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ORIGINAL CONTRIBUTIONS

Prospective Longitudinal Trends in Body Composition and Clinical Outcomes 3 Years Following Sleeve Gastrectomy

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Abstract

Background and Aims Longitudinal assessment of body composition following bariatric surgery allows monitoring of health status. Our aim was to elucidate trends of anthropometric and clinical outcomes 3 years following sleeve gastrectomy (SG).

Methods A prospective cohort study of 60 patients who underwent SG. Anthropometrics including body composition analysis measured by multi-frequency bioelectrical impedance analysis, blood tests, liver fat content measured by abdominal ultrasound and habitual physical activity were evaluated at baseline and at 6 (M6), 12 (M12), and 36 (M36) months post-surgery.

Results Sixty patients (55% women, age 44.7 ± 8.7 years) who completed the entire follow-up were included. Fat mass (FM) was reduced significantly 1 year post-surgery (55.8 ± 11.3 to 26.7 ± 8.3 kg; $P < 0.001$) and then increased between 1 and 3 years post-operatively, but remained below baseline level (26.7 ± 8.3 to 33.1 ± 11.1 kg; $P < 0.001$). Fat free mass (FFM) decreased significantly during the first 6 months (64.7 ± 14.3 to 56.9 ± 11.8 kg; $P < 0.001$), slightly decreased between M6 and M12 and then reached a plateau through M36. Weight loss "failure" (< 50% excess weight loss) was noticed in 5.0% and 28.3% of patients at M12 and M36, respectively. Markers of lipid and glucose metabolism changed thereafter in parallel to the changes observed in FM, with the exception of HDL-C, which increased continuingly from M6 throughout the whole period analyzed (45.0 ± 10.2 to 59.5 ± 15.4 mg/dl; $P < 0.001$) and HbA1c which continued to decrease between M12 and M36 (5.5 ± 0.4 to 5.3 ± 0.4%; $P < 0.001$). There were marked within-person variations in trends of anthropometric and clinical parameters during the 3-year follow-up.

Conclusions Weight regain primarily attributed to FM with no further decrease in FFM occurs between 1 and 3 years post-SG. FM increase at mid-term may underlie the recurrence of metabolic risk factors and can govern clinical interventions.

Keywords Bariatric surgery · Clinical parameters · Excess weight loss · Fat mass · Fat free mass

Abbreviations

BIA	Bioelectrical impedance analysis
BMI	Body mass index
CRP	C-reactive protein
DEXA	Dual X-ray absorptiometry
EWL	Excess weight loss

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FFM	Fat free mass
FM	Fat mass
HbA1C	Hemoglobin A1c
HRI	Hepato-renal index
HDL-C	High-density lipoprotein cholesterol
HOMA	Homeostasis model assessment
IBW	Ideal body weight
IR	Insulin resistance
LDL-C	Low-density lipoprotein cholesterol
NAFLD	Nonalcoholic fatty liver disease
RCT	Randomized clinical trial
RYGB	Roux-en-Y gastric bypass
RMR	Resting metabolic rate
SG	Sleeve gastrectomy
TC	Total cholesterol
WC	Waist circumference

Introduction

Sleeve gastrectomy (SG) has become the most commonly performed bariatric surgery (BS) worldwide in recent years, but data on long-term outcomes are still limited [1–3]. Recent studies have shown a wide variation in the amount of weight loss and weight regain following SG [2, 4–6]. Outcomes post-BS are usually reported using metrics such as percent excess weight loss (%EWL) [4]. It was suggested that body composition measurement is more accurate in assessing the quality of weight loss [7], has a close relationship with metabolism [8], and should become a routine part of the clinical evaluation pre- and post-surgery [7].

Changes in body composition post-BS such as a sustained loss of body fat mass (FM) are frequently associated with an inevitable loss of fat free mass (FFM) [9]. FFM loss may contribute to an undesirable disturbance in resting metabolic rate (RMR), weight maintenance, metabolic impairment, functional loss, sarcopenia, and frailty development [9–11]. Presently, no definition for "standard" FFM or FM loss post-BS exists [12] and the longevity and time course of these changes are unclear [10]. There is emerging data on body composition changes following different types of bariatric procedures [10, 13–25]. However, only limited studies followed BS patients for more than 2 years [26–29], when weight recidivism might begin [4, 30] or correlated these changes to other metabolic parameters [27] or functionality [28]. Tracking of body composition through longer postoperative period may yield clinically relevant information to better identify and treat patients by lifestyle and medical care [27]. Thus, our aim was to evaluate trends of body composition and clinical outcomes 3 years following SG.

Materials and Methods

Subjects This prospective cohort study was part of a randomized clinical trial (RCT) of a 6-month treatment period with probiotic vs. placebo and a 6-month follow-up of 100 nonalcoholic fatty liver disease (NAFLD) patients who underwent SG surgery from February 2014 to January 2015 at the Tel-Aviv Assuta Medical Center [31]. Inclusion criteria were those of the primary RCT: age between 18 and 65 years old, body mass index (BMI) > 40 kg/m^2 or BMI > 35 kg/m^2 with co-morbidities, approval of the Assuta Medical Center committee to undergo BS, and ultrasound (US) diagnosed NAFLD. The major exclusion criteria included infection with hepatotrophic viruses, fatty liver suspected to be secondary to hepatotoxic drugs, excessive alcohol consumption, use of antibiotics or probiotics in the last 3 months, and previous BS. Diabetic patients who were treated with anti-diabetic medications, other than exclusive treatment with Metformin at a stable dose for at least 6 months, were also excluded [31].

Patients were invited to attend an additional follow-up visit 3.3 ± 0.2 years (range 3.0–3.7) (defined as "36M") following the surgery and were excluded if they underwent conversion surgery or were presently pregnant. Data of the original RCT combined treatment groups are presented, since no difference between them was observed for the measurements discussed here. Medical history and demographic details were obtained from the patients' medical records. Baseline (M0) and follow-up evaluations at 6 (M6), 12 (M12), and 36 months (M36) were performed at the Tel-Aviv Medical Center.

Anthropometric Measurements Weight and height were measured on a digital medical scale, BMI was calculated, and waist circumference (WC) was measured twice at the level of the umbilicus. EWL percentage and percentage of total weight loss were calculated as recommended [32]. Cut-off points for FM percent were used for defining overweight (20.0–24.9% for men and 30.0–34.9% for women) and obesity (≥ 25.0% for men and ≥ 35.0% for women) as frequently used in the literature [27, 33, 34]. Patients with EWL < 50% at M12 were considered as primarily poor weight-loss responders and patients with EWL ≥ 50% at M12, but EWL < 50% at M36, were considered as secondarily poor weight-loss responders [35].

Patients were measured for body composition using multi-frequency bioelectrical impedance analysis (BIA) (Inbody220®, InBody Co., Ltd.). All patients were evaluated after an overnight fast of 12 h and according to the manufacturer's standard specifications.

BIA is a simple, low-cost, and non-invasive procedure used for the evaluation of body composition [29]. Multiple-frequencies BIA instruments determine body composition by applying electrical current across a range of frequencies to obtain fluid volumes [36].

Fatty Liver by US All US (Preirius Scanner Hitachi Medical Corporation, Tokyo, Japan) were performed by the same radiologist. Hepato-renal index (HRI) score, a validated index highly correlated with fat content, was calculated [37].

Biochemical Tests All blood tests were drawn following a 12-h fast and included lipids profile, glucose, hemoglobin A1C (HbA1c), insulin, and C-reactive protein (CRP).

The homeostasis model assessment of insulin resistance (HOMA-IR) was calculated [38].

Normal values of blood tests were defined according to the recommended outcome reporting standards [32].

Physical Activity Assessment Weekly minutes spent per week in performing physical activity were calculated by the multiplication of the number of training sessions per week with the duration of exercise in minutes [39].

Handgrip Strength Handgrip muscle strength test, which measures static muscle strength of the upper extremities [40], was measured at 36M by a digital hand dynamometer (Jamar Plus Digital). Three measurements were taken using the dominant hand and an average was calculated. Results were compared to the manufacturer's normal values for age and gender.

Statistical Analysis Statistical analyses were performed using SPSS (version 24.0). To compare continuous variables between 2 time-points, the *t* test for dependent groups was performed, and in dichotomous/categorical variables, the McNemar test was performed. To compare continuous variables between ≥3 time-points, repeated-measures ANOVA was used including the Bonferroni correction, and for dichotomous variables, the Cochran-Q test was performed. The Pearson or Spearman correlation coefficients were used to assess correlations between continues variables. The data presented unify both genders since no significant gender differences were found in trends for the great majority of the parameters discussed in the study. $P < 0.05$ was considered statistically significant for all analyses.

Results

Characteristics of the SG Cohort Study One hundred patients were recruited for the RCT study; 80, 77, and 60 attended the M6, M12, and M36 visits, respectively. A total of 60 patients (55% women, mean age 44.7 ± 8.7 years) who completed the entire follow-up were included in the analysis. Characteristics of the SG cohort study in all time-points are presented in Table 1.

Trends in Anthropometrics Weight regain was 6.0 ± 6.8 kg between M12 and M36, but the range was wide (10.4 kg loss to 22.8 kg weight regain), with 43.3% of participants regaining ≥5 kg. The percentages of primarily poor weight loss and secondarily poor weight loss were 5.0% and 23.3% at M12 and M36, respectively. Mean FM decreased significantly 1 year following the surgery (55.8 ± 11.3 to 26.7 ± 8.3 kg; $P < 0.001$) and then increased between 1 and 3 years post-operatively, but remained below baseline level (26.7 ± 8.3 to 33.1 ± 11.1 kg; $P < 0.001$).

FFM decreased significantly during the first 6 months (64.7 ± 14.3 to 56.9 ± 11.8 kg; $P < 0.001$), slightly decreased between M6 and M12 and then reached a plateau through M36 (Table 1). Significant correlations were found between FFM and hours spent per week in physical activity at M0 ($r = 0.384$; $P = 0.002$) and M12 ($r = 0.274$; $P = 0.034$), but not at M6 and M36.

Variability in anthropometric parameters between patients along the study period is presented in Fig. 1a–e.

Markers of Glucose Homeostasis Mean levels of glucose and HbA1c uniformly decreased during the first 6 months post-surgery and remained stable between M6 and M12, and then variable trends occurred. While mean glucose increased slightly between the M12 and M36 following the surgery, mean HbA1c continued to decrease during this period (5.5 ± 0.4 to 5.3 ± 0.4%; $P < 0.001$). Mean HOMA-IR decreased through the first post-operative year and then slightly increased between M12 and M36. Rates of abnormality levels of glucose (> 100 mg/dl) and HbA1C (> 5.7%) improved significantly between baseline and M36 (Table 1). Of note, great variability between patients in markers of glucose homeostasis was found along the study period (Fig. 2a–c).

Markers of Lipid Metabolism While TC and LDL-C means decreased only moderately during the first post-operative year and then increased significantly between M12 and M36, mean HDL-C increased continuously from 6 months post-operatively throughout the whole period analyzed (45.0 ± 10.2 to 59.5 ± 15.4 mg/dl; $P < 0.001$). Mean of triglycerides decreased significantly through the first post-operative year and then slightly increased between M12 and M36. Rates of abnormal levels of triglycerides (> 150 mg/dl) and HDL-C (< 40 mg/dl) improved significantly between baseline and M36, but increased significantly for TC (> 200 mg/dl) and non-significantly for LDL-C (> 130 mg/dl) (Table 1). Again, great variability between patients in markers of lipid metabolism during follow-up was observed (Fig. 2d–g).

HRI Score Mean HRI score was reduced significantly 1 year following the surgery (2.3 ± 0.5 to 1.2 ± 0.2; $P < 0.001$) and then slightly increased between 1 and 3 years post-operatively (Table 1). As in other measurements, great variability between patients in HRI score trends during follow-up was found (Fig. 2h).

Table 1 Anthropometrics and clinical characteristics of the study participants at all time-points

Parameter†	Baseline (M0) $n = 60$	6 month post-SG (M6) $n = 60$	12 months post-SG (M12) $n = 60$	36 months post-SG (M36) $n = 60$	P for trend
Age (years)	44.7 ± 8.7	–	–	–	–
Gender (%women)	55	–	–	–	–
Marital status (%married)	83.3	–	–	–	–
Co-morbidities					
Type 2 diabetes (%)	13.3	–	–	–	–
Use of type-2 diabetes medications (%)	8.3	0.0	0.0	0.0	0.002
Dyslipidemia (%)	55.0	–	–	–	–
Use of lipid-lowering medications (%)	13.3	5.0	5.0	6.7	0.010
Hypertension (%)	28.3	–	–	–	–
Use of anti-hypertension medications (%)	23.3	13.3	13.3	13.3	0.023
Current smoker (%)	6.7	–	–	–	–
Anthropometrics					
Weight (kg)	120.9 ± 19.7	90.8 ± 13.9[a]	83.4 ± 13.6[a,b]	89.4 ± 17.2[a,c]	< 0.001
BMI (kg/m^2)[1]	41.8 ± 4.9	31.4 ± 3.7[a]	28.8 ± 3.6[a,b]	30.9 ± 5.0[a,c]	< 0.001
Normal weight (%)	0	0	13.3	10.0	
Overweight (%)	0	41.7	60.0	35.0	
Obese (%)	100.0	58.3	26.7	55.0	
WC (cm)	124.1 ± 11.9	99.9 ± 10.3[a]	94.5 ± 9.8[a,b]	98.1 ± 12.1[a,c]	< 0.001
EWL (%)	–	63.6 ± 14.4	78.4 ± 19.4[b]	67.2 ± 24.2[c]	< 0.001
EWL < 50% (%)	–	–	5.0	28.3[3]	
Total weight loss (%)	–	24.7 ± 5.1	30.6 ± 7.9[b]	26.0 ± 8.8[c]	< 0.001
Body composition					
FFM (kg)	64.7 ± 14.3	56.9 ± 11.8[a]	56.1 ± 12.1[a,b]	56.1 ± 12.6[a]	< 0.001
FM (kg)	55.8 ± 11.3	33.4 ± 9.2[a]	26.7 ± 8.3[a,b]	33.1 ± 11.1[a,c]	< 0.001
FM (%)[2]	46.5 ± 6.5	37.1 ± 8.1[a]	32.3 ± 8.5[a,b]	36.8 ± 8.9[a,c]	< 0.001
Normal weight (%)	0	0	13.3	1.7	
Overweight (%)	0	8.3	21.7	16.7	
Obese (%)	100	91.7	65.0	81.7	
FM/FFM	0.9 ± 0.2	0.6 ± 0.2[a]	0.5 ± 0.2[a,b]	0.6 ± 0.2[a,c]	< 0.001
FFM loss/weight loss (%)	–	24.8 ± 10.0	23.0 ± 8.2	27.6 ± 9.4[b,c]	< 0.001
FM loss/weight loss (%)	–	75.6 ± 10.6	77.7 ± 8.6[b]	71.6 ± 10.2[b,c]	< 0.001
Physical activity					
Physical activity (hours/week)	1.0 ± 1.8	2.7 ± 2.6[a]	2.4 ± 2.2[a]	2.1 ± 2.2[a]	< 0.001
Physical activity (% who declared on exercising)	38.8	73.3[a]	76.7[a]	71.7[a]	< 0.001
Fatty liver by US					
US (HRI score)	2.3 ± 0.5	1.4 ± 0.4[a]	1.2 ± 0.2[a,b]	1.3 ± 0.3[a,c]	< 0.001
HRI score ≥ 1.5 (%)	96.7	41.7[a]	18.6[a,b]	33.3[a,c]	< 0.001
Blood tests					
TC (mg/dl)	185.5 ± 31.4	171.3 ± 28.7[a]	174.0 ± 25.8[a]	200.2 ± 30.5[a,b,c]	< 0.001
TC (% > 200 mg/dl)	31.7	13.3[a]	15.0[a]	50.0[a,b,c]	< 0.001
LDL-C (mg/dl)	112.1 ± 26.3	105.9 ± 25.6	102.0 ± 22.9[a]	119.5 ± 26.7[b,c]	< 0.001
LDL-C (% > 130 mg/dl)	21.7	13.3	11.7	33.3[b,c]	0.001
HDL-C (mg/dl)	44.5 ± 10.1	45.0 ± 10.2	54.0 ± 12.6[a,b]	59.5 ± 15.4[a,b,c]	< 0.001
HDL-C (% < 40 mg/dl)	35.0	36.7	10.0[a,b]	6.7[a,b]	<0.001
Triglycerides (mg/dl)	145.0 ± 67.3	102.7 ± 38.7[a]	90.7 ± 32.8[a,b]	105.7 ± 37.8[a,c]	<0.001
Triglycerides (% > 150 mg/dl)	38.3	11.7[a]	6.7[a]	10.0[a]	<0.001
Glucose (mg/dl)	90.1 ± 13.1	79.1 ± 6.8[a]	77.6 ± 6.6[a]	80.1 ± 8.6[a,c]	<0.001
Glucose (% > 100 mg/dl)	13.3	1.7[a]	1.7[a]	1.7[a]	<0.001
HbA1c (%)	5.8 ± 0.6	5.5 ± 0.4[a]	5.5 ± 0.4[a]	5.3 ± 0.4[a,b,c]	<0.001

Table 1 (continued)

Parameter†	Baseline (M0) $n = 60$	6 month post-SG (M6) $n = 60$	12 months post-SG (M12) $n = 60$	36 months post-SG (M36) $n = 60$	P for trend
HbA1c (% > 5.7%)	40.0	23.7[a]	20.0[a]	15.0[a]	<0.001
HOMA-IR[4]	5.8 ± 3.8	1.7 ± 0.8[a]	1.4 ± 0.8[a,b]	1.9 ± 1.1[a,c]	<0.001
CRP (mg/L)	10.7 ± 8.0	5.8 ± 6.9[a]	2.9 ± 4.1[a,b]	3.3 ± 4.3[a,b]	<0.001

Body mass index (BMI), waist circumference (WC), excess weight loss (EWL), fat free mass (FFM), fat mass (FM), hepato-renal index (HRI), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), hemoglobin A1c (HbA1C), homeostasis model assessment (HOMA), insulin resistance (IR), C-reactive protein (CRP)

†Values expressed as the average ± SD, unless otherwise stated

[a] $P < 0.05$ compared to baseline

[b] $P < 0.05$ compared to 6 months post-surgery

[c] $P < 0.05$ compared to 12 months post-surgery

[1] Cut-off points for BMI were defined as normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), obesity (30 ≤ kg/m^2)

[2] Cut-off points for FM percent were used for defining normal weight (< 20% for men and < 30% for women), overweight (20.0–24.9% for men and 30.0–34.9% for women), and obesity (≥ 25.0% for men and ≥ 35.0% for women)

[3] 5% of them were primarily poor weight-loss responders

[4] HOMA-IR = [fasting insulin (μU/mL) × fasting plasma glucose (mg/dl)]/405

Handgrip Strength Mean handgrip strength at M36 was 38.8 ± 12.8 kg. High significant correlation was found between handgrip strength and FFM at 36M ($r = 0.883$; $P < 0.001$) (Fig. 3), but not with hours spent in doing physical activity at M36 ($r = 0.119$; $P = 0.364$). Only 53.3% of the patients (45.5% of women and 63.0% of men) had normal muscle-strength values for their age at M36.

Discussion

In the present study, we present comprehensive, prospective 3-year data from 60 patients who underwent SG and are being followed as part of a long-term follow-up of a RCT. We observed a substantial decrease in FM during the first-year post-surgery, while FFM also decreases post-surgery, albeit to a lesser extent, as might be expected and discussed also by others [9, 41, 42]. An important finding from our study is the concerning trend of weight regain, primarily as FM between 1 and 3 years post-surgery, with no further decrease in FFM.

In the individual level, variations in anthropometrics trends were noticed with some patients continuing to lose weight while others gaining weight at 3 years post-surgery. In clinical practice, variation in weight loss between patients undergoing the same bariatric procedure is commonly observed, with most studies typically using the mean ± SD to report weight and metabolic changes following the surgery [4]. The long-term implications of BS on body composition have hitherto received only modest attention [26–29]. Similar to our results, a study that prospectively followed Roux-en-Y gastric bypass (RYGB) patients ($n = 81$) for a period of 3 years post-surgery showed that FM was markedly reduced after the first year, but increased progressively during the second and third years while FFM was minimally reduced in the follow-up period [27]. Another study in RYGB women participants ($n = 43$) showed only slight and non-significant changes in FFM and FM between the first and the fourth years post-surgery, but the weight was maintained during this period and they reported great variations in body composition data between individuals [29]. A small study on women ($n = 5$) following RYGB observed continued FFM loss over a 9-year period accompanied by a trend towards weight regain, primarily as FM, beginning after the first year [28].

Our finding that the weight regain between 1 and 3 years post-surgery was primarily as FM gain and not FFM gain is in contrast to previous findings on body weight regulation in non-BS populations, indicating that weight regain comprises also 20–30% of excess weight as FFM gain [43]. However, other studies which followed body composition of BS populations support our results [27, 28]. This point should be investigated in future studies as worsening body composition may result in a decrease in RMR and energy needs [43].

In accordance with previous studies [27, 33], we observed discrepancies between the definitions of obesity according to the BMI compared to other anthropometric indices. Participants with the same BMI were observed to have wide variations in FM and muscle mass [33]. Thus, it may be better to classify obesity on the basis of FM composition and distribution, rather than simply by increase in body weight and BMI [33].

Weight regain, a mid- to late-term complication occurring after the weight loss nadir, and insufficient weight loss are likely to have different causative mechanisms, and thus may require different management [2]. We found a mean weight

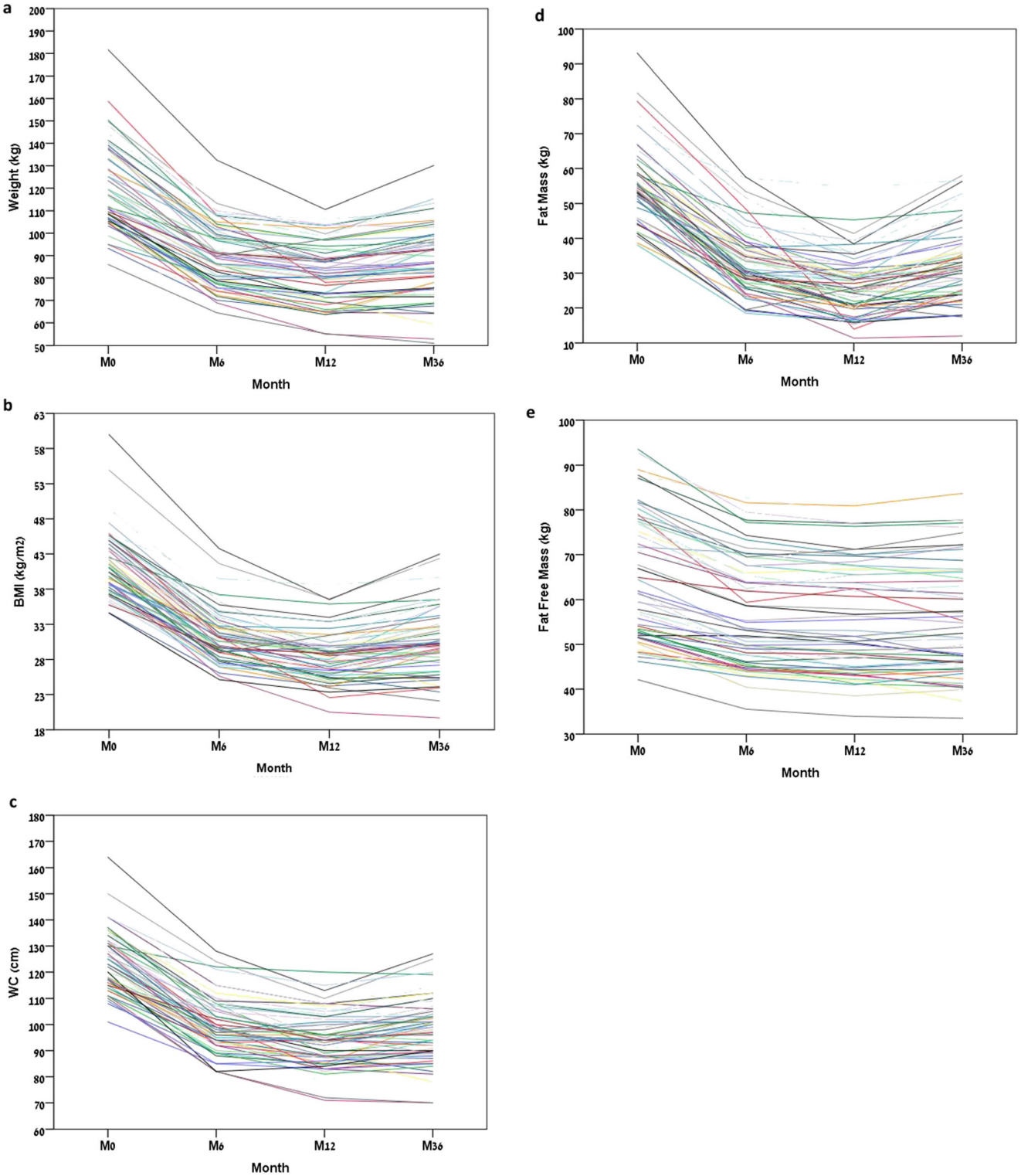

Fig. 1 Variability in weight (**a**), BMI (**b**), WC (**c**), fat mass (**d**), and fat free mass (**e**) between patients along the study period. Body mass index (BMI), waist circumference (WC)

regain of ~ 6 kg between M12 and M36, 5% primarily poor weight-loss responders, and 23.3% secondarily poor weight-loss responders. In agreement with our results, a recent published meta-analysis on the long-term (≥ 7 years, n = 652) outcomes of SG presented weight recidivism (defined as < 50% EWL) rate of 27.8% with a range of 14 to 37% [5].

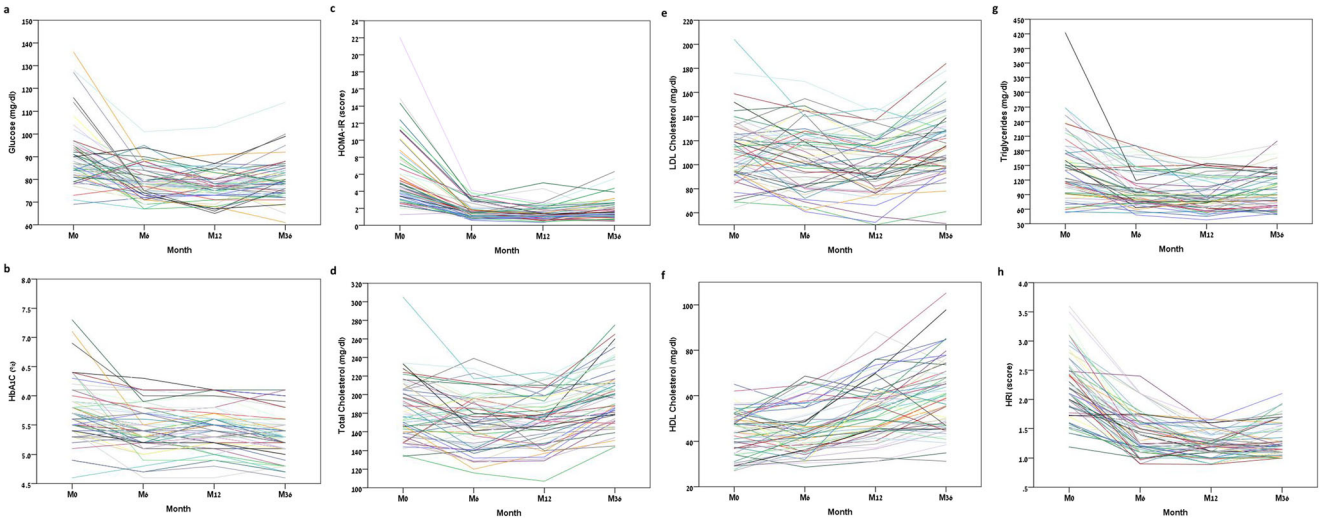

Fig. 2 Variability in glucose (**a**), HbA1c (**b**), HOMA-IR (**c**), total cholesterol (**d**), LDL cholesterol (**e**), HDL cholesterol (**f**), triglycerides (**g**), and HRI (**h**) between patients along the study period. Hemoglobin A1c (HbA1C), homeostasis model assessment (HOMA), insulin resistance (IR), low-density lipoprotein (LDL), high-density lipoprotein (HDL), hepato-renal index (HRI)

The benefit of SG on dyslipidemia is still a matter of debate [44]. In the current study, we found that most markers of lipid metabolism changed in parallel to the changes observed in FM with only minimal use of lipid-lowering medications, except HDL-C. The maintenance of the increase in HDL-C concentrations across the entire follow-up is in agreement with previous observations following SG [6, 45], but the mechanisms governing this phenomenon are still unclear and may be independent of weight loss [45].

As we and others reported, significant improvements in NAFLD occurred during the mid-term following SG [46, 47]. However, the HRI score slightly increased in parallel to the FM increase between M12 and M36, as might be expected.

In accordance with other studies [48], we found a sufficient glycemic control at 36M in the great majority of patients without the use of anti-diabetic medications. However, the prevalence of diabetes in our study was only 13.3% at baseline, and one of our exclusion criteria was diabetic patients who were treated with anti-diabetic medications except Metformin [31]. Thus, these results should be interpreted cautiously. Except for HbA1c which continued to decrease between M12 and M36, other markers of glycemic metabolism changed in parallel to the changes observed in FM.

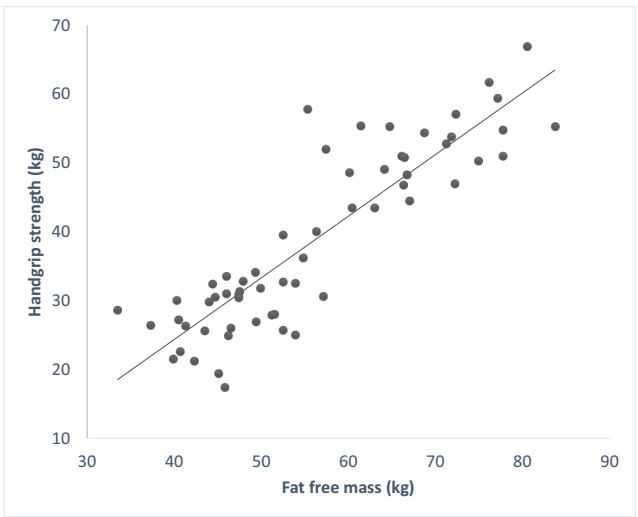

Fig. 3 Correlation between handgrip strength and fat free mass at 36 months post-surgery. $^{**}r = 0.883$, $P < 0.001$

To our knowledge, studies analyzing the changes in body composition 3 years or more after BS and specifically SG are very scarce [26–29]. Thus, our study strengths are the longitudinal assessment of both body composition and clinical parameters following SG and the presentation of personal variations between individuals of these outcomes.

At the same time, there are several weaknesses to this study. First, the cohort was rather small and comparison to a control group was impossible. Second, we used multi-frequency BIA which is not the gold standard for body composition analysis. However, a recent systematic review suggested it is useful if implemented as a longitudinal assessment tool under the same standard conditions [49]. Moreover, additional review found that multi-frequency BIA is reliable in patients with obesity, although FM underestimation and FFM overestimation in comparison with reference methods are probably common due to excessive fluid and fat depositions and the inherent equations on which the measurements are based [36]. Furthermore, some studies demonstrated strong correlations between results from dual X-ray absorptiometry (DEXA) and multiple frequencies-BIA (Inbody720®) [7] and between doubly labeled water and multiple frequencies-BIA (InBody230®) [50] in obese populations.

Third, our study was not focused on causes of weight regain or insufficient weight loss post-surgery, but rather on their consequences. Future studies should focus on understanding reasons for the wide variation between individuals undergoing the same BS type.

In conclusion, a concerning trend of weight regain, primarily manifested as an increase in FM, was seen in patients 1 to 3 years post-SG, without further decrease in FFM. Identification of FM increase at mid-term may underlie the recurrence of metabolic risk factors and may require initiation or enhancement of medical intervention. We observed great variability in mid-term outcomes among participants following SG. Our data highlight the need for closer monitoring of body composition and suggest that clinical therapy protocols to maintain favorable body composition may be warranted in the long-run post-BS.

Author Contributions The authors' responsibilities were as follows—SSD, OS, SZS, NS, DG, AR, and AD designed the research; SSD, AB, NB, and MW performed the research; SSD and SZS analyzed the data; SSD, SZS, and OS wrote the manuscript. All authors critically revised the manuscript, agree to be fully accountable for ensuring the integrity and accuracy of the work, and read and approved the final manuscript.

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Compliance with Ethical Standards

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

Ethical Approval All procedures performed in this study were approved by the institutional review board and in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The RCT study was pre-registered in the NIH registration website (TRIAL no. NCT01922830).

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

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