Journal of Endocrinological Investigation
https://doi.org/10.1007/s40618-018-0868-2

ORIGINAL ARTICLE

Predictors of fat-free mass loss 1 year after laparoscopic sleeve gastrectomy

B. Guida[1,2] · M. Cataldi[2,3] · L. Busetto[4] · M. L. Aiello[1] · M. Musella[2,5] · D. Capone[2] · S. Parolisi[1] · V. Policastro[6] · G. Ragozini[6] · A. Belfiore[1,2]

Received: 6 September 2017 / Accepted: 9 March 2018
© Italian Society of Endocrinology (SIE) 2018

Abstract

Purpose Laparoscopic sleeve gastrectomy (LSG) is one of the most frequently performed bariatric surgery interventions because of its safety and efficacy. Nevertheless, concerns have been raised on its detrimental effect on patient nutritional state that can ultimately lead to the loss of fat-free mass (FFM). There is interest in identifying predictors for the early identification of patients at risk of this highly unwanted adverse because they could benefit of nutritional preventive interventions. Therefore, we investigated whether anthropometric parameters, body composition or resting energy expenditure (REE) measured before surgery could predict FFM loss 1 year after LSG.

Methods Study design was retrospective observational. We retrieved data on body weight, BMI, body composition and REE before and 1 year after LSG from the medical files of 36 patients operated on by LSG at our institutions. Simple regression, the Oldham's method and multilevel analysis were used to identify predictors of FFM loss.

Results Averaged percentage FFM loss 1 year after LSG was 17.0 ± 7.7% with significant differences between sexes (20.8 ± 6.6 in males and 12.2 ± 6.1% in females, $p < 0.001$). FFM loss was strongly predicted by pre-surgery FFM and this effect persisted also after correcting for the contribution of sex.

Conclusions High FFM values before surgery predict a more severe FFM loss after LSG. This factor could also account for the higher FFM loss in men than in women. Our finding could help in the early identification of patient requiring a nutritional support after LSG.

Keywords Laparoscopic sleeve gastrectomy · Fat-free mass · Resting energy expenditure · BIA · Gender difference

Introduction

Current guidelines recommend bariatric surgery in obese patients with a BMI ≥ 40, or BMI ≥ 35 and at least one or more major obesity-related co-morbidities [1, 2]. Available evidence suggests that in patients with severe obesity, bariatric surgery causes a durable reduction of body weight and an effective control of co-morbidities that persist for years hence improving short- and medium-term prognosis [3]. Considering the limited and highly variable results of drug therapy, it has been suggested that bariatric surgery could represent the most effective therapeutic option in severely obese patients [4]. Consequently, the demand for bariatric procedures is strongly increasing making relevant the issue of their safety [5]. Because of the improvements in surgical techniques and thanks to the implementation of laparoscopic procedures, surgical complications substantially decreased over the years and nowadays, their prevalence

✉ B. Guida
bguida@unina.it

1 Division of Physiology, Department of Clinical Medicine and Surgery, Federico II University of Naples, Via Pansini n°5, 80131 Naples, Italy

2 Federico II University Hospital, Naples, Italy

3 Division of Pharmacology, Department of Neuroscience, Reproductive Sciences and Dentistry, Federico II University of Naples, Naples, Italy

4 Department of Medicine, University of Padova, Padua, Italy

5 Division of Surgery, Department of Advanced Biomedical Sciences, Federico II University of Naples, Naples, Italy

6 Division of Statistics, Department of Political Science, Federico II University of Naples, Naples, Italy

is similar to those of any general surgical intervention [6]. Conversely, the unwanted consequences of bariatric surgery on nutritional status and body composition continue to represent a major concern. Among them, the loss of fat-free mass (FFM) is especially worrying because it is expected to cause a decrease in resting energy expenditure (REE) [7] that may predispose to weight regain and negatively impact on long-term success of bariatric surgery [8]. The need to preserve FFM during whatsoever weight loss program is widely acknowledged and it has been suggested that FFM loss should never exceed 22% of the basal values in order to not impair REE [9]. All bariatric procedures cause FFM loss to a certain extent and restrictive procedures are considered safer than malabsorptive procedures under this respect. However, we recently reported that unlike other restrictive procedures such as gastric banding, laparoscopic sleeve gastrectomy (LSG) induces a significant FFM loss [10, 11]. This finding was not totally unexpected because LSG severely impairs the release of hormones controlling feeding such as ghrelin that are unaffected by more conventional restrictive procedures [12], hence lowering patient compliance to the specific postoperative nutritional program. Especially worrying is the difficulty experienced by many patients in achieving the recommended daily protein intake of 1.5–2.1 g/kg ideal weight [13] because protein malnutrition can further worsen FFM loss.

Because FFM loss can be prevented by specific nutritional interventions involving, for instance, the administration of a high-protein diet, it could be important to establish predictive criteria for the early identification, even before the surgical intervention, of patients at high risk of developing a severe FFM loss. To this aim, we performed the present retrospective observational study looking for the association between FFM loss after LSG and several clinical variables including sex, age, basal FFM and REE.

Patients and methods

Study design

The design of the present study was retrospective observational. To identify the variables associated with FFM loss after LSG, we retrospectively analyzed the medical records of 36 obese patients that underwent this bariatric surgical intervention at our institutions between 2014 and 2016. In all these patients, BMI, waist circumference and body composition with bioelectrical impedance analysis (BIA) were assessed as detailed below both before surgery and during follow-up 1 year after the surgical intervention. At the same time points, indirect calorimetry was performed. All procedures were performed in accordance with the 1964 Helsinki declaration and its later amendments.

LSG surgery and postsurgical care

Laparoscopic sleeve gastrectomy was performed under a 36-Fr calibration bougie as previously described [14–16]. Liquid diet was started on 4th postoperative day and was allowed for 10–15 days under strict nutritionist surveillance. Thereafter, the patient was switched to a puree-based diet that was gradually changed with a soft solid-food diet. Diet composition was adjusted to provide 1.0 g/kg/ideal body weight proteins and no more than 130 g/day of carbohydrates and 20 g/day of fat [11].

Body composition assessment

Body composition was determined with bioelectrical impedance analysis (BIA) using a single-frequency 50-kHz bioelectrical impedance analyzer (BIA 101 RJL, Akern Bioresearch, Firenze, Italy). Resistance (R) and reactance (Xc) were measured by the standard tetrapolar technique, with the subject in supine position and the electrodes placed on the dorsal surface of the right foot and ankle, and the right wrist and hand. FM and FFM were extrapolated from bioelectrical measurements using the software provided by the manufacturer [17]. Hydration was estimated from BIA vector's length using the following equation: $[Z]=\sqrt{[R/\mathrm{H}]^2+[\mathrm{Xc}/\mathrm{H}]^2}$ and the vector's phase angle as the arctan of Xc/R. The shorter is the vector, the higher the hydration [18].

Assessment of resting energy expenditure (REE)

Resting energy expenditure assessed was measured by indirect calorimetry using a canopy system (V max 29 N, Sensor Medics, Anaheim, USA). REE was calculated from measured oxygen consumption and carbon dioxide production using the appropriate Weir's formula neglecting protein oxidation [19]. The apparatus was calibrated with gas mixtures of known composition before each test and regularly checked by burning ethanol.

All REE examinations were performed under the same experimental conditions in accordance with the current best practice recommendations [20]. Specifically, patients were informed that before undergoing the test they had not to eat any food and not to perform heavy physical activity for 12 h, not to have coffee or water for 4 h, and not to smoke for 1 h. To minimize diurnal interindividual variations, REE measurements were always performed in the same room under thermoneutral conditions, between 8.00 and 10 a.m. once that the patient had half-an-hour rest in supine position after coming at our outpatient clinic.

Statistical analysis

Statistical analysis was performed IBM SPSS statistics 20.0 and R [21] with $p<0.05$ as the threshold for statistical significance. Data were examined for normality with the Shapiro–Wilk test and expressed as mean ± SD if normally distributed and as median and interquartile range, if not.

Data obtained before and after LSG were compared using paired Student's *t* test or with the Wilcoxon matched pair test as appropriate. We estimated that using these tests and assuming an SD of 10, a minimum sample size of 15 patients was required to detect a difference of 10 kg in FFM with the power of 0.95 and an α value of 5%. To compare REE–FFM ratios, we used residual analysis described as per Leibel et al. [22] because spurious results are obtained when directly comparing this kind of data [23]. Briefly, we first performed a regression analysis of pre-surgery REE and FFM values and then, calculated the differences (residuals) between each of the post-LSG REE value and the respective value predicted by aforementioned regression line. Finally, we tested with *z* test whether these residuals were significantly different from zero.

To identify the potential predictors of FFM loss after LSG, we performed a linear regression analysis between the pre- and post-surgery FFM difference (ΔFFM) and several anthropometric and metabolic variables including pre-surgery body weight, BMI and REE. Considering that because of a phenomenon known as *mathematical coupling* spurious results are obtained when the correlation between pre- and post-treatment values of the same variable is evaluated, we used the Oldham's method instead of an ordinary linear regression to examine the possible role of pre-surgery FFM as a predictor [24]. This method prevents the effects of *mathematical coupling* by examining the correlation between the difference and the average of the pre- and post-treatment values of a selected variable [24]. Likewise, to minimize the risk of spurious correlations, we used a peculiar form of multilevel regression analysis to evaluate the effect of the covariates age, sex and BMI in a model predicting ΔFFM as a function of pre-surgery FFM [25]. More specifically, we built our multilevel model considering the treatment (before and after surgery) as the first level and the individuals as the second level. Using this approach, the relation between baseline (pre-surgery) and post-treatment (post-surgery) values was evaluated by measuring the correlation between the variance of the intercepts and the variance of the random slopes for the covariate time that codes the two occasions of pre- and post-surgery [25]. This covariate was parameterized as 0.5 (pre-surgery) and −0.5 (post-surgery) because with this parameterization multilevel modeling equates the Oldham's method (which, however, does not allow including additional covariates). As detailed in Blance et al. [25], to make the estimation of model's parameters possible we set the residual variance to zero by constraining measurement variability to be zero, and therefore, we conventionally attributed to biological variance, all the variability observed. Multilevel analysis was performed using the lme4 R package [26].

Results

Study population

Table 1 reports the main characteristics of the 36 obese patients of our study population at the time of their pre-surgical evaluation. Sixteen of them were females and the others males. Their median age with interquartile interval was 41.5 [34.5–44.0] years and average BMI was 46.8 ± 5.3 kg/m^2 with no significant difference between sexes. All of the patients met guideline requirements for bariatric surgery. More specifically, 34 of them had a BMI higher than 40 whereas in the remaining two patients (both males) the BMI was higher than 35 and lower than 40 but they had at least one major comorbidity. Median preoperative FFM with interquartile interval measured by bioimpedance was 81.9 [62.4–90.9] kg, corresponding to 57.9 ± 8.1% of whole body mass. Median and interquartile range values of REE and RQ were 2049.0 kcal/day [1743.0–2547.5] and 0.84 [0.82–0.87], respectively. We observed significant gender-related differences in body composition with higher FM% values in females and higher FFM% in males (Fig. 1). Phase angle and BIA vector length were not significantly different in males and females (phase angle: 6.60 [5.95–7.30] vs 6.75 [6.30–7.15]; vector length: 175.3 ± 38.6 vs 169.6 ± 23.5 Ω/m) suggesting that patients of the two sexes had a similar hydration. Residual analysis showed that the gender-related difference in REE was totally accounted for by the difference in FFM between the two sexes (Fig. 2).

Clinical response to LSG

Table 1 reports the changes in anthropometric parameters, body composition and REE that we observed 1 year after LSG in our study population. The LSG intervention was successful in lowering body weight and BMI. Both FM and FFM significantly decreased after LSG. FFM loss was also confirmed by a significant decrease of phase angle. Males and females were less hydrated after LSG as indicated by BIA vector lengthening with no difference between sexes. We also observed a significant decrease in REE (Table 1). Because FFM is a major determinant of REE, the observed decrease in REE after LSG could be merely the consequence of the LSG-induced loss of FFM. To establish whether FFM loss totally accounted for the decrease in REE, we performed an analysis of the residuals between the REE values

Table 1 Anthropometric, body composition and basal metabolism parameters before and 1 year after LSG in the whole study population

	Before LSG	1 year after LSG
Age (years)	41.5 (34.5–44.0)	
Height (cm)	169.3 ± 10.2	
Body weight (kg)	130.7 (118.1–143.6)	90.4 (83.0–99.8)**
Body weight loss (percent decrease)	na	30.9 ± 8.3
BMI (kg/m^2)	46.8 ± 5.4	32.1 ± 3.8**
FFM (kg)	81.9 (62.4–90.9)	65.7 (52.6–72.4)**
FFM (% of total body weight)	57.9 ± 8.1	69.4 ± 9.0**
FFM loss (kg)	na	14.3 ± 8.7
FFM loss (percent decrease)	na	17.0 ± 7.7
FM (kg)	56.2 ± 11.8	28.3 ± 9.5**
FM loss (kg)	na	27.9 ± 10.8
FM loss (percent decrease)	na	27.9 ± 10.8
Phase angle (degree)	6.65 (6.15–7.20)	6.00 (5.55–6.40)**
BIA vector length (Ω/m)	172.5 ± 31.8	198.5 ± 37.3**
REE (kcal/day)	2049.0 (1743.0–2547.5)	1518.0 (1398.0–1655.5)**
RQ	0.84 (0.82–0.87)	0.82 (0.76–0.87)*

* $p < 0.05$, ** $p < 0.01$ vs before LSG

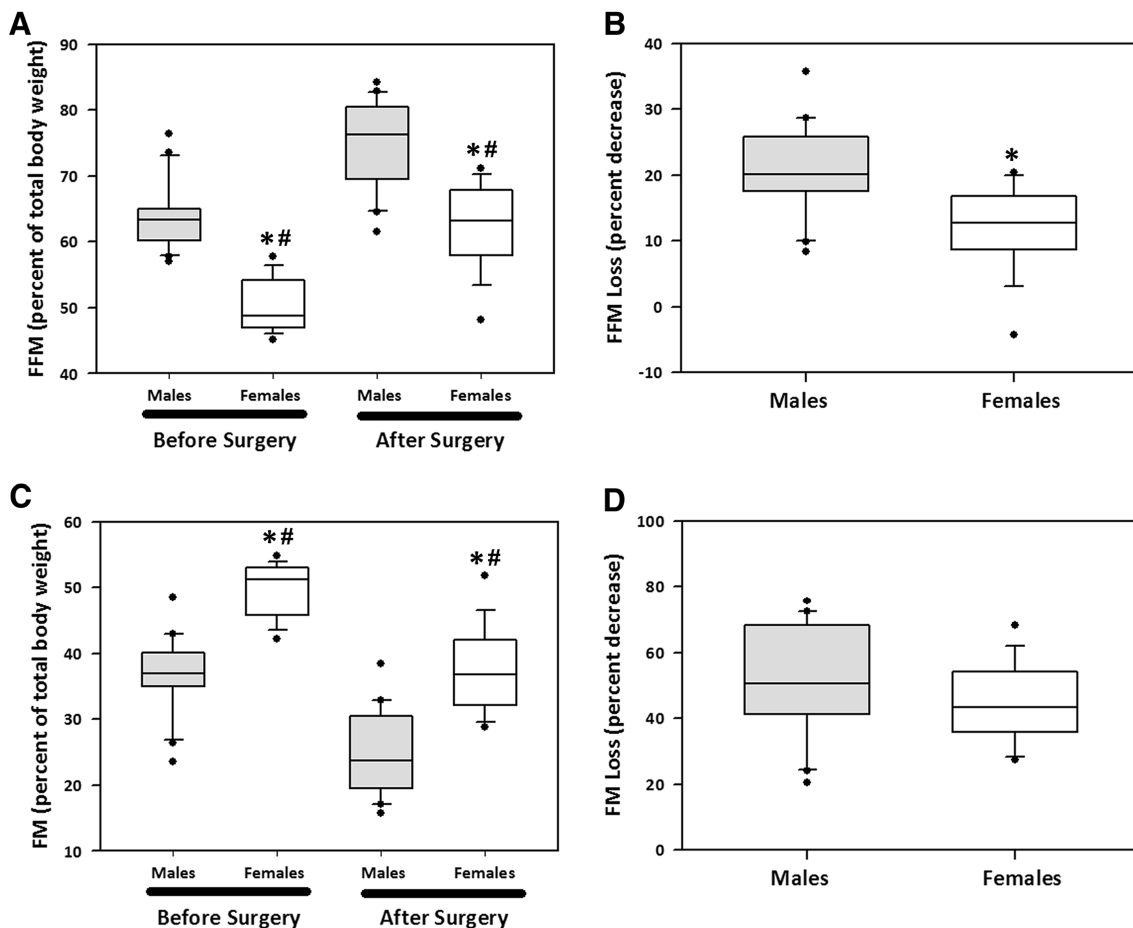

Fig. 1 Changes in body composition in male and female patients 1 year after LSG. The box plots show median, interquartile values and outliers of pre- and post-surgery FFM as percent of body weight (**a**), FFM percent loss after LSG (**b**), pre- and post-surgery FM as percent of body weight (**c**) and FM percent loss after LSG (**d**) in males ($n = 16$) and females ($n = 20$) patients. *$p < 0.01$ vs males, $^{\#}p < 0.01$ vs before surgery

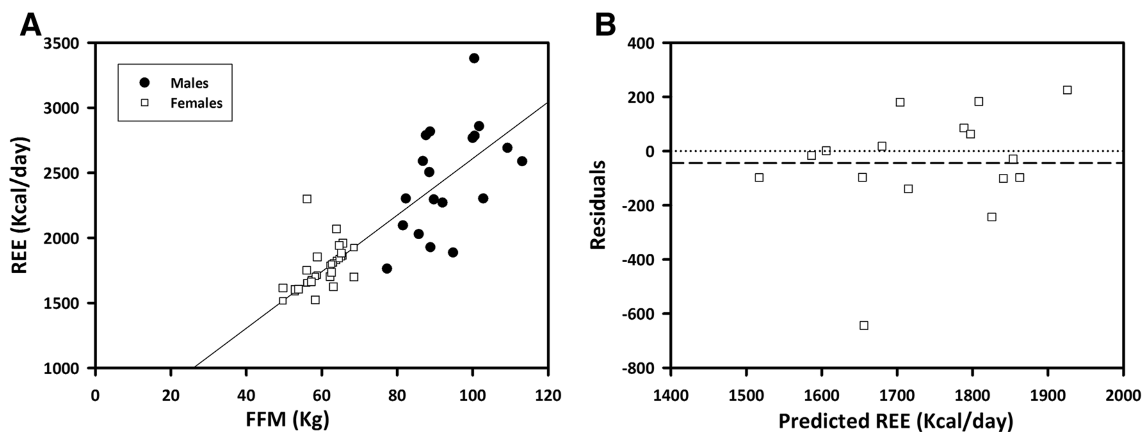

Fig. 2 Gender-related differences in REE. **a** The scatter plot shows the values of pre-surgery REE as a function of pre-surgery FFM. Notice that male (•) and female (□) patients segregate in two clearly separated groups with males having higher FFM and REE values. The regression line between FFM and REE shown in the plot was obtained fitting only the data from males. **b** Residual plot of REE in females. The panel shows REE residual in females (i.e., the difference between observed REE and REE predicted with the regression equation of REE versus FFM in males) as a function of predicted REE. Notice that residuals were symmetrically distributed around their average (dashed line) and not significantly different from zero (dotted line) suggesting that FFM was the sole determinant of REE

observed post-LSG and those predicted from the values of post-LSG FFM values. Results showed that these residuals were significantly different from zero ($p<0.001$) (Fig. 3). This finding showed that the difference in REE was larger than what the sole FFM decrease could account suggesting a direct effect of LSG on REE.

We did not observe significant differences between sexes in mean percent decrease in body weight (32.7 ± 8.8 in males and $28.6 \pm 7.2\%$ in females, ns). Conversely, marked gender-related differences emerged when we looked at the different contributions of FM and FFM to LSG-induced weight loss. Indeed, males lost much more FFM than females (FFM Δ%: 20.8 ± 6.6 in males and $12.2 \pm 6.1\%$ in females, $p<0.001$) (Fig. 1). Conversely, no significant difference between sexes was observed in the percent decrease of FM Δ% (52.2 ± 16.94 in males and $45.2 \pm 11.7\%$ in females, ns) (Fig. 2). Also, REE decreased more in males than in females (REE Δ%: 33.5 [24.6–43.8] in males and 22.0 [13.7–27.5] in females, $p<0.001$) whereas RQ decreased only marginally and to a similar extent in the two sexes (Fig. 4).

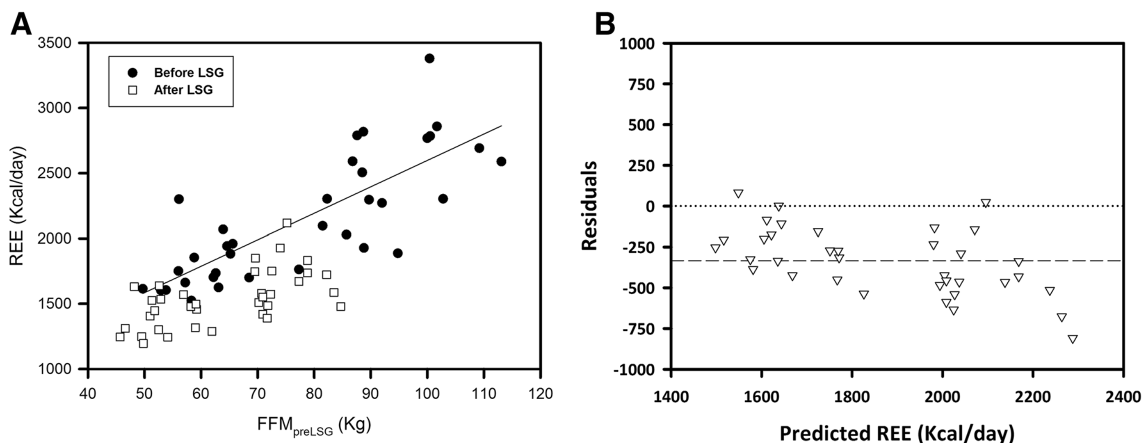

Fig. 3 Residual analysis of the changes in REE after LSG. **a** The scatter plot shows the values of pre- (•) and post-surgery (□) REE as a function of pre-surgery FFM. The regression line between FFM and REE shown in the plot was obtained fitting only pre-surgery data. **b** Residual plot of post-surgery REE. The panel shows REE post-surgery residual (i.e. the difference between observed post-surgery REE and REE predicted with the regression equation of REE versus pre-surgery FFM) as a function of predicted REE. Notice that residuals were symmetrically distributed around their average (dashed line) and significantly different from zero (dotted line) suggesting that the effect of surgery on REE was not explained only by the decrease in FFM that it caused

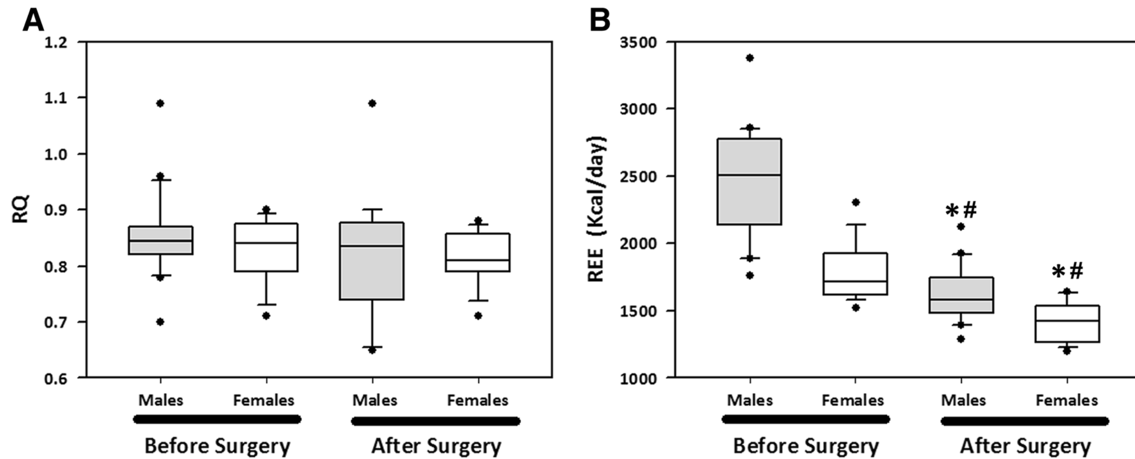

Fig. 4 Changes in basal metabolism in male and female patients 1 year after LSG. The box plots show median, interquartile values and outliers of RQ (**a**) and REE (**b**) in males ($n = 16$) and females ($n = 20$) patients, before and 1 year after LSG. $^{*}p < 0.01$ vs males, $^{\#}p < 0.01$ vs before surgery

Predictors of FFM loss 1 year after LSG

To establish whether any of the anthropometric, body composition and resting energy expenditure parameters that were measured before surgery was related to the loss of FFM 1 year after LSG, we first performed single regression analyses. As shown in Fig. 5, FFM loss (ΔFFM) was significantly associated with pre-surgery body weight and BMI, but not with vector length or phase angle. As explained more in detail in the "Patients and methods" section, we used the Oldham's method to minimize the effect of *mathematical coupling* in evaluating the association between pre-surgery FFM and post-LSG FFM loss. The results showed a strong correlation between these two parameters ($r = 0.77$, $t = 7.11$ $p = 1.6\text{e}{-08}$) (Fig. 6).

To evaluate the effect of covariates on the relation between pre-surgery FFM and post-surgery FFM loss, we used multilevel modeling as described in detail in the

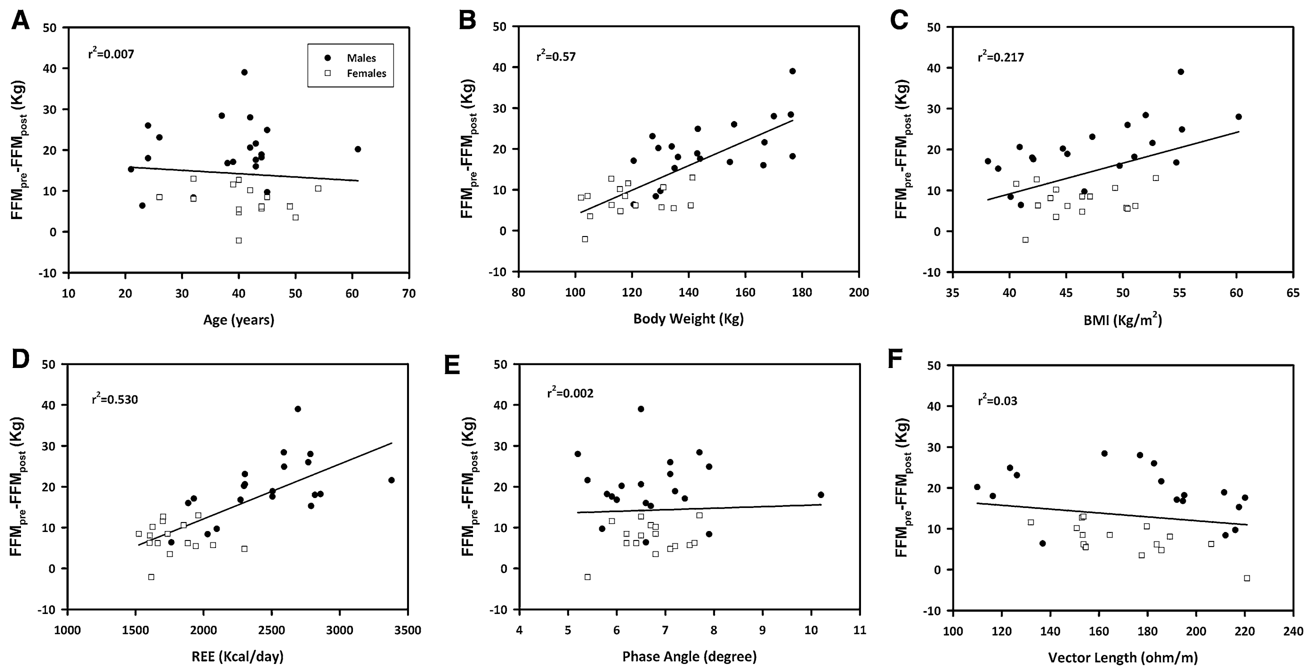

Fig. 5 Simple linear regression analysis of variables associated with FFM loss 1 year after LSG. The figure shows the linear regression plots of FFM loss (i.e., the difference between pre- and post-surgery FFM) 1 year after LSG with body weight (**b**), BMI (**c**), and REE (**d**). In each plot, the regression line and its confidence interval are shown. The inset shows the r^2 value and the significance level

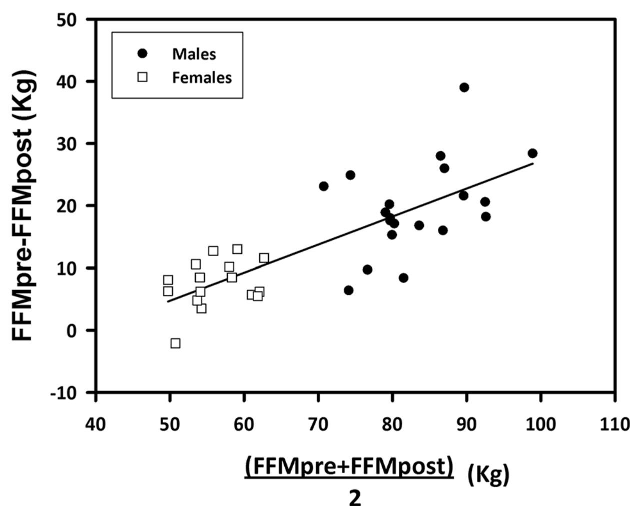

Fig. 6 Correlation between pre- and post-surgery FFM evaluated with the Oldham's method. The plot graph shows the LSG-induced FFM loss (pre- minus post-surgery FFM) plotted as a function of the average of pre- and post-FFM. As discussed in the "Patients and methods" section, this approach minimizes the consequence of mathematical coupling. Notice that males and females segregate in two clearly separated groups

"Patients and methods" section. The results reported in Table 2 showed that post-LSG FFM was significantly correlated with FFM even when we corrected for the effect of sex which was also related with FFM loss. Conversely, neither age nor BMI showed any significant effects on FFM loss. Other anthropometric and body composition variables such as body weight or FM were not include in the multilevel model because they showed a significant collinearity with the independent variable pre-surgery FFM.

Discussion

Fat-free mass loss is an important adverse effect of bariatric surgery and it would be important to identify patients at risk that could benefit of a tailored nutritional intervention for its prevention. With this aim, in the present paper, we investigated whether body composition parameters and/or resting energy expenditure measured before surgery could predict FFM loss. The main finding of our study is that patients with the highest FFM before surgery are also those with the highest FFM loss 1 year after LSG. We also found that males loose more FFM than females.

The reason why high values of pre-surgery FFM could be predictive of a higher percent FFM loss after LSG is not obvious. However, considering that FFM is largely contributed for by skeletal muscles and that skeletal muscle metabolism is a major determinant of resting energy expenditure [27], we believe that our results could actually indicate that patients with a higher muscle mass before surgery are at higher risk of losing more muscles in conditions of decreased energy intake such as those induced by LSG. This hypothesis is in agreement with the evidence that physiological signals that increase skeletal muscle mass also increase the relative prevalence in skeletal muscles of type II fibers that not only synthesize more proteins but have also a higher ability to degrade them [28–32]. Therefore, type II fibers are the most susceptible muscle fiber type to become

Table 2 Multilevel analysis of the correlation between FFM loss (DFFM) and pre-surgery FFM

Parameter	Random effects		Fixed effects			*r*	*t*	*p*
	Variance	Standard deviation	Estimate	Standard error	*T*			
(a) Two-level model								
Intercept	3.053e+02	17.4726	71.159	2.912	24.435	0.69	5.56	1.6e−06
OCC	1.205e+02	10.9780	14.265	1.830	7.796			
Residual	1.000e−08	0.0001						
(b) Best multilevel model incorporating covariates								
Intercept	4.593e+01	6.7770	59.062	1.544	38.26	0.55	3.84	0.0002554839
OCC 0.5	7.824e+01	8.8454	14.264	1.474	9.68			
Male sex			−21.772	1.894	−11.49			
Residual	1.000e−08	0.0001						

The model in reported in (a) was obtained using only two levels: the first one was the treatment (pre- and post-surgery) and the second the individuals. OCC indicates the occasion (time) variable used to code the treatment (pre- and post-) as 0.5 and − 0.5. The model (b) is the best of the different models that we tested including covariates as additional levels in multilevel analysis. In this model, sex was the only covariate because in the other tested models neither age nor BMI were significant. As detailed in the Methods section, anthropometric and BIA parameters correlating with FFM were not considered because of collinearity issues. Notice that the effect of sex in the model (b), which is apparently opposite to the effect of pre-surgery FFM, does not reflect per se the consequence of being male on FFM loss but quantifies the effect of male sex on the position of the intercept (the average of pre- and post-surgery FFM). Indeed, because males have on average higher pre- and post-surgery FFM, also the intercept will be higher. In this sense, male sex attenuates the effect of pre-surgery FFM on post-surgery FFM loss

atrophic in conditions of nutrient deprivation [28–32]. Interestingly, whereas type I fibers are essentially lipolytic and therefore can easily adapt to the conditions induced by LSG by burning fatty acids, the predominant metabolism of type II fibers is glycolytic in subtype IIa and oxidative in type IIb and is expected to be seriously affected by decreased nutrient availability [28].

Another important finding of our study was that males lost much more FFM than females after LSG. However, sex was not an independent risk factor in GLM analysis because its effect was fully explained by gender-related differences in pre-surgery FFM that, as expected, was higher in males than in females. Interestingly, evidence has been reported that not only muscle mass is higher in males than in females but also differs in its fiber composition and metabolic activity [32, 33]. More specifically, skeletal muscles of females have a higher ability than skeletal muscles of males to metabolize fat lipids and, therefore, better adapt to endurance and to conditions of nutrient deprivation [34, 35].

An additional factor to be considered in the interpretation of our results is that other components besides skeletal muscles such as extracellular water contribute to FFM. The results that we obtained, and in particular the lengthening of the impedance vector, showed that after surgery a hypohydration status did occur. We also observed a decrease in phase angle, but this parameter reflect both fluid status and lean body mass and therefore cannot be considered a specific indicator of hydration. Because of the decrease in the extracellular water, FFM could have been underestimated and its loss overestimated. However, we did not observe any correlation between the length of pre-surgery BIA vector and FFM loss hence suggesting that FFM loss was not dependent on differences in hydration.

Our evidence that the higher baseline FFM is a risk factor for losing more FFM could have important implications because it may help the early identification of patients that need a nutritional support to preserve their FFM after LSG. As we already emphasized in the introduction, it is important to prevent the FFM loss that takes place after bariatric surgery because it may cause a profound decrease in resting energy expenditure [9]. Here, we report that 1 year after LSG, REE was about 26% lower than that before surgery. This decrease was essentially due to the decrease in FFM, and indeed, no significant difference was observed when comparing the pre- and post-surgery values of REE normalized per kilogram of FFM indicating that the unitary metabolic activity of FFM was maintained. Similar results have been reported by Das et al. [36] and by Carey et al. [37]. These data alongside with the evidence that in our patients the percent decrease of FFM was about 18% suggest that although LSG has been traditionally considered as one of the better-tolerated bariatric surgery interventions, it could actually profoundly affect body composition and metabolism. Moreover, LSG is one among the bariatric surgical procedures that cause the steepest curve of weight loss in the first postoperative months [38]. These considerations highlight the need of being vigilant on FFM loss also when the patients have been operated on by LSG and the importance of identifying patients at high risk to begin, as soon as possible, a protein supplementation aiming to preserve FFM.

In conclusion, we have shown that high FFM% and REE values before surgery predict a more severe FFM loss after LSG. These factors can also account for the higher percentage FFM loss in men than in women. Our finding could help in the early identification of patients requiring a nutritional support with proteins before FFM loss takes place.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval For this type of study formal consent is not required.

Informed consent No informed consent.

References

1. Yumuk V, Tsigos C, Fried M, Schindler K, Busetto L, Micic D, Toplak H (2015) Obesity Management Task Force of the European Association for the Study of Obesity. European Guidelines for Obesity Management in Adults. Obes Facts 8:402–424
2. De Luca M, Angrisani L, Himpens J, Busetto L, Scopinaro N, Weiner R, Sartori A, Stier C, Lakdawala M, Bhasker AG, Buchwald H, Dixon J, Chiappetta S, Kolberg HC, Frühbeck G, Sarwer DB, Suter M, Soricelli E, Blüher M, Vilallonga R, Sharma A, Shikora S (2016) Indications for surgery for obesity and weight-related diseases: position statements from the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO). Obes Surg 26:1659–1696
3. Sjöström L (2013) Review of the key results from the Swedish Obese Subjects (SOS) trial—a prospective controlled intervention study of bariatric surgery. J Intern Med 273:219–234
4. Colquitt JL, Pickett K, Loveman E, Frampton GK (2014) Surgery for weight loss in adults. Cochrane Database Syst Rev 8:CD003641
5. O'Neill KN, Finucane FM, le Roux CW, Fitzgerald AP, Kearney PM (2016) Unmet need for bariatric surgery. Surg Obes Relat Dis 13:1052–1056
6. Böckelman C, Hahl T, Victorzon M (2017) Mortality following bariatric surgery compared to other common operations in Finland during a 5-year period (2009–2013). A Nationwide Registry Study. Obes Surg 27:2444–2451
7. Cunningham JJ (1991) Body composition as a determinant of energy expenditure: a synthetic review and a proposed general prediction equation. Am J Clin Nutr 54:963–969
8. Faria SL, Kelly E, Faria OP (2009) Energy expenditure and weight regain in patients submitted to Roux-en-Y gastric bypass. Obes Surg 19:856–859
9. Webster JD, Hesp R, Garrow JS (1984) The composition of excess weight in obese women estimated by body density, total body water and total body potassium. Hum Nutr Clin Nutr 38:299–306

10. Guida B, Belfiore A, Angrisani L, Micanti F, Mauriello C, Trio R, Pecoraro P, Falconi C (2005) Laparoscopic gastric banding and body composition in morbid obesity. Nutr Metab Cardiovasc Dis 15:198–203
11. Belfiore A, Cataldi M, Minichini L, Aiello ML, Trio R, Rossetti G, Guida B (2015) Short-term changes in body composition and response to micronutrient supplementation after laparoscopic sleeve gastrectomy. Obes Surg 25:2344–2351
12. Fruhbeck G, Diez Caballero A, Gil MJ (2004) Fundus functionality and ghrelin concentrations after bariatric surgery. N Engl J Med 350:308–309
13. Sherf Dagan S, Tovim TB, Keidar A, Raziel A, Shibolet O, Zelber-Sagi S (2017) Inadequate protein intake after laparoscopic sleeve gastrectomy surgery is associated with a greater fat free mass loss. Surg Obes Relat Dis 13:101–109
14. Galloro G, Magno L, Musella M, Manta R, Zullo A, Forestieri P (2014) A novel dedicated endoscopic stent for staple-line leaks after laparoscopic sleeve gastrectomy: a case series. Surg Obes Relat Dis 10:607–611
15. Musella M, Milone M, Bianco P, Maietta P, Galloro G (2016) Acute leaks following laparoscopic sleeve gastrectomy: early surgical repair according to a management algorithm. J Laparoendosc Adv Surg Tech A 26:85–91
16. Hayes K, Eid G (2016) Laparoscopic sleeve gastrectomy: surgical technique and perioperative care. Surg Clin North Am 96:763–771
17. Guida B, Cataldi M, Maresca ID, Germanò R, Trio R, Nastasi AM, Federico S, Memoli A, Apicella L, Memoli B, Sabbatini M (2013) Dietary intake as a link between obesity, systemic inflammation, and the assumption of multiple cardiovascular and antidiabetic drugs in renal transplant recipients. Biomed Res Int 2013:363728
18. Guida B, De Nicola L, Trio R, Pecoraro P, Iodice C, Memoli B (2000) Comparison of vector and conventional bioelectrical impedance analysis in the optimal dry weight prescription in hemodialysis. Am J Nephrol 20:311–318
19. Cunningham JJ (1990) Calculation of energy expenditure from indirect calorimetry: assessment of the Weir equation. Nutrition 6:222–223
20. Compher C, Frankenfield D, Keim N, Roth-Yousey L (2006) Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review. J Am Diet Assoc 106:881–903
21. R Core Team (2016) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. https://www.R-project.org/
22. Leibel RL, Rosenbaum M, Hirsch J (1995) Changes in energy expenditure resulting from altered body weight. N Engl J Med 332:621–628
23. Ravussin E, Bogardus C (1989) Relationship of genetics, age, and physical fitness to daily energy expenditure and fuel utilization. Am J Clin Nutr 49(5 Suppl):968–975
24. Tu YK, Gilthorpe MS (2007) Revisiting the relation between change and initial value: a review and evaluation. Stat Med 26:443–457
25. Blance A, Tu YK, Gilthorpe MS (2005) A multilevel modelling solution to mathematical coupling. Stat Methods Med Res 14:553–565
26. Bates D, Maechler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Software 67(1):1–48
27. Zurlo F, Larson K, Bogardus C, Ravussin E (1990) Skeletal muscle metabolism is a major determinant of resting energy expenditure. J Clin Investig 86:1423–1427
28. van Wessel T, de Haan A, van der Laarse WJ, Jaspers RT (2010) The muscle fiber type–fiber size paradox: hypertrophy or oxidative metabolism? Eur J Appl Physiol 110:665–694
29. Schiaffino S, Reggiani C (2011) Fiber types in mammalian skeletal muscles. Physiol Rev 91:1447–1531
30. Wang ZM, Heshka S, Gallagher D, Boozer CN, Kotler DP, Heymsfield SB (2000) Resting energy expenditure–fat-free mass relationship: new insights provided by body composition modeling. Am J Physiol Endocrinol Metab 279:E539–E545
31. Ciciliot S, Rossi AC, Dyar KA, Blaauw B, Schiaffino S (2013) Muscle type and fiber type specificity in muscle wasting. Int J Biochem Cell Biol 45:2191–2199
32. Haizlip KM, Harrison BC, Leinwand LA (2015) Sex-based differences in skeletal muscle kinetics and fiber-type composition. Physiology (Bethesda) 30:30–39
33. Lundsgaard AM, Kiens B (2014) Gender differences in skeletal muscle substrate metabolism—molecular mechanisms and insulin sensitivity. Front Endocrinol (Lausanne) 5:195
34. Roepstorff C, Thiele M, Hillig T, Pilegaard H, Richter EA, Wojtaszewski JF, Kiens B (2006) Higher skeletal muscle alpha2AMPK activation and lower energy charge and fat oxidation in men than in women during submaximal exercise. J Physiol 574:125–138
35. Hoyenga KB, Hoyenga KT (1982) Gender and energy balance: sex differences in adaptations for feast and famine. Physiol Behav 28:545–563
36. Das SK, Roberts SB, McCrory MA, Hsu LK, Shikora SA, Kehayias JJ, Dallal GE, Saltzman E (2003) Long-term changes in energy expenditure and body composition after massive weight loss induced by gastric bypass surgery. Am J Clin Nutr 78:22–30
37. Carey DG, Pliego GJ, Raymond RL (2006) Body composition and metabolic changes following bariatric surgery: effects on fat mass, lean mass and basal metabolic rate: six months to one-year follow-up. Obes Surg 16:1602–1608
38. Maïmoun L, Lefebvre P, Jaussent A, Fouillade C, Mariano-Goulart D, Nocca D (2017) Body composition changes in the first month after sleeve gastrectomy based on gender and anatomic site. Surg Obes Relat Dis 13:780–787