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ORIGINAL ARTICLE

Decreased energy density and changes in food selection following Roux-en-Y gastric bypass

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BACKGROUND/OBJECTIVES: The main objective was to test the hypothesis that dietary energy density (DED) decreases after Roux-en-Y gastric bypass (gastric bypass).
SUBJECTS/METHODS: A total of 43 patients (31 women and 12 men) aged 43 (s.d. 10) years, with body mass index (BMI) 44.3 kg/m^2 (4.9), were assessed preoperatively at 6 weeks and 1 and 2 years after gastric bypass. Self-reported energy intake (EI), food weight (FW) and food choice were assessed using a dietary questionnaire. DED was calculated by dividing EI by FW (kcal/g). Number of dropouts was 4 of 203 visits.
RESULTS: Percent weight loss (%WL) was 13.5% at 6 weeks, 30.7% at 1 year and 31.8% at 2 years post surgery ($P<0.001$ for all). EI decreased from 2990 to 1774, 2131 and 2425 kcal after 6 weeks and 1 and 2 years postoperatively, respectively ($P<0.001$ at all time points). FW changed from 2844 to 1870 g/day at 6 weeks ($P<0.001$) and 2416 g/day after 1 year ($P<0.05$), but was not significantly different from baseline 2 years postoperatively (2602 g/day, $P=0.105$). DED decreased from 1.07 to 0.78 kcal/g at 6 weeks ($P<0.001$) and 0.90 kcal/g ($P<0.001$) and 0.96 kcal/g ($P=0.001$) after 1 and 2 years, respectively. All statistical comparisons were made from baseline. There was no correlation between changes in DED and %WL, neither after 1 year ($r=-0.215$; $P=0.183$) nor after 2 years ($r=-0.046$; $P=0.775$) post surgery.
CONCLUSIONS: Besides substantial reduction in EI and large variation in FW, patients reported decreased DED over 2 years following gastric bypass. Despite lack of association between the reduction in DED and percentage weight loss, changes in food choice were overall nutritionally beneficial.

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Keywords: dietary energy density; energy intake; food weight; food choice; Roux-en-Y gastric bypass

INTRODUCTION

Dietary energy density (DED) is the amount of energy in a particular weight of foods, generally presented as kilocalories per gram of food (kcal/g).[1] Because of its high-energy content (9 kcal/g), fat influences DED more than carbohydrate or protein (4 kcal/g, each). DED is also influenced by water-containing foods such as fruits and vegetables, which reduce dietary DED.[2] Short-term experimental studies show that people tend to eat a consistent volume of food;[2] thus, even small changes in DED may have significant effects on energy intake (EI).[2] Diets with low DED have also been associated with high nutrient quality.[3]

Accumulating evidence from normal-weight, overweight and obese adults suggest that lowering DED can reduce EI in short-term experimental and intervention studies.[4–6] A low DED diet affects satiety or feeling of fullness.[2] Starters with various DEDs affect *ad libitum* intake of the subsequent meal;[7] thus, water-rich dishes, such as soups or salads with low DED, can significantly reduce EI in a subsequent meal. However, it appears that water intake during meals does not have similar effects on satiety as if incorporated into the food.[8] Low DED diets have been used in dietary management of obesity in several studies, where they usually,[9–11] but not always,[6] lead to greater weight loss compared with higher DED diets. Low DED diets have also been satisfactorily used for weight maintenance.[12]

Gastric bypass is the most frequently used surgical procedure to treat patients with morbid obesity and is by many regarded as the gold standard in bariatric surgery.[13] The popularity of gastric bypass can be attributed to achieving excellent weight loss together with improved dietary quality. Subjects tend to increase intake of low-fat foods and fruits and vegetables after gastric bypass.[14–17] This change in food choice after gastric bypass has been suggested to be because of altered taste,[18,19] aversions for fatty foods[20] and increased risk of attaining dumping syndrome,[21] which *per se* has been regarded as a beneficial feature of gastric bypass as patients learn to avoid calorie-dense foods and eat smaller portions.

The main purpose of the present study was to test the hypothesis that DED decreases after gastric bypass. The secondary aims were: (1) to analyze how the components of DED, that is, the weight of food and EI, change after gastric bypass; (2) to analyze whether changes in food selection are based on DED; and also (3) to analyze whether changes in DED are associated with changes in body weight after gastric bypass.

SUBJECTS AND METHODS

Study design

This is a longitudinal cohort study of patients undergoing gastric bypass surgery.

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Recruitment

Patients on the waiting list for laparoscopic gastric bypass at Sahlgrenska University Hospital, Gothenburg, Sweden, were consecutively invited to participate in this study, and enrolled from April 2004 until April 2008. Inclusion criteria were body mass index (BMI) 35–50 kg/m^2 and willingness to participate. Exclusion criteria included inability to understand oral and written instructions as well as possible confounding medical conditions, for example, insulin-treated type II diabetes mellitus, as gastroparesis, a well-known complication of diabetes, may influence food choice. In all, 50 patients were asked to participate in the present study. Of these, 12 men and 35 women (94%) accepted. The results from two female participants were excluded from the analyses because of unrealistic reported preoperative EI (42 vs 60 kcal/kg body weight) and not completing the 1- and 2-year visits. Two other females were excluded because of having breast cancer and chronic obstructive pulmonary disease. Previously, we have presented a paper from this study regarding eating behavior and meal pattern.[22]

Methods

All surgeries were primary bariatric procedures completed laparoscopically. The operative gastric bypass technique included an antecolic-antegastric Roux-en-Y construction with a 10–20 ml gastric pouch and a 100–150 cm Roux limb, as described in detail elsewhere.[23] The participants received regular dietary advice from dieticians according to dietary guidelines in the usual protocol for bariatric patients.[22,24,25] The protocol for patients undergoing surgical treatment at Sahlgrenska University Hospital involves six visits to a dietician, of which five individual visits. Patients have a gradual escalation of consistencies in the food eaten during the firs 2 months postoperatively. This time period include 1 week of liquid diet followed by 3 weeks of semi-solid food. After that, there were another 4 weeks with avoidance of foods that are generally considered difficult to digest, such as raw carrots and asparaguses. At all postoperative re-visits to the dietician, a dietary intake interview and information on meal-related gastrointestinal symptoms was taken, and suggestions for adjustments in food choices and eating behavior were given when necessary. The collection of data in the study was made on separate occasions apart from the dietician visits and by staff other than the staff at the usual follow-up visits.

Assessments

Anthropometric measurements. Body height was measured to the nearest 0.01 m, with the subject standing back to a wall-mounted stadiometer in bare feet. Weight was measured to the nearest 0.1 kg with calibrated scales. BMI was calculated as weight in kilograms divided by height in meters squared (kg/m^2). Weight loss was reported as percent total weight loss (%WL).

Dietary questionnaire. Food intake was calculated from a dietary questionnaire,[26] originally designed and validated for the Swedish Obese Subjects study. This questionnaire has been described in detail by Lindroos *et al.*[27] and the validity for EI has been demonstrated as satisfactory in normal-weight, overweight and obese subjects. The self-administered dietary questionnaire consists of 51 questions that are answered without oral instructions. The questions cover habitual dietary intake over the past 3 months, with emphasis on portion size and frequencies per day or per week. Subjects estimated portion sizes by looking at pictures of three different portion sizes in terms of meat/fish/poultries, potatoes/rice/pasta and vegetables. Besides the three photographed portion sizes, it was possible to select additional variations on portion sizes, for example, 'half of the portion A' or 'double the portion C' for each component. In cooked meals, vegetables were included with the portion size described by the subjects. In light meals, vegetables were included, and cannot be determined separately. Reported food amounts were converted into grams, from which daily intake of energy and nutrients were calculated. The values for physical activity level were calculated for each patient by dividing reported EI by the calculated resting metabolic rate using the Mifflin–St Jeor formula[28,29] to demonstrate disproportionate physical activity level values, where 1.35 is recommended as a cutoff value.[30] In addition to total energy and nutrient intake data, the dietary questionnaire makes it possible to obtain these data from 15 different food groups. The food groups were categorized into the following four DED groups, calculated from the mean DED from the dietary questionnaire, as suggested elsewhere:[3] very low energy density: <0.6 kcal/g; low energy density: 0.6–1.5 kcal/g; medium energy density: 1.5–4 kcal/g; and high energy density: >4 kcal/g. Nutritional values were obtained from food database of the Swedish National Food Administration, Version 04.1.1; Uppsala, Sweden.

Definitions of EI and food weight (FW). EI includes energy from food, milk, alcohol and energy-containing drinks (soft drinks, fruit syrups and juice), coffee and plain tea, but excluding water, bottled water and diet sodas (which contain no or very little energy). FW includes weight from food, milk, alcohol and energy-containing drinks (soft drinks, fruit syrups and juice), coffee and plain tea, but excluding water, bottled water and diet sodas. The DED was calculated by dividing EI by FW, as defined above.

Statistical methods

All data are expressed as mean (s.d.) for demographic data and mean (95% confidence intervals) for other variables. Because of limited sample size and skewed distribution, Friedman's test and *post hoc* Wilcoxon's test were chosen to study the changes between pre- and post-surgery states. Spearman's correlation was used to analyze associations between changes in DED and %WL. The statistical analyses were performed with SPSS version 18.0 (SPSS, Chicago, IL, USA).

The study was conducted according to the Declaration of Helsinki Principles. The study protocol was approved by the Regional Ethical Review Board in Gothenburg (Dnr: S 674-03) and all subjects signed an informed consent. No financial or other types of compensation were given to participants.

RESULTS

Participants

Patients (31 women and 12 men) aged 43 (s.d. 10) years, with BMI 44.5 kg/m^2 (4.9), were followed for 2 years postoperatively. During the postoperative follow-up period, one patient could not attend the 6-week visit because of undergoing cholecystectomy. At 1-year follow-up visits, one patient was pregnant and another did not show up to the prescheduled visit and could not be reached thereafter. At 2 years, one patient was breastfeeding. Otherwise, all patients attended all planned visits in the study.

Body weight change

Body weight decreased from 131.7 kg (s.d. 19.9) to 114.1 kg (16.8; $P<0.001$) at 6 weeks after surgery. After 1 year, body weight further decreased to 91.2 kg (16.8; $P<0.001$) and stabilized at 89.9 kg (18.4; $P<0.001$) at 2 years. WL was 13.5% (3.2) at 6 weeks, 30.7% (6.7) at 1 year and 31.8% (9.3) at 2 years post surgery ($P<0.001$ for all).

EI, FW and energy density

EI was 59% of presurgical EI ($P<0.001$) at 6 weeks after surgery. EI after 1 year was 71% ($P<0.001$) and was 81% after 2 years ($P<0.001$) (Figure 1a) in comparison with that before surgery. At 6 weeks post surgery, food and energy-containing drink weight (FW) was 66% of reported FW before surgery ($P<0.001$; Table 1). At 1 and 2 years after surgery, FW was 85% ($P=0.01$) and 91% of preoperative values ($P=0.105$), respectively (Figure 1b).

Dietary energy density. DED was 1.07 kcal/g (0.99–1.16) before surgery and 0.78 kcal/g (0.74–0.83) at 6 weeks ($P<0.001$) post surgery (Figure 1c). At 1 and 2 years post surgery, DED values were 0.90 kcal/g (0.84–0.97; $P<0.001$) and 0.96 kcal/g (0.86–1.05; $P<0.001$), respectively. Although DED increased between 6 weeks and 2 years post surgery, it remained significantly lower than presurgical value ($P=0.001$; Table 2).

Changes between components of DED

At 1 year post surgery, EI decreased by 29%, FW decreased by 15% and DED decreased by 16%. Both EI and DED were relatively normally distributed, whereas FW had a skewed distribution.

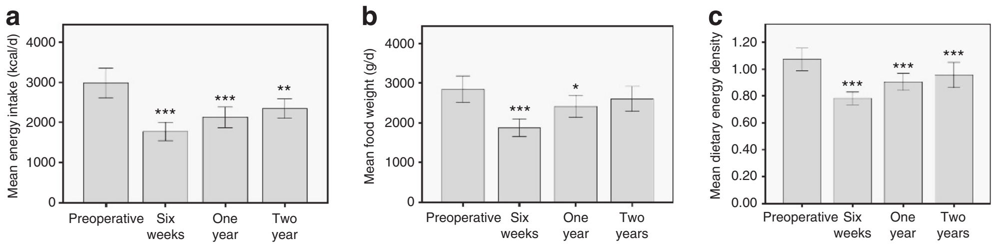

Figure 1. (**a**) Energy intake. (**b**) FW including energy-containing drinks, coffee and plain tea. (**c**) DED—assessed with food frequency questionnaire preoperatively ($N=43$) and up to 2 years after gastric bypass surgery. ***$P<0.001$, **$P<0.01$, *$P<0.05$.

Table 1. Energy % (E%) from different food groups, and mean (95% CI) in morbidly obese patients undergoing Roux-en-Y gastric bypass surgery

Food groups	*Presurgery (N = 43)*	*Post surgery 6 weeks (N = 42)*	*Post surgery 1 year (N = 41)*	*Post surgery 2 years (N = 42)*
E% nonalcoholic drinks	4.5 (3.0–6.0)	6.2 (3.8–8.7)	2.5* (0.6–4.4)	3.8 (2.2–5.4)
E% milk	7.1 (5.4–8.8)	13.0*** (10.9–15.1)	7.0 (5.3–8.8)	7.3 (5.3–9.3)
E% fruit	5.4 (4.4–6.9)	9.8*** (8.1–11.5)	10.4*** (8.6–12.3)	8.1*** (6.3–9.8)
Σ Very low DED (<0.6 kcal/g)	17.1 (14.5–19.6)	29.0*** (25.4–32.6)	21.7** (19.2–24.3)	19.2 (16.2–22.2)
E% cooked meals	23.9 (20.7–27.2)	20.9* (17.4–24.5)	20.5** (17.8–23.3)	19.4*** (16.2–22.5)
E% light meals	4.4 (2.5–6.2)	11.3 (7.3–15.4)	7.5 (4.8–10.1)	6.9 (4.8–9.0)
Σ Low DED (0.6–1.5 kcal/g)	28.3 (24.9–31.6)	32.3 (27.9–36.6)	28.0 (24.7–31.3)	26.2 (23.0–29.4)
E% egg	1.4 (1.1–1.9)	2.4 (1.7–3.2)	1.6 (1.1–2.0)	1.6 (1.0–2.2)
E% cereals	2.0 (1.2–2.8)	3.3 (2.1–4.5)	4.2 (2.5–5.9)	3.1 (2.0–4.2)
E% desserts	1.9 (1.1–2.6)	3.4 (0.9–5.9)	1.1 (0.6–1.6)	1.0* (0.6–1.5)
E% fast foods	4.4 (3.4–5.5)	1.9** (0.7–3.2)	1.9** (0.9–3.0)	3.0 (1.6–4.4)
E% sandwiches	17.7 (15.3–20.2)	18.8 (16.1–21.6)	18.1 (15.6–20.6)	19.1 (16.5–21.7)
E% ham and cheese	2.4 (1.6–3.1)	2.3 (1.1–3.4)	1.7 (1.0–2.3)	2.2 (1.4–3.0)
Σ Medium DED (1.5–4 kcal/g)	29.8 (27.4–32.2)	32.2 (28.1–36.2)	28.6 (25.9–31.3)	30.2 (27.1–33.2)
E% cakes and cookies	5.0	1.4***	3.9	5.5
E% candies and chocolate	10.4	2.5***	6.6*	8.0
E% snacks	7.9	1.6***	8.8	7.4
Σ High DED (>4 kcal/g)	22.4 (18.5–26.2)	5.6*** (3.5–7.7)	19.2 (15.5–23.0)	20.9 (17.3–24.6)

Abbreviations: CI, confidence interval; DED, dietary energy density. Statistical comparisons were calculated between preop and 6 weeks; preop and 1 year; and preop and 2 years, ***$P<0.001$, **$P<0.01$, *$P<0.05$.

Table 2. Mean (95% CI) values of reported EI, calculated RMR, PAL by dividing EI by RMR, kcal/kg body weight, food weight and dietary energy density and energy % from fat and alcohol before and after gastric bypass surgery

	Presurgery (N = 43)	*Post surgery 6 weeks (N = 42)*	*Post surgery 1 year (N = 41)*	*Post surgery 2 years (N = 42)*
Reported EI (kcal/day)	2986 (2619–3354)	1774*** (1547–2002)	2131*** (1873–2390)	2425** (2103–2591)
Calculated RMR	3312 (3160–3464)	NA	2348 (2215–2481)	2314 (2173–2455)
PAL (EI/RMR)	0.90 (0.80–1.00)	NA	0.92 (0,82–1.02)	1.04 (0.92–1.16)
Kcal/kg body weight	22.7 (20.2–25.2)	15.9*** (13.8–18.0)	27.0* (24.0–30.0)	27.1** (23.9–30.4)
Food weight (g/day)	2844 (2508–3180)	1870*** (1649–2091)	2416* (2141–2690)	2602 (2286–2917)
DED	1.07 (0.99–1.16)	0.78*** (0.74–0.83)	0.90*** (0.84–0.97)	0.96*** (0.86–1.05)
Energy % from fat	37.0 (34.2–38.8)	25.3*** (22.4–28.6)	34.3*** (32.6–35.9)	35.3*** (32.7–36.3)
Energy % from alcohol	2.47 (1.31–3.63)	0.94*** (0.25–1.63)	2.39 (1.31–3.48)	2.42 (2.08–4.76)

Abbreviations: DED, dietary energy density (kcal/g); EI, energy intake; NA, not applicable; PAL, physical activity level; RMR, resting metabolic rate according to Mifflin–St Jeor formula. ***$P<0.001$, **$P<0.01$, *$P<0.05$.

Therefore, changes in FW and EI were divided into tertiles to analyze associations between changes in FW and EI. At 1 year after surgery, the difference in daily EI between the first and third tertile was ~1500 kcal and after 2 years the difference was ~800 kcal (Figures 2a and b). At 2 years post surgery, EI, FW and DED had all increased but were still 19%, 8% and 10% below presurgery values, respectively. At 1 year post surgery, those who reported greatest decreases in EI had a correspondingly larger decrease in FW in comparison with subjects in the other two tertiles (Figure 2a). At 2 years post surgery, those who reported greatest increases in FW were those with highest reported EI (Figure 2b), which is a logical relationship between EI and FW. However, reduced EI was because of reduced FW in some subjects, whereas others reduced their EI while maintaining FW. This also implies that changes in FW were not significantly associated with changes in DED, but once the 14 subjects in the lowest tertile of FW (largest decrease) at 1 year post surgery were excluded, a statistically significant association between changes in FW and DED was found among subjects from the other two tertiles.

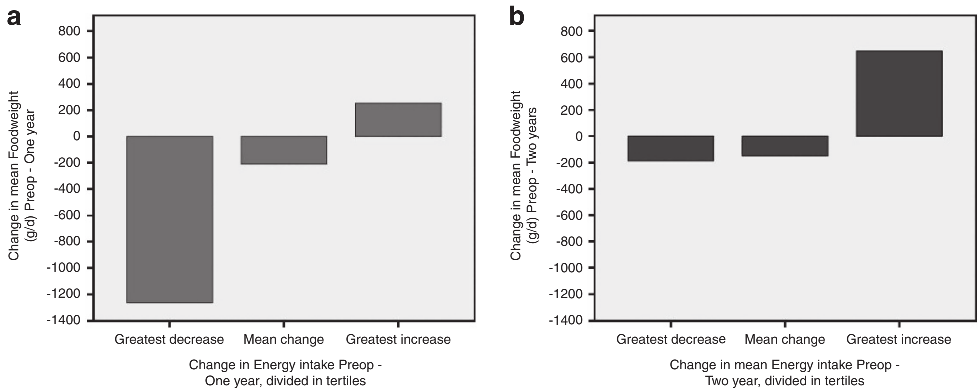

Figure 2. (**a**, **b**) Mean change in EI (x) and change in FW (y) divided into tertiles at 1 (**a**) and 2 (**b**) years after gastric bypass surgery.

Associations between EI and DED

Preoperatively, the correlation between EI and DED was $r = 0.51$ ($P < 0.001$). Postoperatively, this association was nonsignificant at either 6 weeks ($r = 0.13$, $P = 0.933$) or 1 year ($r = 0.24$, $P = 0.130$). At 2 years, a nonsignificant trend was found between EI and DED ($r = 0.29$, $P = 0.062$).

Associations between DED and weight change

There was no correlation between changes in DED and %WL, neither after 1 year ($r = -0.215$; $P = 0.183$) nor after 2 years ($r = -0.046$; $P = 0.775$) post surgery.

Fat intake and food choice

Energy% (E%) from fat decreased substantially 6 weeks postoperatively ($P < 0.001$) from 37.0 to 25.3 E% and was still significantly lower after 1 year (34.3 E%; $P < 0.001$) and 2 years (35.3 E%; $P < 0.001$) as compared with that before surgery (Table 2). The largest change in EI from foods with different DED was found 6 weeks after the gastric bypass when EI from very low DED foods (Table 1) had increased, with a concomitant reduction in EI from high DED foods. The increased percentage of foods from very low DED food groups maintained at 1 year, but not at 2 years, post surgery. The decreased percentage intake from foods from high DED was not maintained at 1 or 2 years post surgery compared with baseline intakes. EI from low and medium DED (Table 1) did not change post surgery at any time point. EI from fruits increased significantly, and was maintained 1 and 2 years post surgery. The increased fruit intake corresponded to an average increase of one to two fruits daily at 1 year post surgery. Fruits, however, are low in energy content and therefore represent only a relatively small proportion of total EI. EI from nonalcoholic drinks did not increase significantly at any time point postoperatively (Table 1).

DISCUSSION

In this longitudinal assessment of energy and food intake before and during a 2-year follow-up after gastric bypass, we found a substantial reduction in calorie intake and DED. Reported FW, however, varied considerably. The largest changes were seen in the short term after surgery and were differentially sustained during the first 2 years post surgery depending on food type. Changes in self-reported EI and DED post surgery were, however, not significantly associated with weight loss at any time point up to 2 years.

Dietary questionnaire

Although subjects reported higher EI compared with many other studies[31–35] the physical activity level value (EI/estimated resting metabolic rate) indicate that there has been an underreporting. This underreporting may be a selective underreporting derived from intake of high energy density foods, as these are often seen as socially undesirable to consume.[36] Dietary questionnaires also provide, except specific reporting errors, random errors and therefore measures of dietary intake in individuals should be assessed with caution. In addition to the risk of underreporting of energy-dense foods, the dietary questionnaire do not estimate absolute EI with precision.[37] The dietary questionnaire used in this study has been validated on energy and protein intake in groups of obese subjects and used in severely obese populations in long-term follow-ups after bariatric surgery.[27,38]

Food selection

Changes in food selection after gastric bypass were first demonstrated by Kenler *et al.*,[34] who found that intake of sweets and high-calorie beverages, milk and ice-cream decreased after gastric bypass. Two studies[14,15] found that gastric bypass-treated patients made healthier food choices and adopted more balanced diets in terms of more fruits and eggs but less chocolate compared with patients treated with gastric banding. Bobbioni-Harsch *et al.*[39] found that reduced EI was the most important dietary factor contributing to weight reduction at 12 months after gastric bypass, whereas nonsignificant associations were found between macronutrient intake and weight loss, which was also found in the present study. Recently, it is shown that urine volumes do not increase 2–10 years after gastric bypass despite increased diuresis; this is further evidence that fluid intake does not increase postoperatively.[40] In addition, we could demonstrate that percent nonalcoholic beverage intake did not increase post surgery, further contributing to the assumption that there was a true reduction of DED. There is no real consensus on the changes in EI and food selection,[19] likely because of different dietary assessments and changes across time periods after surgery. The changes in dietary intake and eating behavior occurring after gastric bypass may be related to hormonal and taste changes, deficiencies of micronutrients such as zinc, digestive reflexes through the vagus nerve and finally dumping syndrome, in a very complex way.[19–21,41,42]

Food weight

FW was higher than we expected, and 2 years post surgery, there was no difference in the consumption of the amount of food (g/day) when compared with presurgery condition. As the high intake of food was not because of an increased intake of nonalcoholic beverages and milk, the change in DED was because of changes in solid food.

Moreover, as there was a large variation in reported FW, there might be an insufficient number of observations, that is, a low statistical power and, yet, if more observations had been available, it is not definite that a significant correlation would have been found because of the apparently large variation in reported food intake between individuals.

DED and WL

On one hand, given the limitation of dietary intake methodology and presumably low statistical power, it is not surprising that estimated total EI and thus DED was not associated with %WL. On the other hand, the lack of association between DED and WL raises significant questions that may be issues in future research. Should specific sets of dietary intake questionnaires be developed for bariatric surgery patients? Does an interindividual capacity for EI as well as food volume post surgery affect the associations between dietary intake and weight loss? In addition, EI may be affected by several other factors, for example satiety hormones, not measured in this study. Some patients lost weight after gastric bypass because their reported EI reduction was because of a substantial decrease in FW, whereas others reduced their EI by an altered food selection reflected in reduced DED. In addition, the relation between EI and weight loss was not linear and may require a more complex mathematical modeling.[43] Thus, more studies are needed to disentangle how EI and FW are interrelated and differentially change during periods of energy imbalance, and the effect on weight loss in morbidly obese subjects.

Potential mechanisms underlying gastric bypass are multiple and may vary between patients. Further studies in larger patient groups should define changes in DED and whether lack of change in DED is a risk factor for weight regain after gastric bypass, as studies have shown a weight gain of 7% during the first decade after surgery.[44,45] We also need studies including analyses of specific changes in food preference and selection after gastric bypass in relation to energy density, a phenomenon that is highly clinically significant.

The limitations of the study include the relatively small sample size, potentially affecting the generalizability of the results. Also, the present study lacks information on changes in physical activity and body composition after gastric bypass surgery. This information may have increased our understanding of associations or lack thereof, found among changes in EI, FW, DED and weight loss after gastric bypass surgery. In addition, we have not been able to quantify the effect of the preoperative dietary education that may have had different effects in different subjects on postoperative eating behavior.

CONCLUSION

Besides substantial reduction in EI and large variation in FW, patients reported decreased DED over 2 years following gastric bypass. Despite lack of association between the reduction in DED and %WL, changes in food choice were overall nutritionally beneficial.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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