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ORIGINAL CONTRIBUTIONS

Changes in Body Composition, Dietary Intake, and Substrate Oxidation in Patients Underwent Laparoscopic Roux-en-Y Gastric Bypass and Laparoscopic Sleeve Gastrectomy: a Comparative Prospective Study

Mahdieh Golzarand[1] · **Karamollah Toolabi**[2] · **Kurosh Djafarian**[1]

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Abstract

Purpose Laparoscopic Roux-en-Y gastric bypass (LRYGB) and laparoscopic sleeve gastrectomy (LSG) are the most popular procedures to treat morbid obesity among bariatric surgeries. However, only few studies have compared the changes in body composition, dietary intake, and substrate oxidation after LRYGB and LSG. Therefore, the present study was conducted to compare the changes in body composition, dietary intake, and substrate oxidation 6 months postoperatively in obese patients who underwent LRYGB and LSG.

Materials and Methods In this prospective study, a total of 43 adult obese patients participated (LRYGB = 22 and LSG = 21). Their body composition was measured by bioelectric impedance analysis. Dietary intake was assessed using 3-day food record. Substrate oxidation was measured by indirect calorimetry. All participants were followed up for 6 months.

Results The percentage of weight loss was 22.8 ± 4.5 and 23.3 ± 5.7% in LRYGB and LSG, respectively. Fat mass (FM), fat-free mass (FFM), and percentage of fat mass (PFM) significantly reduced in LRYGB and LSG, while the percentage of fat-free mass (PFFM) significantly increased in both surgeries. Dietary energy intake significantly reduced by 63.5 ± 30.6% in LRYGB and 66.7 ± 20.1% in LSG. Dietary intake of protein, carbohydrate, fat, and fiber significantly decreased in each group. The percentage of energy from protein, carbohydrate, and fat did not change in each group. Protein oxidation and carbohydrate oxidation significantly reduced in both procedures postoperatively. Changes in body composition, dietary intake, and substrate oxidation from baseline were equal in LRYGB and LSG.

Conclusion Therefore, LRYGB and LSG have similar effect on total and regional FM and FFM, dietary macronutrients intake, and substrate oxidation.

Keywords Gastric bypass · Sleeve gastrectomy · Body composition · Dietary intake · Bariatric surgery

✉ Karamollah Toolabi
tolabika@tums.ac.ir

✉ Kurosh Djafarian
kdjafarian@tums.ac.ir

Mahdieh Golzarand
mahdieh_golzarand@yahoo.com

[1] Department of Clinical Nutrition, School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences, P.O.Box:19395-4763, No 44, Hojatdoost St., Naderi St., Keshavarz Blvd, Tehran, Iran

[2] Department Surgery, Imam Khomeini Hospital, Tehran University of Medical Sciences, P.O.Box: 13145-158, Keshavarz Blvd., Imam Khomeini Hospital, Tehran, Iran

Introduction

Obesity has become an epidemic problem that is associated with type 2 diabetes, cardiovascular disease (CVD), hypertension, sleep apnea, and some cancers [1]. Its prevalence is on the increase worldwide and has doubled since 1980 [2]. The results of a recent study based on 1698 population-based studies (aged ≥ 18 years) showed that in 2014 approximately 641 million adults suffered from obesity worldwide, of which 184 million adults were morbidly obese [3]. It is known that bariatric surgery is an efficient therapy to treat morbid obesity and its-related comorbidities [4]. Moreover, it has been reported that the Roux-en-Y gastric bypass (RYGB) and especially the sleeve gastrectomy (SG) are the most popular bariatric surgery among surgeons and morbidly obese patients, and can lead to greater percentage of excess weight loss (%EWL) as compared with adjustable gastric banding (AGB) and non-surgical therapies in the long term [5, 6].

Ideally, surgery-induced weight loss should be concomitant loss of fat mass (FM) and protect fat-free mass (FFM) to keep resting metabolic rate (RMR) and strength of muscles [7, 8]. However, it has been reported that body composition changed after bariatric surgery and both FM and FFM decreased significantly [8, 9]. Several studies have assessed body composition after RYGB [7, 10–12] and SG [4, 9, 13, 14], and only few studies have compared body composition after RYGB and SG [15–17]. In addition, most of the previous studies only reported changes in FM, percentage of FM (PFM), and FFM or lean body mass (LBM). There is a dearth of studies regarding the assessment of body cell mass (BCM) [14, 18] and phase angle [14] alteration after RYGB or SG. BCM comprised metabolically active tissues, that is, muscles, organs, bones, and total body water. It is a marker of nutritional status and decreases in response to metabolic condition such as protein-energy-malnutrition (PEM), cancers, and AIDS [4]. Phase angle is computed using body resistance and reactance and correlated with BCM. Also, it is a marker of nutritional status and decreases in response to LBM loss or FM elevation [19, 20].

Dietary macro- and micronutrients intake changes after RYGB and SG. Although surgical technique varied between RYGB (a restrictive-malabsorptive procedure) and SG (a restrictive procedure), but it has been reported that both procedures resulted in decreased food consumption by reducing stomach volume and increasing satiety-related hormones such as ghrelin, peptide YY, and glucagon-like peptide-1 (GLP-1) [21, 22]. Previous studies have investigated dietary intake after RYGB [23–25] and SG [26, 27] and showed a significant decrease in foods and dietary intake postoperatively. However, only a few studies have assessed dietary intake after RYGB as compared with SG [28, 29].

Therefore, it is important to evaluate the effect of LRYGB and LSG on total and regional FM and FFM and dietary intake especially dietary protein in order to compare the efficacy of the mentioned procedures to preserve FFM and metabolic rate. Therefore, the present study was designed to compare the changes in body composition, dietary intake, and substrate oxidation 6 months postoperatively in obese patients who underwent LRYGB and LSG.

Materials and Methods

In this prospective study, 43 obese patients that were referred to a surgeon's office (K.T) for obesity management were enrolled. The inclusion criteria included (a) body mass index (BMI) ≥ 40 kg/m^2 or ≥ 35 kg/m^2 with an obesity-related comorbidity and (b) aged > 18 years. While, the exclusion criteria included (a) previous history of bariatric surgery, (b) uncontrolled hypo- and hyperthyroidemia, (c) drugs abuse, (d) alcohol addiction, (e) aged ≤ 18 years, (f) pregnancy and lactation, and (g) hepatic, kidney, heart or psychiatric diseases. The protocol of the study was approved by the ethical committee of Tehran University of Medical Sciences and written consent was signed by all the patients.

All patients were operated between January 2017 and September 2017 at Erfan hospital, Tehran, Iran by a particular surgeon (K.T). RYGB (a 25–30 mL pouch and 150-cm Roux-en-Y limb) and SG (a 32-Fr bougie) were performed using laparoscopic technique with five-port approach.

All patients consulted a dietitian immediately at discharge (to follow a clear liquid diet), 1 week (to follow liquid and soft diet), 1 month (to follow solid diet), 3 months, and 6 months postoperatively and received nutritional advises including recommendation on intake of dairy, red and white meat, egg, legumes, fruit and vegetables consumption, and avoidance of sweets and salty snack. Nutritional supplements including oral multivitamin-mineral, iron, and calcium, once a day and intravenous B-complex and B12 once a month were administrated for all patients. No protein supplement was administrated during follow-up periods.

All patients advised to exercise especially strength activities (5 to 6 h per week) in order to improve weight loss and keep muscles strength.

Measurements

All variables were measured at the Nutritional Sciences and Dietetics School, Tehran University of Medical Sciences preoperatively and 6 months postoperatively by specific investigator (M.G) using the same protocol. Weight was measured using scale (Seca, Germany), and height was measured with stadiometer (Seca, Germany) without shoe. The body composition was assessed by multi-frequency (1, 5, 50, 250, 500, 1000 kHz) and hand-to-hand and leg-to-leg bioelectric impedance analysis (BIA) (InBody770, Korea). For accurate results, it was recommended that the patients stay hydrated, that is, drink 1–2 glasses of water 3 h before test and avoid tea, coffee, and alcohol consumption and physical activity 8 h before test. Body composition analysis included FM, PFM, FFM, BCM, total body water (TBW), extracellular water (ECW), intracellular water (ICW), and phase angle. The percentage of FFM (PFFM) was calculated as: (FFM/weight) × 100. To compute %EWL, the following equation was used: [(pre-operative weight − post-operative weight)/(pre-operative weight − ideal weight)] × 100. Ideal body weight was estimated based on BMI of 25 kg/m^2. The percentage of weight loss (%WL) was calculated as: [(pre-operative weight − post-operative weight)/pre-operative weight] × 100. Substrate oxidation analysis was assessed by indirect calorimetry using spiroergometry system (MetaLyzer®3B, Germany). It is one of the standard methods for measuring substrate oxidation based on oxygen (O_2) consumption and carbon dioxide (CO_2) production of the body over a specific period. In this approach, patient breathed into a face masque that collects expired gas in the supine position for 30 min. All patients were fasted for 8 h and avoided moderate physical activity for 8 h and vigorous physical activity for 14 h before test. A custom certified gas mixture (15% O_2, 5% CO_2, and balance N_2) was used to calibrate CO_2 and O_2 analyzer before each measurement. Substrate oxidation included respiratory quotient (RQ), carbohydrate, protein, and fat oxidation. RQ is calculated as the CO_2 production to O_2 consumption ratio and it depends on the substrate metabolism. RQ for carbohydrate is 1, for fat is 0.7, for protein is 0.82, and for mixed diet is 0.85.

To assess dietary intake, 3-day food record (two work days and one holiday) were obtained from all patients at baseline and 6 months after surgery. The U.S. Department of Agriculture (USDA) food content table was used to analyze the dietary intake.

Physical activity was examined by validated international physical activity questionnaire (IPAQ) [30] and presented as (MET-h per week).

Statistical Analysis

This study used SPSS (version 20.0; SPSS, Inc., Chicago, IL, USA) for statistical analyses. The Kolmogorov-Smirnov test was used to assess the normal distribution of variables. Baseline variables between two groups were compared using Student's *t* test and Chi-squared test. To assess the changes in each outcome from baseline after LRYGB and LSG, paired *t* test was applied. Repeated measures regression analysis was performed to assess the time-by-surgery interaction effect on each outcome after adjustment for the initial weight. ANCOVA test was used to compare %EWL and %WL between the two groups after adjustment for the initial weight. Level of significance was defined as $P < 0.05$.

Results

In the present prospective study, a total of 43 morbidly obese patients participated and underwent LRYGB ($n = 22$) and LSG ($n = 21$). The mean age of participants was 40.6 ± 6.8 and 40.3 ± 12.7 years in LRYGB and LSG, respectively. 95.5% of the patients who underwent LRYGB and 100% LSG were female. The mean BMI was 45.9 ± 4.6 kg/m^2 and 39.5 ± 4.2 kg/m^2 in LRYGB and LSG, respectively. There were no significant differences on the prevalence of obesity-related comorbidities including type 2 diabetes (36.4 vs. 23.8%), dyslipidemia (31.8 vs. 38.1%), hypertension (22.7 vs. 14.3%), fatty liver (81.8 vs. 66.7%), and sleep apnea (60.2 vs. 58.7%) between two groups.

Physical activity level insignificantly increased in LRYGB (from 196 ± 313 to 867 ± 956 Met-h/week) and LSG (from 392 ± 457 to 1003 ± 1121 Met-h/week) 6 months after follow-up. But its changes from baseline were not significant between two groups ($P = 0.83$) (data not shown).

The weight and body composition preoperatively and 6 months postoperatively are shown in Table 1. After 6 months of follow-up, the weight, BMI, PFM, FM, FFM, BCM, and phase angle significantly reduced in both groups of LRYGB and LSG. Mean %EWL was 52.3 ± 13.4% and 66.4 ± 23.8% ($P = 0.21$) and mean %WL was 22.8 ± 4.5% and 23.3 ± 5.7% ($P = 0.75$) in LRYGB and LSG, respectively. Changes in weight and body composition from baseline were not significantly different between two procedures. The proportion of weight loss from FFM (24.9 ± 7.1% in LRYGB vs. 24.5 ± 6.6% in LSG, $P = 0.92$) and FM (75.1 ± 7.1% in LRYGB vs. 75.5 ± 6.6% in LSG, $P = 0.98$) was similar between two groups. However, PFFM significantly increased 6 months postoperatively in both groups.

The regional body composition is shown in Table 2. Regional FM and lean mass (LM) significantly decreased 6 months after LRYGB and LSG. In both procedures, the total FM and LM loss was higher in upper limbs than lower limbs ($P < 0.001$). Regional FM and LM changes from baseline were not significant between LRYGB and LSG.

The dietary macronutrients intake is shown in Table 3. Six months after surgery, energy, protein, carbohydrate, fat, and fiber intake significantly decreased from baseline in LRYGB and LSG. Dietary intake of energy, protein, carbohydrate, fat, and fiber was equal between LRYGB and LSG 6 months after surgery. Moreover, the proportion of energy from macronutrients in LRYGB was the same as LSG preoperatively and 6 months postoperatively.

Substrate oxidation is shown in Fig. 1. At baseline, carbohydrate (281 ± 61 and 247 ± 93 g/d), protein (23.8 ± 3.0 and 21.7 ± 2.8 g/d), fat (92.2 ± 31.3 and 89.0 ± 43.3 g/d), and RQ (0.86 ± 0.03 and 0.86 ± 0.06) were similar between LRYGB and LSG, respectively. After 6 months of follow-up, carbohydrate and protein oxidation significantly reduced in LRYGB (− 87.7 ± 74.4 and − 5.2 ± 2.3 g/d, respectively) and LSG (− 94.7 ± 92.5 and − 5.5 ± 3.1 g/d, respectively). RQ and fat oxidation decreased 6 months postoperatively but their alteration was not significant in LRYGB and LSG. There was no significant differences in carbohydrate ($P = 0.71$), protein ($P = 0.87$), fat oxidation ($P = 0.85$), and RQ ($P = 0.52$) changes from baseline between the two procedures. RMR significantly decreased in parallel with weight reduction in LRYGB (from 2109 ± 268 to 1662 ± 300 kcal/day) and LSG (from 1932 ± 238 to 1454 ± 175 kcal/day). However, its changes from baseline were not significantly different between the two groups ($P = 0.76$) (data not shown).

Discussion

The current study compared effect of two bariatric surgeries on the body composition, dietary intake, and substrate

Table 1 Body composition analysis of participants based on surgical procedure

Body composition	LRYGB			LSG		
	Before	After	Change (%)	Before	After	Change (%)
Weight (kg)	117 ± 18	89.6 ± 12.8*	− 22.3 ± 4.3	101 ± 9**	78.4 ± 9.8*	− 23.7 ± 5.6
EWL (%)		52.3 ± 13.4			66.4 ± 23.8	
WL (%)		22.8 ± 4.5			23.3 ± 5.7	
BMI (kg/m^2)	45.9 ± 4.6	35.0 ± 3.6*	− 22.2 ± 4.3	39.5 ± 4.2**	30.3 ± 4.0*	− 23.7 ± 5.4
PFM (%)	51.8 ± 2.5	45.7 ± 4.2*	− 12.8 ± 5.7	48.9 ± 4.4**	41.1 ± 6.1*	− 17.4 ± 7.2
FM (kg)	60.0 ± 9.0	41.0 ± 8.1*	− 32.3 ± 7.0	49.7 ± 8.0**	32.8 ± 8.1*	− 37.1 ± 8.7
PFFM (%)	48.1 ± 2.5	54.2 ± 4.2*	13.9 ± 5.5	51.0 ± 4.4**	58.8 ± 6.1*	16.6 ± 6.9
FFM (kg)	55.6 ± 8.9	48.0 ± 4.9*	− 11.7 ± 3.9	51.3 ± 4.1	45.9 ± 4.1*	− 11.8 ± 4.3
TBW (L)	41.1 ± 6.6	35.4 ± 3.6*	− 12.1 ± 3.8	37.8 ± 2.9	33.8 ± 3.0*	− 12.0 ± 4.2
ICW (L)	24.7 ± 2.3	21.5 ± 2.5*	− 13.1 ± 3.9	23.7 ± 1.6	20.7 ± 2.0*	− 12.5 ± 4.3
ECW	15.5 ± 1.5	13.9 ± 1.4*	− 10.5 ± 3.9	14.8 ± 1.2	13.2 ± 1.4*	− 10.7 ± 3.9
BCM (kg)	36.3 ± 5.9	30.8 ± 3.2*	− 12.5 ± 5.3	33.7 ± 2.9	29.9 ± 2.9*	− 11.3 ± 5.6
Phase angle (°)	5.4 ± 0.7	4.6 ± 0.4*	− 22.3 ± 4.3	5.5 ± 0.5	4.9 ± 0.4*	− 23.7 ± 5.6
PWL from FM (%)		75.1 ± 7.1			75.5 ± 6.6	
PWL from FFM (%)		24.9 ± 7.1			24.5 ± 6.6	

BCM, body cell mass; *BMI*, body mass index; *ECW*, extracellular water; *EWL*, excess weight loss; *FFM*, fat-free mass; *FM,* fat mass; *ICW,* intracellular water; *PFFM*, percentage of fat-free mass; *PFM*, percentage of fat mass; *PWL*, percentage of weight loss; *TBW*, total body water; *WL*, weight loss

* Significant differences from baseline ($P < 0.05$)

** Significant differences between two groups ($P < 0.05$)

oxidation over 6 months of follow-up. Our study revealed that weigh, total and regional FM, and FFM significantly reduced 6 months after LRYGB and LSG. Energy and dietary protein, carbohydrate, fat, and fiber intake significantly decreased from baseline in each group but the percent of calorie from these macronutrients did not change. In addition, protein and

Table 2 Regional body composition of participants based on surgical procedure

RMR analysis	LRYGB			LSG		
	Before	After	Change (%)	Before	After	Change (%)
Lean mass (kg)						
Trunk	25.8 ± 2.7	22.0 ± 2.35*	− 14.4 ± 3.9	25.1 ± 3.1	21.0 ± 2.28*	− 15.9 ± 6.5
Right arm	3.28 ± 0.43	2.68 ± 0.37*	− 18.0 ± 5.6	3.04 ± 0.31	2.49 ± 0.39*	− 18.5 ± 6.2
Left arm	3.23 ± 0.43	2.70 ± 0.42*	− 16.4 ± 7.3	3.02 ± 0.32	2.46 ± 0.37*	− 18.6 ± 5.9
Right leg	7.87 ± 0.79	7.05 ± 0.97*	− 10.5 ± 5.3	7.86 ± 0.73	7.01 ± 0.76*	− 10.8 ± 3.9
Left leg	7.82 ± 0.77	6.94 ± 1.01*	− 11.4 ± 6.7	7.75 ± 0.67	6.91 ± 0.77*	− 10.9 ± 5.0
Extremities	22.2 ± 2.3	19.3 ± 2.6*	− 12.8 ± 4.4	21.6 ± 1.8	18.8 ± 2.1*	− 13.0 ± 4.3
Fat mass (kg)						
Trunk	26.9 ± 2.4	19.8 ± 3.2*	− 26.4 ± 7.7	24.1 ± 3.5**	16.5 ± 4.2*	− 32.2 ± 10.2
Right arm	7.48 ± 1.77	3.98 ± 1.27*	− 47.3 ± 7.7	5.72 ± 1.76**	2.94 ± 1.36*	− 49.8 ± 9.8
Left arm	7.51 ± 1.80	4.16 ± 1.65*	− 45.7 ± 10.6	5.77 ± 1.75**	2.96 ± 1.35*	− 49.9 ± 9.6
Right leg	8.06 ± 0.75	5.72 ± 1.14*	− 29.2 ± 10.3	7.13 ± 1.11**	4.78 ± 1.13*	− 33.2 ± 10.4
Left leg	7.98 ± 0.75	5.67 ± 1.12*	− 29.1 ± 10.6	7.05 ± 1.11**	4.74 ± 1.14*	− 33.0 ± 10.5
Extremities	31.0 ± 4.8	19.5 ± 4.7*	− 37.5 ± 7.6	25.6 ± 5.3	15.4 ± 4.9*	− 40.6 ± 9.2

* Significant differences from baseline ($P < 0.001$)

** Significant differences between two groups ($P < 0.05$)

Table 3 Dietary macronutrients intake of participants based on surgical procedure

Dietary intake	LRYGB			LSG		
	Before	After	Change (%)	Before	After	Change (%)
Energy (kcal/d)	2215 ± 879	824 ± 176*	− 63.5 ± 30.6	2565 ± 1065	844 ± 256*	− 66.7 ± 20.1
Protein						
Gram per day	82 ± 40	38.8 ± 12.8*	− 53.8 ± 23.6	111 ± 56	36.7 ± 12.5*	− 65.1 ± 19.3
Percentage of energy	14.2 ± 3.0	18.1 ± 7.2	28.8 ± 34.5	16.5 ± 4.0	17.0 ± 3.6	4.5 ± 17.0
Carbohydrate						
Gram per day	288 ± 88	97.0 ± 40.6*	− 65.5 ± 23.2	280 ± 89	99.4 ± 30.5*	− 65.8 ± 18.3
Percentage of energy	51.8 ± 9.7	46.8 ± 13.9	− 8.2 ± 5.6	45.6 ± 9.2	46.2 ± 7.4	0.6 ± 2.3
Fat						
Gram per day	87 ± 48	32.6 ± 10.8*	− 63.4 ± 36.8	117 ± 92	36.3 ± 15.7*	− 67.3 ± 38.5
Percentage of energy	34.0 ± 7.8	35.1 ± 8.8	2.7 ± 10.5	37.9 ± 9.1	36.8 ± 9.7	− 1.5 ± 12.3
Fiber (g/day)	25.1 ± 9.1	13.5 ± 7.9*	− 45.6 ± 18.9	27.9 ± 20.3	11.7 ± 6.0*	− 56.8 ± 19.3

* Significant differences from baseline ($P < 0.05$)

carbohydrate oxidation, but not fat oxidation, significantly declined postoperatively. There were no significant differences on the outcomes between two procedures.

In the present study, %EWL was higher in LSG than LRYGB. %EWL is significantly associated with baseline weight and BMI, and subjects with more weight experience lower %EWL [31]. In the present study, patients who underwent LRYGB were heavier than those who underwent LSG, and this resulted in lower %EWL. To compensate for the selection bias and validate comparison, ANCOVA test was run with adjustment for the baseline weight. After adjustment, no significant difference was found in %EWL between the two groups. In addition, since there was difference in initial weight between the LRGB and LSG groups, we calculated the %WL to reduce the effect of initial weight. Thus, the %WL was not significantly different between the two groups. In a study by van de Laar et al. [31], it was shown that %WL is a good method to compare the difference in baseline weight.

Previous studies have reported changes in body composition after LRYGB and LSG [7, 10, 11, 16, 32–34]. The results

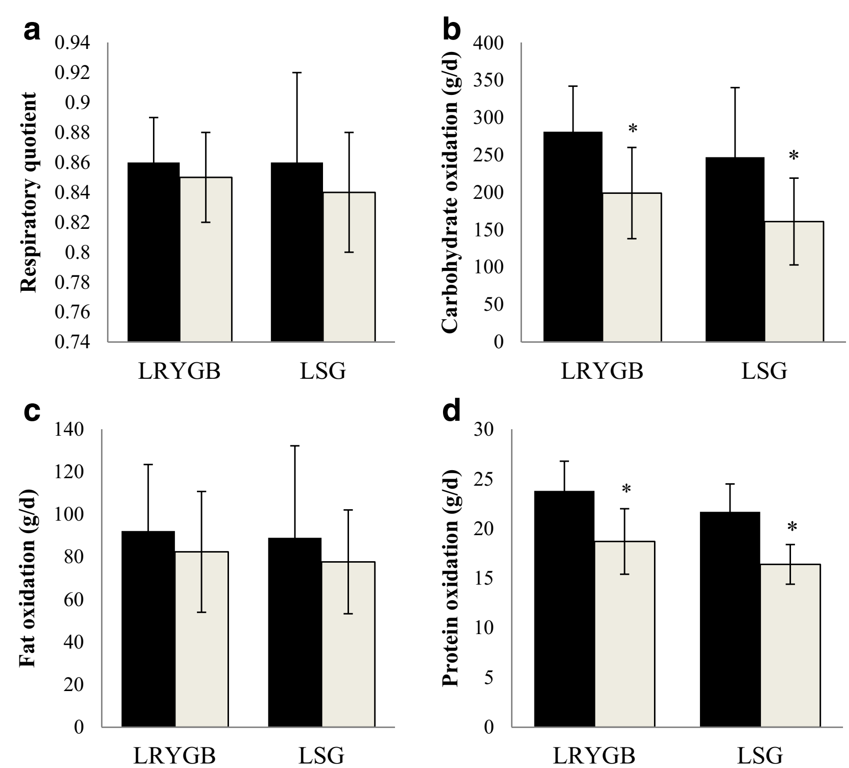

Fig. 1 Substrate oxidation at baseline and after 6 months of follow-up in patients underwent LRYGB and LSG. *$P < 0.001$ (■ at baseline and □ after 6 months)

of the present study are in agreement with those of Otto et al. [16] who showed that there was no significant difference in %EWL (50 vs. 40%), BMI loss (− 11 vs. 10 kg/m^2), FM loss (− 34 vs. − 27 kg) PFM (− 11 vs. − 8%), LBM loss (− 9 vs. − 9 kg), and BCM loss (− 7.8 vs. − 8.0 kg) between LRYGB and LSG, respectively, 6 months postoperatively. BIA is a safe and simple technique widely used to assess body composition by measuring body resistance that is associated with TBW and body reactance associated with the capacitance of cell membrane [19]. It is a reliable method among subjects with BMI range of 16–34 kg/m^2 and fluid balance, but imbalanced hydration and severe obesity decrease its accuracy in measuring body composition [35]. Hydration status is inversely associated with body resistance and imbalanced dehydration by increasing in body impedance, resulting in overrating of body FM and underrating of FFM as compared with normal hydration subjects [19]. Morbid obesity also, through over hydration of FFM and decrease in body resistance, leads to overestimation of FFM in morbidly obese subjects than non-obese counterpart [4, 18]. On the contrary, BIA overrates FFM reduction due to high TBW loss following weight reduction [14].

However, BIA is the only method used to calculate phase angle [4]. Phase angle is an impedance parameter which was estimated based on body resistance and reactance ratio [19]. Phase angle ranged from 5 to 7° in healthy subjects and increased to 9.5° in athletes; however, it was significantly associated with BMI and gender [35]. There are sex-differences in body composition, and females have been shown to have higher FM and lower FFM as compared with males [36]. Therefore, phase angle in females is lower than in males. Morbidly obese patients also due to fluid imbalance had lower phase angle [35]. Recently, phase angle has been proposed as a main parameter in clinical assessment that can evaluate nutritional status due to its correlation with LBM and TBW [4, 35]. In the present study, energy and protein deficiency (as shown in Table 3) due to low intake of foods is the main reason for BCM and phase angle loss after LRYGB and LSG. Therefore, it can be said that high-protein diet or protein supplement and physical activity especially strength exercise may protect against FFM loss and subsequently BCM loss and phase angle reduction [4]. Schiavo et al. [18] showed that consumption of high-protein diet (2 g/kg of ideal body weight) after LSG resulted in greater FM and PFM loss and lower FFM, PFFM, and BCM loss as compared with normal protein diet (1 g/kg of ideal body weight). In addition, the results of a recent study demonstrated that physical inactivity in patients who underwent bariatric surgery reduced the strength of muscle by 33% and resulted in significant loss of muscles over 12 months after surgery [8].

The result of the present study showed that the higher mean regional FM in the upper limbs compared with the lower limbs reduced. A recent study has shown that upper limb and lower limb BIA are the markers of visceral and subcutaneous adiposity, respectively [37]. The observed higher FM loss in the arms than legs may indicate higher decrease in abdominal fat tissue as compared with the subcutaneous fat tissue. This may explain the remission or resolution of obesity-related comorbidities after LRYGB and LSG because visceral adiposity is associated with insulin resistance, dyslipidemia, CVD, hypertension, and metabolic syndrome [38].

Studies have shown that dietary intake changed after RYGB and SG [24–27, 39, 40]. Low calorie intake following a decrease in gastric capacity is the cause of weight loss after LRYGB and LSG. In the present study, 3-day food record was used to assess dietary intake. Food record is an accurate tool to evaluate dietary intake as compared with food recall and food frequency questionnaire (FFQ) [41]. American Society of Metabolic and Bariatric Surgery (ASMBS) suggested that patients after bariatric surgeries should consumed 35% of calorie from protein, 45% from carbohydrate, and 20% from fat [42]. In the present study, all patients were visited at regular intervals by a dietitian and were instructed to consume more protein foods group, fruit, and vegetables than other food groups. Although the patients changed their food choices, however, due to small stomach volume, dietary intake of protein was very low and fat was higher than the recommended values by ASMSB. Carbohydrate intake also was slightly higher than the ASMBS guideline. The results obtained in the present study are in agreement with those of previous studies that showed lower percentage of energy from protein and higher fat than the ASMBS guideline [32, 40]. In the same study with 6 months of follow-up, Moize et al. [29] reported that total energy intake from foods was 1160 vs. 1163 kcal/day, the percentage of energy from carbohydrate was 40.3 vs. 38.3%, from protein was 21.2 vs. 23.0%, and from fat was 38.5 vs. 38.5% among patients who underwent LRYGB and LSG, respectively. They also showed that there were no significant differences in terms of energy, carbohydrate, and fat intake between the two procedures. It seems that dietary protein supplement is essential to achieve ASMBS recommendation.

In accordance with dietary intake reduction, protein and carbohydrate oxidation significantly decreased in both procedures postoperatively, while fat oxidation increased, but was not significant. Only a few studies have assessed substrate oxidation after surgery-induced weight loss. The results of the present study are in line with those of Tamboli et al. [12] who reported a significant decrease in carbohydrate oxidation with no significant changes in fat oxidation from baseline 6 months after RYGB. The observed decrease in protein- and carbohydrate oxidation in the present study is associated with energy and protein deficiency due to low dietary intake (as shown in Table 3). This elevates the circulation of fatty free acids (FFAs), as an energy substrate, in response to FM loss during weight reduction period [17, 43, 44]. On the contrary, Schneider et al. [17] showed that fat oxidation reduced and carbohydrate oxidation increased 1 year after LRYGB and

LSG. This may be attributed to the differences in follow-up duration. The most considerable weight loss occurred in the first 6 months postoperatively [12], while in the second 6 months postoperatively, its changes were insubstantial. In addition, in the second 6 months after surgery, patient's dietary intake increased as compared with the first 6 months postoperatively. This resulted in a decrease in fat oxidation and an increase in carbohydrate oxidation [12, 17].

The main strength of the present study was the assessment of body composition and substrate oxidation 6 months after LRYGB and LSG. This is because the most changes in weight and body composition occurred in the first 6 months postoperatively. However, our study has several limitations. The main limitation of the present study was the use of BIA to measure body composition. Although multi-frequency BIA is more precise than single-frequency BIA, but its accuracy is lower than dual-energy X-ray absorptiometry (DEXA) in morbidly obese patients. In addition, the present study was compromised as the use of only females limits the validity of our results in males due to sex-differences in body composition and food consumption. The last limitation of study was the use of self-reported food record to assess dietary intake. Food record is the most accurate method to evaluate nutritional status if the amounts of food eaten are noted at the time of consumption; otherwise, it will result in errors from memory which limits the accuracy of the study.

Conclusion

In conclusion, the results of the present study showed that both LRYGB and LSG have similar effect on weigh, total, and regional FM, FFM, dietary intake, and substrate oxidation 6 months postoperatively.

Compliance with Ethical Standards

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

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