Obesity Surgery (2019) 29:2503–2510
https://doi.org/10.1007/s11695-019-03879-4

ORIGINAL CONTRIBUTIONS

Comparative Effects of Medical Versus Surgical Weight Loss on Body Composition: a Pilot Randomized Trial

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Published online: 17 April 2019

Abstract

Objective Bariatric surgery leads to more rapid and greater weight loss (WL) compared to medical weight loss (MWL), but the differences in body composition (BC) changes for these modalities remain unclear. Due to the known health risks associated with central adiposity, we compared the changes in regional distribution of fat mass (FM) and lean mass (LM) after surgical versus MWL.

Methods In this 1:1:1 randomized trial among 15 persons with type 2 diabetes and body mass index (BMI) 30–39.9 kg/m^2, we compared changes in BC, by dual-energy X-ray absorptiometry and abdominal computerized tomography, at time of 10%WL or 9 months after intervention (whichever came first). Participants underwent MWL, adjustable gastric banding (AGB), or Roux-en-Y gastric bypass (RYGB). Non-parametric tests evaluated BC differences (FM, LM, and visceral adipose tissue [VAT]) within and across all three arms and between pair-wise comparisons.

Results Twelve female participants (75% African American) completed the study. Patient age, BMI, and baseline anthropometric characteristics were similar across study arms. AGB lost more LM (MWL − 5.2%, AGB − 10.3%, $p = 0.021$) and VAT (MWL + 10.9%, AGB − 28.0%, $p = 0.049$) than MWL. RYGB tended to lose more VAT (MWL +10.9%, RYGB − 20.2%, $p = 0.077$) than MWL. AGB tended to lose more LM than RYGB (AGB − 12.38%, RYGB − 7.29%, $p = 0.15$).

Conclusions At similar WL, AGB lost more LM and VAT than MWL; RYGB similarly lost more VAT. Given the metabolic benefits of reducing VAT and retaining LM, larger studies should confirm the changes in BC after surgical versus medical WL.

Clinical Trial Registration NCTDK089557 – ClinicalTrials.gov

Keywords Bariatric surgery · Body composition · Weight loss · Clinical trial

Introduction

While the effects of bariatric surgery on total body weight loss and diabetes remission have been well documented, much less is known about the consequential changes in body composition. Body composition is often divided into fat mass (FM) and lean mass (LM) compartments (i.e., skin, water, bone, ligaments, tendons, internal organs, and muscles). The FM compartment can be further categorized by regional distribution. Of particular interest is visceral adipose tissue in the abdominal compartment. Visceral adipose tissue (VAT) is associated with metabolic dysregulation in obesity, including

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dyslipidemia, hypertension, insulin resistance, and type 2 diabetes [1]. LM accounts for the majority of resting metabolic rate, regulation of core body temperature, preservation of skeletal integrity, and maintenance and quality of life as the body ages [2, 3]. There is some evidence to suggest that surgical weight loss induces a disproportionate decrease in LM as compared to FM.

There are suggested metabolic benefits of losing excess fat, particularly visceral adipose tissue while retaining LM, during intensive weight loss. Thus, we sought to compare the relative changes in LM and regional distribution of FM in participants with type 2 diabetes and mild-to-moderate obesity, who achieved approximately the same amount of total weight loss (10%) through either medical weight loss (MWL), adjustable gastric banding (AGB), or Roux-en-Y gastric bypass (RYGB).

Methods

Study Design and Participants

We conducted a secondary analysis of a parallel-arm randomized control trial to evaluate the differential effects of surgical versus medical weight loss interventions on body composition in adults with type 2 diabetes and mild-to-moderate obesity. From July 2013 to July 2014, participants aged 21–64 years were randomized 1:1:1 to MWL ($n = 4$), AGB ($n = 4$), or RYGB ($n = 4$), and stratified by body mass index (BMI, 30.0–34.9 versus 35.0–39.9 kg/m^2) by a computerized program. Inclusion criteria were diagnosis of diabetes mellitus with hemoglobin A1c (HbA1c) greater than 6.5%, class 1 or 2 obesity with BMI 30.0–39.9 kg/m^2, and insurance by a participating single health insurer. Participants were followed until 10% of highest starting body weight was lost or at 9 months of follow-up, whichever occurred first. The participants and investigators of this trial were not blinded to intervention. This study was approved by the Institutional Review Board and all subjects provided informed, written consent.

Medical Weight Loss Arm

The MWL intervention was based on a combination of principles used in the Diabetes Prevention Program, the Look AHEAD trial, and the POWER Trial [4–6]. The MWL intervention employed a reduced calorie diet based on participants' starting weight (1200–1500 kcal/day for < 220 pounds, 1500–1800 kcal/day > 220 pounds) and was typically comprised of two shakes, one nutrition bar, one-to-two low calorie, high-fiber snacks, and a conventional meal. Participants attended weekly one-on-one educational visits with a research dietitian with a focus on reviewing progress, ensuring adherence for reducing calories, and increasing physical activity and kept food and exercise log. In order to achieve at least 180 min of exercise per week, participants were advised to exercise at increments of at least 15 min and to choose exercise activities that they enjoy whether they are aerobic or strength-training exercise. Participants self-reported the type and duration of exercise and the total exercise minutes were tallied.

Surgical Arms: RYGB and AGB

All surgical procedures were performed at the Johns Hopkins Center for Bariatric Surgery using standardized protocols. Participants had visits with a registered dietitian 2–4 weeks pre-operatively and at 2- and 6-weeks post-operatively. They were instructed to follow nutrition guidelines developed for the Johns Hopkins Bayview Medical Center, in order to specify dietary recommendations in accordance with the American Society for Metabolic and Bariatric Surgery [7]. Payment for the surgical procedures was covered by the insurer, regardless of baseline BMI, under a research agreement.

Demographics and Clinical Characteristics

All values considered are baseline (at randomization) versus final (at 10% weight loss or 9-month follow-up). Demographic characteristics (age, sex, race) and medical history were collected at baseline. Hemoglobin A1c (HbA1c) and fasting glucose were measured at our institution's clinical laboratory according to standardized clinical protocols.

Dual-Energy X-ray Absorptiometry

Total and regional body FM and LM were measured using dual-energy X-ray absorptiometry (DXA; Lunar Prodigy Densitometer). Total FM, LM, truncal FM, and peripheral FM were obtained as DXA results. Peripheral and trunk regions were defined via existing software parameters. Percent change values were determined by the following equation: 100 × (final – baseline) / baseline.

Abdominal Computerized Tomography

The area of intra-abdominal fat and subcutaneous fat were estimated using abdominal computerized tomography (CT). Intra-abdominal fat was used as a surrogate for VAT in this study. Subjects underwent a single slice CT scan at L4-L5 at our institution (coefficient of variation of a single abdominal scan is < 1.5% in this laboratory). The images were then digitized by optical density to separate fat compartments using a modified version of the National Institute of Health Image program (1.33), and pixel units were converted to area measurements using an internal calibration standard. Digitized images were analyzed in a blinded fashion by a trained radiologist.

Statistical Analysis

Non-parametric summary statistics were used to describe participant characteristics given the small sample size. To evaluate the effect of the three interventions on body composition characteristics, we used Kruskal-Wallis tests to assess any differences between the arms. We used Wilcoxon Mann-Whitney test for three pair-wise group contrasts on the change in body composition characteristics: (1) MWL versus RYGB, (2) MWL versus AGB, and (3) RYGB versus AGB. All variables were examined at the $p < 0.05$ level of significance. All analyses were conducted using STATA 15 (StataCorp, College Station, TX).

Results

Participant Clinical Characteristics

Fifteen participants were randomized to an intervention, and three withdrew prior to receipt of any intervention. We analyzed the results of the 12 remaining participants who completed the study. The clinical characteristics of study participants in each of the three study arms were comparable (Table 1). Median ages of study participants in the MWL, AGB, and RYGB arms were 56, 45, and 57 years, respectively. All study participants were women, and 75% were African American with type 2 diabetes. One third had a BMI of 30–34.9 kg/m^2 (and two thirds a BMI of 35–39.9 kg/m^2). All arms experienced a similar reduction in mean HbA1c levels after intervention. In addition, all participants experienced a reduction or no change in the number of diabetes medications after intervention.

Anthropometry

The baseline anthropometric characteristics of the study participants were similar (Table 1). Time to 10%WL was significantly shorter for the AGB and RYGB arms than the MWL arm ($P_{\text{AGB vs. MWL}} = 0.043$, $P_{\text{RYGB vs. MWL}} = 0.021$). All three interventions showed decrease in weight, BMI, and waist circumference following the intervention. However, the AGB and RYGB arms lost significantly more weight than the MWL arm ($P_{\text{AGB vs. MWL}} = 0.021$, $P_{\text{RYGB vs. MWL}} = 0.043$). There were no significant differences in the changes in waist circumference across the three groups following the intervention.

Changes in Body Composition Characteristics by DXA

Baseline body composition characteristics were similar across all three intervention arms (Table 2). Similarly, percent change in total FM was similar across the three intervention arms. The AGB arm tended to lose the most LM of the three intervention arms (AGB −10.3%, MWL −5.2%, RYGB −6.2%; $p = 0.069$), and the AGB arm had significantly greater reduction in LM compared to MWL ($p = 0.021$). There were notable regional DXA differences in the change between baseline and follow-up truncal FM or peripheral FM.

Change in Intra-Abdominal and Subcutaneous Abdominal Fat in CT Imaging

One AGB and one MWL participant did not have complete abdominal CT imaging appropriate for comparison; thus, these two participants were excluded from this analysis, leaving three participants appropriate for analysis in each of the two groups. The MWL arm lost the least amount of subcutaneous FM among the three arms, and the two surgical arms lost subcutaneous fat similarly. The AGB arm lost more VAT compared to the MWL arm ($p = 0.049$), and the RYGB arm showed a similar pattern ($p = 0.077$). Two out of three MWL participants had increased VAT area at the end of MWL intervention. Overall, the two surgical arms similarly lost VAT (Table 3).

Discussion

We identified two findings important for the clinical care of patients who undergo intensive weight loss. First, at comparable weight loss and diabetes improvement, participants randomized to AGB tended to lose the greatest amount of total LM of the three intervention arms, particularly notable in comparison to the MWL arm. Second, both surgical arms lost more visceral adipose tissue than the MWL arm, which was particularly significant in comparison to the AGB arm. While there have been few trials which randomized participants to two interventions and a handful of prospective studies with varying results and little definitive data, this is one of the first to suggest such evidence by means of a randomized trial comparing these three weight loss modalities [8–12].

Lean Body Mass

The AGB arm had the greatest LM reduction, particularly when compared to MWL. Prior studies, reported a 12–33% decrease in LM, ranging from 6 months to 7 years, and one directly compared AGB and MWL with similar results, though with the use of orlistat and a hypocaloric diet, instead of caloric restriction and exercise as in our study [8, 13–15]. Changes after restrictive procedures are characterized by loss of body protein rather than fat, presumably due to impaired nutritional intake and accelerated proteolysis for support of post-operative gluconeogenesis [16]. AGB has also been associated with reduced post-operative levels of pre-albumin and serum total protein, likely due to significant reduction of

Table 1 Demographic and clinical characteristics of study participants ($n = 12$)

	MWL ($n = 4$)	AGB ($n = 4$)	RYGB ($n = 4$)	P_{ALL}	$P_{AGB\ vs.\ RYGB}$	$P_{AGB\ vs.\ MWL}$	$P_{RYGB\ vs.\ MWL}$
Age (years)	56 (32–62)	45 (41–53)	57 (43–60)	0.35			
Female	4 (100%)	4 (100%)	4 (100%)				
Race							
Black	3 (75%)	3 (75%)	3 (75%)				
White	1 (25%)	1 (25%)	1 (25%)				
Class 1 obesity, BMI 30–34.9 kg/m^2	1 (25%)	1 (25%)	2 (50%)				
Class 2 obesity, BMI 35–40 kg/m^2	3 (75%)	3 (75%)	2 (50%)				
Weight (kg)							
Baseline	109.8 (87.1–112.3)	98.7 (88.1–99.9)	94.2 (80.0–111.0)	0.31	1.0	0.25	0.15
Final	101.1 (84.5–106.0)	88.6 (79.3–91.2)	84.7 (71.8–100.4)				
% change	− 6.3 (− 8.8, − 3.0)	− 9.9 (− 10.7, − 8.5)	− 10.0 (− 10.3, − 9.5)	0.039	1.0	0.043	0.021
$P_{Intragroup}$	$p = 0.15$	$p = 0.083$	$p = 0.25$				
Waist circumference (cm)							
Baseline	113 (109–122)	117 (104–128)	115 (85–131)	0.93	0.77	0.77	1.0
Final	104 (101–115)	107 (99–119)	106 (83–122)				
% change	− 7.5 (− 9.8, − 4.1)	− 9.0 (− 10.0, − 5.0)	− 9.4 (− 10.0, − 2.2)	0.83	0.77	0.72	1.0
$P_{Intragroup}$	$p = 0.29$	$p = 0.31$	$p = 0.39$				
BMI, kg/m^2 (range)							
Baseline	38.5 (31.0–40.5)	35.8 (33.0–37.6)	35.1 (31.3–38.6)	0.49	0.77	0.25	0.39
Final	36.0 (30.3–37.8)	32.3 (29.8–33.8)	31.8 (29.2–34.8)				
% change	− 5.6 (− 8.6, − 2.4)	− 9.9 (− 10.6, − 8.5)	− 9.8 (− 9.8, − 9.13)	0.039	0.77	0.043	0.021
$P_{Intragroup}$	$p = 0.15$	$p = 0.043$	$p = 0.25$				
Time to 10% weight loss (months)	7.9 (4.4–9.6)	2.3 (2.1–4.3)	1.8 (0.9–5.6)	0.039	0.77	0.021	0.043
HbA1c (%)							
Baseline	8.4 (6.3–9.9)	8.4 (7.2–10.0)	8.5 (6.3–9.8)	0.94	0.77	0.77	0.89
Final	7.2 (6.3–7.4)	7.4 (6.8–8.0)	7.1 (6.0–8.8)				
% change	− 1.2 (− 2.6, 0)	− 1.0 (− 2.2, − 0.4)	− 1.2 (− 1.5, − 0.3)	1.0	1.0	1.0	1.0
$P_{Intragroup}$	$p = 0.38$	$p = 0.11$	$p = 0.31$				
Number of diabetes drugs							
Baseline	1.5 (0–4)	2 (1–3)	3 (1–6)				
Follow-up	1 (0–3)	2 (1–2)	2.5 (0–4)				
Change from baseline	− 0.5 (− 1, 0)	0 (− 1, 0)	− 1 (− 2, 0)	0.38			

All continuous variables displayed are median (range). P^{ALL} for comparison across groups using Kruskal-Wallis test. $P^{AGB\ vs\ RYGB}$, $P^{AGB\ vs\ MWL}$, and $P^{RYGB\ vs\ MWL}$ represent comparison of AGB to RYGB, AGB to MWL, and RYGB to MWL groups, respectively, using Wilcoxon-Mann-Whitney test. Percent (%) change was calculated using the following: 100 × (final − baseline) / baseline

BMI body mass index, HbA1c hemoglobin A1c, DM diabetes mellitus

Table 2 Body composition characteristics at baseline vs follow-up intervention at comparable weight loss ($n = 12$)

	MWL ($n = 4$)	AGB ($n = 4$)	RYGB ($n = 4$)	P_{ALL}	$P_{AGB\ vs.\ RYGB}$	$P_{AGB\ vs.\ MWL}$	$P_{RYGB\ vs.\ MWL}$
Total fat mass (kg)							
Baseline	49.5 (43.7–57.2)	43.7 (38.2–46.3)	43.8 (37.3–53.3)	0.23	1.0	0.08	0.25
Final	44.9 (42.5–49.8)	37.2 (36.0–40.5)	38.0 (31.0–48.8)				
% change	− 9.8 (− 13.0, − 1.6)	− 12.6 (− 18.7, − 3.9)	− 12.6 (− 18.0, − 8.2)	0.67	1.0	0.77	0.25
$P_{Intragroup}$	$p = 0.15$	$p = 0.043$	$p = 0.25$				
Total lean mass (kg)							
Baseline	56.3 (40.7–59.8)	51.7 (42.7–60.2)	49.4 (33.8–55.0)	0.69	0.55	1.0	0.39
Final	52.5 (39.4–57.3)	46.2 (38.9–48.5)	44.8 (32.4–51.2)				
% change	− 5.2 (− 7.4, − 3.0)	− 10.3 (− 20.1, − 8.9)	− 6.2 (− 12.4, − 4.2)	0.069	0.15	0.021	0.56
$P_{Intragroup}$	$p = 0.39$	$p = 0.15$	$p = 0.39$				
Truncal fat mass (kg)							
Baseline	24.9 (22.1–26.0)	24.1 (23.4–27.4)	23.7 (20.5–29.0)	0.93	0.77	0.77	0.77
Final	22.1 (19.9–22.8)	23.0 (18.2–23.9)	19.5 (16.0–26.5)				
% change	− 11.1 (− 12.4, − 9.5)	− 11.5 (− 22.2, 1.5)	− 17.2 (− 22.1, − 8.6)	0.67	0.77	1.0	0.25
$P_{Intragroup}$	$p = 0.083$	$p = 0.25$	$p = 0.15$				
Peripheral fat mass (kg)							
Baseline	24.7 (17.5–30.0)	17.3 (13.5–19.8)	19.1 (15.1–23.5)	0.12	0.56	0.083	0.08
Final	22.6 (19.4–25.0)	14.7 (11.7–16.6)	18.4 (11.6–21.1)				
% change	− 7.2 (− 16.0, 10.7)	− 14.3 (− 19.2, − 11.9)	− 12.1 (− 23.0, 12.2)	0.67	0.56	0.39	0.77
$P_{Intragroup}$	$p = 0.56$	$p = 0.15$	$p = 0.56$				

All continuous variables displayed as median (range). P^{ALL} for comparison across groups using Kruskal-Wallis test. $P^{AGB\ vs\ RYGB}$, $P^{AGB\ vs\ MWL}$, and $P^{RYGB\ vs\ MWL}$ represent comparison of AGB to RYGB, AGB to MWL, and RYGB to MWL groups, respectively, using Wilcoxon-Mann-Whitney test. Percent (%) change was calculated using the following: 100 × (final − baseline) / baseline

FM fat mass, LM lean mass, TFM truncal fat mass, PFM peripheral fat mass

food consumption (protein intake < 60 g/day) [17–19]. The loss of LM is theoretically concerning, since significant reduction could lead to protein malnutrition, which could hinder functional status and long-term prognosis. Indeed, purely restrictive procedures may not be entirely harmless and may accordingly require protein supplementation with close post-operative monitoring to preserve LM [19, 20].

While we show that LM reduction after AGB was greater than after RYGB, we are limited in making this comparison due to the study's small sample size. Olbers et al. support a greater loss of LM after AGB relative to RYGB after 1 year of follow-up. Differential effects were thought to be due to dietary differences, where RYGB patients reported avoiding fats, and AGB patients reported avoiding vegetables and meats [21]. More recently, Davidson et al. reported the opposite [22]. Importantly, RYGB patients typically have higher protein recommendations given that patients may experience both malabsorption and to prevent dumping syndrome, a fairly common phenomenon in the setting of carbohydrate-rich meals [23]. Future prospective trials may be needed to characterize this difference in LM reduction, its biologic underpinnings, and the appropriate recommendations for protein intake that may prevent such reductions.

The MWL arm had the least reduction in LM. MWL participants were instructed to pursue activity of at least 180 min per week; lifestyle intervention with physical activity is known to attenuate LM loss [24]. Further, slower rates of weight loss lead to less total loss of LM [25]. The Look AHEAD study reported similar results, in which female participants had a 2.3% LM reduction within 1 year [10]. Finally, despite intensive efforts, the MWL group loss less total weight overall, which may be a reflection of the LM findings.

Visceral Adipose Tissue

We show evidence that the two surgical arms lost more VAT than the MWL arm. While significant changes in VAT (20–35%) after either RYGB or AGB have been reported with both CT and MRI at 3 to 12 months post-operatively, there is no consensus on the comparative reduction between the two modalities [21, 26–29]. These changes in VAT are thought to lead to the improvement or remission of metabolic complications of obesity, particularly type 2 diabetes, in males and females 6 to 12 months post-surgery [30, 31]. AGB is associated with improvements in insulin resistance related to loss of VAT rather than total weight loss [27]. Moreover, the metabolic

Table 3 Subcutaneous abdominal and visceral adipose tissue at baseline vs follow-up intervention at comparable weight loss ($n = 10$)

	MWL ($n = 3$)[a]	AGB ($n = 3$)[a]	RYGB ($n = 4$)	P_{ALL}	$P_{AGB\ vs.\ RYGB}$	$P_{AGB\ vs.\ MWL}$	$P_{RYGB\ vs.\ MWL}$
Subcutaneous abdominal fat (cm^2)							
Baseline	457 (395–556)	447 (382–572)	471 (444–623)	0.90	0.72	0.83	0.72
Final	440 (405–519)	385 (371–474)	439.5 (373–526)				
% change	− 3.7 (− 6.7, 2.5)	− 17.0 (− 17.1, 0.8)	− 12.5 (− 16.0, − 4.2)	0.22	0.48	0.28	0.77
$P_{Intragroup}$	$p = 0.83$	$p = 0.51$	$p = 0.39$				
Visceral adipose tissue (cm^2)							
Baseline	138 (60–236)	211 (182–293)	133 (80–217)	0.32	0.16	0.28	0.72
Final	153 (54–262)	175 (108–211)	98 (59–213)				
% change	10.9 (− 10, 11.0)	− 28.0 (− 40.7, − 17.1)	− 20.2 (− 38.9, − 1.8)	0.066	0.29	0.049	0.077
$P_{Intragroup}$	$p = 0.83$	$p = 0.18$	$p = 0.31$				

All continuous variables displayed as median (range). P^{ALL} for comparison across groups using Kruskal-Wallis test. $P^{AGB\ vs\ RYGB}$, $P^{AGB\ vs\ MWL}$, and $P^{RYGB\ vs\ MWL}$ represent comparison of AGB to RYGB, AGB to MWL, and RYGB to MWL groups, respectively, using Wilcoxon-Mann-Whitney test. Percent (%) change was calculated using the following: 100 × (final − baseline) / baseline

[a] One participant in each of the MWL and AGB arms did not have complete baseline and final data for abdominal computerized tomography appropriate for analysis

benefits of VAT reduction include an improvement of lipid profile, hepatic insulin resistance, improvement in adipokine signaling, and decreased TNF-alpha signaling in adipose tissue. Some evidence contrarily suggests that effects of VAT may be linked to total body weight loss and that VAT alone may not have an effect in improving cardiovascular risk factors [32]. Consequences of undergoing a restrictive and/or malabsorptive surgery with regard to VAT reduction warrant further evaluation [33].

Among the three weight loss intervention arms, there was only a 5% reduction in VAT after MWL. Results in the literature vary due to several different types of interventions (i.e., physical activity and/or hypocaloric diet combinations) and follow-up periods. Koo et al. also used a 1200-cal restriction and similarly reported a 4% reduction in VAT by CT [34]. Notably, two MWL participants showed a gain in VAT at the end of intervention. This may be related to the slower rate of weight loss, modest degree of total body weight loss, relatively short follow-up period, small number of participants, or an inability to adhere to the dietary or physical activity in the MWL intervention.

Strengths and Weaknesses

A major strength of this study is the randomized design, which minimizes selection bias and confounding, allowing for valid inferences about the effects of each intervention. Standardized interventions by arm were used for each participant, who had either mild or moderate obesity, accounting for the vast majority of an obese population. All outcomes were measured before and after similar degrees of diabetes improvement and weight loss, allowing for unbiased comparisons. DXA and abdominal CT imaging (read in a blinded fashion) are considered the gold standard for assessing body composition. Participants received regular support and advice (within intervention arms) regarding eating behaviors, diet, multivitamin supplementation, and physical activity throughout the follow-up period, delivered by a single interventionist.

Limitations to this study include a small sample size and relatively short-term (2.5–9 months) follow-up. Since we recruited only female participants, although unintentional, the results may not be generalizable to male patients. Participant menopausal status was not collected and may confound results related to body composition. Furthermore, we did not verify whether the study participants who received bariatric surgery adhered during the study period to the recommended protein intake after bariatric surgery, which is 60–80 g/day or 1.1–1.5 g/kg of ideal body weight [35]. In addition, we did not control for the type, duration, or amount of diabetes medications that participants were taking prior to, during, or after intervention, and changes were managed by personal providers. Most participants were on either or a combination of the following medications: insulin/sulfonylureas, metformin, or GLP-1 agonists at baseline, which have been shown to possibly alter body composition. Finally, there may be differences among the participants with regard to individualized instruction on protein intake and physical activity; future assessments should control for these variables.

Conclusion

In this randomized trial, we show that at similar weight loss and diabetes improvement, AGB leads to a greater loss of LM and VAT compared to MWL; RYGB had similar but lesser effects on these changes. Given the metabolic benefit of retaining LM, patients who undergo restrictive procedures may warrant close follow-up to monitor for post-operative LM reduction and personalized management, including higher-protein diets and emphasis on physical activity. Moreover, our results suggest that the changes in VAT after MWL are less remarkable than the changes after bariatric surgery, which may have important implications for the metabolic sequelae of VAT reduction. Further studies, with larger study populations and longer follow-up, are warranted to confirm our findings regarding changes in body composition over time after bariatric surgery and the correlating metabolic changes.

Acknowledgements The authors would like to thank the patients and staff at the Johns Hopkins Center for Bariatric Surgery and the Institute for Clinical and Translational Research staff, without whom this research would not be possible. The study protocol is available upon request (submit request to jclark1@jhmi.edu) beginning at the time of publication and ending 36 months after publication. We are unable to share the individual participant data from this study.

Funding Sources JMC and NMM were supported by Grant Number 1R01DK089557 (PI: J Clark, NIH, NIDDK). CJL was supported by Grant Number 5KL2TR001077-02 as part of the Institute for Clinical and Translational Research Grant from the NIH/NCAT and career development award from the NIH/NIDDK (K23DK107921). This study was also supported by the Translational Research Enhancement Core of the Hopkins Digestive Diseases Basic Research Development Center (P30, DK089502-01 NIDDK/NIH) and by the Johns Hopkins Institute for Clinical and Translational Research (ICTR) which is funded in part by Grant Number UL1 TR001079 from the National Center for Advancing Translational Sciences (NCATS) a component of the National Institutes of Health (NIH), and NIH Roadmap for Medical Research.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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