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ORIGINAL CONTRIBUTIONS

Comparative Study of Resting Metabolic Rate and Plasma Amino Acid Profile in Patients Who Underwent Laparoscopic Roux-en-Y Gastric Bypass and Laparoscopic Sleeve Gastrectomy: 6-Month Follow-up Study

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Abstract

Purpose Laparoscopic Roux-en-Y gastric bypass (LRYGB) and laparoscopic sleeve gastrectomy (LSG) are the most common techniques for treatment of morbid obesity. However, a few studies have compared the energy expenditure and plasma amino acid profile after LRYGB and LSG. The present study was conducted to assess the resting metabolic rate (RMR) and plasma amino acid profile in obese patients who underwent LRYGB and LSG before and 6 months after the surgery in order to compare these changes from baseline between the two procedures.

Materials and Methods Forty-three adult obese patients participated in this study (LRYGB = 22 and LSG = 21) and were followed up for 6 months. RMR was measured by indirect calorimetry. The plasma amino acid profile was determined using high-performance liquid chromatography (HPLC).

Results Mean percent excess weight loss (%WL) were 22.8 ± 4.5% and 23.3 ± 5.7% in LRYGB and LSG, respectively. RMR reduced significantly from baseline by − 459 ± 202 kcal/day in LRYGB and − 500 ± 262 kcal/day in LSG. RMR reduced beyond the expected decrease in both procedures. A decreasing trend was observed in the plasma concentration of branched-chain amino acids (BCAA), aromatic amino acids (AAA), and amino acid index (AAI) in both techniques. There was no significant difference in weight, RMR analysis, and amino acid change from baseline between LRYGB and LSG.

Conclusion Our results showed that the effects of LRYGB and LSG on RMR and amino acid profile were comparable.

Keywords Gastric bypass · Sleeve gastrectomy · Resting metabolic rate · Amino acid profile · Branched-chain amino acid · Energy expenditure

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Introduction

Obesity, especially morbid obesity (body mass index (BMI) ≥ 40 kg/m^2 or ≥ 35 kg/m^2 with an obesity-related co-morbidity), is a major concern worldwide that has social, economic, physical, and psychiatric adverse outcomes [1]. The results of a systemic analysis of 9.1 million adults indicated that BMI increased by 0.4 kg/m^2 per 10-year period from 1980 worldwide [2]. According to Strum et al. [3], the prevalence of morbid obesity increased by 70% during 2000–2010 and reached 6.6% (15.5 million adults) in America. A review of the literature suggests that bariatric surgery is the most successful approach for treatment of morbid obesity and long-term weight loss maintenance [4, 5]. Among bariatric procedures, laparoscopic Roux-en-Y gastric bypass (LRYGB) and laparoscopic sleeve gastrectomy (LSG) are the most common techniques used for treatment of morbid obesity [6, 7].

There is evidence that weight loss after dietary restriction is associated with a decrease in energy expenditure and resting metabolic rate (RMR). If this decrease is beyond the predicted reduction in RMR, it is known as “metabolic adaption” or “adaptive thermogenesis” [8–11]. Metabolic adaption includes decreased energy expenditure and a feeling of satiety and increased metabolic efficiency, which is associated with increased risk of weight regain after ending the diet [12]. Decreased RMR is reported following bariatric surgery-induced weight loss [13, 14]. A few studies have assessed energy expenditure after RYGB [15–17] and SG [18, 19]. However, a very limited number of studies have compared RMR alteration after RYGB and SG [19]. Changes in body composition, especially lean body mass (LBM), are the main causes of decreased RMR [20, 21]. However, it is possible that various procedures have different effects on the metabolic rate due to different anatomies and changes in metabolism-related hormones such as leptin, grelin, and peptide YY [22]. Hence, it is necessary to perform a comparative study to evaluate the effect of LRYGB and LSG on RMR and its difference with the predicted RMR (p-RMR) in order to the preserve metabolic rate and minimize the risk of weight regain.

Moreover, it has been shown that plasma amino acids are involved in the pathology of obesity [23]. Recent surveys have revealed changes of the plasma amino acid profile, especially branched-chain amino acids (BCAA) and aromatic amino acids (AAA), in obesity, mainly due to insulin resistance, in association with increased risk of cardiovascular disease (CVD) and diabetes mellitus [24, 25]. A recent cohort study of 804 obese patients showed plasma amino acid profile changes after a weight loss program [26]. However, there are scarce data on whether plasma amino acid profile is modified after LRYGB- and LSG-induced weight loss.

Hence, the present research was conducted to assess the RMR and plasma amino acid profile before and 6 months after surgery in obese patients undergoing LRYGB or LSG and to compare their changes between the two procedures.

Materials and Methods

Forty-three adult obese patients with a BMI ≥ 40 kg/m^2 or ≥ 35 kg/m^2 and obesity-related co-morbidities who were referred to the surgeon’s office (K.T) were included in this study. It should be noted that patients with a previous history of bariatric surgery; uncontrolled hypo- or hyperthyroidism; drug or alcohol addiction; and liver, renal, and psychiatric disorders were excluded from the study. The study protocol was approved by the Ethics Committee of Tehran University of Medical Sciences and written consent was obtained from all patients.

The surgical procedure started with counseling each patient regarding the type of bariatric surgery. Pre-operative work-up comprised laboratory tests, abdominal ultrasound, and upper gastrointestinal endoscopy. Consultation with a dietitian was done if the baseline BMI was ≥ 50 kg/m^2 to lose 10% of the weight before the operation. In addition, consultation with a psychiatrist was requested if a patient suffered from psychiatric disorders. All patients underwent LRYGB or LSG by one surgeon (K.T) at Erfan Hospital, Tehran, between January 2017 and September 2017. The patients were counseled by a dietitian at discharge and followed up post-operatively at 1 week, 1 month, 3 months, and 6 months at the surgeon’s office by the dietitian and the surgeon. Nutritional advice and supplements have been reported previously [27]. In brief, all patients have followed a liquid and soft diet for 1 month and then followed a regular diet containing milk and dairy products, meat and eggs, pulses, fruits, and vegetables. Daily multivitamins plus mineral, iron, and calcium oral and monthly B-complex intramuscular were administrated for all patients.

Operation Technique

LRYGB and LSG were performed using the five-port approach. LRYGB has been already described elsewhere [28]. In brief, a small pouch (25–30 mL) was created and the length of the Roux-en-Y limb was 150 cm (the pancreatic limb was 50 cm and the alimentary limb was 100 cm).

As for LSG, the greater curvature of the stomach was resected from 5 cm proximal to the pylorus and dividing is continued from the gastrosplenic ligament up to the angle of His by LigaSure. LSG was performed with a linear stapler using a 32-Fr orogastric tube in the lesser curvature of the stomach for sleeve gastrectomy calibration. The stapler line was over-sewn by running PDS 2–0 sutures.

Measurements

In the morning before surgery, the patients were referred to the School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences, to measure their weight, height, body composition, and RMR. Weight was measured using a scale (Seca, made in Germany) to the nearest 0.5 kg and height was measured with a stadiometer (Seca, made in Germany) to the nearest 0.5 cm without shoes. BMI was calculated as weight (kg) divided by height (m) squared. The body composition was determined by a multi-frequency (1, 5, 50, 250, 500, 1000 kHz) bioelectric impedance analysis (BIA) device (InBody770, made in Korea). Body composition analysis included fat mass (FM), percentage of fat mass (PFM), fat-free mass (FFM), percentage of fat-free mass (PFFM), skeletal muscle mass (SMM), and total body water (TBW). The following equation was used to calculate the percentage of weight loss: (%WL) : [(pre − operative weight –

post − operative weight)/pre − operative weight] × 100. Ideal body weight was estimated based on a BMI of 25 kg/m^2. RMR was measured by indirect calorimetry using a spiroergometer (MetaLyzer®3B, made in Germany). The patients were advised to limit food and fluid intake except water (8 h), and to do moderate and light physical activity (8 h) and vigorous physical activity (14 h) before indirect calorimetry. The indirect calorimetry device was calibrated before each assessment. To measure RMR (m-RMR), the patients assumed the supine position without movement for 30 min and the mid 20 min was considered for calculation (the first and the last 5 min were ignored). RMR per weight (RMR/wt), RMR per FFM (RMR/FFM), and RMR per FM (RMR/FM) were calculated as m-RMR divided by weight, FFM, and FM, respectively. Six months after the surgery, body composition and RMR were measured by the same protocol applied at baseline. All measurements were conducted by one investigator (M.G). Metabolic adaption was determined according to a previously reported method [20, 29]. Baseline p-RMR was calculated using a linear regression analysis based on baseline FFM, FM, age, and surgery group. This formula was applied to calculate post-operative p-RMR using post-operative FFM and FM. Metabolic adaption was defined as a significant difference between RMR residuals (i.e., m-RMR minus p-RMR) and zero point [29].

Two 10-h fasting blood samples (3 mL) were collected from each patient to assess the amino acid profile on the day of surgery and 6 months later. All blood samples were collected in tubes containing ethylenediaminetetraacetate (EDTA) and centrifuged at 3500 rpm for 30 min to separate plasma. Then, the plasma was stored at − 20 °C until analysis within 4 weeks. The amino acid profile was determined using high-performance liquid chromatography (HPLC). The following 20 amino acids were investigated: aspartic acid (Asp), glutamic acid (Glu), aspargine (Asn), serine (Ser), histidine (His), glumatine (Gln), arginine (Arg), citrulline (Cit), glycine (Gly), threonine (Thr), alanine (Ala), tyrosine (Tyr), tryptophane (Trp) and phenylalanine (Phe), valine (Val), isoleucine (Ile) and leucine (Leu), methonine (Met), ornithine (Orn), and lysine (Lys). Amino acid index (AAI) was calculated using the following formula: (−3.5250) + (0.0379 × Glu) + (−0.0070 × Gly) + (0.0034 × Ala) + (0.0196 × Tyr) + (−0.0216 × Trp) + (0.0054 × BCAA) [30].

Statistical Analysis

SPSS (version 20.0; SPSS, Inc., Chicago, IL, USA) was used for statistical analysis. The normal distribution of variables was assessed using the Kolmogorov-Smirnov test. The student *t* test and chi-squared test were applied to compare baseline variables between LRYGB and LSG groups. Paired *t* test was administered to compare the variables before and after the surgical procedure in each group. To assess the effect of time × surgery interaction on each outcome, repeated measures regression analysis was conducted after adjustment for the baseline BMI. *P* values less than 0.05 were considered significant.

Results

Forty-three morbidly obese patients who were scheduled for LRYGB ($n = 22$) and LSG ($n = 21$) participated in the present prospective study and were followed up for 6 months. The mean age of the participants was 40.4 ± 10.0 years, their mean BMI was 42.6 ± 5.4 kg/m^2, and 97.7% of them were female. There were no significant differences in general characteristics (except weight) between the two groups (Table 1).

Body composition before and 6 months after the surgery is illustrated in Table 2. The mean %WL were 22.8 ± 4.5% in the LRYGB and 23.3 ± 5.7% in the LSG group ($P = 0.75$), respectively. BMI, FM, FFM, PFM, SMM, and TBW reduced significantly and PFFM increased in both groups on the 6-month follow-up.

RMR analysis is presented in Table 3. At baseline, m-RMR in patients who underwent LRYGB was significantly higher than patients who underwent LSG (2109 ± 268 kcal/day vs. 1932 ± 238 kcal/day, $P = 0.04$, respectively), which could be due to the difference in baseline BMI. However, there were no significant differences in RMR/wt, RMR/FFM, RMR/FM, and RMR/BSA between the patients in the two groups at baseline. All patients had a normal metabolic rate at baseline. Six months after the surgery, m-RMR decreased significantly by − 459 ± 202 kcal/day in LRYGB and − 500 ± 262 kcal/day in LSG, with no significant difference between the two groups ($P = 0.76$).

Moreover, p-RMR was exactly similar to m-RMR in both groups at baseline. Six months after the surgery, m-RMR decreased significantly compared to p-RMR in LRYGB (− 230 ± 234 kcal/day, $P = 0.001$) and LSG (− 308 ± 210 kcal/day, $P < 0.001$) groups; however, no significant difference was

Table 1 General characteristics of participants based on surgical procedure

General characteristics	LRYGB	LSG	*P* value
Age (year)	40.6 ± 6.8	40.3 ± 12.7	0.92
Female (%)	21 (95.5)	21 (100)	0.51
Height (cm)	159.9 ± 6.5	160.7 ± 5.7	0.66
Weight (kg)	116.0 ± 17.7	103.1 ± 11.2	0.007
Diabetes (%)	8 (36.4)	5 (23.8)	0.28
Dyslipidemia (%)	7 (31.8)	8 (38.1)	0.45
Hypertension (%)	5 (22.7)	3 (14.3)	0.37
Fatty liver (%)	18 (81.8)	14 (66.7)	0.21

LRYGB laparoscopic Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy

Table 2 Body composition analysis of participants based on surgical procedure

Body composition	LRYGB		LSG	
	Before	Changes	Before	Changes
Body mass index (kg/m^2)	45.9 ± 4.6	− 10.4 ± 2.4*	39.5 ± 4.2‡	− 9.3 ± 2.4*
Fat mass (%)	51.8 ± 2.5	− 6.6 ± 2.7*	48.9 ± 4.4‡	− 8.1 ± 3.5*
Fat mass (kg)	60.0 ± 9.0	− 19.2 ± 3.5*	49.7 ± 8.0‡	− 18.4 ± 4.7*
Fat-free mass (%)	48.1 ± 2.5	6.7 ± 2.8*	51.0 ± 4.4‡	8.1 ± 3.5*
Fat-free mass (kg)	55.6 ± 8.9	− 6.3 ± 2.2*	51.3 ± 4.1	− 6.0 ± 2.0*
Skeletal muscle mass (kg)	30.3 ± 3.1	− 4.2 ± 1.3*	28.9 ± 2.1	− 3.8 ± 1.2*
Total body water (L)	41.1 ± 6.6	− 4.8 ± 1.6*	37.8 ± 2.9	− 4.5 ± 1.5*

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

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

observed between the two groups ($P = 0.55$). RMR/wt did not change after the surgery in the two groups. Although RMR/FFM, RMR/FM, and RMR/BSA decreased significantly in LRYGB (− 4.5 ± 4.5 kcal/kg, $P = 0.01$; 6.1 ± 6.8 kcal/kg, $P = 0.004$; and − 124 ± 113 kcal/m^2, $P = 0.002$, respectively) and LSG (− 5.8 ± 5.3 kcal/kg, $P < 0.001$; 7.6 ± 11.4 kcal/kg, $P = 0.01$; and − 156 ± 142 kcal/m^2, $P = 0.01$, respectively), their difference was not significant between the two procedures ($P = 0.44$ and $P = 0.06$, respectively).

The plasma amino acid profile is shown in Table 4. Overall, during 6 months of follow-up, a significant decreasing trend was observed in the plasma concentration of BCAA ($P = 0.02$), AAA ($P = 0.03$), Glu ($P = 0.002$), Val ($P = 0.005$), and AAI ($P = 0.002$) and a significant increasing trend was noted in the plasma concentration of Gln ($P = 0.006$), Cit ($P = 0.01$), and Gly ($P = 0.03$). The rest of the amino acids remained unchanged. Moreover, there was no significant difference in amino acid changes from baseline between LRYGB and LSG.

Discussion

The current study was designed to compare the effect of two bariatric surgical techniques on the RMR and amino acid profile in a 6-month follow-up. The results revealed that m-RMR decreased compared to baseline over 6 months concurrent with weight loss and its changes were greater than the changes of p-RMR in both groups. RMR/wt did not change during the follow-up period. Although other amino acids remained unchanged from baseline, plasma levels of BCAA, AAA, and AAI decreased significantly after the surgery without any significant differences between the two groups.

The results of the present study showed that in parallel with weight reduction, RMR decreased significantly from baseline in both LRYGB and LSG with no significant differences between the two procedures. Our findings were consistent with the results of previous studies that assessed RMR changes after bariatric surgery [31–34]. However, the results of few studies comparing RMR or energy expenditure changes after RYGB and SG indicate comparable effects of LRYGB and LSG on RMR [19, 35, 36].

In the present study, p-RMR was exactly similar to m-RMR in both groups before surgery. Six months after the surgery, m-RMR decreased more than p-RMR in both procedures. Decreased RMR following a restricted calorie diet has been shown in humans [37]. Studies have documented that RMR decreases in response to low-calorie diets in such a way that ≥ 10% weight loss reduces the RMR by − 20 to − 25% [38]. Knuth et al. [21] reported that hypocaloric diet-induced weight loss led to metabolic adaption (− 419 ± 169 kcal/day, $P < 0.001$) after 6 months. Their findings were in agreement with the results of a systematic review indicating metabolic adaption was greater in patients undergoing a restricted calorie diet than those who underwent bariatric surgery [37]. Our results were consistent with the findings of previous studies reporting metabolic adaption after LRYGB and LSG [18, 21, 35, 39]. The cause of metabolic adaption after weight reduction is unclear. FFM is a metabolically active component of the body and is the main determinant of energy expenditure. RMR decrement after bariatric surgery can partly be explained by FFM reduction [17]. However, it has been suggested that due to the large volume of FM mass in the obese patients, FM loss after bariatric surgery may also contribute to the RMR fall [11]. The decreased RMR/FFM after the surgery in the present study confirmed this hypothesis. Preservation of FFM through physical activity, especially strength exercise, in order to avoid metabolic adaption, is encouraged. Moreover, it has been reported that metabolic adaption may be related to decreased levels of leptin following weight loss and it has been suggested that leptin therapy during weight reduction may prevent metabolic adaption [21]. Nevertheless, it should be noted that we evaluated metabolic adaption 6 months post-operatively and it is possible that it fades 12 months after surgery because evidence suggests that metabolic adaption occurs during the weight loss phase and disappears after weight stabilization [21, 40]. Therefore, additional studies

Table 3 RMR analysis of participants based on surgical procedure

RMR analysis	LRYGB			LSG		
	Before	After	Change (%)	Before	After	Change (%)
m-RMR (kcal/day)	2109 ± 268	1662 ± 300*	− 21.8 ± 9.6	1932 ± 238‡	1454 ± 175*	− 24.1 ± 11.7
p-RMR (kcal/day)	2118 ± 174	1912 ± 165*	− 9.6 ± 3.5	1946 ± 129‡	1762 ± 157*	− 10.0 ± 3.8
Residual[a] (kcal/day)		− 250 ± 234†			− 308 ± 214†	
RMR per weight (kcal/kg)	18.3 ± 1.8	18.6 ± 3.0	2.0 ± 16.3	18.9 ± 2.7	18.4 ± 2.9	1.0 ± 20.0
RMR per FFM (kcal/kg)	39.0 ± 3.3	34.5 ± 4.6*	− 11.3 ± 11.7	37.3 ± 3.7	31.4 ± 4.1*	− 14.8 ± 14.2
RMR per FM (kcal/kg)	35.4 ± 4.1	41.5 ± 9.2*	16.6 ± 19.0	38.7 ± 8.9	46.4 ± 13.1*	21.5 ± 36.6
RMR per BSA (kcal/m^2)	992 ± 94	871 ± 134*	− 12.5 ± 11.5	948 ± 114	792 ± 100*	− 14.3 ± 14.4

BSA body surface area, *FFM* fat-free mass, *LRYGB* laparoscopic Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *m-RMR* measured RMR, *p-RMR* predicted RMR, *RMR* resting metabolic rate

[a] p-RMR was calculated based on the following equation: 427.46 + 34.71 × FFM − 0.86 × FM − 1.04 × age − 104.31 × surgery (R^2 = 0.51, $P < 0.001$)

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

† Significantly differences from predicated-RMR ($P < 0.05$)

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

with longer follow-up periods are required to evaluate the presence of metabolic adaption during the weight loss and weight maintenance periods.

In the current study, we found no significant changes in RMR/wt after both operations. These findings were consistent with the results of some studies indicating no significant alteration in RMR/wt after LSG and LRYGB [11, 18, 32]. By contrast, some investigations have shown that RMR/wt increases after surgery [14, 19]. Studies have found that increased PFFM or LBM percentage may play a role in augmentation of RMR/wt after RYGB [11]. In the present study, PFFM increased significantly over 6 months of follow-up but there was no significant increase in RMR/wt. The reason for this inconsistency is unclear and further studies are required to confirm the effect of RYGB on RMR/wt.

Previous studies have indicated that the plasma levels of Ala, Glu, His, BCAA, Lys, Met, Orn, AAA, and Pro are higher and the plasma levels of Asn, Gln, Gly, Ser, and Cit are lower among obese patients than in normal weight subjects [23, 30]. It has been stated that this increase in the amino acid profile is associated with the visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) volume [23]. In the present study, the plasma levels of Ala, Glu, His, BCAA, Lys, Orn, AAA, and Pro decreased and Asn, Gln, Gly, Ser, and Cit increased 6 months after surgery; however, only changes in Gln, Gly, Cit, Glu, Orn, BCAA, and AAA were significant. These findings were consistent with the results of some previous studies reporting a significant decrease in the plasma level of BCAA in patients undergoing RYGB and SG beyond reduction resulting from dietary restriction programs [41–45]. Studies have documented that obese patients have higher BCAA and AAA circulation levels compared with normal weight subjects that are positively associated with risk of diabetes type 2 and CVD in these patients [24, 26, 46]. It has been shown that obesity-induced dow-nregulation of BCAA catabolism enzyme-related gene expression (i.e., BCAA aminotransferase and branched-chain α-keto acid dehydrogenase) and insulin resistance, the latter of which suppresses muscular uptake and catabolism of BCAA, plays an important role in elevation of the BCAA level [25, 26, 47]. By contrast, weight loss by up-regulation of gene expression involved in BCAA catabolism and improvement of insulin sensitivity results in decreased BCAA and increased BCAA catabolism-derived metabolites, which may reduce the risk of diabetes and CVD development [45, 47].

Moreover, Tan et al. [45] found that plasma levels of Gly and Cit significantly increased after RYGB and LSG while the levels of other amino acids (except BCAA) did not change. Nicoletti et al. [44] reported that the plasma levels of Asp, Lue, and Lys diminished and the plasma levels of His, Gly, and Met increased while the rest of the amino acids remained unchanged in patients who underwent RYGB. Future investigations are essential to evaluate the mechanisms underlying these changes in plasma amino acids.

In the current study, AAI significantly decreased 6 months after the surgery-induced weight loss. It has been proposed that AAI is a marker of VAT and its changes can predict VAT alterations. Visceral fat mass is a source of circulating adipokines in association with insulin resistance and endothelial dysfunction development [30]. In the present study, the significant AAI reduction during the follow-up period confirmed a significant VAT decrease after the operation, which may contribute to the improvement of metabolic disorders after surgery-induced weight loss by decreasing adipokines released into the circulation.

Table 4 Plasma amino acid profile of participants based on surgical procedure

Amino acid profile	Total		LRYGB		LSG	
	Before	After	Before	After	Before	After
Aspartic acid (μmol/L)	9.5 ± 7.6	7.5 ± 7.3	10.7 ± 5.9	9.1 ± 9.8	8.4 ± 8.8	6.0 ± 3.7
Glutamic acid (μmol/L)	86.2 ± 48.7	52.5 ± 24.0*	105 ± 46	60.2 ± 29.7*	68.6 ± 44.9	45.4 ± 14.3
Aspargine (μmol/L)	39.9 ± 9.7	43.5 ± 16.4	40.3 ± 8.5	47.0 ± 20.8	39.4 ± 10.8	40.4 ± 10.6
Serine (μmol/L)	103 ± 39	114 ± 42	97.2 ± 43.6	117 ± 47	108 ± 34	112 ± 39
Histidine (μmol/L)	68.8 ± 45.4	65.3 ± 38.2	63.4 ± 42.8	77.6 ± 49.8	73.9 ± 48.4	53.9 ± 17.8
Glumatine (μmol/L)	465 ± 119	579 ± 148*	425 ± 101	607 ± 178*	502 ± 126	553 ± 112
Arginine (μmol/L)	55.7 ± 27.3	63.1 ± 26.5	48.1 ± 23.9	59.1 ± 31.1	62.8 ± 29.1	66.8 ± 21.8
Citrulline (μmol/L)	22.5 ± 7.7	30.5 ± 13.4*	18.7 ± 7.5‡	32.5 ± 16.3	26.1 ± 5.7	28.6 ± 10.3
Glycine (μmol/L)	219 ± 87	261 ± 96*	204 ± 99	267 ± 98	225 ± 75	256 ± 97
Threonine (μmol/L)	105 ± 24	106 ± 43	104 ± 23	105 ± 53	106 ± 26	108 ± 33
Alanine (μmol/L)	440 ± 152	386 ± 189	432 ± 146	391 ± 218	447 ± 162	382 ± 164
Valine (μmol/L)	234 ± 59	194 ± 51*	236 ± 59	204 ± 62	232 ± 61	184 ± 38*
Isoleucine (μmol/L)	53.4 ± 24.3	49.4 ± 19.6	57.6 ± 28.2	49.7 ± 19.5	49.5 ± 20.0	49.1 ± 20.4
Leucine (μmol/L)	123 ± 28	110 ± 41	129 ± 33	119 ± 54	117 ± 21	101 ± 24*
BCAA (μmol/L)	410 ± 104	353 ± 105*	422 ± 116	372 ± 129	399 ± 93	334 ± 76
AAA (μmol/L)	195 ± 43	168 ± 52*	192 ± 49	175 ± 59	197 ± 37	163 ± 45
Methonine (μmol/L)	31.2 ± 14.1	31.2 ± 24.2	28.7 ± 12.5	34.9 ± 33.4	33.5 ± 15.5	27.7 ± 10.4
Ornithine (μmol/L)	80.8 ± 23.1	66.0 ± 28.1*	80.2 ± 27.8	74.1 ± 30.0	81.4 ± 18.7	58.5 ± 24.7*
Lysine (μmol/L)	178 ± 53	159 ± 50	172 ± 55	167 ± 57	183 ± 51	152 ± 42
Amino acid index	1.9 ± 2.7	−0.04 ± 1.8	2.8 ± 2.7	0.2 ± 2.1*	1.0 ± 2.4	−0.3 ± 1.5

AAA aromatic amino acids, *BCAA* branched-chain amino acids

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

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

The main limitation of the current study was choosing a single time point at 6 months after operation to assess the RMR and amino acid profile. Hence, further studies with further time points and longer follow-up, i.e., every month for at least 1 year, are suggested to confirm the effect of LRYGB and LSG on the metabolic rate. In addition, the small sample size of each group could have affected the results. Another limitation of study was using BIA to measure body composition. Although we used multi-frequency BIA, this method is less valid and precise than DXA to assess body composition and its alterations after weight loss among obese, especially morbidly obese, patients. In the current study, 98% of the participants were females, which limits the validity of our results in males due to sex differences in body composition that affect RMR.

In conclusion, the results of our study revealed that RMR significantly reduced 6 months after LRYGB and LSG in both groups but its difference was not significant between the two groups. Reduction in RMR decreased energy expenditure and feeling of satiety and may increase associated risk of weight regain. The levels of BCAA, AAA, and AAI significantly decreased 6 months after surgery-induced weight loss but their changes were not significant in each group and between groups. Decrement of BCAA and AAA levels is associated with improvement of insulin resistance, CVD, and diabetes mellitus.

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Compliance with Ethical Standards

The study protocol was approved by the Ethics Committee of Tehran University of Medical Sciences and written consent was obtained from all patients.

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

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