 1.5 compared with 22.3 ± 2.7 MJ (4013 ± 358 compared with 5327 ± 645 kcal), $t(27) = (-1.92)$, $P = 0.066$] or any measures of eating behavior—that is, number ($n$), duration (min), amount (g) and

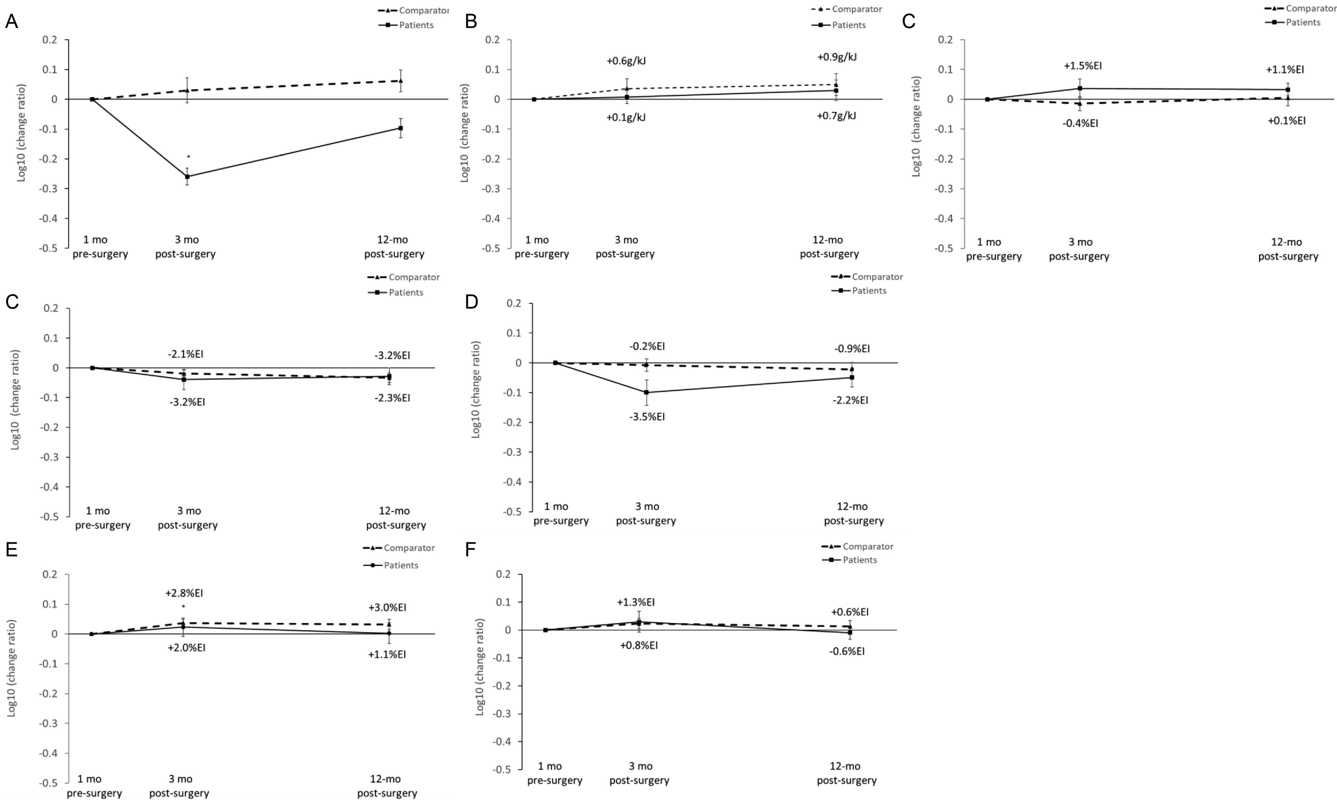


**FIGURE 4** Change [$\log_{10}$ (change ratios)] from baseline (1 mo presurgery) in (A) total energy intake (EI), (B) energy density (ED), (C) protein, (D) total carbohydrate, (E) sugar, (F) fat, and (G) saturated fat at 3 and 12 mo postsurgery in patients (solid line, $n = 20$) and weight-stable comparator participants (dashed line, $n = 25$). Data presented as mean $\log_{10}$ change ratio ± SEM. Two-factor ANOVA (group × time). (A) EI, group: $F(1, 86) = 41.5$, $P < 0.001$; time: $F(1, 86) = 7.85$, $P = 0.006$; group × time: $F(1, 86) = 3.51$, $P = 0.06$. (B) ED, group: $F(1, 80) = 0.19$, $P = 0.66$; time: $F(1, 80) = 2.20$, $P = 0.14$; group × time: $F(1, 80) = 1.20$, $P = 0.28$. (C) Protein, group: $F(1, 86) = 3.32$, $P = 0.07$; time: $F(1, 86) = 0.005$, $P = 0.95$; group × time: $F(1, 86) = 0.63$, $P = 0.43$. (D) Total carbohydrate, group: $F(1, 86) = 0.11$, $P = 0.75$; time: $F(1, 86) = 0.005$, $P = 0.95$; group × time: $F(1, 86) = 0.32$, $P = 0.58$. (E) Sugar, group: $F(1, 86) = 4.08$, $P = 0.047$; time: $F(1, 86) = 0.36$, $P = 0.55$; group × time: $F(1, 86) = 1.20$, $P = 0.28$. (F) Fat, group: $F(1, 86) = 0.84$, $P = 0.36$; time: $F(1, 86) = 0.29$, $P = 0.59$; group × time: $F(1, 86) = 0.11$, $P = 0.75$. (G) Saturated fat, group: $F(1, 86) = 0.10$, $P = 0.75$; time: $F(1, 86) = 0.93$, $P = 0.34$; group × time: $F(1, 86) = 0.33$, $P = 0.57$. *Significant ($P < 0.05$) change from baseline. Datapoint labels indicate the actual measured change from baseline (MJ or %EI).

energy content (MJ) of eating occasions, and eating rate (g/min and kJ/min) between the groups ($n$, 6.9 ± 0.6 compared with 7.3 ± 0.9; duration, 17.2 ± 2.3 compared with 20.8 ± 3.1 min; amount, 609± 69 compared with 572 ± 50 g; energy content, 2.8 ± 0.3 compared with 3.1 ± 0.3 MJ; rate, 37.0 ± 2.3 compared with 31.2 ± 3.7 g/min and 173 ± 13 compared with 172 ± 25 kJ/min, for comparators and patients, respectively; all $P > 0.18$). As expected, total EI in the patient group was lower postsurgery than in the comparator group (Figure 6G). The reduction in EI at 3 mo postsurgery was achieved by consuming less food per eating occasion, both in terms of the amount eaten [g: $t(11) = (-4.77)$, $P = 0.002$] and energy content [kJ: $t(11) = (-6.14)$, $P < 0.001$], but not by reducing the number of eating occasions, which was maintained relative to baseline in the GBP group. The 2-factor ANOVA (group × time) of the ratio change in eating occasion energy content (MJ) relative to baseline (Figure 6C) revealed that the GBP patients reduced the size of their eating occasions more than the comparator group (group effect: $P = 0.003$), but there was no significant interaction of group and time ($P = 0.10$). A similar 2-factor ANOVA on the ratio change in the amount (g) eaten during eating occasions (Figure 6B) revealed a significant group × time interaction ($P = 0.047$). By 12 mo, the amount of food consumed (g) per eating occasion had increased in the GBP group and, together with no significant change in eating occasion frequency, probably accounts for the partial rebound in total EI [+5.4 MJ, $t(15) = (-2.48)$, $P = 0.031$]. The number, size, and duration of eating occasions relative to baseline remained unchanged in comparator subjects.

In summary, the most salient impact of surgery on the patterns of eating behavior was on change in the size (g, MJ) of eating occasions.

## Food preferences

Four GBP patients and 3 comparator participants were excluded from the analysis because of noncompletion of the LFPQ at all study time points, leaving data for 56 participants ($n = 27$ patients; $n = 29$ comparators). A high level of variability was observed in all measures of food preference. At baseline, both groups expressed a preference bias for sweet foods (bias preference score >0), with higher implicit wanting in the comparator group [$t(54) = (-2.33)$, $P = 0.023$]. There were no other baseline differences between the groups in expressed preference for either sweet or high-fat foods (Table 3).

There was an overall effect of surgery on all measures of preference ($P < 0.003$) for sweet foods but no effect of surgery over time ($P > 0.07$). Between-group analyses showed that compared with the comparator group, the GBP group had diminished their implicit and explicit preference for sweet foods at 3 mo ($P < 0.009$; sweet bias score <0). However, only implicit

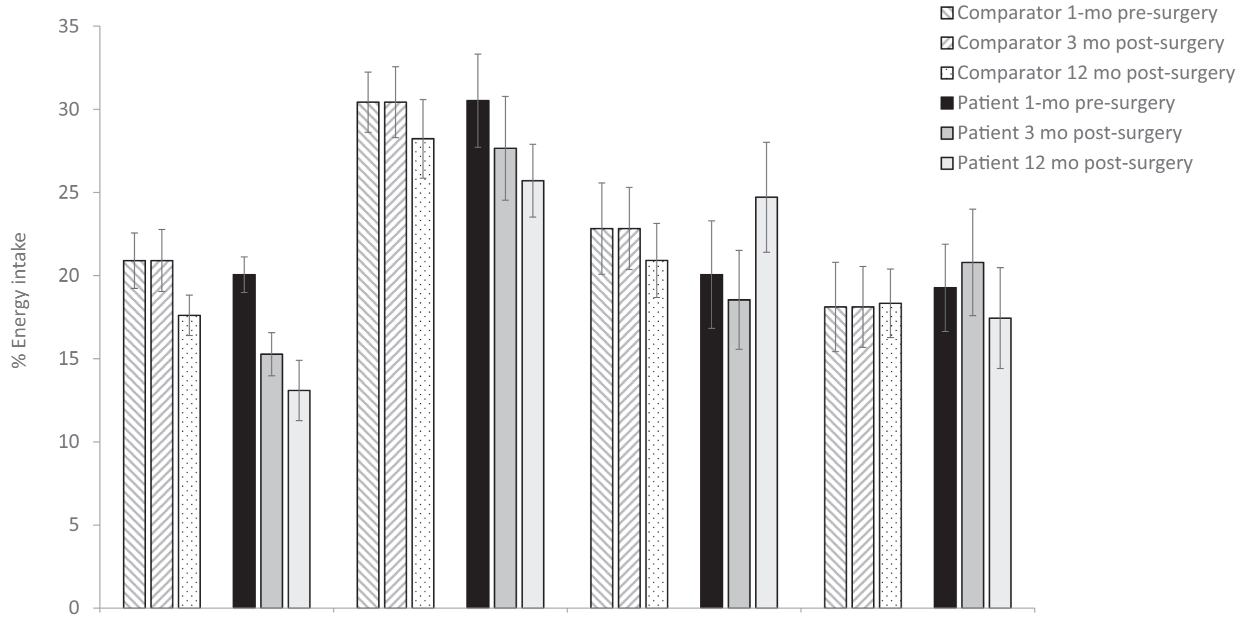


**FIGURE 5** Distribution of energy intake (EI) in patients ($n = 20$) at baseline (1 mo presurgery) and at 3 and 12 mo postsurgery, compared with weight-stable comparator participants ($n = 25$). Data presented as mean ± SEM. Baseline 2-factor ANOVA (group × epoch), epoch: $F(3, 168) = 9.34$, $P < 0.001$; group: $F(1, 168) = 0.12$, $P = 0.73$; epoch × group: $F(3, 168) = 0.23$, $P = 0.87$. Three-factor ANOVA [group × time (3- and 12-mo time points) × epoch], time: $F(1, 336) = 0.203$, $P = 0.653$, epoch: $F(3, 336) = 18.28$, $P < 0.001$; group: $F(1, 336) = 1.08$, $P = 0.30$; time × group: $F(1, 336) = 0.032$, $P = 0.56$; time × epoch × group: $F(3, 336) = 2.08$, $P = 0.10$. *Significantly different ($P < 0.05$) from baseline within group.

wanting bias for sweet foods remained different between groups at 12 mo [$t(54) = (-5.01)$, $P < 0.001$]. There were no changes, or group differences, in the bias scores for high-fat foods at any time point.

There were no associations between change in patients' implicit wanting bias for sweet food with either changes in relative intake of sugar [$R^2 = -0.003$, $P = 0.34$; $R^2 = -0.06$, $P = 0.97$] or high-sugar foods [$R^2 = -0.05$, $P = 0.79$; $R^2 = -0.05$, $P = 0.73$ at 3 and 12 mo after surgery, respectively].

Similarly, at 3 mo after surgery, there were no associations between changes in patients' implicit wanting bias for high-fat food with either changes in relative contribution of fat ($R^2 = -0.06$, $P = 0.91$) or high-fat foods ($R^2 = -0.05$, $P = 0.99$). However, at 12 mo after surgery, change in preference for high-fat food was weakly positively associated with change in the relative intake of fat ($R^2 = 0.21$, $P = 0.03$) but not high-fat foods ($R^2 = 0.08$, $P = 0.12$).

Within-patient group analyses to assess if those with the greatest decrease in dietary ED experienced the greatest changes in food preferences were conducted by comparing across tertiles of change in dietary ED (kJ/g) at 3 mo (Table 4) and 12 mo (data not shown).

At 3 mo, the patients who experienced the greatest decrease in dietary ED after surgery [tertile 1 (T1)] reported both the strongest preference for sweet [Table 4, $t(10) = 4.16$, $P = 0.002$] and high-fat food [Table 4, $t(10) = 2.71$, $P = 0.022$] at baseline and the greatest reduction in preference 3 mo postsurgery [Table 4; sweet food, $t(5) = 2.57$, $P = 0.049$; high-fat food, $t(5) = 3.00$, $P = 0.031$]. Additionally, although a lower EI was observed in all tertile groups at 3 mo postsurgery, those who had reduced their dietary ED the most (T1) had also reduced their EI by more than half of presurgery values [$-14.1 \pm 3.07$ MJ ($3360 \pm 734$ kcal)]. However, there was no difference in weight loss between the tertile groups. The observed changes in stated food preference were no longer evident at 12 mo postsurgery.

## Discussion

This is the first fully residential study using state-of-the-art methodology to evaluate the impact of GBP surgery on food intake and eating behavior, food preferences, and body composition over multiple eating occasions at 1 mo presurgery and 3 and 12 mo after RYGB or OAGB surgery.

The initial steep decline in EI at 3 mo after surgery (–44% from baseline) was followed by a partial rebound at 12 mo (–18% from baseline), with a greater reduction in EI but no difference in BW loss observed in OAGB patients. Irrespective of the surgical procedure, at both time points, dietary ED and relative macronutrient intake remained constant relative to baseline. In the comparator group, there was an increase in relative fat intake after 3 mo; otherwise, no other changes were observed in their food intake. Thus, the decline in EI in the patient group was simply the result of eating the same foods as consumed presurgery and by decreasing the size (g, MJ) but not the number of eating occasions. These findings fully endorse those of the only other study that objectively assessed changes in food intake at a single meal (16, 17) and raise important questions about the fitness for purpose of some of the methodologies currently employed for assessing food intake. A fundamental limitation of many studies has been the tacit assumption that self-reported data provide valid measures of usual food intake. However, independent validation studies have repeatedly demonstrated that the (4, 7) EI data of people with obesity are highly likely to be systematically flawed by underreporting. Furthermore, dual bias is likely to be present in the self-reported dietary intakes: underreporting of EI compounded by food-specific misreporting with consequences

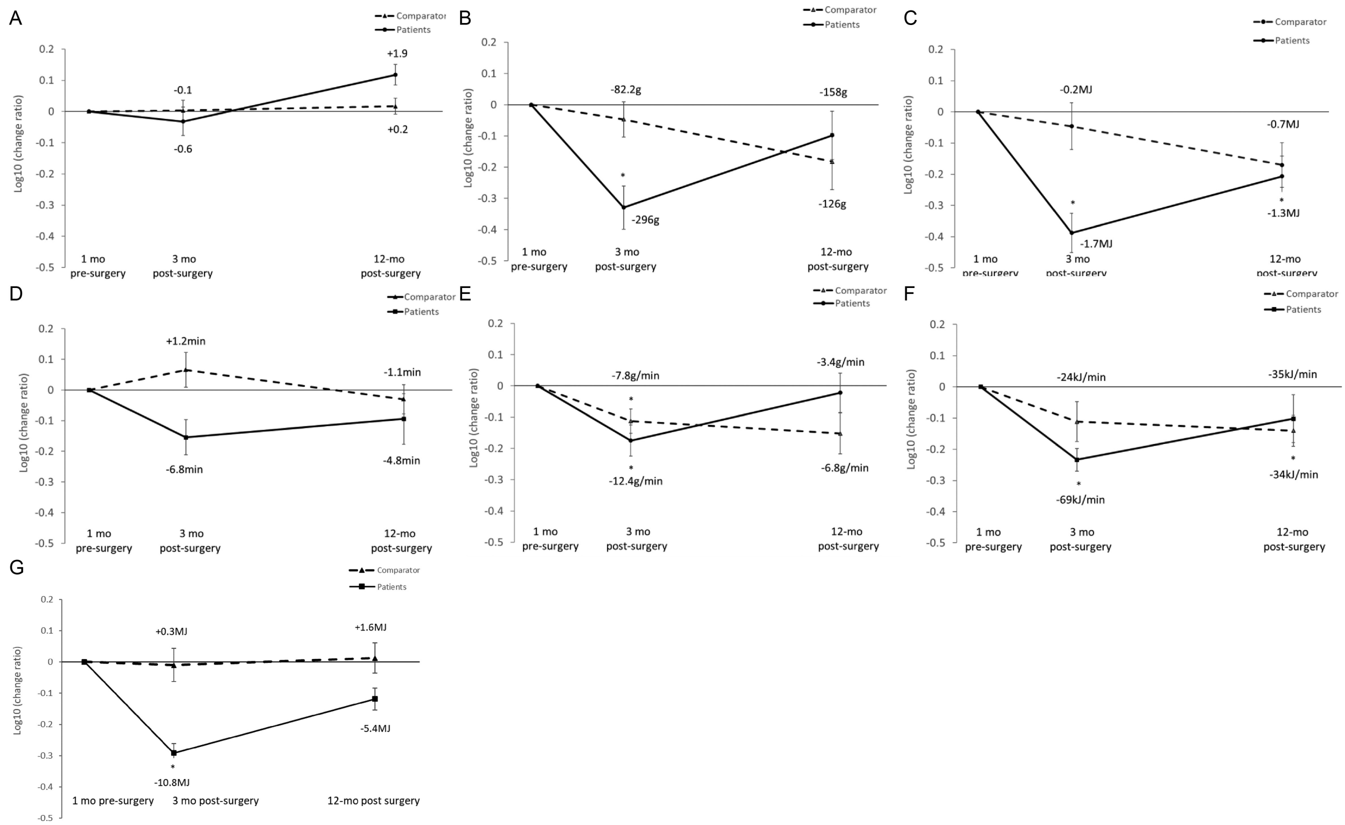


**FIGURE 6** Change ($\log_{10}$ change ratios) from baseline (1 mo presurgery) in (A) number of eating occasions (*n*), (B) eating occasion size (g), (C) eating occasion size (MJ), (D) eating occasion size duration (min), (E) eating rate (g/min), (F) eating rate (kJ/min), and (G) energy intake (EI) (MJ/d) at 3 and 12 mo postsurgery in patients (solid line, $n = 12$) and weight-stable comparator participants (dashed line, $n = 17$). Data presented as mean ± SEM. Data in B–F include only eating occasions where the beginning and end of the eating occasion were visible on the closed-circuit television . $\text{Log}_{10}$ change ratio 2-factor ANOVA (group × time) on ratios of change from baseline. (A) Number of eating occasions, group: $F(1, 54) = 0.54$, $P = 0.47$; time: $F(1, 54) = 3.29$, $P = 0.07$; group × time: $F(1, 54) = 2.26$, $P = 0.14$. (B) Eating occasion amount (g), group: $F(1, 54) = 2.71$, $P = 0.11$; time: $F(1, 54) = 0.07$, $P = 0.79$; group × time: $F(1, 54) = 4.14$, $P = 0.047$. (C) Eating occasion energy content (MJ), group: $F(1, 54) = 9.65$, $P = 0.003$; time: $F(1, 54) = 0.003$, $P = 0.96$; group × time: $F(1, 54) = 2.87$, $P = 0.10$. (D) Eating occasion duration (min), group: $F(1, 54) = 6.46$, $P = 0.014$; time: $F(1, 54) = 0.32$, $P = 0.57$; group × time: $F(1, 54) = 0.90$, $P = 0.35$. (E) Eating rate (g/min), group: $F(1, 54) = 0.34$, $P = 0.56$; time: $F(1, 54) = 0.95$, $P = 0.34$; group × time: $F(1, 54) = 2.74$, $P = 0.10$. (F) Eating rate (kJ/min), group: $F(1, 54) = 0.99$, $P = 0.32$; time: $F(1, 54) = 0.27$, $P = 0.61$; group × time: $F(1, 54) = 0.98$, $P = 0.33$. (G) EI (MJ/d), group: $F(1, 54) = 25.5$, $P < 0.001$; time: $F(1, 54) = 5.71$, $P = 0.20$; group × time: $F(1, 54) = 3.37$, $P = 0.07$. *Significant ($P < 0.05$) change from baseline using Bonferroni corrected 1-sample *t* tests. Datapoint labels indicate the actual measured change from presurgery.

that are both unpredictable and complex for interpreting data 8–10. Despite this compelling evidence, the phenomenon of biased food intake data has largely been overlooked or ignored (11, 30) and has severely undermined efforts to address key scientific questions in the area of bariatric surgery.

Of course, it would be naive to recommend that future studies in obesity research should employ only direct measures of food intake as this will simply not be feasible in most studies. Although the robustly controlled fully residential conditions in the present study have permitted the capture of accurate data on food intake and eating behavior, it is also debatable if these are representative of the free-living scenario where food choice decisions are dictated by a myriad set of complex factors. Furthermore, the potential for residual confounding and for making a type I error in the analysis of the secondary outcomes and the use of post hoc testing following nonsignificant group/time effects are acknowledged limitations of the study design.

Admittedly, the problem of how to *accurately* measure habitual food intake in studies of obesity remains an enigma in nutrition research. Doing nothing is also no longer an option (31) because the implications for the clinical care of people living with obesity are profound. Any effective long-term treatment modalities for obesity are likely to be associated with appetite control and reduced food intake. If these behaviors cannot be measured accurately, any attempts to manipulate them with therapeutic intent will be impossible to evaluate with confidence. Several procedures (32–35) are available for screening implausible EI data based on estimated energy requirements, and although these tools do have drawbacks, they will at least allow researchers to acknowledge the limitations of self-reported dietary data and to analyze and interpret them appropriately. Until the efficacy of these techniques has been evaluated in bariatric research, only tentative conclusions should be drawn from subjectively reported food intake data.

Another strength of this study is that eating times were not prescribed with participants able to eat when and what they wished from an extensive personalized menu. It was evident from CCTV data that the circadian organization of food intake and eating patterns were largely not disrupted by surgery. By 3 mo postsurgery, the observed energy deficit was achieved by reducing the size (g, MJ), but not the number, of eating occasions

**TABLE 3** Changes in explicit and implicit preference for sweet and high-fat foods from baseline (1 mo presurgery) to 3 and 12 mo postsurgery in patients compared with weight-stable comparator participants[1]

| Characteristic | Participants, *n* | Baseline | 3 mo postsurgery | Change[2] | 1 y postsurgery | Change[2] | ANOVA *P* value[3] (*df*), *F* (group) | ANOVA *P* value[3] (*df*), *F* (group × time) |
|---|---|---|---|---|---|---|---|---|
| Explicit liking (sweet foods) | | | | | | | | |
| Patients | 27 | 9.66 ± 4.17 | −1.90 ± 2.99[$] | −11.6 ± 4.67 | 2.42 ± 2.64 | −7.24 ± 3.95 | <0.001* | 0.07 |
| Comparators | 29 | 7.18 ± 1.92 | 13.0 ± 2.22[$] | 5.77 ± 2.22 | 7.74 ± 2.70 | 0.55 ± 2.03 | (1,108) = 14.6 | (1,108) = 3.26 |
| Explicit wanting (sweet foods) | | | | | | | | |
| Patients | 27 | 6.63 ± 4.40 | −1.63 ± 3.33[$] | −8.25 ± 5.41 | 0.71 ± 2.22 | −5.91 ± 4.36 | 0.003* | 0.18 |
| Comparators | 29 | 5.84 ± 1.81 | 8.60 ± 1.73[$] | 2.76 ± 1.43 | 4.66 ± 1.90 | −1.19 ± 1.67 | (1,108) = 9.13 | (1,108) = 1.80 |
| Implicit wanting (sweet foods) | | | | | | | | |
| Patients | 27 | 7.44 ± 7.08[$] | −8.31 ± 6.73[$] | −15.8 ± 7.76 | −7.74 ± 6.07[$] | −15.2 ± 6.52 | <0.001* | 0.83 |
| Comparators | 29 | 28.5 ± 5.70[$] | 38.9 ± 5.43[$] | 10.4 ± 4.8 | 36.7 ± 6.43[$] | 8.19 ± 4.22 | (1,108) = 55.0 | (1,108) = 0.05 |
| Explicit liking (high-fat foods) | | | | | | | | |
| Patients | 27 | 2.39 ± 3.21 | −0.55 ± 2.29 | −2.94 ± 3.47 | 0.54 ± 3.50 | −1.85 ± 3.33 | 0.87 | 0.38 |
| Comparators | 29 | −0.19 ± 2.02 | 1.26 ± 2.27 | 1.46 ± 2.19 | −2.11 ± 1.92 | −1.92 ± 2.08 | (1,108) = 0.03 | (1,108) = 0.78 |
| Explicit wanting (high-fat foods) | | | | | | | | |
| Patients | 27 | 1.36 ± 3.11 | −1.67 ± 1.98 | −3.02 ± 3.64 | −2.93 ± 2.95 | −4.29 ± 3.14 | 0.75 | 0.22 |
| Comparators | 29 | −1.34 ± 1.56 | 1.84 ± 1.96 | 3.18 ± 2.13 | −4.98 ± 2.05 | −3.64 ± 2.22 | (1,108) = 0.11 | (1,108) = 1.51 |
| Implicit wanting (high-fat foods) | | | | | | | | |
| Patients | 27 | 3.94 ± 5.40 | −1.17 ± 5.31 | −5.11 ± 6.72 | −2.87 ± 5.17 | −6.81 ± 4.69 | 0.06 | 0.37 |
| Comparators | 29 | 7.47 ± 5.17 | 13.18 ± 5.50 | 5.70 ± 5.37 | 2.26 ± 4.25 | −5.21 ± 3.92 | (1108) = 3.68 | (1,108) = 0.82 |

[1] Data presented as means ± SEM. Food preference bias scores of >0 indicate a preference for sweet/high-fat foods and a higher score indicates a greater preference.
[2] Change indicates change from baseline values.
[3] Main effects assessed using two-way ANOVA.
*Data considered significant at the $P < 0.05$ level. [$] Significant differences between groups.

**TABLE 4** Changes in energy intake, BMI, and implicit preferences for sweet and high-fat foods from baseline (1 mo presurgery) to 3 mo postsurgery in patients by tertiles of change in energy density at 3 mo postsurgery[1]

| Characteristic | T1 [ED: −1.01 to (−0.81) kJ/g] ($n = 6$) Baseline | 3 mo | Change[2] | T2 (ED: −0.24 to 0.64 kJ/g) ($n = 6$) Baseline | 3 mo | Change[2] | T3 (ED: 0.67 to 2.13 kJ/g) ($n = 6$) Baseline | 3 mo | Change[2] | $P$ value ($df$) = $F$[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| Sex, female/male | 7/0 | 7/0 | — | 4/2 | 4/2 | — | 4/2 | 4/2 | — | 0.70 |
| BMI | 49.3 ± 4.66 | 40.8 ± 3.52* | −8.48 ± 1.43 | 43.3 ± 2.57 | 34.9 ± 1.62* | −8.38 ± 1.26 | 45.6 ± 2.27 | 38.2 ± 1.41* | −7.37 ± 0.94 | 0.25 (2,15) = 1.55 |
| 24-h EI, MJ/d | 26.7 ± 3.3 | 12.6 ± 1.54* | −14.1 ± 1.5 | 19.0 ± 2.45 | 10.2 ± 2.46* | −8.87 ± 2.26 | 18.2 ± 2.84 | 11.2 ± 1.70 | −7.01 ± 3.40 | 0.68 (2,15) = 0.39 |
| IW sweet bias[4] | 42.5 ± 7.03[a] | −0.27 ± 11.4* | −42.8 ± 16.6 | −17.4 ± 12.6[b] | −23.4 ± 8.23 | −5.97 ± 9.64 | 17.9 ± 6.29[a] | 7.74 ± 16.1 | −10.2 ± 14.4 | 0.21 (2,15) = 1.71 |
| IW fat bias[4] | 19.0 ± 8.43 | 0.26 ± 11.9* | −18.7 ± 6.29 | −17.5 ± 10.5 | −3.11 ± 15.0 | 14.4 ± 16.7 | 13.5 ± 17.1 | 3.87 ± 9.84 | −9.61 ± 21.5 | 0.93 (2,15) = 0.08 |

[1]Data expressed as mean ± SEM unless otherwise stated. Patient groups determined by tertile split in change in dietary ED: tertile 1 (T1), decreased ED; tertile 2 (T2), maintained ED; and tertile 3 (T3), increased ED. ED, energy density (kJ/g); EI, energy intake; IW, implicit wanting.
[2]Change indicates change from baseline values.
[3]Differences across tertiles measured using 1-factor ANOVA (tertile). Differences between categorical variables measured using $\chi^2$.
[4]Food preference bias scores of >0 indicate a preference for sweet/high-fat foods and a higher score indicates a greater preference.
*Difference from baseline within tertile group ($P < 0.05$). Unalike superscripted letters (a or b) denote a significance between tertile groups at baseline ($P > 0.05$).

and by eating slower. These behaviors are compatible with compliance with the prescribed postoperative diet, increased satiety hormone responses (36, 37) to eating more slowly, and trial-and-error learning linked to managing any unpleasant postingestive reactions associated with eating high-fat/high-sugar foods. However, by 12 mo postsurgery, this compliance was unlikely to be an imperative, and as a result, the amount of food eaten per eating occasion had increased, leading to a partial rebound in EI. Whether this pattern of eating in a subset of the participants is typical of eating behavior in the 12 mo following surgery is unclear. It is also inconceivable that food intake behavior will not transition in other ways over time and justifies further investigation.

Currently, much of the evidence in support of a shift in food preference in favor of a reduced hedonic drive to consume energy-dense foods following surgery is inferred from subjective food intake data of uncertain validity. In turn, this has generated much debate about the mechanisms modulating this food intake behavior. including changes in the sensory and reward domain of eating and conditioned food aversion consequent upon postingestive responses following surgery. However, if valid food intake data are accepted as surrogate measures of food preferences, then, as demonstrated by Nielsen et al. (16, 17) and reinforced by the present study, the reward value of eating highly palatable energy-dense foods is not diminished postsurgery, albeit these foods are eaten in smaller amounts.

Assessing the hedonic domain of human eating behavior is complex. Most available tools assess only conscious (explicit) but not unconscious (implicit) preferences, even though the latter, although more challenging to measure, are thought to be better predictors of EI (13, 27). LFPQ, which has not previously been used in bariatric surgery research, has been developed to measure both domains, and unlike other questionnaires that present participants with a single-choice decision (e.g., high-fat food compared with low-fat food), the LFPQ presents multiple pairs using a 4-compartment matrix model to control for other sensory factors that may affect preference (38). Intuitively, any changes in food preferences (using tools specifically designed for the purpose) following surgery should be reflected in corresponding changes in food selection, but this was not the case in the present study. Thus, although patients reported a diminished hedonic pleasure (explicit liking) for sweet foods at 3 mo postsurgery and a lower desire to consume them at both 3 and 12 mo postsurgery, intake of high-sugar foods was maintained.

However, patients whose dietary ED decreased most by 12 mo postsurgery reduced their preference for sweet foods compared with those whose dietary ED had increased and who retained their desire to consume these foods. Interestingly, Nielsen et al. (17) also reported that greater BW loss after surgery was associated with both a reduction in ED and an early decline in preference for energy-dense foods (39). Taken together, these findings suggest that there may be considerable individual variability in expressed preferences for and consumption of energy-dense foods that merit further investigation to identify early postoperative differences in eating behavior, which may be predictive of longer-term weight change.

Whether these study outcomes are representative of eating behavior in the first year following surgery requires verification before the implications of the findings are fully understood. Perhaps the most significant contribution has been to highlight that consensus on the dynamics of food intake behavior following bariatric surgery will never be achieved if current practice in measuring food intake behavior goes unchallenged.

The legitimacy of using food intake data, irrespective of whether these are self-reported or objectively measured, as a surrogate measure of food preferences has been questioned. Most crucially, given the pervasiveness of invalid reporting of food intake in obesity research, continuing to measure food intake without checking its biological plausibility, in the mistaken belief that any data are better than none, is misguided. Maintaining the status quo will only serve to generate more erroneous conclusions, lead to misleading hypotheses, and reap confusion in an already confused area.

In conclusion, the outcomes of this study do not support the initial hypotheses. In the GBP group, the steep decline in EI at 3 mo postsurgery, followed by a partial rebound at 12 mo, was attributed to eating the same foods as eaten presurgery but in smaller amounts. At both time points, ED and relative macronutrient intake did not differ from baseline. Moreover, any expressed changes in both explicit and implicit preference for high-sugar foods did not manifest in their decreased consumption. However, potential individual variability in changing food preference for energy-dense foods merits further investigation.

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## Data Availability

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval.

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