Reduced food intake after jejunoileal bypass: a possible association with prolonged gastric emptying and altered gut hormone patterns

Erik Näslund, Ingela Melin, Per Grybäck, Anna Hägg, Per M Hellström, Hans Jacobsson, Elvar Theodorsson, Stephan Rössner, and Lars Backman

ABSTRACT The object of this study was to examine whether eating behavior, food preference, gastric emptying, and gut hormone patterns are altered after jejunoileal bypass (JIB) in patients with severe obesity. Eight obese [mean (± SD) body mass index (BMI; in kg/m²) 42.9 ± 4] subjects were studied prospectively before and 9 mo after JIB with eight age- and sex-matched normal-weight control subjects. Total energy intake, data from the universal eating monitor (VIKTOR), eating motivation measured by visual analog scales, a food-preference checklist, a forced-choice list, solid-phase gastric emptying, and postprandial concentrations of cholecystokinin, motilin, and neuropeptin were studied. BMI was reduced by 29% after JIB. Compared with normal subjects, the JIB patients showed a reduced desire to eat, decreased hunger, and reduced prospective consumption before a test meal. After surgery, obese subjects selected fewer food items and showed a reduced preference for high-carbohydrate and high-fat items before a test meal. There was a trend from an accelerated toward a decelerated eating pattern in obese subjects after JIB. After JIB, gastric emptying of obese subjects was slowed and similar to that in control subjects. Obese subjects had lower postprandial cholecystokinin concentrations that were lower than those of control subjects both before and after JIB. Postprandial concentrations of neuropeptin were higher after JIB. We conclude that after JIB, the desire to eat and preference for high-carbohydrate and high-fat items is reduced, resulting in decreased energy intake. That gastric emptying is prolonged and gut hormone patterns are altered with low postprandial plasma cholecystokinin and high neuropeptin plasma concentrations may at least partly account for these observations.


KEY WORDS Gastric emptying, gut hormones, universal eating monitor, jejunoileal bypass, obesity, eating behavior, surgery, neuropeptin, cholecystokinin, humans

INTRODUCTION

In addition to producing weight loss in obese patients, jejunoileal bypass (JIB) surgery serves as an interesting model for the study of gastrointestinal function in humans (1). Despite extensive studies, the mechanisms for weight loss after JIB are still not clear. The original rationale for performing intestinal bypass procedures in obesity was to cause malabsorption (2-5). In addition to malabsorption, several studies found a substantial reduction in food intake as an explanation of weight loss (6, 7). Condon et al (8) found that malabsorption of fat could only account for 21% of the observed weight loss in those patients who ate less after the procedure. Also, after biliopancreatic bypass surgery, weight loss does not positively correlate with malabsorption at 30 mo of follow-up (9).

Infusion of fat into the ileum of normal subjects decreases the total energy intake and delays gastric emptying (10). After JIB, there is a rapid passage of nutrients to the terminal ileum (11). JIB has also been shown to be associated with significant changes in gut hormone concentrations. Postprandial concentrations of motilin have been shown to be reduced, whereas cholecystokinin and neuropeptin are elevated after intestinal bypass surgery (12-14). In addition to other effects, these hormones affect gastric emptying and intestinal transit as well as decrease food intake (15-18).

In light of these data, we speculated that after JIB there is a change in satiety and eating behavior that may be caused by a reduction in the rate of gastric emptying as well as changes in postprandial gut hormone patterns. The aim of this study was therefore to study whether JIB alters eating behavior and food preference, whether obese subjects and normal-weight subjects have different rates of gastric emptying and whether weight reduction with JIB alters gastric emptying, and whether postprandial concentrations of cholecystokinin, neuropeptin, and motilin are altered after JIB.

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SUBJECTS AND METHODS

Obese subjects

Ten morbidly obese subjects were enrolled in the study. One subject did not complete the study after surgery because of aversion to the test meal, and for another subject, the gastric-emptying data before surgery were lost. Therefore, complete data before [body mass index (BMI; in kg/m²) 42.9 ± 4.0] and after (BMI 30.4 ± 3.7, P < 0.01) JIB surgery were available for eight (five females and three males) obese subjects with a mean age of 38.5 ± 12.4 y. The preoperative studies were performed between 1 and 5 mo before surgery. The postoperative studies were performed 9 mo ± 2 wk after JIB. The characteristics of the obese subjects are summarized in Table 1.

Control subjects

Two groups of sex- and age-matched control subjects with BMIs of 21.3 ± 2 and 22.4 ± 1.4, respectively (P < 0.01 compared with obese subjects before and after surgery), and ages of 37.8 ± 8.3 and 40.7 ± 6.6 y, respectively, were used for comparison. Control subjects for eating behavior and food preference were recruited from a previous study (21) in which 19 normal-weight females and males were examined five times. Of the sex-matched groups, the best age match was selected and the data from the first three study times were used. The normal-weight males were selected from a random sample of the Stockholm population and the females from the staff at the Karolinska Hospital (21). Control subjects for the gastric-emptying results were recruited from the staff at the Karolinska Hospital. None of the patients or volunteers suffered from gastrointestinal disease, bulimia, or diabetes mellitus.

Both obese and control subjects gave their informed consent to participate. The study was approved by the Karolinska Hospital Ethics and Isotope Committees.

Surgical procedure and clinical follow-up

A modified end-to-side JIB described originally by Payne and DeWind (22) was performed through a transverse incision in the right iliac fossa. The length of the intestine from the ileocecal valve to the ligament of Treitz was measured (23). Thereafter, 40 cm of the jejunum from the ligament of Treitz was anastomosed end-to-side to a segment of ileum corresponding to 2% of the total length of the small intestine (24).

The blind loop of the small intestine was closed, left in place, and sutured to the proximal jejunum. The patients were seen in the clinic 1 mo after surgery and then at 3-mo intervals for 1 y. All patients were given oral multivitamins and intramuscular vitamin B-12 supplements as well as electrolyte and mineral supplements when needed.

Test procedure for eating behavior and food preference assessment

The subjects were studied on three occasions 1 wk apart before surgery. The first experimental run was carried out to accustom the patient to the universal eating monitor (UEM) equipment and rating scales. Thereafter, two separate runs were carried out in the obese subjects before surgery as well as in the control subjects. Two runs were carried out again 1 wk apart 9 mo after surgery in the obese subjects. A mean value was calculated for the two test runs and used for statistical analysis. The subjects were instructed to eat the same breakfast at home between 0700 and 0800 on each test day. Compliance with this dietary instruction was checked before each test meal. The test meal was served at 1200 and consisted of an industrially produced Swedish hash with a standard energy content of 6.3 MJ (1500 kcal)/kg consisting of diced meat, onions, and potatoes that were mixed and fried (Nestlé AB, Helsingborg, Sweden). Protein provided 16% of energy, carbohydrate provided 41%, and fat provided 43%. Immediately before and after the test meal the visual analog scales (VAS), food preference checklists, and forced-choice food preference lists were completed by the subjects.

Universal eating monitor

Eating behavior was studied by using the UEM VIKTOR, which is a modified version of the original model described by Kissileff et al (25). Details of the VIKTOR equipment were described elsewhere (26). The total food intake, duration, eating rate, and relative rate of consumption (Im), defined as intake of food during the first half of the meal minus intake during the second half of the meal divided by the total intake of food, were measured. Im values > 0.1 indicate a decelerated eating pattern during the meal.

Eating motivation

The desire to eat, hunger, fullness, prospective consumption, and meal satisfaction were studied with VAS as described by Blundell et al (27). Ratings were made on 100-mm horizontal scales before and after the test meal, and the scales were anchored with the description in parenthesis as follows:

1) “How strong is your desire to eat?” (Not strong at all—Very strong).
2) “How hungry do you feel?” (Not hungry at all—Very hungry).
3) “How full do you feel?” (Not full at all—Very full).
4) “How much food do you think you could eat?” (Nothing—A very big portion) (also referred to as prospective consumption).
5) “How pleasant have you found the food?” (Not at all pleasant—Very pleasant).

Food-preference checklist

Before and after the test meal the patients were prompted to tick off food items they would like to eat immediately from a

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Table 1

<table>
<thead>
<tr>
<th>Characteristics of the eight obese subjects before and 9 mo after jejunoileal bypass (JIB) surgery</th>
<th>Before JIB</th>
<th>After JIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>38.5 ± 12.4</td>
<td>—</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>127.2 ± 8.2</td>
<td>90.5 ± 11.7</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>42.9 ± 4</td>
<td>30.4 ± 3.7</td>
</tr>
<tr>
<td>Calculated energy intake (MJ)</td>
<td>12.1 ± 1.9</td>
<td>9.9 ± 1.6</td>
</tr>
<tr>
<td>(kcal)</td>
<td>2913 ± 477</td>
<td>2382 ± 284</td>
</tr>
</tbody>
</table>

¹ ± SD. The average daily metabolic rate was derived from the WHO formula for basal metabolic rate (19) and multiplying by 1.35 according to Goldberg et al (20) to correct for moderate physical activity; this gives an estimate of energy expenditure, and thus the calculated energy intake needed to maintain energy balance.
list of 32 food items (27). The different food items represent four food groups (eight food items from each of the following groups: high protein, high fat, high carbohydrate, and low energy).

**Forced-choice list**

Before and after the test meal, the patients were prompted to choose between 32 pairs of high-carbohydrate and high-protein items (27). The forced-choice list is designed to reveal a specific high preference for proteins or carbohydrates.

**Seven-day estimated food record**

A 7-d estimated food record was completed the week before the VIKTOR test meal in the obese group, before surgery, and 9 mo after surgery. The subjects were instructed to keep a record of portion sizes of all meals and beverages consumed daily during a 7-d period (28). All records were examined together with the obese subject and two of the authors (AH and IM). The records were used to calculate the mean daily energy intake as well as the proportion of energy in the meal consumed as fat, protein, and carbohydrate.

**Scintigraphic gastric-emptying test**

The scintigraphic gastric-emptying test of a solid meal was described in detail elsewhere (29). In short, subjects were studied after an overnight fast by using a 1.3-MJ (310 kcal) omelet with 12-15 MBq 99mTc-labeled macroaggregated albumin (Pulmonate; Amersham International PLC, Little Chalfont, United Kingdom). Anterior and posterior 1-min acquisitions were performed with the patient in a sitting position. Registration was undertaken every 5 min during the first 50 min and every 10 min thereafter during the remaining 70 min.

The following indexes were calculated: 1) lag phase, defined as the time period from termination of the meal until 90% of radioactivity remained in the stomach; 2) gastric-emptying rate, defined as %/min during the linear slope after termination of the lag phase; and 3) half-emptying time (t50), defined as the time for 50% emptying of gastric contents after termination of the meal.

**Gastrointestinal hormones**

After an overnight fast, the subjects were given a 1.2-MJ (280 kcal) standardized meal (9 g fat, 35 g carbohydrate, and 14 g protein) consisting of Swedish meatballs and mashed potatoes (Weight Watchers; Helsingborg, Sweden). Blood samples were collected with heparin in 10-mL tubes 10 min before the start of the meal, at the start of the meal, and then every 10 min after the meal for 60 min. The blood samples were placed on ice and centrifuged at 4°C at 2000 × g (3000 rpm) for 10 min. Plasma was collected and stored at −20°C and all samples were analyzed in one series.

Frozen plasma samples were thawed and extracted onto Sep-Pak C-18 cartridges (Waters Associates, Milford, MA). Motilin-like immunoreactivity was analyzed by using antisera to motilin-4 raised against conjugated porcine motilin. HPLC-purified 125I-labeled motilin was used as radioligand and porcine motilin as calibrator. The antiserum cross-reacted < 0.1% with gastrin pancreatic polypeptide, gastrin, vasoactive intestinal peptide, enteroglucagon, neurotensin, neuropeptide Y, calcitonin gene-related peptide, substance P, neuropeptide A, atrial natriuretic peptide, insulin, C-peptide, and cholecystokinin. The detection limit of the assay was 3.9 pmol/L and the intra- and interassay CVs were 7% and 10%, respectively, at 50 pmol/L. Neurotensin-like immunoreactivity was analyzed by using antiserum H, which reacts with neurotensin (100%), neurotensin(4-13) (18%), neurotensin(8-13) (67%), and neurotensin(9-13) (15%) but not with N-terminal fragments of neurotensin. The detection limit of the assay was 8 pmol/L. Intra- and interassay CVs were 8% and 13%, respectively (30). Cholecystokinin was analyzed by using antiserum against cholecystokinin-8 with a cross-reactivity against gastrin of 0.5%. The detection limit of the assay was 0.3 pmol/L. Intra- and interassay CVs were 5.5% and 13.7%, respectively (Euro-Diagnostica, Malmö, Sweden).

**Data analysis**

Values are given as mean ± SD and median (range) as appropriate. Kaplan-Meier plots and the log-rank test were used to illustrate and compare the lag phase and t50 results (31). Paired and unpaired t tests were used for the analysis of gastric emptying rate, BMI, age, 7-d estimated food record, and UEM results. Wilcoxon signed-rank test for matched pairs and the Mann-Whitney U test were used where appropriate to analyze results of the forced-choice, VAS, and food-preference checklists. A multivariate analysis test (MANOVA) with repeated measures was used to compare the results of the hormonal analysis and single time points were compared with Tukey’s honestly significant-difference post hoc test. A P value < 0.05 was considered statistically significant.

**RESULTS**

**Clinical progress**

At 9-mo follow-up there were no electrolyte disturbances. One patient showed a slight reduction in serum albumin concentration to 36 g/L (reference: 40–51 g/L). All patients reported fewer than four loose stools per day. During rapid weight loss, all patients showed slight elevations of liver function test results. One patient was treated for a renal stone 3 wk after surgery and one patient was cholecystectomized because of acute cholecystitis 3 mo after surgery.

**Eating behavior (VIKTOR)**

The eating rate was significantly faster both before and after surgery in obese subjects than in normal-weight control subjects. The relative rate of consumption (Im) showed an accelerating pattern in the obese subjects before surgery, with a trend toward a decelerating pattern after surgery (Table 2).

**Eating motivation (VAS)**

The desire to eat, hunger, and prospective consumption before the test meal were similar in obese and control subjects, but reduced after JIB. In the obese subjects, only the desire to eat was significantly reduced after JIB (Table 3).

**Food-preference checklist**

The total number of high-carbohydrate and high-fat items selected before a test meal were significantly reduced after JIB (Table 4).
TABLE 2
Results from the universal eating monitor for eight normal-weight control subjects and eight obese subjects before and 9 mo after jejunoileal bypass (JIB) surgery

<table>
<thead>
<tr>
<th></th>
<th>Normal-weight control subjects</th>
<th>Obese subjects</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before JIB</td>
<td>After JIB</td>
<td></td>
</tr>
<tr>
<td>Intake of food (g)</td>
<td>331 ± 98</td>
<td>367 ± 223</td>
<td>309 ± 98</td>
</tr>
<tr>
<td>Eating rate (g/min)</td>
<td>27.6 ± 8.8</td>
<td>54.1 ± 22.1²</td>
<td>59.9 ± 17.4²</td>
</tr>
<tr>
<td>Relative rate of</td>
<td>0.10 ± 0.09</td>
<td>0.04 ± 0.11</td>
<td>0.12 ± 0.13¹</td>
</tr>
<tr>
<td>consumption (lm)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ t ± SD.
² Significantly different from normal-weight control subjects, P < 0.01 (unpaired t test).
³ P = 0.09 (paired t test).

Forced-choice list

There was a trend toward a higher preference for carbohydrates in obese subjects than in control subjects before the test meal [median for 32 paired high-carbohydrate (HC) and high-protein (HP) items: ratio of 10 HC to 22 HP and 2 HC to 30 HP, respectively; P = 0.08]. After the test meal there was a trend toward a reduced preference for carbohydrates after JIB in the obese group (ratio of 12 HC to 20 HP and 22 HC to 10 HP, respectively; P = 0.08).

Seven-day estimated food record

The obese subjects reported a significant decrease in the mean daily energy intake after JIB. The amounts of energy consumed as fat and carbohydrates were significantly reduced after JIB (Figure 1). There were no significant differences in the distribution of energy provided by fat, carbohydrate, and protein before and after surgery.

TABLE 3
Motivation to eat measured by visual analog scales in eight normal-weight control subjects and eight obese subjects before and 9 mo after jejunoileal bypass (JIB) surgery

<table>
<thead>
<tr>
<th></th>
<th>Normal-weight control subjects</th>
<th>Obese subjects</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before JIB</td>
<td>After JIB</td>
<td></td>
</tr>
<tr>
<td>Desire to eat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>78 (59–100)</td>
<td>71 (16–97)</td>
<td>52 (9–75)³</td>
</tr>
<tr>
<td>After test lunch</td>
<td>6.3 (0–9)</td>
<td>2.8 (1.5–7.5)</td>
<td>2.8 (1–7)</td>
</tr>
<tr>
<td>Hunger</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>78 (58–89)</td>
<td>73 (9–90)</td>
<td>51 (6–80)⁴</td>
</tr>
<tr>
<td>After test lunch</td>
<td>6.5 (1.5–8)</td>
<td>2.5 (1.5–8)</td>
<td>2 (1–8.5)</td>
</tr>
<tr>
<td>Fullness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>10 (6–49)</td>
<td>17 (1–51)</td>
<td>18 (2–52)</td>
</tr>
<tr>
<td>After test lunch</td>
<td>86 (79–99)</td>
<td>95 (69–97)</td>
<td>95 (76–97)</td>
</tr>
<tr>
<td>Prospective consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>71 (52–88)</td>
<td>68 (3–88)</td>
<td>51 (2–67)³</td>
</tr>
<tr>
<td>After test lunch</td>
<td>7.5 (0–10)</td>
<td>2.5 (0–8)</td>
<td>2.5 (0–8)</td>
</tr>
<tr>
<td>Palatability</td>
<td>76 (44–100)</td>
<td>68 (8–97)</td>
<td>66 (3–98)</td>
</tr>
</tbody>
</table>

¹ Median; range in parentheses.
² Significantly different from normal-weight control subjects (Mann-Whitney U test): ³ P = 0.03, ⁴ P = 0.01, ² P = 0.007.

TABLE 4
Food-preference checklist for eight normal-weight control subjects and eight obese subjects before and 9 mo after jejunoileal bypass (JIB) surgery

<table>
<thead>
<tr>
<th></th>
<th>Normal-weight control subjects</th>
<th>Obese subjects</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before JIB</td>
<td>After JIB</td>
<td></td>
</tr>
<tr>
<td>Total items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>12.3 (8.5–20)</td>
<td>21.3 (5.5–29)</td>
<td>11.2 (3.5–31)²</td>
</tr>
<tr>
<td>After test lunch</td>
<td>6.8 (1–12.5)</td>
<td>6.5 (0–11)</td>
<td>3.3 (0–10.5)</td>
</tr>
<tr>
<td>High-protein items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>7.5 (3.5–8)</td>
<td>5.5 (1–8)</td>
<td>2.8 (0–8)</td>
</tr>
<tr>
<td>After test lunch</td>
<td>0 (0–1.5)</td>
<td>0 (0–1)</td>
<td>0 (0–0.5)</td>
</tr>
<tr>
<td>High-carbohydrate items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>2 (1–4)</td>
<td>5 (1–8)</td>
<td>2 (0–4)⁴</td>
</tr>
<tr>
<td>After test lunch</td>
<td>0.3 (0–2.5)</td>
<td>0.1 (0–4)</td>
<td>0.3 (0–4)</td>
</tr>
<tr>
<td>Low-energy items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before test lunch</td>
<td>4.8 (0–7.5)</td>
<td>5.3 (2.5–7.5)</td>
<td>5.3 (0–5–8)</td>
</tr>
<tr>
<td>After test lunch</td>
<td>3.5 (1–7)</td>
<td>2.8 (0–7)</td>
<td>3 (0–5)</td>
</tr>
</tbody>
</table>

¹ Median; range in parentheses.
² Significantly different from before JIB (Wilcoxon signed-rank test for matched pairs): ³ P = 0.04, ⁴ P = 0.01.
² Significantly different from normal-weight control subjects, P = 0.02 (Mann Whitney U test).

EATING, GASTRIC EMPTYING, AND INTESTINAL BYPASS

Gasstic emptying

Compared with the control subjects, the obese subjects had a significantly shorter gastric half-emptying time. After JIB, gastric half-emptying time was significantly prolonged. No significant difference in t₅₀ was observed between obese subjects 9 mo after JIB and normal-weight control subjects (Table 5).

FIGURE 1. Mean (± SD) daily calculated energy intake (EI) the average daily metabolic rate was derived from the WHO formula for basal metabolic rate (19) and multiplying by 1.35 according to Goldberg et al (20) to correct for moderate physical activity; this gives an estimate of energy expenditure, thus, the EI needed to maintain energy balance] and measured EI (total, carbohydrate, fat, and protein) from the daily mean of the 7-d estimated food record in eight obese subjects before and 9 mo after jejunoileal bypass (JIB) surgery. Significantly different from before JIB (paired t test): *P < 0.05, #P < 0.07.
TABLE 5
Results of gastric emptying of solids test in eight normal-weight control subjects and eight obese subjects before and 9 mo after jejunoileal bypass (JIB) surgery

<table>
<thead>
<tr>
<th></th>
<th>Normal-weight control subjects</th>
<th>Obese subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before JIB</td>
<td>After JIB</td>
</tr>
<tr>
<td>Lag phase 90% (min)</td>
<td>27.9 ± 4</td>
<td>21.2 ± 3.2</td>
</tr>
<tr>
<td>1/2 (min)</td>
<td>86.4 ± 10.7</td>
<td>69.5 ± 4.1</td>
</tr>
<tr>
<td>Emptying rate (%/min)</td>
<td>0.75 ± 0.23</td>
<td>0.84 ± 0.11</td>
</tr>
</tbody>
</table>

1 ± SD.
2 Significantly different from normal-weight control subjects, \( P < 0.05 \) (log-rank test).
3 Significantly different from before JIB, \( P < 0.05 \) (log-rank test).

Postprandial gut hormone concentrations

Obese subjects had cholecystokinin values that were lower than those normal-weight control subjects at 20, 30, and 40 min after meal intake both before and after JIB. Neurotensin concentrations were significantly higher after JIB than before JIB in obese subjects and compared with control subjects at 50 min after meal intake. No differences were seen in motilin concentrations either overall or at individual time points (Figure 2).

DISCUSSION

The results of this study indicate that after JIB in obese subjects, there is a reduction in energy intake and total items selected from a food-preference checklist. Furthermore, there is a lower desire to eat and less hunger and prospective consumption before a given test meal than in normal-weight subjects. In addition, gastric emptying is prolonged and postprandial concentrations of neurotensin are elevated. In short, JIB seems to shift gastric-emptying rate and food preference toward a normal pattern, concomitantly with a reduced desire to eat.

The mechanism behind reduced energy intake after JIB is not yet fully understood. It has been suggested that some of the reduction in energy intake may be due to the discomfort of flatulence and diarrhea often seen after JIB (31). On the other hand, Robinson et al (7) reported that diarrhea, nausea, and general discomfort did not account for the reduced food intake seen in their patients. None of our patients reported loose stools > 4 times/d or nausea at the time of the postoperative investigations.

It is clear that signals from the stomach and small intestine influence both hunger and satiation (32, 33). Such signals may be changed after JIB and important in the induced weight loss. A rapid distribution of nutrients to the lower parts of the small intestine occurs after JIB (11) and several studies have shown that infusion of nutrients into the ileum inhibits gastric emptying and food intake (10, 34, 35). A reduction in gastric distention and a decline in the exposure of the upper small intestine to the stimuli of nutrients have been implicated as factors regulating the return of hunger after a meal (36). It is possible that the prolongation of gastric emptying seen in this study was associated with a prolonged gastric distention and stimulation of duodenal receptors, which may increase the period of satiation (32). Also, stimulation of the ileum with nutrients is associated with a slowed small intestinal transit (34). This is a likely physiologic response after JIB to increase the absorptive capacity of the intact jejunum, which may increase the time for stimulation of receptors in the upper small intestine and regulate food intake (33). It has been suggested that the return of the fasting migrating motor complex is correlated with the return of hunger (37). The effect of JIB on the migrating motor complex pattern is unknown.

Hormonal factors have been suggested to be at least partly responsible for the reduction in food intake after JIB. Rats injected with postprandial plasma from bypassed rats ate less than sham-injected rats (38). It is well known that the postprandial gut hormone profile is altered after JIB (12, 13).
Cholecystokinin and neurotensin have been shown to be elevated after a test meal (12, 13, 39). Cholecystokinin has been shown to decrease hunger feelings, the desire to eat, and prospective feeding intentions if infused into normal-weight and obese subjects (40). Neurotensin decreases food intake if injected into the cerebral ventricle or paraventricular nucleus in rats (41). Neurotensin was significantly increased and may be a hormonal candidate for explaining the decreased energy intake either directly as a central effect or by peripheral mechanisms leading to changes in gastric emptying and intestinal transit. Other hormonal factors after JIB not measured in this study, such as increased enteroglucagon and decreased insulin concentrations (12, 13), may influence satiety mechanisms either centrally or peripherally.

A surprising observation was the fact that the obese subjects both before and after JIB had significantly lower postprandial cholecystokinin concentrations than the control subjects. This is not in accordance with previous reports in which no difference was found between obese and normal-weight subjects (42). Also, obese subjects respond with higher cholecystokinin concentrations after a high-fat meal than do control subjects, suggesting decreased receptor sensitivity in obese subjects. This was not shown for a low-fat meal (43). Because cholecystokinin is known to inhibit gastric emptying, our observed lower postprandial cholecystokinin concentrations in the obese subjects may agree with the observation that obese subjects in this study had more rapid gastric emptying than did normal-weight control subjects.

Several studies have shown that the eating rate during a meal decreases in normal-weight subjects, but also that obese subjects have a different eating pattern and display a more linear or even an accelerating eating curve (44, 45). It has been suggested that the accelerating eating curve in obese subjects represents a deficiency of satiety signals (46). Our subjects had a high eating rate although none of the patients fulfilled the Diagnostic and Statistical Manual (DSM) IV criteria for bulimia (47). The obese subjects had an accelerating eating curve before JIB with a trend toward a decelerated eating curve after surgery. How this is correlated with the observed change in the rate of gastric emptying is not clear. Obese subjects tend to have larger stomachs than normal-weight subjects (48) and weight loss has been shown to decrease stomach volume (49). It is possible that changes in feedback signals from gastric distension are responsible for the observed trend toward a decelerated eating pattern after JIB.

Underreporting of energy intake is a common source of error when measuring food intake (50). We estimated the minimum energy expenditure for the obese subjects in this study by calculating the average daily metabolic rate using the WHO formula (19) for the basal metabolic rate and multiplying it by 1.35 to account for moderate physical activity (20). This gives an estimate of the energy intake needed to maintain energy balance. Based on this, all the obese subjects underreported their energy intake (Figure 1). Energy expenditure is expected to decrease after JIB as weight is lost after surgery. However, the measured reduction in energy intake during the 7-d recall after JIB was greater than the estimated energy intake (expenditure) due to the weight loss observed after surgery. This difference was not significant probably because the number of subjects studied was small. Therefore, the data for food intake should be interpreted with some caution.

Other factors that may influence our results are patient selection and the length of time between surgery and the postoperative examination. We currently perform < 10 JIBs/y, mainly in patients who request the procedure. The group studied may therefore not be representative of obese subjects in general. The obese subjects were studied 9 mo after surgery while they were still losing weight, although the major weight loss for these patients occurred during the first 6 mo. The possible influence of rapid weight loss on food intake is unknown. It is possible that the observed trend toward an alteration in carbohydrate and protein intake ratio merely represents a depletion of protein in patients after JIB and that the decreased preference for high-fat items after JIB is due to the increase in loose stools associated with a high-fat intake after JIB.

Despite the above-mentioned potential confounding factors and the fact that JIB is reserved for a select group of patients, studies of gastrointestinal function after JIB may yield useful information regarding the regulation of food intake. This study showed that 9 mo after JIB there was a decreased food intake, changed food preference, and desire to eat, a reduction in the rate of gastric emptying, and alterations in postprandial gut hormone concentrations. These changes were most likely due to a combination of gastrointestinal motility factors and hormonal influences on feeding behavior.

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