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THERMOGENIC CHANGES AFTER GASTRIC BYPASS, ADJUSTABLE GASTRIC BANDING OR DIET ALONE

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Abstract

Background—The mechanisms by which bariatric surgery achieves weight loss (WL) are under scrutiny. We assessed changes in resting energy expenditure (REE) after gastric bypass (RYGB) and gastric banding (AGB) to determine if changes in REE are associated with WL and type of surgery.

Methods—Three groups of morbidly obese patients were studied: RYGB (n=12), AGB (n=8), and a control group that underwent caloric restriction alone (Diet, n=10). Studies were performed at baseline and after 14 days in all groups, and 6 months after RYGB and AGB. REE (kcal/day) was measured by indirect calorimetry and adjusted for body weight (Wt-REE), and lean body mass by dual-energy X-ray absorptiometry (LBM-REE).

Results—At baseline, REE did not differ significantly among groups (RYGB=2,114±337, AGB=1,837±154, Diet=2,091±363 kcal/day, p=0.13). After 14 days, the groups had similar percent excess WL (%EWL). Neither Wt-REE nor LBM-REE changed significantly in any group. After six months %EWL was 49±10% after RYGB and 21±11% after AGB (p<0.01); RYGB patients had greater increase in the percent of weight that was LBM (RYGB=7.9±3.0 vs. AGB=1.6±1.5%, p<0.01). Wt-REE increased significantly only after RYGB (+2.58±1.51 kcal/kg/day, p<0.01). There was a significant correlation between changes in Wt-REE and %EWL (r=0.670, p=0.003).

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Conclusion—The increase in Wt-REE may be a factor supporting WL after RYGB.

INTRODUCTION

Obesity affects 500 million people worldwide¹ and is associated with severe metabolic disorders, poor quality of life and decrease in life span². Bariatric surgery is currently the most effective treatment for severe obesity and achieves sustained weight loss (WL) in the majority of morbidly obese patients³. However, WL results vary significantly with the different surgical techniques in practice, and the mechanisms promoting WL after bariatric surgery are still under scrutiny.

Two procedures commonly in use are Roux-en-Y gastric bypass (RYGB) and adjustable gastric banding (AGB). AGB seems to promote WL only by restricting food intake, while RYGB is thought to combine the restriction caused by a small pouch with several other physiologic changes caused by the Roux-en-Y anatomy, as RYGB prevents contact of the food bolus with most of the stomach and the duodenum while allowing for early delivery to the proximal jejunum. Caloric restriction with AGB and RYGB is known to lead to negative energy balance and different degrees of WL, and decreases in total fat and lean body mass and fat in the liver, visceral and peripheral tissues⁴. These changes are also associated with a decrease in hepatic glucose production and an increase in insulin sensitivity in the liver, muscle and adipose tissue⁵. RYGB is also known to promote post-prandial changes in many gastrointestinal (e.g. ghrelin, glucagon-like-peptide 1, glucose-dependent insulinotropic polypeptide, peptide YY) and pancreatic (insulin, glucagon, pancreatic polypeptide) hormone levels⁵. These hormones affect gastric emptying, glucose regulatory mechanisms, central nervous system hunger and satiety mechanisms⁶ in addition to changes in diet induced thermogenesis⁷, bile acid metabolism⁸ and gut microbiota composition⁹. It has been recently suggested that persons undergoing RYGB may also have increases in weight-adjusted resting energy expenditure (Wt-REE) after substantial WL has occurred.¹⁰ However most studies reporting changes in REE after RYGB either lacked control groups (i.e. diet and other surgical control)^{4, 10–13}, or did not use uniform reporting, i.e., have not routinely adjusted REE for changes in body weight and body composition¹². Adjusting REE is particularly important in the morbidly obese due to the large magnitude of the post-operative body composition and weight changes. On the other hand, studies have suggested that lesser degrees of WL induced by diet alone results in a 6 to 10% reduction in unadjusted REE¹⁴, which may be one of the many barriers to successful WL by non-surgical means.

The aims of this study were to determine if there are changes in REE as well as Wt-REE and lean body mass-adjusted REE (LBM-REE) after RYGB and AGB and if these changes are associated with the magnitude of WL that occurs after surgery.

MATERIAL AND METHODS

Morbidly obese non-diabetic patients, selected to undergo RYGB or AGB, were recruited at the University of California San Francisco's (UCSF) Bariatric Surgery Program. They met the National Institutes of Health and UCSF Bariatric Surgery Program eligibility criteria for bariatric surgery as described previously¹⁵. Exclusion criteria included previous WL

surgery, foregut and/or hindgut surgery, and diagnosis of endocrine or chronic renal disease. This project was approved by the UCSF Committee on Human Research and San Francisco General Hospital Clinical Research Center (CRC) Advisory Committee. Written consent was obtained from each participant.

Three groups of morbidly obese patients were studied: RYGB followed by caloric restriction (RYGB, n=12), AGB followed by caloric restriction (AGB, n=8), and a group that underwent equivalent caloric restriction alone (Diet, n = 10). Studies were performed after admission to the CRC following a protocol previously described¹⁵. In short, studies were done at baseline (visit 1, V1) and after 14 days' (visit 2, V2) consumption of identical calorically restricted diets in all three groups, and again 6 months (visit 3, V3) following RYGB and AGB, to assess the changes after more substantial WL had occurred. The current study presents original and unpublished data (thermogenic, indirect calorimetry data) together with selected results (demographics and weight loss) from previously published studies in two patients groups (RYGB and Diet)^{15, 16} as well as unpublished data and results obtained in a newly reported group (AGB) that was studied contemporaneously using an identical protocol.

Allocation to RYGB or AGB was based on patient preferences. Patients either underwent immediate surgery (RYGB, n=12 or AGB, n=8) followed by calorie restriction, or calorie restriction only (Diet, n=10). Allocation to immediate vs. delayed surgery was determined by randomization in the initial 20 patients and then by CRC and surgery date availability in the last ten patients. Patients in the Diet group went on to have their desired surgery after finishing V2.

Baseline evaluation (Visit 1, V1)

Participants underwent dual-energy X-ray absorptiometry (DXA, Hologic Discovery Wi, Bedford, MA, USA) to measure total body fat and LBM. Scanning was not performed in 4 subjects who weighed >160 kg, the weight limit for the scanner.

After an overnight fast (12 hours) open-circuit indirect calorimetry (SensorMedics, Deltatrac II Metabolic Monitor) was performed. Participants rested at least 30 minutes in a supine position in a thermo-regulated and quiet room after which they were placed under a plastic hood connected to the metabolic monitor for 30 minutes. Resting energy expenditure [in kilocalories (kcal)/day (d)] was calculated using measurements obtained during the last 20 minutes after stable values were achieved. REE was adjusted for body weight [Wt-REE, kcal/kilogram (kg)/d] and LBM (LBM-REE, kcal/kg of LBM/d).

Follow-up in Patients Undergoing Immediate Surgery

The participants assigned to immediate surgery underwent the procedure the day after discharge from the CRC after V1. RYGB and AGB were performed in a standardized fashion by one author (GC) as previously described^{15, 17}. In brief, RYGB was performed laparoscopically, a 30-mL gastric pouch created and connected to an alimentary limb of 100 cm and a biliopancreatic limb of 50 cm. AGB (Lap Band; Allergan, Inc, Irvine, California) was inserted laparoscopically, using the pars flaccida technique according to the manufacturer's guidelines. AGB adjustments started at 6 weeks after surgery, thus at visit 2

(V2) the AGB was empty. Additional office visits occurred at every 2 months after surgery and further AGB adjustments were done according to patients needs as per standard manufacturer guidelines.

Participants were then followed as outpatients for 14 days, during which they consumed a standardized low calorie diet: Optifast HP (Novartis Nutrition Corporation), which provides 800 kcal/day (25% carbohydrate, 48% protein, and 27% fat). Participants were allowed to consume calorie-free, noncarbonated soft drinks and water ad libitum. They were given prepackaged servings and instructed to follow a specific meal schedule. Each participant met with the dietitian during the initial inpatient admission for counseling and individualized instructions regarding the diet. During the 14-day outpatient period, participants were contacted daily by a research fellow or dietitian from the UCSF Bariatric Surgery Program.

Follow-up in Patients Undergoing Diet Alone

After completing the baseline evaluation and discharge from the CRC, participants assigned to the Diet group started the 14-day diet period at home, consuming the identical standardized diet and with the same follow-up procedures as described for the RYGB and AGB groups above. Physical activity was not assessed in any group.

Follow-up Assessments (Visit 2 and Visit 3)

After 14 days of hypocaloric feeding, all participants were readmitted to the CRC (visit 2, V2) and underwent the same assessments that were performed at V1. They were then discharged and continued their standard medical treatment. Six participants in the Diet group underwent RYGB after the V2 assessment. A total of 14 participants (10 who were originally assigned to RYGB and 4 originally assigned to Diet who subsequently underwent RYGB) had a third inpatient evaluation 6 months after RYGB (visit 3, V3). In the AGB group 7 participants (6 who were originally assigned to AGB and 1 originally assigned to Diet who subsequently underwent AGB) underwent a third evaluation (V3). The remaining participants decided to drop out of the study after visit 2 and were not studied further; these were 5 patients from the Diet Group (3 that eventually underwent RYGB and 2 Band), and 2 patients from RYGB and Band groups each.

Statistical Analysis

Data are summarized as mean and standard deviation unless otherwise stated. The unadjusted association of proportions between groups was determined by chisquare test. Changes in continuous variables from V1 to V2 and V1 to V3 were compared between and within groups using two-sided and paired t tests, respectively. Resting energy expenditure (REE) is presented in three ways: REE (kcal/d) – the unadjusted number of calculated kilocalories per day; weight-adjusted REE (Wt-REE) (kcal/kg/d) - number of calculated kilocalories per kilogram of body weight per day and LBM-adjusted REE (LBM-REE) (kcal/kg of LBM/day) - number of calculated kilocalories per kilogram of LBM per day. LBM-REE was not available in the 4 participants who did not undergo DXA scanning at baseline (RYGB group, n=3, AGB group, n=1). Calculation of percent excess weight loss (%EWL) used Metropolitan Life Insurance tables to determine ideal weight¹⁶. Correlations were calculated using Pearson Correlation Coefficient. Statistical significance was

considered to be $p < 0.05$. SPSS, version 13.0.1 (SPSS Inc, Chicago, IL, USA), was used for all statistical analyses.

RESULTS

At baseline, demographic, clinical and thermodynamic characteristics did not differ significantly among groups (Table 1, modified from¹⁵). After 14 days, %EWL was similar in all three groups (Table 2).

There was a decrease in unadjusted REE in the AGB group and a trend to decreases in RYGB and Diet groups after two weeks (Table 2); although there was no significant difference in the magnitude of changes between the groups. Wt-REE and LBM-REE did not change significantly in any group after two weeks (Table 2).

At 6 months, patients who underwent RYGB had significantly greater %EWL than those who underwent AGB (Table 3). The loss of fat mass and the percentage of body mass lost as fat were significantly greater in the RYGB group. LBM decreased significantly in both groups, but there was a significantly greater increase in the percentage of LBM (%LBM), indicative of relative preservation of LBM, in the RYGB group. Unadjusted REE decreased in both groups, but Wt-REE increased significantly after RYGB only. At six months, in both groups combined, there was a significant positive correlation between changes in Wt-REE and %EWL (Fig.1).

DISCUSSION

In this study body weight and unadjusted REE decreased significantly 6 months after both RYGB and AGB, and those who underwent RYGB experienced greater WL. Wt-REE increased significantly at 6 months only in the RYGB group, and this increase correlated with %EWL. Body composition changed significantly in both surgical groups at 6 months, and the proportional amount of fat loss (% of fat loss) and the corresponding increase in %LBM were significantly greater after RYGB. This relative preservation of LBM and increase in Wt-REE may be factors associated with greater WL after RYGB.

REE is the largest component of total energy expenditure, being responsible for 70% to 75% of daily total energy expenditure in sedentary populations¹⁰. Therefore changes in REE after WL could play an important role in limiting or aiding further WL or preventing weight regain in the long-term¹⁸. WL after bariatric surgery or by dieting alone includes loss of both fat mass and LBM, but the proportional changes of each compartment may differ with the magnitude of WL and the various surgical approaches. In turn this difference may then have a differential impact on changes in REE. LBM is the greatest determinant of REE (estimates vary from 60 to 80%)^{10, 18} as it has a higher metabolic rate than fat^{11, 19}. Notably, the proportions of weight as LBM and fat mass are significantly altered in morbidly obese patients, who have a significantly greater amount of both total body and visceral fat. Thus, the proportional contribution of fat mass to REE is greater in morbidly obese individuals than in lean individuals. Others have shown that the rapid WL caused by bariatric surgery is associated with a significant reduction of visceral fat⁴ and that the reduction in unadjusted REE observed during WL can partly be explained by reduction of visceral fat, independent

of changes in LBM²⁰. Busetto et al.²⁰ found a significant decrease in REE 6 months after AGB, that was significantly correlated with loss of visceral fat measured by computed tomography ($r=0.57$, $p<0.05$) and LBM measured by bioelectrical impedance analysis ($r=0.63$, $P<0.05$), but not total fat. In multiple regression analysis, LBM and visceral fat changes were independently correlated with REE. Although adjusting REE for actual body weight and body composition takes the large amount of fat loss and the changes in LBM into account, it is possible that unmeasured decreases in visceral fat may have also affected our results.

A few previous studies examined body composition and thermogenic changes after RYGB^{4, 10–13} or AGB^{21, 22}, but, to our knowledge, no study had both diet and surgical control groups as ours. Faria et al.¹⁰ examined 46 patients before and at least 6 months after RYGB and studied body composition and REE. Postoperative they found a significant decrease in %fat and a corresponding significant increase in %LBM, which is similar to our study. In our study %EWL correlated with changes in Wt-REE, confirming the findings from others^{10, 21}. Carey et al.¹³ assessed body composition and REE prior to bariatric surgery (18 RYGB and 1 AGB) at 1, 3 and 6 months after surgery. They found at all three postoperative time points a significant loss in fat mass and LBM and a significant reduction in REE after 1 month but no more significant changes at 3 and 6 months. In our study we examined patients after 2 weeks and we found that, other than weight, there were no significant changes in body composition and LBM- and Wt-REE. However, there was some evidence of a decrease in unadjusted REE. REE also decreased in the study by Faria et al.¹⁰, while Wt-REE increased significantly after 6 months and this increase was positively correlated with %LBM, a finding similar to our study. While the magnitude of fat mass loss may in part explain this relationship, this is also consistent with the notion that LBM is closely correlated with REE, thus the increased %LBM observed after RYGB in our study may partly explain the increase in Wt-REE. Of note, the differential change in %LBM may be a result of greater fat loss achieved with RYGB but may also reflect improved physical activity, improved nutritional choices and other unmeasured factors.

The possible factors, other than relative preservation of LBM, leading to an increase in Wt-REE after RYGB are speculative. They include many changes that are known to impact REE and are also known to occur with RYGB and WL, including increases in diet-induced thermogenesis after RYGB⁷ and other known physiologic changes such as post-prandial levels of gastrointestinal and pancreatic hormone levels^{5, 14}, changes in gut microbiota⁹ and others. RYGB promotes changes in postprandial levels of many gastrointestinal and pancreatic hormone levels including peptide YY (PYY) and glucagon-like-peptide 1 (GLP-1) that have been found to alter diet-induced energy and resting energy expenditure¹⁴. PYY has been documented to increase total energy expenditure¹⁴, and infusion of PYY in normal weight and obese adults resulted in an increase of total energy expenditure²³. Pannacciulli et al.²⁴ found that higher fasting plasma GLP-1 concentrations were associated with higher rates of REE independent of age, sex and body composition in 46 patients with BMI ranging from 18.5 to 50 kg/m². Other studies, however, showed a reduction in diet-induced thermogenesis after GLP-1 infusion in lean and obese humans²⁵. RYGB results in

enhanced postprandial release of GLP-1 and PYY⁵ and therefore, both could impact REE and diet-induced thermogenesis¹⁴.

In our study REE changes at six months were different for AGB compared to RYGB. After AGB, Wt- or LBM-REE did not change. This is in contrast to other studies reporting results after AGB. Galtier et al.²¹ reported an increase in Wt-REE and both Galtier et al.²¹ and Coupaye et al.²² reported a significant decrease of LBM-REE after AGB. Potential reasons for these findings to differ from our study are differences in study time point (6 months versus 12 months in the other two studies), the relatively modest WL with AGB in our population, and differences in the body composition and other characteristics of the study populations. We acknowledge that, had the RYGB and AGB groups in the current study been matched for WL and changes in body composition, we may have seen increases in Wt-REE and %LBM in the AGB group that are comparable to those observed with RYGB.

Limitations of the present study include the relatively small sample size in each group, absence of DXA results in four participants whose weight exceeded the limit of the scanner, unmeasured possible differences in visceral and subcutaneous fat mass at baseline and after surgery, and possible differences between groups in physical activity and dietary intake between visits.

CONCLUSION

In conclusion, our study shows that Wt-REE increased significantly after RYGB, and this increase was associated with an increase %EWL. The relative preservation of LBM and increase in Wt-REE may be factors supporting the substantial and sustained WL after RYGB.

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ABBREVIATIONS

WL	weight loss
RYGB	Roux-en-Y gastric bypass
AGB	adjustable gastric banding
REE	resting energy expenditure (kcal/day)
Wt-REE	weight-adjusted REE (kcal/kg/day)
LBM	lean body mass
LBM-REE	LBM-adjusted REE (kcal/kg of LBM/day)
CRC	Clinical Research Center
V1	visit 1 (baseline)

V2	visit 2 (after 14 days)
V3	visit 3 (after 6 months)
kcal	kilocalories
d	day
kg	kilogram
%EWL	percent of excess body weight loss
%LBM	percentage of weight as lean body mass
BMI	body mass index

References

1. Buchwald H, Oien DM. Metabolic/bariatric surgery worldwide 2011. *Obes Surg.* 2013; 23(4):427–436. [PubMed: 23338049]
2. Buchwald H, Avidor Y, Braunwald E, et al. Bariatric surgery: a systematic review and meta-analysis. *Jama.* 2004; 292(14):1724–1737. [PubMed: 15479938]
3. 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(3):248–256. e5. [PubMed: 19272486]
4. Del Genio F, Del Genio G, De Sio I, et al. Noninvasive evaluation of abdominal fat and liver changes following progressive weight loss in severely obese patients treated with laparoscopic gastric bypass. *Obes Surg.* 2009; 19(12):1664–1671. [PubMed: 19526270]
5. Dirksen C, Jorgensen NB, Bojsen-Moller KN, et al. Mechanisms of improved glycaemic control after Roux-en-Y gastric bypass. *Diabetologia.* 2012; 55(7):1890–1901. [PubMed: 22538359]
6. Ashrafian H, le Roux CW. Metabolic surgery and gut hormones - a review of bariatric entero-humoral modulation. *Physiol Behav.* 2009; 97(5):620–631. [PubMed: 19303889]
7. Faria SL, Faria OP, Cardeal Mde A, de Gouvea HR, Buffington C. Diet-induced thermogenesis and respiratory quotient after Roux-en-Y gastric bypass. *Surg Obes Relat Dis.* 2012; 8(6):797–802. [PubMed: 22884301]
8. Ashrafian H, Athanasiou T, Li JV, et al. Diabetes resolution and hyperinsulinaemia after metabolic Roux-en-Y gastric bypass. *Obes Rev.* 2011; 12(5):e257–e272. [PubMed: 20880129]
9. Ley RE, Turnbaugh PJ, Klein S, Gordon JI. Microbial ecology: human gut microbes associated with obesity. *Nature.* 2006; 444(7122):1022–1023. [PubMed: 17183309]
10. Faria SL, Faria OP, Buffington C, de Almeida Cardeal M, Rodrigues de Gouvea H. Energy expenditure before and after Roux-en-Y gastric bypass. *Obes Surg.* 2012; 22(9):1450–1455. [PubMed: 22592393]
11. Tamboli RA, Hossain HA, Marks PA, et al. Body composition and energy metabolism following Roux-en-Y gastric bypass surgery. *Obesity (Silver Spring).* 2010; 18(9):1718–1724. [PubMed: 20414197]
12. Das SK, Roberts SB, McCrory MA, et al. Long-term changes in energy expenditure and body composition after massive weight loss induced by gastric bypass surgery. *Am J Clin Nutr.* 2003; 78(1):22–30. [PubMed: 12816767]
13. Carey DG, Pliego GJ, Raymond RL, Skau KB. Body composition and metabolic changes following bariatric surgery: effects on fat mass, lean mass and basal metabolic rate. *Obes Surg.* 2006; 16(4):469–477. [PubMed: 16608613]
14. Thivel D, Brakonietki K, Duche P, Beatrice M, Yves B, Laferrere B. Surgical weight loss: impact on energy expenditure. *Obes Surg.* 2013; 23(2):255–266. [PubMed: 23224568]
15. Campos GM, Rabl C, Peeva S, et al. Improvement in peripheral glucose uptake after gastric bypass surgery is observed only after substantial weight loss has occurred and correlates with the magnitude of weight lost. *J Gastrointest Surg.* 2010; 14(1):15–23. [PubMed: 19838759]

16. Campos GM, Rabl C, Havel PJ, et al. Changes in post-prandial glucose and pancreatic hormones, and steady-state insulin and free fatty acids after gastric bypass surgery. *Surg Obes Relat Dis.* 2013
17. Campos GM, Rabl C, Roll GR, et al. Better weight loss, resolution of diabetes, and quality of life for laparoscopic gastric bypass vs banding: results of a 2-cohort pair-matched study. *Arch Surg.* 2011; 146(2):149–155. [PubMed: 21339424]
18. Bosy-Westphal A, Kossel E, Goele K, et al. Contribution of individual organ mass loss to weight loss-associated decline in resting energy expenditure. *Am J Clin Nutr.* 2009; 90(4):993–1001. [PubMed: 19710198]
19. Wang Z, Ying Z, Bosy-Westphal A, et al. Evaluation of specific metabolic rates of major organs and tissues: comparison between nonobese and obese women. *Obesity (Silver Spring).* 2012; 20(1):95–100. [PubMed: 21836642]
20. Busetto L, Perini P, Giantin V, et al. Relationship between energy expenditure and visceral fat accumulation in obese women submitted to adjustable silicone gastric banding (ASGB). *Int J Obes Relat Metab Disord.* 1995; 19(4):227–233. [PubMed: 7627245]
21. Galtier F, Farret A, Verdier R, et al. Resting energy expenditure and fuel metabolism following laparoscopic adjustable gastric banding in severely obese women: relationships with excess weight lost. *Int J Obes (Lond).* 2006; 30(7):1104–1110. [PubMed: 16477271]
22. Coupaye M, Bouillot JL, Coussieu C, Guy-Grand B, Basdevant A, Oppert JM. One-year changes in energy expenditure and serum leptin following adjustable gastric banding in obese women. *Obes Surg.* 2005; 15(6):827–833. [PubMed: 15978155]
23. Sloth B, Davidsen L, Holst JJ, Flint A, Astrup A. Effect of subcutaneous injections of PYY1-36 and PYY3-36 on appetite, ad libitum energy intake, and plasma free fatty acid concentration in obese males. *Am J Physiol Endocrinol Metab.* 2007; 293(2):E604–E609. [PubMed: 17566112]
24. Pannacciulli N, Bunt JC, Koska J, Bogardus C, Krakoff J. Higher fasting plasma concentrations of glucagon-like peptide 1 are associated with higher resting energy expenditure and fat oxidation rates in humans. *Am J Clin Nutr.* 2006; 84(3):556–560. [PubMed: 16960169]
25. Flint A, Raben A, Ersboll AK, Holst JJ, Astrup A. The effect of physiological levels of glucagon-like peptide-1 on appetite, gastric emptying, energy and substrate metabolism in obesity. *Int J Obes Relat Metab Disord.* 2001; 25(6):781–792. [PubMed: 11439290]

Figure 1.

Correlation between the changes in weight-adjusted REE (between V1 and V3) and %EWL at 6 months. %EWL = percent excess weight loss; Wt-REE = weight-adjusted resting energy expenditure, kcal/kg/d ; V1 = Visit 1 (baseline); V3 = Visit 3 (6 months); AGB patients = dots RYGB patients = circles

Table 1

Demographics, clinical and thermogenic characteristics of the RYGB, AGB and Diet groups at baseline (modified from Campos et al.¹⁵).

	RYGB (n=12)	AGB (n=8)	Diet only (n=10)	<i>p value</i>
Female/Male	9:3	7:1	6:4	<i>0.42</i>
Age (years)	47.4±8.7	49.0±10.7	40.2±13.4	<i>0.19</i>
Weight (kg)	138.0±21.6	120.5±17.5	134.7±16.9	<i>0.14</i>
BMI (kg/m ²)	48.4±6.8	44.3±5.0	48.3±6.6	<i>0.31</i>
% EBW	55.4±6.4	51.4±6.3	55.3±6.8	<i>0.34</i>
% Fat [*]	48.6±6.8	48.1±5.4	46.8±4.7	<i>0.78</i>
% LBM [*]	49.2±6.7	49.6±5.1	51.1±4.5	<i>0.75</i>
REE (kcal/d)	2114±337	1837±154	2091±363	<i>0.13</i>
Wt-REE	15.1±1.2	15.4±1.9	15.8±1.3	<i>0.60</i>
LBM-REE [*]	32.0±4.0	32.4±4.4	32.7±2.1	<i>0.92</i>

RYGB = Roux-en-Y gastric bypass; AGB = adjustable gastric banding; kg = kilogram; BMI = body mass index; EBW = excess body weight; LBM = lean body mass; REE = resting energy expenditure; Wt-REE = weight-adjusted REE, kcal/kg/d; LBM-REE = LBM adjusted REE, kcal/kg/d.

^{*} fat and LBM by DXA (dual-energy X-ray absorptiometry)

Table 2

Body weight, body composition and thermogenic changes in the RYGB, AGB and Diet groups at 14 days (Visit 2).

	RYGB (n=12)	AGB (n=8)	Diet only (n=10)	<i>p value</i>
Weight (kg), V1	138.0±21.6	120.5±17.5	134.7±16.9	
Weight (kg), V2	128.1±19.8	113.4±18.0	126.5±15.6	
Weight (kg) V1–2	–9.9±2.4	–7.1±1.9	–8.2±2.3	0.03
<i>p value</i>	<0.01	<0.01	<0.01	
%EWL V1–2	12.7±2.4	12.0±4.3	10.9±2.8	0.38
Fat* (kg), V1	59.8±5.7	57.8±13.2	61.2±8.6	
Fat* (kg), V2	57.0±5.9	55.3±13.7	59.1±9.1	
Fat (kg) V1–V2	–2.8±1.2	–2.5±1.0	–2.0±1.2	0.42
<i>p value</i>	<0.01	<0.01	<0.01	
% Fat*, V1	48.6±6.8	48.1±5.4	46.8±4.7	
% Fat*, V2	49.0±7.0	48.3±5.3	47.3±5.2	
% Fat V1–2*	0.47±0.95	0.27±1.01	0.56±0.76	0.80
<i>p value</i>	0.2	0.51	0.04	
LBM* (kg), V1	61.9±15.4	59.0±7.6	67.2±11.5	
LBM* (kg), V2	57.7±14.4	55.4±6.5	63.4±11.2	
LBM (kg) V1–V2	–4.2±1.5	–3.6±2.3	–3.9±0.8	0.80
<i>p value</i>	<0.01	<0.01	<0.01	
% LBM*, V1	49.2±6.7	49.6±5.1	51.1±4.5	
% LBM*, V2	48.6±6.9	49.1±4.9	50.4±5.0	
% LBM V1–2*	–0.59±0.94	–0.48±1.04	–0.63±0.76	0.94
<i>p value</i>	0.12	0.27	0.03	
REE, V1	2145±338	1831±165	2091±363	
REE, V2	2024±252	1678±231	1985±288	
REE V1–2	–121±196	–153±119	–107±205	0.88
<i>p value</i>	0.08	0.02	0.19	
Wt-REE, V1	15.1±1.2	15.2±1.9	15.8±1.3	
Wt-REE, V2	15.3±1.4	14.6±1.5	15.8±1.0	
Wt-REE V1–2	0.22±1.23	–0.61±1.10	0.03±1.27	0.37
<i>p value</i>	0.58	0.19	0.95	
LBM-REE, V1	31.4±4.0	31.8±4.5	32.7±2.1	
LBM-REE, V2	32.6±5.0	31.3±2.9	33.2±3.2	
LBM-REE V1–2	1.24±1.89	–0.45±2.67	0.47±3.0	0.55
<i>p value</i>	0.17	0.7	0.67	

RYGB = Roux-en-Y gastric bypass; AGB = adjustable gastric banding; EWL = excess weight loss; LBM = lean body mass; REE = resting energy expenditure, kcal/d; V1 = Visit 1 (baseline); V2 = Visit 2 (14 days); Wt-REE = weight adjusted REE, kcal/kg/d; LBM-REE = LBM adjusted REE, kcal/kg LBM/d;

* fat and LBM by DXA (dual-energy X-ray absorptiometry);

Table 3

Body weight, body composition and thermogenic changes in the RYGB and AGB groups at 6 months (Visit 3).

	RYGB (n=14)	AGB (n=7)	<i>p value</i>
Weight (kg), V1	134.2±19.5	119.8±11.6	
Weight (kg), V3	98.5±15.9	107.3±14.5	
Weight (kg) V1–3	–35.7±5.2	–12.5±6.3	<i><0.01</i>
<i>p value</i>	<i><0.01</i>	<i><0.01</i>	
%EWL V1–3	48.7±10.0	20.5±11.4	<i><0.01</i>
Fat* (kg), V1	60.2±8.3	56.1±7.2	
Fat* (kg), V3	36.4±8.3	49.0±7.9	
Fat (kg) V1–3	–23.9±4.6	–7.2±3.6	<i><0.01</i>
<i>p value</i>	<i><0.01</i>	0.01	
% Fat*, V1	48.3±5.9	47.2±4.7	
% Fat*, V3	39.6±8.1	44.3±4.7	
% Fat V1–3*	8.67±3.18	–2.90±2.31	<i><0.01</i>
<i>p value</i>	<i><0.01</i>	0.03	
LBM* (kg), V1	62.4±12.7	60.2±8.4	
LBM* (kg), V3	53.1±11.4	56.2±8.8	
LBM(kg) V1–3	–9.2±2.9	–4.0±3.0	0.01
<i>p value</i>	<i><0.01</i>	0.02	
% LBM*, V1	49.5±5.7	50.5±4.4	
% LBM*, V3	57.4±7.8	52.1±4.5	
% LBM V1–3*	7.95±3.02	1.58±1.54	<i><0.01</i>
<i>p value</i>	<i><0.01</i>	0.05	
REE, V1	2096±298	1840±202	
REE, V3	1777±270	1684±278	
REE V1–3	–318±149	–157±145	0.05
<i>p value</i>	<i><0.01</i>	0.05	
Wt-REE, V1	15.0±1.0	15.2±1.4	
Wt-REE, V3	17.6±1.8	15.4±1.4	
Wt-REE V1–3	2.58±1.51	0.20±0.70	<i><0.01</i>
<i>p value</i>	<i><0.01</i>	0.52	
LBM-REE, V1	30.9±2.6	31.3±4.8	
LBM-REE, V3	32.1±4.0	31.3±3.7	
LBM-REE V1–3	1.14±2.56	0.05±1.59	0.37
<i>p value</i>	0.25	0.95	

RYGB = Roux-en-Y gastric bypass; AGB = adjustable gastric banding; %EWL = percent excess weight loss; LBM = lean body mass; V1 = Visit 1 (baseline); V3 = Visit 3 (6 months); REE = resting energy expenditure, kcal/d; Wt-REE = weight-adjusted REE, kcal/kg/d; LBM-REE = LBM adjusted REE, kcal/kg/d;

* fat and LBM by DXA (dual-energy X-ray absorptiometry)