Changes in Taste Perception and Eating Behavior After Bariatric Surgery-Induced Weight Loss in Women

Marta Yanina Pepino, David Bradley, J. Christopher Eagon, Shelby Sullivan, Nada A. Abumrad and Samuel Klein

Objective: Roux-en-Y gastric bypass (RYGB) surgery causes greater weight loss than laparoscopic adjustable gastric banding (LAGB). We tested the hypothesis that RYGB has weight loss-independent effects on taste perception, which influence eating behavior and contribute to the greater weight loss.

Methods: Subjects were studied before and after ~20% weight loss induced by RYGB (n = 17) or LAGB (n = 10). The following have been evaluated: taste sensitivity for sweet, salty and savory stimuli, sucrose and monosodium glutamate (MSG) preferences, sweetness palatability, eating behavior, and expression of taste-related genes in biopsies of fungiform papillae.

Results: Weight loss induced by both procedures caused the same decrease in: preferred sucrose concentration (~12 ± 10%), perceived sweetness of sucrose (~7 ± 5%), cravings for sweets and fast-foods (~22 ± 5%), influence of emotions (~27 ± 5%), and external food cues (~30 ± 4%) on eating behavior, and expression of α-gustducin in fungiform papillae (all P values <0.05). RYGB, but not LAGB, shifted sweetness palatability from pleasant to unpleasant when repetitively tasting sucrose (P = 0.05). Neither procedure affected taste detection thresholds nor MSG preferences.

Conclusions: LAGB and RYGB cause similar alterations in eating behaviors, when weight loss is matched. These changes in eating behavior were not associated with changes in taste sensitivity, suggesting other, as yet unknown, mechanisms are involved.

Introduction

Bariatric surgery is the most effective weight loss therapy for obesity because of its profound effects on eating behavior and food intake. Procedures that divert ingested nutrients away from the upper gastrointestinal tract, such as Roux-en-Y gastric bypass (RYGB), cause greater weight loss than those that simply restrict size, such as laparoscopic adjustable gastric banding (LAGB). Data obtained from studies that used dietary recall methods and eating behavior questionnaires suggest that patients who have had RYGB surgery decrease the proportion of their daily calorie intake from sweetened foods and beverages more than subjects who have had banded gastroplasty (2-5), a behavior that could significantly contribute to the greater reduction in total energy intake observed after RYGB than LAGB surgery.

The mechanisms responsible for the decreased intake of sweetened foods after RYGB surgery are unknown, but could involve changes in taste perception. Taste perception involves two major psychological components, including a sensory-discriminative component and a hedonic component (6). The sensory-discriminative component refers to taste quality (sweet, salty, savory, bitter, and sour) and taste sensitivity, which ranges from what is the lowest concentration of taste stimuli that can be detected (taste detection thresholds) to how intense a taste stimulus is perceived (above-threshold responses). The hedonic component of taste perception accounts for how much the stimulus is liked or disliked (6).

RYGB is associated with decreased hedonic value for sweet or highly palatable foods (7-11). However, the effect of RYGB on taste sensitivity is unclear because of conflicting results from different studies, which have reported subjects became more sensitive (lower taste thresholds) to bitterness but not sweetness (12) or more sensitive to sweetness (13) but not bitterness (14) after RYGB surgery. An important limitation of these studies is that taste thresholds usually do not correlate with above-threshold sensory function (15,16); therefore the consequence of having an altered taste threshold in food selection is unclear. In addition, it is not known whether changes in taste perception are due to altered food intake and weight loss itself or whether the anatomical alteration associated with RYGB has weight loss-effect...
independent effects on taste perception. The primary purpose of the present study was to test the hypothesis that anatomical diversion of ingested nutrients from the upper gastrointestinal tract by RYGB has weight-loss-independent and diet-independent effects on taste perception and eating behavior compared with LAGB. Accordingly, we evaluated the sensory-discriminative and hedonic components of taste perception, and eating behavior in obese women before and after subjects lost 20% of their body weight induced by either RYGB or LAGB surgery. We also evaluated the effects of surgery-induced weight loss on the cellular factors involved in the transduction of taste signals in fungiform papillae in a subsample of study subjects.

Methods

Subjects

The study population consisted of 27 consecutive obese women who were scheduled to undergo either RYGB (n = 17) or LAGB (n = 10) procedures at Barnes-Jewish Hospital (St. Louis, MO, USA). Subjects who had LAGB served as a control group to account for the independent effects of weight loss and dietary intake on our study outcome measures. We only studied women because most patients who have bariatric surgery are women and sex can affect taste perception (18). We excluded potential subjects who had diabetes, smoked cigarettes, were taking any medication that might affect taste (18), and the FCI, subjects score their answers using a 5-point Likert scale ranging from “Never” to “Very often/Always,” the STQ identifies two factors associated with sweet food consumption: 1) sensitivity to the mood altering effects of sweets, and 2) impaired control over eating sweet foods (24). In the STQ, subjects respond to 12 items using 7-point Likert scales ranging from “Strongly disagree” to “Strongly agree.” The DEBQ measures three common psychological dimensions of eating behavior: 1) emotional eating (an inclination to eat in response to negative emotions such as depression or feelings of loneliness), 2) external eating (an inclination to eat in response to external food cues such as the smell of food), and 3) restrained eating (an inclination to consciously restrict food intake to control body weight) (22). The FCI is a validated measure of the frequency of overall food cravings as well as cravings for specific types of foods (high fats, sweets, carbohydrates/starches, and fast-food fats) during the past month (23). For the DEBQ and the FCI, subjects score their answers using a 5-point Likert scale (1 = never, 5 = very often/always). The STQ identifies two factors associated with sweet food consumption: 1) sensitivity to the mood altering effects of sweets, and 2) impaired control over eating sweet foods (24). In the STQ, subjects respond to 12 items using 7-point Likert scales ranging from “Strongly disagree” to “Strongly agree.” The FPQ is a validated instrument that assesses the preference for dietary fat by measuring the percentage of food sets in which high fat foods were selected over lower-fat choices of the same food to “taste better” (TASTE score) and to “be eaten more often” (FREQ score) (25).

Tongue Biopsy. Lingual fungiform papillae biopsies were obtained as described previously (26). Fungiform papillae were clipped from the...
TABLE 1 Primer sequences used for quantitative PCR analysis of fungiform taste papillae

| Gene       | Forward                | Reverse                |
|------------|------------------------|------------------------|
| 36B4       | GTGATGTGCAGCTGATCAAGACT | CATGGGAGGAGGAGGACAGAA  |
| PLCB2      | TGCCAGATCTGCAAGAGACAA  | AGCGTACGTTGATGATGCTGTC |
| α-Gustducin| TCCCCCGTGCGAGGAGGACCA  | TCAGCCTGCTGCTGCTGCTGTC |
| TAS1R1     | GGCACCATCTCCAAATGAAAGTA| CATTCGGCTAGCTGCTGCTGCT |
| TAS1R2     | ACTCTTGTTGTTGTTGTTGTT  | TGGCCGCTGATGATGATGATGCT |
| TAS1R3     | TCTGACACCAGAAGCCGAGTT  | ATGTGCCTGCTGCTGCTGCTGTC |

Surgical Procedures

Bariatric surgeries were performed using standard laparoscopic approaches. The RYGB procedure involved creating a small (~20 ml) proximal gastric pouch and a stapled gastrojejunostomy. A 75-150 cm Roux-Y limb was constructed by transecting the jejunum 30 cm distal to the ligament of Treitz and performing a stapled jejunoojnostomy at this site (27). The standard pars flaccid technique was used for LAGB (Lap-Band, Allergan, Irvin, CA, USA) (27).

Diet Management After Surgery

Subjects participated in an individual supervised weight management program to help subjects in both groups consume a similar energy-deficit diet and achieve a 20% weight loss within 4-6 months after surgery. Subjects were instructed to consume a liquid diet for the first week after surgery, followed by a 2-4 weeks progression to a regular food diet containing 1,000-1,200 kcal/day and 1.0 g of protein/kg body weight/day. A study dietician with expertise in weight management met with the subjects, or contacted them by phone, weekly to monitor body weight, review dietary intake, provide standard weight management behavioral education, and adjust recommended energy intake as needed to achieve weight loss targets. After subjects achieved the targeted 20% weight loss, a weight maintenance diet was prescribed, and subjects maintained a stable body weight (~2% change) for at least 2 weeks before repeated studies were performed.

Tongue Sample Analyses

Quantitative PCR. RNA from tongue biopsy samples was isolated using TRIzol reagent (Life Technologies, Carlsbad, CA, USA) cDNA was synthesized (Superscript VILO kit, Life Technologies) and gene-specific amplification was performed utilizing SYBR Green chemistry on an ABI 7500 FAST qPCR cycler (Applied Biosystems, Foster City, CA, USA). Expression levels of each gene was determined using the formula 2^(-ΔΔCt) after correcting the threshold crossing (Ct) of each sample to the housekeeping control gene, acidic ribosomal phosphoprotein P0 (36B4). The primer sequences used are shown in Table 1. Fold changes were calculated by dividing the value of post-surgery by the value of pre-surgery. Whenever the number was less than one, the (negative) reciprocal is shown (e.g., 0.3 or a drop of 75% from before surgery is reported as = 0.3 or a drop of 75% from before surgery).

Statistical Analyses

Two-way ANOVAs with group (RYGB and LAGB) as the between-subjects factor and time (before after surgery) were used to determine whether surgery-induced weight loss and the specific surgical procedure causes changes in: 1) taste detection thresholds, 2) perceived intensity of above-threshold concentrations, 3) degree of pleasure from tasting sweetness, 4) desire for tasting something non-sweet, and 5) eating behavior questionnaires scores. Sucrose and MSG detection thresholds were positively skewed and required logarthmic transformation to approximate a normal distribution, whereas perceived taste intensity of sucrose and MSG, and desire for a different taste required square root transformations.

Differences in the expression of taste-related genes in fungiform papillae were assessed by using Wilcoxon-matched pairs tests. Pearson correlation coefficients were used to determine whether there was a relationship between changes in perceived sweetness intensity and the most preferred sucrose concentration before versus after surgery. Data in the tables and figures are presented as mean ± SD unless otherwise indicated, or medians with semi-interquartile range (SIQR = [75th – 25th percentile]/2) for skewed data sets. All analyses were performed with Statistica 8.0 (StatSoft Inc., Tulsa, OK), and criterion for statistical significance was P ≤ 0.05.

Differences in taste detection thresholds were the primary outcome measures of this study. Based on reproducibility data from a previous study (28), we estimated that 10 subjects in each surgery group would be needed to detect a 60% difference in taste detection thresholds between the RYGB and the LAGB group with a β-value of 0.20 (i.e., 80% power) and an α-value of 0.05. This proposed difference was a reasonable expectation based on data from other taste perception studies conducted in women, which found obesity is associated with a 100% increase in detection thresholds for MSG (16).

Results

Characteristics of Subjects

Characteristics that have been associated with sweetness preferences are presented in Table 2. There were no significant differences in

www.obesityjournal.org

Obesity | VOLUME 22 | NUMBER 5 | MAY 2014 | E15
age, BMI before and after surgery, race, co-morbidities, and years of education or income level between groups.

**Effects that were similar Between RYGB and LAGB**

There were no differences in taste detection thresholds, the above-threshold perception of taste intensity, or taste preferences for sucrose or MSG between RYGB and LAGB groups, so the values from each surgical group were combined.

**Sensory-Discriminative Component of Taste Perception**

Taste detection thresholds after surgery-induced weight loss were not different than those measured before surgery (all \( P > 0.30 \); Table 3). The above-threshold perception of taste intensity increased progressively with an increase in stimulus concentration (sucrose sweetness: \( P < 0.00001 \), glucose sweetness: \( P < 0.0001 \); NaCl saltiness: \( P < 0.00001 \); and MSG savoriness: \( P < 0.00001 \)) both before and after surgery. Sucrose was perceived as 7 ± 5% less sweet after surgery than before surgery (\( P = 0.03 \); Figure 1A). In contrast, the perceived sweetness of glucose, savoriness of MSG, and saltiness of NaCl did not change after surgery-induced weight loss (all \( P \) values >0.45; Figure 1B-D).

**Hedonic Component of Taste Perception**

**Preference.** Lower sucrose concentrations were preferred after than before surgery-induced weight loss in both groups (\( P = 0.008 \); Figure 2A). Furthermore, there was a negative association between changes in perceived sweetness intensity and the most preferred sucrose concentration (\( r = -0.53 \); \( P = 0.004 \)). Therefore, when the change in the perception of sweetness intensity was included as a covariate in the analysis of sucrose preference, the statistical significance of the effect of surgery on preferred sucrose concentration was even stronger (\( P = 0.00002 \)). In contrast, the preferred concentration of MSG did not change after surgery (\( P > 0.37 \); Figure 2B).

**Eating Behavior**

RYGB tended to cause a greater decrease in the mood-altering effects of sweets than did LAGB (\( P = 0.07 \)) (Table 3). Weight loss induced by both surgical procedures was associated with a similar improvement in the control of eating sweets and a similar decrease in the frequency of cravings for sweets and fast-food, emotional eating behavior, and external eating behavior (all \( P \) values <0.001; Table 3).

**Cellular Factors Involved in Taste Signaling**

Weight loss induced by both surgical procedures caused a threefold decrease in lingual fungiform papillae gene expression of \( \alpha \)-gustducin (\( P < 0.05 \)), a protein involved in the transduction pathways of sweet, bitter, and savory-sensing taste cells, but did not affect gene expression of the T1R family (i.e., T1R1 + T1R3 for savory and T1R2 + T1R3 for sweet receptors) or of phospholipase C-\( \beta 2 \), a taste bud-specific phospholipase (Figure 3).

**Effects that were Dissimilar between RYGB and LAGB**

**Sweet Taste Palatability.** Both surgery groups experienced similar levels of pleasure, which decreased slightly during repetitive tasting of sucrose before surgery. However, the hedonic value elicited by repetitive tasting of sucrose changed from pleasant to unpleasant after RYGB, but did not change after LAGB (\( P = 0.05 \); Figure 4A and B). The desire to taste something different than sweet tend to increase more when repetitively tasting sucrose after RYGB than after LAGB (\( P = 0.08 \); Figure 4C and D).

**Discussion**

The primary findings of this study is that both RYGB and LAGB cause marked changes in eating behavior, including: i) decreased cravings for fast food and sweets, ii) decreased effect of eating sweets on mood, iii) increased control of eating sweets, iv) decreased preference for high sucrose concentration, and v) reduced influence of emotions and external cues of food on eating behavior. These results demonstrate that the same weight loss induced by either RYGB or LAGB causes similar alterations in eating behavior, which cannot be explained by changes in the sensory-discriminatory domain of taste perception. However, RYGB surgery, but not LAGB, affected the hedonic component of taste perception, characterized by a rapid shift in sweetness palatability from pleasant to unpleasant when repetitively tasting sucrose, which demonstrates a unique effect of RYGB that might further decrease the ingestion of sweet foods and increase adherence to a low-calorie diet.

Our study is not able to determine whether the changes in specific eating behaviors detected after bariatric surgery were caused by

| TABLE 2 Subjects characteristics | RYGB (\( n = 17 \)) | LAGB (\( n = 10 \)) | \( P \) value |
|---------------------------------|------------------|------------------|-------------|
| Age (years)                     | 42.1 ± 8.4       | 46.8 ± 13.9      | 0.28        |
| Body weight (kg)                |                  |                  |             |
| Before surgery                  | 123.8 ± 19.7     | 127.1 ± 31.0     | 0.74        |
| After surgery                   | 98.7 ± 15.6      | 103.7 ± 26.4     | 0.54        |
| Percent weight loss             | 20.3 ± 3.0       | 18.4 ± 2.0       | 0.11        |
| BMI (kg/m\(^2\))                |                  |                  |             |
| Before surgery                  | 46.3 ± 7.7       | 48.5 ± 10.5      | 0.53        |
| After surgery                   | 36.9 ± 5.9       | 39.7 ± 9.5       | 0.34        |
| Co-morbidities (%)              |                  |                  |             |
| Hypercholesterolemia            | 35               | 30               | 0.56        |
| Hypertension                    | 65               | 50               | 0.11        |
| Depression                      | 71               | 60               | 0.44        |
| Race (%)                        |                  |                  |             |
| White                           | 70               | 80               |             |
| Black                           | 18               | 20               | 0.53        |
| Other/mixed                     | 12               | 0                |             |
| Yearly income (% of group)      |                  |                  |             |
| <$35,000                        | 17.7             | 30.0             |             |
| $35,000-75,000                  | 52.9             | 40.0             | 0.72        |
| >$75,000                        | 29.4             | 30.0             |             |
| Years of education              | 14.1 ± 2.0       | 14.3 ± 2.1       | 0.83        |

Values are mean ± SD.

E16 Obesity | VOLUME 22 | NUMBER 5 | MAY 2014 www.obesityjournal.org
surgery itself or were a consequence of changes in dietary intake and weight loss. The observation that both RYGB and LAGB, which are radically different surgical procedures, caused such similar changes in eating behaviors suggests that changes in dietary intake and weight loss were primarily responsible for these changes. The reduction in food cravings that we found after both RYGB and

<FIGURE 1 Perceived sweetness of increasing concentrations of sucrose (A) and glucose (B), savoriness of increasing concentrations of MSG (C) and saltiness of increasing NaCl concentrations (D) before (open symbols) and after (closed symbols) 20% weight loss induced by bariatric surgery. Data are mean values ± SEM. *Significantly different from sucrose sweetness perception before surgery, P < 0.05. MSG, monosodium glutamate; NaCl, sodium chloride; BD, barely detectable; W, weak; M, moderate; S, strong.

<FIGURE 2 Sucrose (A) and MSG (B) preferences before (white bars) and after bariatric (black bars) 20% weight loss induced by bariatric surgery. Data are mean values ± SEM. *Significantly different from sucrose preference before surgery, P < 0.05. MSG, monosodium glutamate.
Taste Perception and Bariatric Surgery

LAGB is consistent with the results from a previous study that examined changes in food cravings after bariatric surgery (29). Moreover, data from previous diet studies have found that caloric restriction, itself, diminishes food cravings (30), and foods that are restricted the most are those that are craved the least (31). In addition, decreasing the amount of sensory experience with a particular taste can reduce the preference for that taste (32-34). Therefore, the restriction of sweets and fast foods after bariatric surgery can reduce the preference and cravings for those foods. It is also possible that a weight loss-induced increase in brain insulin sensitivity (35) contributes to changes in eating behavior after bariatric surgery, because insulin regulates brain dopamine signaling in key areas that control appetite and reward (36). Additional studies are needed to fully elucidate the mechanisms responsible for the alterations in eating behaviors and the decrease in total energy intake that occur after bariatric surgery.

We found that RYGB, but not LAGB, affected the hedonic response to sweet taste, manifested by a more rapid and greater change from pleasant to unpleasant after repetitive tasting of sweetness. This observation is consistent with data from previous studies conducted in people that demonstrated RYGB-induced weight loss: 1) reduced neural activation in reward-related brain areas when looking at pictures of highly palatable foods (2,7,11) decreased the motivation to work for a sweet candy (8), and 3) lowered the hedonic drive to consume palatable food (10). Our results are also consistent with data from previous studies conducted in rodents, which found RYGB-induced weight loss leads to a shift in hedonic value, favoring low-sucrose over high sucrose concentrations (13,37,38). Our results extend these previous findings by demonstrating that RYGB has effects on the hedonic component of sweet taste perception, independent of weight loss.

To our knowledge, this is the first study to assess the effects of bariatric surgery-induced weight-loss on above-threshold taste intensity ratings. The assessment of above-threshold taste is important because detection thresholds do not provide meaningful information about food palatability and preferences and do not predict above-threshold sensory function in real-world settings (15,16). The intensity of sweetness at sucrose concentrations above-threshold were perceived to be slightly weaker after both RYGB- and LAGB-induced weight loss than before surgery. It is possible that the decrease in lingual x-gustducin gene expression that we observed after surgery contributed to the decreased perception of sucrose intensity, because x-gustducin is involved in the transduction pathways of sweetness (39), and sucrose perception is altered in x-gustducin knock-out animals (40).

An important strength of this study is also a limitation. By controlling dietary intake and matching weight loss in the two surgical groups, we were able to eliminate the potential confounding effects of these

---

**TABLE 3 Taste detection thresholds and eating behavior questionnaires scores before and after bariatric surgery-induced weight loss**

| Taste Detection Thresholds | RYGB (n = 17) | LAGB (n = 10) | P value Group × Time interaction |
|----------------------------|---------------|---------------|---------------------------------|
|                            | Before        | After         | Before                         | After                        |                                      |
| Glucose (mmol/L)           | 27.6 ± 10.9   | 27.6 ± 9.2    | 28.6 ± 15.4                    | 31.7 ± 4.7                   | 0.19                                |
| Sucrose (mmol/L)           | 8.7 ± 4.6     | 6.5 ± 1.0     | 8.1 ± 2.5                      | 7.5 ± 4.3                    | 0.60                                |
| NaCl (mmol/L)              | 1.8 ± 1.2     | 1.6 ± 0.5     | 2.4 ± 1.5                      | 1.9 ± 1.4                    | 0.66                                |
| MSG (mmol/L)               | 1.2 ± 0.8     | 1.2 ± 0.7     | 1.2 ± 0.8                      | 1.2 ± 0.4                    | 0.93                                |
| Food Cravings              |               |               |                                |                              |                                      |
| High fat                   | 2.2 ± 0.7     | 1.7 ± 0.6a    | 2.0 ± 0.8                      | 1.9 ± 0.7b                   | 0.18                                |
| Carbohydrates              | 2.3 ± 0.9     | 2.1 ± 0.8     | 2.2 ± 0.5                      | 1.9 ± 0.6                    | 0.84                                |
| Sweets                     | 2.5 ± 0.7     | 1.7 ± 0.6a    | 2.7 ± 0.7                      | 2.3 ± 0.5b                   | 0.23                                |
| Fast food                  | 3.0 ± 0.7     | 2.2 ± 0.6a    | 2.6 ± 0.8                      | 2.2 ± 0.5a                   | 0.15                                |
| DEBQ                       |               |               |                                |                              |                                      |
| Restrained                 | 2.8 ± 0.5     | 2.9 ± 0.7a    | 2.8 ± 0.5                      | 3.4 ± 1.0b                   | 0.22                                |
| Emotional                  | 2.8 ± 0.8     | 1.9 ± 0.7a    | 3.2 ± 1.0                      | 2.3 ± 1.0a                   | 0.81                                |
| External                   | 3.1 ± 0.5     | 2.1 ± 0.5a    | 3.4 ± 0.5                      | 2.4 ± 0.6a                   | 0.68                                |
| Fat Preferences            |               |               |                                |                              |                                      |
| Taste (better)             | 70 ± 14%      | 63 ± 19%b     | 63 ± 17%                      | 54 ± 20%b                    | 0.84                                |
| FREQ (often)               | 54 ± 23%      | 21 ± 14%a     | 48 ± 20%                      | 18 ± 14%a                    | 0.72                                |
| STQ                        |               |               |                                |                              |                                      |
| Mood altering effect       | 25.8 ± 7.5    | 14.3 ± 5.8a   | 26.9 ± 6.0                     | 21.3 ± 10.8b                 | 0.07                                |
| Impaired control           | 13.8 ± 6.1    | 4.1 ± 4.6a    | 15.0 ± 5.7                     | 9.5 ± 5.6a                   | 0.11                                |

Values are mean ± SD with the exception of taste detection thresholds values that are median ± IQR. RYGB, roux-en-Y gastric bypass; LAGB, laparoscopic adjustable gastric banding; DEBQ, Dutch Eating Behavior Questionnaire; MSG, monosodium glutamate; FREQ, eaten more frequently; STQ, Sweet Taste Questionnaire.

*a*Values after surgery significant different from values before surgery (*P* < 0.001).

*b*Trend for values After surgery to be different from values before surgery (*P* = 0.06).
factors on changes in taste perception and eating behavior. Therefore, our study evaluated whether upper gastrointestinal bypass itself has independent effects on our study outcomes. However, patients who have LAGB and RYGB might not consume similar diets and RYGB usually causes greater weight loss than does LAGB, so our results might not represent what actually occurs in clinical practice. In addition, we cannot completely exclude the possibility that weight loss induced by LAGB or RYGB has weight loss-independent effects on taste perception, because we did not study a non-surgical weight loss group. Finally, our study cannot determine whether taste perception and eating behavior in our obese subjects were different than lean subjects because we did not study a lean control group.

In conclusion, weight loss-induced by LAGB and RYGB surgeries is associated with similar modifications in eating behavior, when subjects are matched on the amount of weight lost. RYGB had independent effects on the hedonic value of sweetness, which could further contribute to consuming a low-calorie diet and weight loss. However, the changes in eating behavior and sweet taste palatability were not associated with changes in taste sensitivity. Additional studies are needed to understand the mechanism(s) responsible for the decreased intake of sweetened foods after bariatric surgery.

**FIGURE 3** Hedonic value (top panel) and desire for other taste (bottom panel) when tasting an unswallowed sucrose solution across 10 trials before (open symbols) and after (closed symbols) 20% weight loss induced by LAGB (A, C) or RYGB (B, D). Data are mean values ± SEM. LAGB, laparoscopic adjustable gastric banding; RYGB, Roux-en-Y gastric bypass; MP, moderately pleasant; WP, weakly pleasant; N, neutral; WU, weakly unpleasant; MU, moderately unpleasant; W, weak; M, moderate; S, strong.

**FIGURE 4** Fold change in fungiform papillae gene expression of α-gustducin (a taste-specific G protein), PLCb2 (a taste bud-specific phospholipase), and TAS1R1, TAS1R2, and TAS1R3 (taste receptor genes) after 20% weight loss induced by LAGB and RYGB surgeries. Data are median values ± semi-interquartile range (75th-25th percentile)/2. *Significantly different from gene expression before surgery, P < 0.05. LAGB, laparoscopic adjustable gastric banding; RYGB, Roux-en-Y gastric bypass.
Acknowledgments
The authors thank Johanna Sonnenschein, Nancy Allen, and Terri Pietka for technical assistance, Courtney Tiemann for helping with subject recruitment, and the study subjects for their participation.

© 2013 The Obesity Society

References
1. Buchwald H, Estok R, Fahrbach K, et al. Weight and type 2 diabetes after bariatric surgery: systematic review and meta-analysis. Am J Med 2009;122:248-256e5.
2. Sugerman HJ, Starkey JV, Birkenhauer R. A randomized prospective trial of gastric bypass versus vertical banded gastroplasty for morbid obesity and their effects on sweets versus non-sweets eaters. Ann Surg 1987;205:613-624.
3. Brolin RE, Robertson LB, Kenler HA, Cody RP. Weight loss and dietary intake after vertical banded gastroplasty and Roux-en-Y gastric bypass. Ann Surg 1994;220:782-790.
4. Kenler HA, Brolin RE, Cody RP. Changes in eating behavior after horizontal gastroplasty and Roux-en-Y gastric bypass. Am J Clin Nutr 1990;52:87-92.
5. Olbers T, Bjorkman S, Lindroos A, et al. Body composition, dietary intake, and energy expenditure after laparoscopic Roux-en-Y gastric bypass and laparoscopic vertical banded gastroplasty: a randomized clinical trial. Am J Clin Nutr 2006;24:715-722.
6. Breslin PA, Spector AC. Mammalian taste perception. Curr Biol 2008;18:R146-R155.
7. Ochner CN, Kwok Y, Conciao E, et al. Selective reduction in neural responses to high calorie foods following gastric bypass surgery. Ann Surg 2011;253:502-507.
8. Miras AD, Jackson RN, Jackson SN, et al. Gastric bypass surgery for obesity decreases the reward value of a sweet-fat stimulus as assessed in a progressive ratio task. Am J Clin Nutr 2012;96:467-473.
9. Schultes B, Ernst B, Wilms B, Thurnheer M, Hallenschmid M. Hedonic hunger is increased in severely obese patients and is reduced after gastric bypass surgery. Am J Clin Nutr 2010;92:277-283.
10. Ullrich J, Ernst B, Wilms B, Thurnheer M, Schultes B, Roux-en-Y gastric bypass surgery reduces hedonic hunger and improves dietary habits in severely obese subjects. Obes Surg 2013;23:50-55.
11. Scholtz S, Miras AD, Chima N, et al. Obese patients after gastric bypass surgery have lower brain-hedonic responses to food than after gastric banding. Gut 2013 (in press).
12. Scrugeas DM, Buffington C, Cowan GS, Jr. Taste acuity of the morbidly obese before and after gastric bypass surgery. Obes Surg 1994;4:24-28.
13. Bueter M, Miras AD, Chichger H, et al. Alterations of sucrose preference after Roux-en-Y gastric bypass. Physiol Behav 2011;104:709-721.
14. Burge JC, Schaumburg IJZ, Choban PS, DiSilvestro RA, Flanchbaum L. Changes in patients’ taste acuity after Roux-en-Y gastric bypass for clinically severe obesity. J Am Diet Assoc 1995;95:666-670.
15. Bartoshuk LM. The psychophysics of taste. Am J Clin Nutr 1978;31:1068-1077.
16. Pepino MY, Finkbeiner S, Beauchamp GK, Mennella JA. Obese women have lower monosodium glutamate taste sensitivity and prefer higher concentrations than do normal-weight women. Obesity (Silver Spring) 2010;18:959-965.
17. Martin C, Beckley A, Kjorstad R, Sebesta J. Socioeconomic disparities in eligibility and access to bariatric surgery: a national population-based analysis. Surg Obes Relat Dis 2010;6:8-15.
18. Fikentscher R, Roseburg B, Spinhar H, Bruchmuller W. Loss of taste in the elderly: sex differences. Clin Otolaryngol Allied Sci 1977;2:183-189.
19. Bartoshuk LM, Duffy VB, Green BG, et al. Valid across-group comparisons with labeled scales: the gLMS versus magnitude matching. Physiol Behav 2004;82:109-114.
20. Coldwell SE, Mennella JA, Duffy VB, et al. Gustation assessment using the NIH Toolbox. Neurology 2013;80:S20-S24.
21. Beauchamp GK, Vazquez de Vauera M, Pearson PB. Dietary status of human infants and their sensory responses to amino acid flavor In: Kawamura Y and Kare MR (eds). Umami: a basic taste. Marcel Dekker, Inc: New York, NY, USA, 1987, pp 125-138.
22. Van Strien T, Frijters ER, Bergers GPA, Defares PB. The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. Int J Eating Disord 1986;5:295-315.
23. White MA, Whisenhunt BL, Williamson DA, Greenway FL, Netemeyer RG. Development and validation of the food-craving inventory. Obes Res 2002;10:107-114.
24. Kamps-Polevery AB, Alterman A, Khaliitov E, Garbutt JC. Sweet preference predicts mood altering effect of and impaired control over eating sweet foods. Eat Behav 2006;7:181-187.
25. Ledikwe JH, Ello-Martin J, Pelkman CL, Birch LL, Mannino ML, Rolls BJ. A reliable, valid questionaire indicates that preference for dietary fat declines when following a reduced-fat diet. Appetite 2007;49:74-83.
26. Sperling AL, Pepino MY, Feldman R, Brand JG. Technique to collect fungiform (taste) papillae from human tongue. J Vis Exp 2010;42: doi:10.3791/2201.
27. Varela JE. Bariatric surgery: a cure for diabetes? Curr Opin Clin Nutr Metab Care 2011;14:396-401.
28. Pepino MY, Mennella JA. Effects of cigarette smoking and family history of alcoholism on sweet taste perception and food cravings in women. Alcohol Clin Exp Res 2007;31:1891-1899.
29. Leachey TM, Bond DS, Raynor H, et al. Effect of bariatric surgery on food cravings: do food cravings and the consumption of craved food “normalize” after surgery? Surg Obes Relat Dis 2012;8:84-91.
30. Martin CK, O’Neil PM, Pawlow L. Changes in food cravings during low-calorie and very-low-calorie diets. Obesity (Silver Spring) 2006;14:115-121.
31. Martin CK, Rosenbaum D, Han H, Geiselman PJ, Wyatt HR, Hill JO, et al. Change in food cravings, #foodpereferences, and appetite during a low-carbohydrate and low-fat diet. Obesity (Silver Spring) 2011;19:1963-1970.
32. Bertino M, Beauchamp GK, Engelmann K. Long-term reduction in dietary sodium alters the taste of salt. Am J Clin Nutr 1982;36:1134-1144.
33. Beauchamp GK, Bertino M, Engelmann K. Failure to compensate decreased dietary sodium with increased table salt usage. JAMA 1987;258:3275-3278.
34. Mattes RD. Fat preference and adherence to a reduced-fat diet. Am J Clin Nutr 2011;93:373-381.
35. Taulari JJ, Karlsson HK, Hirvenoja J, et al. Weight loss after bariatric surgery reverses insulin-induced increases in brain glucose metabolism of the morbidly obese. Diabetes 2013; e-pub ahead of print Mar 14; doi: 10.2337/db12-1460.
36. Daws LC, Avison MJ, Robertson SD, Niswender KD, Galli A, Saunders C. Insulin signaling and addiction. Neuropharmacology 2011;61:1123-1128.
37. Hajnal A, Kovacs P, Ahmed T, Metrelles K, Lynch CJ, Cooney RN. Gastric bypass surgery alters behavioral and neural taste functions for sweet taste in obese rats. Am J Physiol Gastrointest Liver Physiol 2010;299:G967-G979.
38. Shin AC, Zheng H, Pistell PJ, Berthoud HR. Roux-en-Y gastric bypass surgery changes food reward in rats. Int J Obes (Lond) 2011;35:642-651.
39. Weng GT, Ruiz-Avila L, Margolskee RF. Directing gene expression to gustducin- positive taste receptor cells. J Neurosci 1999;19:5802-5809.
40. Glendinning JJ, Bloom LD, Onishi M, et al. Contribution of alpha-gustducin to taste-guided licking responses of mice. Chem Senses 2005;30:299-316.