Surgery for Obesity and Related Diseases 16 (2020) 599–606

SURGERY FOR OBESITY
AND RELATED DISEASES

Original article

Thermic effect of food and resting energy expenditure after sleeve gastrectomy for weight loss in adolescent females

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Received 26 June 2019; accepted 25 January 2020

Abstract

Background: Few studies have addressed the effect of bariatric surgery on factors related to energy balance, including resting energy expenditure (REE) and thermic effect of food (TEF). To our knowledge, very few studies have examined changes in REE and none have investigated modifications in TEF after sleeve gastrectomy (SG) performed in adolescents.

Objective: To assess energy expenditure in females who underwent SG as adolescents and matched-control participants as preliminary data about the potential of SG to confer differences in postprandial energy expenditure.

Setting: Children's Hospital Medical Center, Cincinnati, Ohio, United States.

Methods: In this observational study, REE and respiratory quotient (RQ) were measured via indirect calorimetry, followed by a standardized meal and assessment of TEF and postprandial RQ. Plasma drawn before and every 15 minutes after the meal was assayed for insulin, glucose, and C-peptide. Usual dietary intake was estimated using 24-hour recall interviews.

Results: Fasting REE and RQ were similar between surgical and control groups. Postmeal TEF also did not differ between groups. The surgical group had higher RQ early in the postprandial period, whereas the control group RQ was higher after 125 minutes post meal. Compared with the control group, the surgical group had lower postprandial glucose, higher insulin and C-peptide, and consumed less daily energy during usual intake.

Conclusions: Postprandial RQ was consistent with the rapid gastric emptying typical of SG, yet we observed no group differences in REE or TEF. These findings may have been due to limited statistical power. More comprehensive studies of EE after SG are warranted. (Surg Obes Relat Dis 2020;16:599–606.) © 2020 American Society for Bariatric Surgery. Published by Elsevier Inc. All rights reserved.

Key words: Bariatric surgery; Clinical research; Energy expenditure; Obesity; Weight maintenance

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This study was conducted in conjunction with Teen Longitudinal Assessment of Bariatric Surgery, a cooperative agreement funded by the National Institute of Diabetes and Digestive and Kidney Diseases of the National Institutes of Health with a grant to the University of Colorado (Dr. Thomas Inge, Primary Investigator; UM1 DK072493) and the University of Cincinnati/CCHMC Data Coordinating Center (UM1 DK095710). The project also was supported by the National Center for Advancing Translational Sciences of the National Institutes of Health, under Award Number 1 UL1 TR001425-01. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

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https://doi.org/10.1016/j.soard.2020.01.025

The prevalence of obesity among adolescents aged 12 to 19 years has not changed significantly since 2003, remaining high at 20.5% [1]. While behavioral interventions are associated with sustained improvement in body mass index (BMI) and health risks in youth with overweight or obesity, these interventions are largely ineffective in teens with severe obesity. Bariatric surgery is increasingly recognized as a treatment option for severe obesity in adolescents, with evidence demonstrating improvement of weight and remission of type 2 diabetes, dyslipidemia, and elevated blood pressure [2]. Current surgical options for adolescents include the Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (SG). A recent systematic review found that SG achieved significant weight loss and improvement of co-morbidities similar to RYGB [3], but with fewer surgical complications [4]. Based on these beneficial outcomes, SG has gained popularity for the treatment of individuals with severe obesity [5].

The significant, rapid weight loss, remedy of a broad range of co-morbidities, and relative safety of bariatric surgery have fueled scientific inquiry into causal mechanisms. While originally proposed as a means of gastric restriction, recent evidence indicates weight loss after surgery cannot be explained solely by mechanical limits on food intake [6]. It is now clear bariatric surgery causes fundamental changes in feeding behavior and effects on key regulatory centers in the brain [7]. However, what is less well understood are the effects of surgery on energy expenditure, particularly whether surgery is protective against the reduced total and resting energy expenditure (REE) that is a hallmark of weight loss due to caloric restriction [8].

To date, only a few studies have addressed the effect of bariatric surgery on factors related to energy balance, including body composition, REE, and thermic effect of food (TEF) [9]. The possibility that enhanced energy expenditure contributes to weight loss and maintenance after bariatric surgery has been examined in animal and human trials, but results are inconclusive [10]. Schneider compared REE in patients 17 months after RYGB or SG and found both procedures increased REE, expressed as kilocalories per kilogram (kcal/kg) weight [11]. TEF, or energy expended during food digestion and metabolism, has been shown to increase in rats after RYGB compared with weight-matched controls [12]. Wilms et al. [13] demonstrated increased TEF in women after RYGB, while Werling et al. [14] confirmed that increased total energy expenditure secondary to increased TEF occurred soon after RYGB and persisted long term.

Two recent studies have examined changes in REE after SG performed in adolescents [15,16], but to our knowledge, no studies have investigated TEF in this population. The objective of this pilot study was to assess REE and TEF in young adults who underwent SG as adolescents and matched control participants, providing preliminary data about the potential of SG to confer differences in postprandial energy expenditure. With the growing popularity of SG among adolescents and the paucity of published studies, this investigation will help to fill a gap in the literature regarding the relationship between SG and energy balance.

Methods

Design, setting, and participants

An observational cohort design was used to compare energy metabolism and endocrine response in postSG females and matched controls. Surgical participants were recruited from the pool of patients who had undergone SG as adolescents if they were 18 to 60 months post surgery. The postsurgery time period for inclusion in the study was based in part on availability of eligible participants as well as on trends for weight loss and stability. The nadir of weight loss in our research cohort of postsurgery adolescents (Teen Longitudinal Assessment of Bariatric Surgery) occurs around 12 months after surgery; after 12 months, weight has tended to stabilize and remain so at 3 and 5 years after surgery [2,17]. Control participants were recruited from nearby university and healthcare settings. Recruitment was performed on a rolling basis between August 2013 and April 2015.

Control participants were frequency matched to post-SG patients by age (±6 mo), race, and body mass index (BMI; ±10 kg/m^2). Individuals were eligible for inclusion if they (1) were female between 18 and 25 years; (2) had reached Tanner stage 5; (3) had a BMI between 25 and 40 kg/m^2; (4) were weight-stable with $<10\%$ weight change in the past 6 months or since the last clinical visit (surgery group), and $<5\%$ change in the past month (self-report); and (5) had age-appropriate cognitive and behavioral skills. Potential participants were excluded if they were taking medicines known to affect energy expenditure, such as oral hormonal contraceptives, corticosteroids, or thyroid hormones; had a prior diagnosis of hypothalamic dysfunction; or were pregnant or lactating. Informed consent was completed with each participant at the start of a 1-day visit at the hospital's Clinical Translational Research Center. The study protocol and informed consent document were reviewed and approved by the institutional review board before enrollment.

Anthropometrics

Height was measured to the nearest .1 cm with a wall-mounted Harpenden stadiometer (Holtain Ltd, Crymych, UK); weight was measured to the nearest .1 kg using a single, calibrated scale (Total Body Composition Analyzer, Tanita, Tokyo, Japan) following standard protocols [18]. Waist circumference was measured at the iliac crest using a nonelastic measuring tape, following standard methods [19]. Body composition was assessed by dual-energy x-ray absorptiometry (DXA Discovery, Hologic, Bedford, MA, USA), which provides accurate estimates of body fat and fat-free mass [20].

Resting energy expenditure, thermic effect of food, and respiratory quotient

After an overnight fast, participants rested for 30 minutes before measurement of REE using a computerized, open-circuit indirect calorimeter (Vmax 29 Encore; Carefusion, Yorba Linda, CA, USA). The V_{max} has been shown to provide valid measurements of REE compared with the DeltaTrac Monitor indirect calorimeter system [21], and to accurately measure O_2 and CO_2 within 1.8% of the “true value” as determined by the methanol combustion test [22]. In our institution, the V_{max} is calibrated using the equipment’s built-in processes for verifying accurate measurements. Before each visit, the mass flow sensor (a device that controls the flow of inspired and expired air) is calibrated using a 3-L syringe delivering various target flow rates the machine must read within a predetermined error range. Then, immediately before each REE test, a gas analyzer calibration is performed wherein respiratory gases from tanks with known concentrations of O_2 (16.0%) and CO_2 (4.0%) are measured. The analyzer must measure these gases within ±1% of the known concentrations before participant testing can proceed. Each REE measurement in this study was performed by 1 of 2 trained, experienced operators, following evidence-based best practices for measuring REE in adults [23]. To conduct the test, a ventilated hood was placed over the participant’s head, and respiratory gas exchange (i.e., oxygen consumption [VO_2] and carbon dioxide production (VCO_2]) was measured over 30 minutes. Values for VO_2 and VCO_2 under steady-state conditions were used to calculate REE with the Weir equation [24]. Steady state was defined as a period of 5 consecutive minutes in which VO_2 and VCO_2 stayed within 10% and respirator quotient (RQ) within 5% [25].

After the baseline REE, participants were given a standardized mixed meal providing 350 kcal of approximately 28% fat, 56% carbohydrate, and 16% protein. The meal was designed by a registered dietitian to ensure tolerability for surgical participants. To determine TEF, respiratory gas exchange was measured for 10 minutes every 30 minutes for up to 6 hours after the meal was ingested, or until energy expenditure returned to within 5% of the baseline REE [26,27]. RQ, the ratio of VCO_2 to VO_2, was used to determine energy substrate utilization. A higher RQ (close to 1.0) indicated greater utilization of carbohydrate and a lower RQ (close to .70) indicated greater use of fat. Fasting RQ was calculated as the average ratio of VCO_2 to VO_2 during the REE measurement. The TEF and postprandial RQ were calculated as the area under the postprandial curves, above the baseline REE and RQ values, respectively [26].

Hunger, satiety, and fullness

Before the REE, and every 30 minutes after the meal (during the rest period between TEF measurements), participants were asked to rate their hunger using a 100-mm visual analog scale anchored with the statements “not at all hungry” and “as hungry as I have ever felt.” Satiety and fullness were similarly assessed and ratings were converted to scores between 0 and 100.

Plasma biochemical assays

Plasma was drawn from an indwelling intravenous catheter before the meal and after each TEF measure. Blood samples were drawn by research nurses blinded to study group, and analyzed in a research laboratory using conventional techniques. Analyses of plasma glucose were conducted on-site using the Stat Plus 2300 Glucose and L-Lactate Analyzer (YSI Incorporated, Yellow Springs, OH, USA) in the Clinical Translational Research Center processing lab. Insulin and C-peptide were analyzed with commercial enzyme-linked immunosorbent assay (Alpco, Salem, NH, USA) using methods as described elsewhere [28].

Diet assessment

Usual dietary intake was estimated via 3 diet recall interviews (2 weekdays and 1 weekend day). The first recall interview was done in-person at the time of the study visit, and the 2 follow-up interviews were conducted by phone within 2 weeks of the visit date. Trained interviewers employed the U.S. Department of Agriculture multiple-pass method to ensure accurate collection of data regarding food items and amounts consumed by participants [29]. The Nutrition Data System for Research (Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN, USA) was used to collect intake data and analyze energy and macronutrients in the diet.

Statistical methods

Descriptive statistics were generated to characterize all outcomes of interest (e.g., REE, TEF) as well as demographic and other clinical measures. Frequencies and counts were tabulated for categoric variables; means/standard deviations or medians/first and third quartiles were calculated for continuous variables. Baseline characteristics and 3-day dietary intake outcomes were univariately compared between surgical and control participants using *t* tests, Wilcoxon rank-sum tests, and Fisher’s exact tests. Linear mixed modeling was used to evaluate TEF (and other outcomes) differences by study group over time with only indicators for study group, time, and their interaction as predictor terms. These models addressed missing data values by maximum likelihood, under the assumption of missing at random. Linear regression was used to evaluate REE by study group, adjusted for fat-free mass and fat mass. Area under the curve was calculated using the trapezoidal rule and was compared between study groups using *t* tests. All analyses were performed using SAS v9.4 (SAS Institute, Cary, NC, USA).

Results

Sixty-four individuals (25 surgical, 39 control) were screened for enrollment. Of these, 45 were not eligible for the study for the following reasons: BMI outside the inclusion criteria (n = 30); hormonal contraceptive use (n = 5); unstable weight (n = 3); unavailable for study visit (n = 6); and pregnant (n = 1). The remaining 19 females were enrolled in the study, with 10 in the surgical group and 9 in the control group. Due to illness, 1 person in the surgical group was not able to complete the assessment, resulting in 9 participants in each group for the data analyses. Study visits took place between October 2013 and May 2015.

The surgical (n = 9) and control (n = 9) groups were similar in terms of participant demographic characteristics and across all baseline metabolic parameters measured (Table 1). Adjusting REE for weight or fat-free mass did not affect the results.

Fasting glucose, insulin, and C-peptide did not differ between the 2 groups. After meal ingestion, the glucose excursions followed similar patterns for the initial 60 minutes, but levels decreased significantly in the SG group after that. Coincident with lower postprandial glycemia, the participants with SG had significantly higher insulin and C-peptide concentrations compared with the control group (group by time interaction, each $P < .05$) (Fig. 1).

Fasting REE and RQ did not differ between groups (Table 1). TEF, expressed as area under the curve for the postprandial period, did not differ between groups (median: 13,563 [quintile 1, quintile 3: 11,881, 14,017] versus 12,314 [10,046, 13,154], surgical and control groups respectively, $P = .39$) (Fig. 1). Adjusting TEF for weight (kcal/kg) did not affect these results.

The mean RQ over the period of the meal did not differ between the 2 groups; however, there was a complex and significant group by time interaction for RQ values. The surgical group had a higher RQ early in the postprandial period, whereas the control group's RQ was higher after 125 minutes post meal (Fig. 1).

The surgical group consumed significantly less energy, fat, and carbohydrate than the control group,

Table 1
Baseline characteristics by study group

	Surgical	Control	*P* value
n	9	9	
Age, yr, mean (SD)	20.5 (2.65)	21.3 (1.57)	.45
Race, n (%)			.08
White	5 (55.6)	2 (22.2)	
Black	2 (22.2)	7 (77.8)	
Multirace	2 (22.2)	0 (.0)	
Ethnicity, n (%)			
Non-Hispanic	9 (100.0)	9 (100.0)	>.99
Weight, kg, mean (SD)	94.2 (14.09)	94.7 (23.81)	.96
Body mass index, kg/m^2, mean (SD)	32.9 (5.47)	33.1 (5.75)	.96
Waist circumference, cm, mean (SD)	104.2 (12.43)	102.6 (16.75)	.84
Body composition, mean (SD)			
Fat mass, kg	39.8 (8.73)	41.4 (16.71)	.81
Fat-free mass, kg	53.7 (6.32)	52.7 (7.40)	.76
Percent fat	42.1 (5.95)	42.6 (7.35)	.90
REE, kcal, mean (SD)	1501 (183)	1537 (294)	.75
REE/weight, mean (SD)	16.0 (1.44)	16.5 (1.52)	.55
REE/fat-free mass, mean (SD)	28.1 (3.5)	29.1 (2.3)	.50
Respiratory quotient, mean (SD)	.84 (.06)	.85 (.05)	.85
Usual dietary intake, mean (SD)			
Energy, kcal	1227 (181)	1783 (415)	<.01
Total fat, g	48 (11)	66 (18)	<.05
% of energy	34 (6)	32 (6)	.40
Total carbohydrate, g	146 (26)	243 (75)	<.01
% of energy	47 (5)	53 (8)	.05
Total protein, g	55 (14)	64 (10)	.13
% of energy	19 (4)	15 (3)	<.05
Glucose, mg/dL, mean (SD)	84.0 (5.95)	83.1 (6.65)	.76
Insulin, pg/mL, median (Q1, Q3)	293 (191, 450)	252 (229, 667)	.56
C-peptide, pg/mL, mean (SD)	1419 (322)	1294 (507)	.56
Hunger, mm, mean (SD)	58.1 (16.86)	39.7 (29.28)	.12
Satisfaction, mm, mean (SD)	31.1 (17.16)	40.0 (17.85)	.30
Fullness, mm, median (Q1, Q3)	9 (6, 14)	30 (14, 50)	.12

SD = standard deviation; REE = resting energy expenditure; Q1 = quintile 1; Q3 = quintile 3.

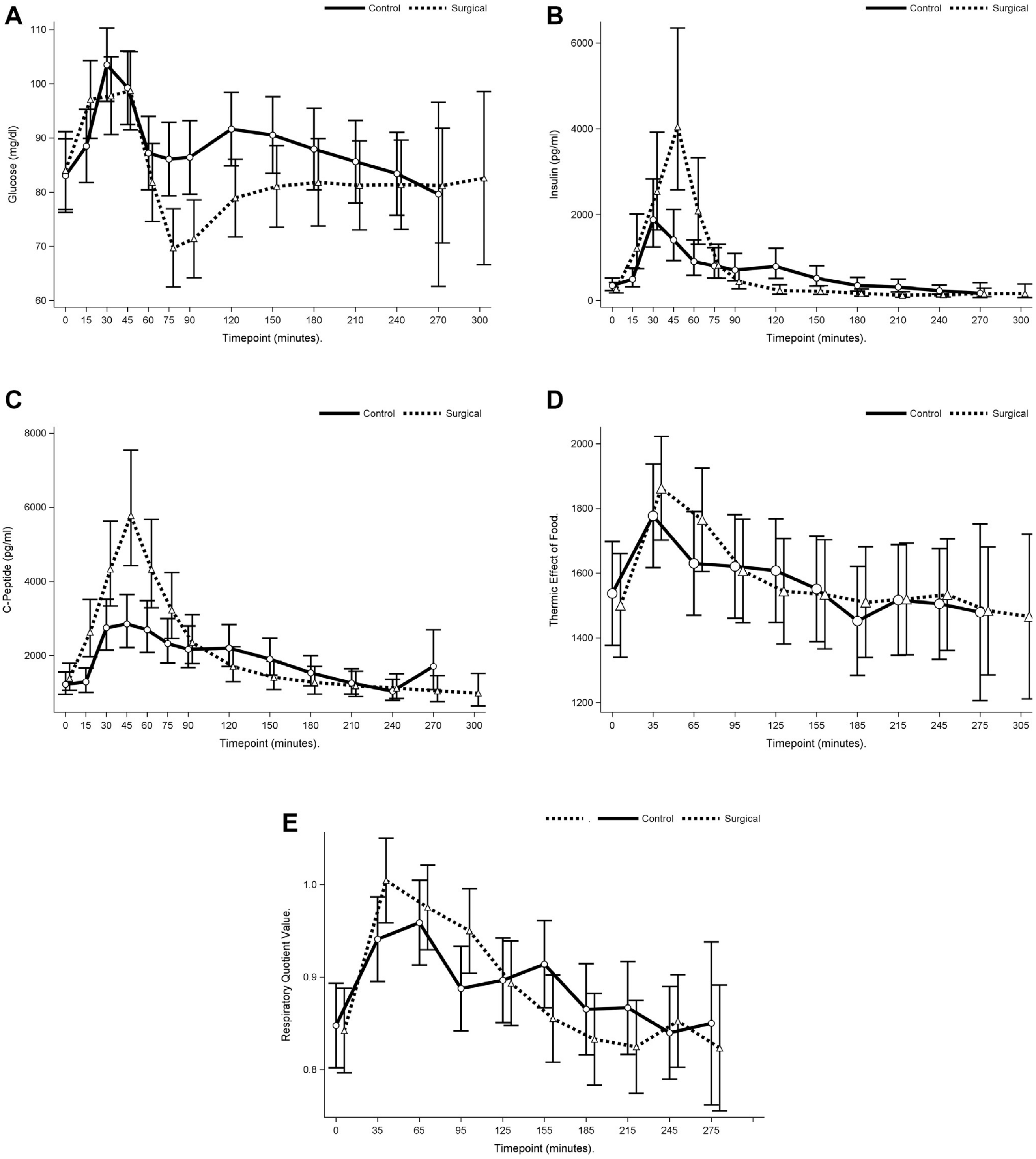

Fig. 1. Laboratory and energy expenditure values by time and study group. (A) Glucose (mg/dL); (B) insulin (pg/mL); (C) C-peptide (pg/mL); (D) thermic effect of food (total kcal); and (E) respiratory quotient (ratio $VCO_2:VO_2$). VCO_2 = volume of carbon dioxide produced; VO_2 = volume of oxygen consumed.

with no difference in protein amount (Table 1). However, when reported in terms of macronutrient distribution, the percent of energy from protein was higher in the surgical compared with the control group ($P < .05$) (Table 1), while percent from both fat and carbohydrate were not significantly different. Hunger, satiety, and fullness over the postprandial period showed no significant differences between groups. There was a nonsignificant trend toward greater satiety and fullness among surgical participants over this period ($P = .09$ and .10, respectively, for group by time interaction).

Discussion

In this study we sought to determine whether SG conferred differences in postprandial energy expenditure in a group of young adult women. In our small but well-matched cohort, these pilot data suggest no difference in baseline REE or TEF between the surgical and control groups. Likewise, the baseline RQ was similar in both groups, but in the postprandial period, we found a significant interaction of group and time in the RQ values, suggesting, after SG, preferential use of carbohydrate occurs early after a mixed meal, with use of fat later. This interpretation is also supported by our insulin and C-peptide excursion data showing higher peak levels early after the meal in the surgical group. Less fluctuation in RQ and insulin was seen in the control group. These findings are compatible with the known effect of SG to increase the rate of gastric emptying into the intestine [30].

Few studies have examined REE after SG in humans and none published to date have measured TEF or RQ in adolescents. In prior studies of REE changes after SG, results were not reported in a uniform fashion, making comparisons between studies difficult. Schneider et al. [11] measured REE in adults who had SG or RYGB approximately 17.5 months previously. In this cohort, REE per kilogram weight increased compared with presurgical values. In contrast, Tam et al. [31] reported that measured and predicted REE were lower 2 years after either SG or RYGB. Finally, Schiavo et al. [32] reported a cross-sectional comparison of REE in 70 weight-stable adults approximately 3 years post-SG and 70 matched controls. In this study, there was no difference in REE between the groups. However, caution must be used in interpreting the latter 2 studies because REE was reported only in terms of kilocalorie per day, rather than kilocalorie per kilogram weight or fat-free mass. Studies of energy metabolism after RYGB are more abundant, with several showing an increase in REE per kilogram weight after surgery [11,33–35], while others noted no change [14,36].

While no data have been published about TEF or RQ after SG, there are several studies of TEF in participants with RYGB, also with mixed results [13,14,37,38]. Two controlled, cross-sectional studies found that participants who were at least 1 year post RYGB had a higher TEF and RQ compared with those with and without obesity [13,38]. However, both studies made postprandial measurements at single time points (i.e., 20 [38] and 90 min [13]), which are unlikely to capture complete meal metabolism. In a study of adults before and 20 months after RYGB, Werling et al. [14] measured postmeal TEF over 150 minutes using a metabolic chamber. They reported an increase in kilocalorie per kilogram compared with preoperative TEF. In the same study, the mean daily RQ increased significantly from .80 at baseline to .87 post surgery. However, Das et al. [37] conducted a 4-hour postmeal measurement of TEF and RQ in patients undergoing RYGB and found no change in either component from presurgery to approximately 14 months after surgery.

To date, there are very few published studies of energy expenditure in adolescents after bariatric surgery. In 2015, Butte et al. [39] examined total energy expenditure by 24-hour room respiration calorimetry in a longitudinal, controlled trial. Eleven adolescents undergoing RYGB and 5 nonsurgical participants matched for initial weight, BMI, and body composition were assessed at baseline and 1.5, 6, and 12 months after surgery. In this study, participants with RYGB had lower total energy expenditure per kilogram fat-free mass compared with presurgery findings, an effect seen within 2 months of surgery and persisting for 1 year. This result differs from findings in adults and is similar to energy changes after diet-induced weight loss.

More recently, Rickard et al [15] published the results of a longitudinal study of energy expenditure with 12 females (mean age 18.8 ± 2.2 yr) before and 1 year after SG, using indirect calorimetry. Findings showed that total REE (kcal/d) decreased over the first year post surgery, consistent with a decrease in total lean mass; however, REE per total weight increased, correlating strongly with percent total weight loss. In another longitudinal study published in 2019, Chu et al. [16] enrolled 15 females and 5 males (mean age 17.2 ± .8 yr) who had undergone either SG ($n = 9$) or RYGB ($n = 11$) in adolescence. Measurements were made before and 1 year after surgery, using bioelectrical impedance and indirect calorimetry to assess body composition and energy expenditure. Consistent with the study by Rickard et al. [15], results indicated that total daily REE was decreased (i.e., 25% lower) at 12 months compared with baseline with both types of bariatric surgery.

Based on the paucity of evidence and the potential importance of energy expenditure on bariatric surgery outcomes, more definitive research is needed. Using only our data, it is difficult to explain the lower daily caloric intake reported by our surgical group compared with controls. Underreporting is surely a factor influencing energy intake results [40], but this phenomenon cannot fully explain the significant difference between the matched groups. As both groups were weight stable and REE was similar between groups, it is intuitive to surmise the daily total energy expenditure must be matched to caloric intake, and thus, must be lower in the surgical group compared with the control group. While we did not measure total daily energy expenditure in our study, Butte et al. [39] found that indeed after they became weight stable, adolescents who had undergone RYGB demonstrated total daily energy expenditure per kilogram lean mass, which was approximately 25% lower than those who had not undergone surgery. Thus, it is plausible both total energy expenditure and caloric intake were lower in our sample of individuals who underwent SG compared with nonsurgical controls. Our results are consistent with other studies that demonstrated relatively low energy intake [41–43] and an increase in protein [44] after bariatric surgery. The phenomenon of lower energy intake after surgery may be further explained by postoperative diet counseling, which is an integral component of the surgical weight loss program at our institution and others. Studies have demonstrated improved outcomes for weight loss [45] and eating behavior [44] in those who received follow-up counseling with a registered dietitian.

Research has consistently shown that SG confers beneficial effects on appetite and satiety through alterations in gastrointestinal hormones (i.e., a decrease in ghrelin and increases in peptide YY and glucagon-like peptide-1) [9,46]. Yet, no significant differences in appetite or satiety were found between groups, potentially because of the modest size of the test meal or the small number of participants.

There are several limitations to our pilot study. First, the cross-sectional design allowed for only 1 measurement of participants, whereas longitudinal studies allow within-subject comparisons that can account for specific characteristics of individuals, a feature noted previously for TEF [47]. Second, the sample size was small because of the single recruitment site and the inclusion of only female participants, thus limiting generalizability of findings, statistical power to detect differences between groups, and the interpretation of TEF changes, potentially resulting in conclusions that differ from those of previous studies. Third, we relied on self-reported data to estimate usual energy intake. This approach, despite its widespread use in research, is notably flawed due to underreporting, which is common across all populations but particularly in those with obesity [40]. Fourth, we did not have a precise and accurate measure of gastric emptying, which would have provided context for interpreting postprandial energy expenditure; also, we did not measure levels of thyroid hormones, potential confounders related to energy regulation. These measures would be valuable additions to future studies. Last, although we used standard hood calorimetry, collecting time-limited measures of REE and TEF and extrapolating those values to a full day, room calorimeters that measure energy expenditure over an entire 24-hour period may provide more precise estimations.

Conclusions

To our knowledge, this study is the only one to examine TEF in young women after SG during adolescence. Prior studies of bariatric surgery during adolescence found a decrease in total energy expenditure and REE 1 year after RYGB and/or SG, but these findings are not consistently supported in the adult literature. The anatomy and physiology of gastrointestinal function after bariatric surgery strongly suggest an impact on rates of nutrient absorption and energy metabolism. More comprehensive studies in this area are warranted, and ongoing follow-up, such as that which is occurring in the Teen Longitudinal Assessment of Bariatric Surgery study, is essential for documenting the durability of these changes for promoting maintenance of weight loss after surgery.

Acknowledgments

The authors would like to thank Lindsey Shaw for the screening, recruitment, enrollment, and scheduling of study participants and overall study coordination, and Laura Benken for assisting with measurements of REE, TEF, and dietary intake (note: these individuals have given written permission to be acknowledged).

Disclosures

The authors have no commercial associations that might be a conflict of interest in relation to this article.

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