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Major dietary patterns and their associations with total weight loss and weight loss composition 2–4 years after sleeve gastrectomy

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Abstract

Background Food intakes 1–2 years following bariatric surgery depend more on patients than the surgery's gastrointestinal tract changes. This study aimed to determine the major dietary patterns of patients after the first two years of sleeve gastrectomy and to investigate their associations with total weight loss (TWL) and the proportion of TWL as fat mass (FM) and fat-free mass (FFM) loss.

Methods This cross-sectional study included 146 patients undergoing sleeve gastrectomy 2–4 years after surgery. Dietary patterns were determined using principal component analysis based on the 19 food groups. The percentage of FM loss relative to TWL (%FML) and FFM loss relative to TWL (%FFML) were calculated. A suboptimal clinical response was defined as a TWL of less than 25%. High FM loss and excessive FFM loss were defined based on the highest tertiles. Linear and logistic regression models were used to derive unstandardized (B) coefficients and odds ratios (OR), with dietary pattern scores serving as both a continuous and a binary variable (higher vs. lower adherence groups based on median).

Results Two predominant dietary patterns were retained. Each 1-unit increase in the first dietary pattern score characterized by high intakes of fast foods, soft drinks, processed meats, sugar confectionary, salty snacks, grains, and organ meats was associated with higher %FFML (B = 1.99; 95% confidence interval (CI) 0.34, 3.66), lower %FML (B = − 1.84; 95% CI − 3.49, − 0.20), and higher odds of excessive FFM loss (OR = 1.84; 95% CI 1.09, 3.11). Participants with higher adherence to the first dietary pattern had lower %TWL, and greater odds of suboptimal clinical response and excessive FFM loss than those with lower adherence. Each 1-unit increase in score for the second dietary pattern characterized by a high intake of fruits, dairy, vegetables, legumes, eggs, nuts, red meats, poultry, and fish was associated with lower odds of suboptimal clinical response (OR = 0.51; 95% CI 0.31, 0.86).

Conclusion Patients should be encouraged to modify their diet by reducing the consumption of ultra-processed foods and increasing their intake of high-quality protein sources, fruits, and vegetables to achieve the best postoperative outcome.

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Keywords Bariatric surgery, Body composition, Healthy eating index, Principal component analysis, Ultra-processed foods, Protein

Introduction

Bariatric surgery is currently recognized as one of the most effective treatment options for severe obesity. Numerous studies have demonstrated that it leads to significant weight loss, including both fat mass (FM) and fat-free mass (FFM) loss, as well as substantial improvements in obesity-related comorbidities [1, 2]. However, the effectiveness of bariatric surgery varies among patients. Unfortunately, the weight loss obtained by some patients is less than anticipated, or there may be excessive FFM loss relative to weight loss, which can reduce the effectiveness of obesity surgery [2, 3]. Studies have indicated that the lifestyle adopted after surgery (i.e., diet, physical activity, and eating behaviors) potentially plays a crucial role in achieving sustainable weight loss and preventing excessive FFM loss in the long term postoperatively [4]. Although differences in surgical outcomes may be explained by several factors, postoperative diet appears to be a key determinant [5].

Studies about food intake after bariatric surgery have indicated that frequent consumption of high-fat or sugary snacks at least 1 year postoperatively can lead to excessive energy intake and may decrease the chances of maintaining weight loss. Additionally, limiting the consumption of soft drinks or carbonated beverages is effective in maintaining weight stability after 2 years since the surgery [6]. The study by Freire et al. showed that the consumption of snacks and sweets, as well as fats and high-fat foods, was significantly higher among those who experienced weight regain [7]. However, it is not possible to draw a definitive conclusion regarding the associations between dietary macronutrients or food groups' intakes and weight outcomes after bariatric surgery due to heterogeneity in study designs and findings [8, 9]. A few studies have also investigated the association between diet as a combination of food groups, weight, and body composition outcomes following bariatric surgery using the healthy eating index (HEI), a measurement for diet quality. In a study a higher HEI score was associated with lower odds of weight regain [10], whereas two other studies found no significant association between HEI, the odds of weight regain, and different weight outcome parameters after bariatric surgery [11, 12]. In addition, one study found no significant associations between HEI and postoperative FM and FFM loss [12]. To our knowledge, no study has determined the major dietary patterns of patients undergoing bariatric surgery and the association between these dietary patterns and weight loss and weight loss composition after the surgery. Therefore, we employed principal component analysis (PCA) to determine the major dietary patterns of patients with sleeve gastrectomy (SG) 2–4 years after surgery. We then examined the associations between these dietary patterns and percentage total weight loss (%TWL), proportion of fat mass loss relative to TWL (%FML), and fat-free mass loss relative to TWL (%FFML) at this time.

Methods

Participants

Participants in this cross-sectional study were recruited from patients in the Tehran Obesity Treatment Study (TOTS). TOTS is a study on an Iranian population with severe obesity who have been referred to the Tehran Obesity Treatment Center to consult for bariatric surgery [13]. Participants undergoing SG between September 18, 2017, and March 16, 2021 and who were at least 18 years old were called for this study. A total of 200 patients agreed to participate in this study, of whom 16 were excluded due to psychiatric and musculoskeletal disorders, cancer, and inadequate cooperation in completing questionnaires. Also, 38 more patients with a time since surgery of less than 2 and more than 4 years were excluded to minimize the potential impact of time since surgery on weight loss and dietary modifications. Ultimately, 146 individuals were selected to participate in the present investigation.

It is thought that patients' effects on food intakes and, consequently, energy intakes will become more evident one to two years after bariatric surgery as opposed to the early postoperative period, when gastrointestinal changes and planned postoperative follow-up visits predominantly influence food intakes [14, 15]. Moreover, weight maintenance challenges typically begin at this time point [16]. Therefore, we recruited patients at least 2 years after the surgery. We conducted the recruitment of participants and data collection for the current study from April to August 2022. Consistent with the Declaration of Helsinki, the investigation was carried out. Each participant provided informed, written consent prior to the study. The Research Ethics Committees of the National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, approved this investigation (approval number: IR.SBMU.NNFTRI.REC.1401.004).

Weight and body composition

Postoperative weight and body composition (FM and FFM) were evaluated using a bioelectrical impedance body composition analyzer (InBody 370S, BioSpace America, Inc.). The body mass index (BMI) was calculated by dividing weight (kg) by height (m^2). Preoperative measurements (weight, FM, and FFM) were obtained from the patient's electronic medical record. The outcomes after surgery were calculated using the following formulas:

$$\%TWL = \left[\left(\text{preoperative weight} - \text{postoperative weight}\right)/\text{preoperative weight}\right] \times 100$$

$$\%FML = \left[(\text{preoperative FM} - \text{postoperative FM})/\left(\text{preoperative weight} - \text{postoperative weight}\right)\right] \times 100.$$

$$\%FFML = \left[(\text{preoperative FFM} - \text{postoperative FFM})/\left(\text{preoperative weight} - \text{postoperative weight}\right)\right] \times 100.$$

Suboptimal clinical response (insufficient weight loss) was defined as TWL less than 25% [17, 18]. Individuals were classified into tertiles according to %FML and %FFML. The highest tertile, with a value greater than 28% of weight loss for FFML and more than 77.9% of weight loss for FML, was defined as excess FFM and high FM loss, respectively.

Dietary intake

Two trained dietitians administered a valid 147-item food frequency questionnaire (FFQ) [19] to evaluate the participants' dietary intake. Based on the frequency and quantity reported by the participants, the daily consumption of each food item over the past year was determined. To derive dietary patterns, we categorized food items into 19 food groups, which included grains, legumes, nuts, vegetables, fruits, dairy, eggs, red meats, poultry and fish, organ meats, processed meats, vegetable oil, animal fat, fast foods, salty snacks, sugar confectionary, sauce, soft drinks, and tea and coffee, to derive dietary patterns. Details on the food grouping are provided in Supplementary Table 1.

Demographic and physical activity variables

Data on age, education, smoking status, marital status, occupation, medical history, and vitamin or mineral supplementation were collected using a questionnaire.

Physical activity was measured in metabolic equivalent task (MET) minutes per week using the International Physical Activity Questionnaire (IPAQ) short form ref. [20]. Participants were classified into three groups based on their physical activity levels: low (< 600 MET-min/week), moderate (600–3000 MET-min/week), and high (> 3000 MET-min/week).

Statistical analysis

PCA was used to generate dietary patterns based on the 19 food categories. The Kaiser–Meyer–Olkin value was 0.72, and Bartlett's sphericity test was statistically significant, indicating that the correlation matrix is factorable. We extracted components using an orthogonal rotation of Varimax. The PCA suggested six components with eigenvalues greater than 1. Based on the screeplot and the Monte Carlo PCA, we decided to retain the first two components for further investigation. Using the regression method, dietary pattern scores were calculated.

Participants based on the median of each score were divided into two groups: higher (≥ median value) and lower (< median) adherence groups. The characteristics of the participants were compared between the two groups with an independent sample t-test for non-skewed continuous variables, a Mann–Whitney U test for skewed variables, and a chi-squared test for categorical variables. The associations between dietary patterns and %TWL, %FFML, and %FML were analyzed using linear regression, and the results were expressed as unstandardized (B) coefficients (95% confidence interval (CI)). The odds of suboptimal clinical response, excessive FFM loss, and high FM loss according to the dietary patterns were also determined using logistic regression, and results were reported as odds ratio (OR) and 95% CI. The results of regression analyses were estimated based on the standard deviation (SD) of each score (as continuous variables) as well as the higher compared with the lower adherence group (binary categorical variables). Age (continuous), sex, preoperative weight (continuous), time since surgery (continuous), occupation (full-time job / without full-time job), smoking (yes/no), marital status (single, married, and divorced/widowed), education (primary, diploma, and academic), physical activity (continuous), B-vitamin supplementation (yes/no), vitamin D/calcium supplementation (yes/no), and energy intake (continuous) were selected as potential confounders based on a literature review. Using linear regression, we investigated the univariate associations between these variables and each outcome. Only variables with a p-value of less than 0.1 in the univariate association made it into the statistical analyses. Statistical analyses were conducted using SPSS (version 20; IBM Corp., Armonk, NY, USA), and $P \leq 0.05$ were deemed significant.

Results

Table 1 shows characteristics of total participants and based on adherence to the dietary patterns. The mean ± SD for age and time since surgery of the participants were 43.6 ± 12.1 years and 30.8 ± 6.5 months, respectively, and 77.4% were women.

A combined 32.4% of the variance in food consumption was accounted for by the two dietary patterns, with pattern 1 accounting for 20.3% and pattern 2 contributing 12.1%. The dietary pattern 1 was characterized by high intakes of fast foods, sauce, soft drinks, processed meats, sugar confectionery, salty snacks, grains, organ meats, poultry and fish, animal fat, and vegetable oil (factor loading > 0.3). The second pattern featured high consumption of fruits, dairy, vegetables, legumes, eggs, nuts, red meats, and poultry and fish (Supplementary Table 1).

Participants' characteristics based on adherence to dietary patterns were compared, showing that those with a higher score for pattern 1 were younger and had higher preoperative and postoperative FFM than those with

Table 1 Characteristics of the participants

Characteristics	Total participants (n = 146)	Dietary pattern 1[a]			Dietary pattern 2[a]		
		Lower (n = 73)	Higher (n = 73)	P-value	Lower (n = 73)	Higher (n = 73)	P-value
Age (years)	43.6 ± 12.1	47.7 ± 10.5	39.5 ± 12.4	< 0.001	43.2 ± 13.0	44.0 ± 11.3	0.664
Women (%)	77.4	90.4	64.4	< 0.001	83.6	71.2	0.113
Time since surgery (months)	30.8 ± 6.5	31.7 ± 6.3	30.0 ± 6.2	0.101	31.6 ± 6.56	30.1 ± 5.94	0.156
Education (%)							
Primary	14.4	21.9	6.8	0.032	21.9	6.8	0.032
Diploma	32.9	31.5	34.2		31.5	34.2	
Academic	52.7	46.6	58.9		46.6	58.9	
Smokers (%)	27.4	15.1	39.7	0.001	35.6	19.2	0.040
Marital status (%)							
Single	24.7	13.7	35.6	0.003	27.4	21.9	0.080
Married	68.5	75.3	61.6		61.6	75.3	
Divorced/widowed	6.8	11	2.7		11	2.7	
Full time job (%)	45.9	35.6	56.2	0.020	39.7	52.1	0.184
Physical activity (Met-min/week)	693 (120, 2338)	693 (122, 2384)	693 (115, 2154)	0.885	480 (66, 226)	1000 (249, 2345)	0.042
Physical activity levels (%)							
< 600	47.9	47.9	47.9	0.973	57.5	38.4	0.020
600–3000	30.8	30.1	31.5		20.5	41.1	
> 3000	21.2	21.9	20.5		21.9	20.5	
Postoperative weight	83.6 ± 13.4	81.6 ± 12.9	85.6 ± 13.8	0.071	83.5 ± 14.3	83.7 ± 12.7	0.933
Total weight loss (%)	29.0 ± 7.64	29.1 ± 7.4	29.0 ± 7.9	0.983	28.9 ± 8.21	29.2 ± 7.09	0.863
Preoperative fat free mass (kg)	58.8 ± 10.2	56.5 ± 8.66	61.1 ± 11.1	0.006	57.5 ± 9.78	60.1 ± 10.4	0.127
Postoperative fat free mass (kg)	50.3 ± 9.29	48.1 ± 7.89	52.5 ± 10.1	0.004	49.0 ± 8.62	51.6 ± 9.81	0.092
Fat free mass loss relative to weight loss (%)	25.1 ± 8.43	25.6 ± 8.31	24.6 ± 8.56	0.469	25.5 ± 7.87	24.6 ± 8.98	0.520
Dietary energy intake (Kcal/day)	2264 ± 995	1917 ± 871	2610 ± 997	< 0.001	1842 ± 867	2685 ± 940	< 0.001
Carbohydrate intake (% of energy)	52.6 ± 8.65	55.4 ± 9.18	49.8 ± 7.11	< 0.001	52.0 ± 8.94	53.2 ± 8.37	0.430
Fat intake (% of energy)	35.1 ± 8.36	32.8 ± 8.67	37.4 ± 7.40	< 0.001	36.5 ± 8.69	33.7 ± 7.83	0.045
Protein intake (% of energy)	12.9 ± 3.25	12.8 ± 3.23	13.1 ± 3.28	0.525	12.0 ± 2.82	13.9 ± 3.38	< 0.001
Vitamins B supplements user (%)	50	47.9	52.1	0.741	52.1	47.9	0.741
Vitamin D/Ca supplements user (%)	32.2	37.0	27.4	0.288	35.6	28.8	0.479

Values are mean ± standard deviation for continuous variables except for physical activity that is median (25th, 75th percentiles)

[a] Lower and higher groups were defined based on the median value of each dietary pattern score

a lower score for the pattern. Those with higher adherence to pattern 1 were also more likely to have an academic education, a full-time job, to be smokers, and to be single. Daily energy intake and proportion of fat were significantly lower, while proportion of carbohydrate was higher in those with a lower score in pattern 1 than those with a higher score. Those with higher adherence to the second pattern were more likely to have academic education and engage in moderate physical activity (600–3000 Met-min/week), but less likely to be smokers. Daily dietary energy intake and proportion of protein were significantly lower, but proportion of fat was higher in participants who obtained a lower score in pattern 2 compared to those with a higher score (Table 1).

Table 2 represents the association of the first dietary pattern with %TWL, %FFML, and %FML. Dietary pattern 1 as a continuous variable was not related to the %TWL, but those with higher adherence to the dietary pattern had a 3.1% lower TWL (B = − 3.08; 95% CI − 5.75, − 0.40) compared to those with lower adherence after adjusting for all potential covariates. Moreover, one SD of the first pattern was linked to 2% (B = 1.99; 95% CI 0.34, 3.66) more FFML and 1.8% (B = − 1.84; 95% CI − 3.49, − 0.20) less FML.

Table 2 Associations of the first dietary pattern with total weight loss, fat-free mass loss, and fat mass loss after sleeve gastrectomy

Variables	Unadjusted			Adjusted		
	B	95% CI	P-value	B	95% CI	P-value
Continuous score						
% TWL	1.24	– 0.001, 2.48	0.050	– 0.39[a]	– 1.94, 1.16	0.617
% FFML	0.30	– 1.09, 1.68	0.674	1.99[b]	0.34, 3.66	0.019
% FML	– 0.18	– 1.55, 1.20	0.799	– 1.84[b]	– 3.49, – 0.20	0.028
Higher vs. lower adherence						
% TWL	– 0.03	– 2.53, 2.48	0.983	– 3.08[a]	– 5.75, – 0.40	0.024
% FFML	– 1.02	– 3.78, 1.75	0.469	1.12[b]	– 1.89, 4.12	0.465
% FML	1.19	– 1.54, 3.93	0.390	– 0.93[b]	– 3.90, 2.04	0.536

TWL: total weight loss; FFML: fat-free mass loss relative to TWL; FML: fat mass loss relative to TWL

[a] Adjusted for age, preoperative weight, education (primary, diploma, and academic), marital status (single, married, and divorced/widowed), occupation (full-time job/without full-time job), smoking (yes/no), and energy intake

[b] Adjusted for age, sex, marital status (single, married, and divorced/widowed), time since surgery (years), B vitamins supplementation, and energy intake (continuous)

Table 3 Associations of the first dietary pattern with suboptimal clinical response, excessive fat-free mass loss, and high fat mass loss after sleeve gastrectomy

Variables	Unadjusted			Adjusted		
	OR	95% CI	P-value	OR	95% CI	P-value
Continuous score						
Suboptimal clinical response[a]	0.85	0.59, 1.21	0.363	1.45[d]	0.87, 2.42	0.159
Excessive fat-free mass loss [b]	1.01	0.72, 1.43	0.951	1.84[e]	1.09, 3.11	0.023
High fat mass loss[c]	1.03	0.73, 1.45	0.882	0.68[e]	0.41, 1.12	0.131
Higher vs. lower adherence						
Suboptimal clinical response[a]	1.14	0.56, 2.28	0.722	2.75[d]	1.11, 6.83	0.029
Excessive fat-free mass loss[b]	1.06	0.53, 2.11	0.861	2.51[e]	1.02, 6.16	0.045
High fat mass loss[c]	1.06	0.53, 2.11	0.861	0.49[e]	0.20, 1.24	0.134

[a] Defined as total weight loss less than 25%

[b] Defined based on the highest tertile of fat-free mass loss relative to total weight loss (more than 28% of weight loss)

[c] Defined based on the highest tertile of fat-mass loss relative to total weight loss (more than 77.9% weight loss)

[d] Adjusted for age, preoperative weight, education (primary, diploma, and academic), marital status (single, married, and divorced/widowed), occupation (full-time job/without full-time job), smoking (yes/no), and energy intake (continuous)

[e] Adjusted for age, sex, marital status (single, married, and divorced/widowed), time since surgery (years), B vitamins supplementation (yes/no), and energy intake (continuous)

Table 3 represents the association between dietary pattern 1 and the odds of suboptimal clinical response, excessive FFM loss, and high FM loss. In the adjusted model, higher adherence to the first dietary pattern was related to higher odds of excessive FFM loss (OR = 1.84, 95% CI 1.09, 3.11). In addition, the odds of suboptimal clinical response (OR = 2.75, 95% CI 1.11, 6.83) and excessive FFM loss (OR = 2.51, 95% CI 1.02, 6.16) were significantly higher in those with higher adherence to the pattern than those with low adherence in the adjusted model.

Table 4 represents the association of the second dietary pattern with %TWL, %FFML, and %FML. The second pattern as a continuous variable showed a negative association with %FFML and a positive association with %FML in the unadjusted model, but the association was no longer significant after covariates were accounted for.

Table 5 represents the association between dietary pattern 2 and the odds of suboptimal clinical response, excessive FFM loss, and high FM loss. The odds of suboptimal clinical response was lower per one SD of the second dietary pattern; the inverse association remained

Table 4 Associations of the second dietary pattern derived with total weight loss, fat-free mass loss, and fat mass loss after sleeve gastrectomy

Variables	Unadjusted			Adjusted		
	B	95% CI	P-value	B	95% CI	P-value
Continuous score						
% TWL	0.79	− 0.46, 2.04	0.213	1.40[a]	− 0.15, 2.95	0.076
% FFML	− 1.60	− 2.96, − 0.237	0.022	− 0.81[b]	− 2.45, 0.84	0.332
% FML	1.63	0.278, 2.98	0.018	0.83[b]	− 0.79, 2.45	0.313
High vs. low adherence						
% TWL	0.22	− 2.29, 2.73	0.863	0.62[a]	− 2.16, 3.39	0.660
% FFML	− 0.90	− 3.66, 1.86	0.520	0.61[b]	− 2.33, 3.54	0.684
% FML	1.08	− 1.66, 3.82	0.437	− 0.39[b]	− 3.28, 2.51	0.792

TWL: total weight loss; FFML: fat-free mass loss relative to TWL; FML: fat mass loss relative to TWL

[a] Adjusted for age, preoperative weight, education (primary, diploma, and academic), marital status (single, married, and divorced/widowed), occupation (full-time job/without full-time job), smoking (yes/no) and energy intake (continuous)

[b] Adjusted for age, sex, marital status (single, married, and divorced/widowed), time since surgery (years), B vitamins supplementation (yes/no) and energy intake (continuous)

Table 5 Associations of the second dietary pattern with suboptimal clinical response, excessive fat-free mass loss, and high fat mass loss after sleeve gastrectomy

Variables	Unadjusted			Adjusted [1]		
	OR	95% CI	P-value	OR	95% CI	P-value
Continuous score						
Suboptimal clinical response[a]	0.70	0.49, 0.99	0.045	0.51[d]	0.31, 0.86	0.011
Excessive fat-free mass loss[b]	0.68	0.47, 0.95	0.026	0.81[e]	0.51, 1.29	0.375
High fat mass loss[c]	1.48	1.01, 2.15	0.042	1.27[e]	0.76, 2.14	0.359
High vs. low adherence						
Suboptimal clinical response[a]	0.78	0.39, 1.56	0.477	0.58	0.24, 1.42	0.232
Excessive fat-free mass loss[b]	0.65	0.33, 1.30	0.221	0.93[e]	0.42, 2.22	0.929
High fat mass loss[c]	1.75	0.87, 3.50	0.116	1.54[e]	0.65, 3.64	0.326

[a] Defined as total weight loss less than 25%

[b] Defined based on the highest tertile of fat-free mass loss relative to total weight loss (more than 28% of weight loss)

[c] Defined based on the highest tertile of fat-mass loss relative to total weight loss (more than 77.9% weight loss)

[d] Adjusted for age, preoperative weight, education (primary, diploma, and academic), marital status (single, married, and divorced/widowed), occupation (full-time job/without full-time job), smoking (yes/no), and energy intake (continuous)

[e] Adjusted for age, sex, marital status (single, married, and divorced/widowed), time since surgery (years), B vitamins supplementation (yes/no), and energy intake (continuous)

significant in the adjusted model (OR = 0.51, 95% CI 0.31, 0.86). Lower odds of excessive FFM loss and higher odds of high FM loss were observed per SD of the second dietary pattern, but the association was not statistically significant after controlling for potential confounding factors. No significant association was observed when the second pattern was treated as a binary categorical variable.

Discussion

We identified two predominant dietary patterns in patients 2–4 years after SG. The first dietary pattern that maximally explained the variation in food groups in these patients was characterized by high intakes of fast foods, sauce, soft drinks, processed meats, sugar confectionery, salty snacks, grains, organ meats, poultry and fish, animal fat, and vegetable oil. After adjusting for potential covariates, those with greater adherence to dietary pattern 1 had significantly lower %TWL and greater odds of suboptimal clinical response. Moreover, a higher score in this pattern was related to lower %FML, higher %FFML, and higher odds of excessive FFM loss. A second dietary pattern, characterized by high intakes of fruits, dairy, vegetables, legumes, eggs, nuts, red meats, and poultry and fish, was associated with lower odds of suboptimal clinical response. The associations of dietary patterns with weight loss and weight loss composition were independent of energy intake.

The observed associations may account for the main characteristics of the first pattern, which include low nutrient density, high-fat foods, high-refined carbohydrates, and overall low nutritional quality. A cross-sectional study assessing the dietary intakes of 100 patients at different postsurgical times of < 2 years, 2–5 years, and more than 5 years after bariatric surgery found that the intakes of snacks and sweets were higher than recommended at all times. Furthermore, those who regained weight consumed significantly more snacks and sweets, as well as oils and fatty foods, than those who did not [7]. The energy density of the meal and the relative quantity of energy ingested from high-fat, low-fat, sweet, and savory foods did not change significantly after bariatric surgery, according to a study that directly examined what people ate at an ad libitum buffet, despite the reductions in total energy consumption and eating rate after the surgery. In that study, a higher reduction in high-fat foods from pre-surgery to 6 months after the surgery was significantly related to a higher TWL 18 months after the surgery [21]. Using the HEI, it has also been demonstrated that the majority of patients undergoing bariatric surgery have inadequate diet quality [10–12].

We demonstrated that a higher score in the first dietary pattern was associated with a lower %FML and a greater %FFML. The odds of excessive FFM loss were also significantly higher with a higher dietary pattern score. Excessive FFM loss after bariatric surgery, like other weight loss programs, is undesirable because of its multiple physiological functions. Despite this, the prevalence of excessive FFM loss after bariatric surgery has been high, indicating that more robust approaches are required to mitigate FFM loss [2, 22]. This excessive FFM loss could potentially contribute to weight regain, the recurrence of obesity-related comorbidities, and an increased risk of sarcopenia and osteoporosis [2]. The ultra-processed foods, such as processed meats, salty snacks, sugar confectionary, soft drinks, and sauce, were highly loaded in the pattern. Previous studies have demonstrated the adverse associations between ultra-processed foods and body composition, such as higher body fat and lower lean mass [23, 24]. Researchers have proposed various mechanisms to explain the negative associations, such as reduced protein intake, increased energy, and refined sugar due to an unbalanced diet composition, increased consumption of advanced glycated end-products, alterations in the intestinal microbiome, and changes in gut-brain signaling of satiety [23].

The second pattern mostly consists of high-nutrient-dense foods and is generally considered a healthy dietary pattern. The odds of suboptimal clinical response approximately 2 years after SG were significantly lower with higher adherance to the pattern. Fruits, vegetables, legumes, and nuts in the second pattern encompass a broad spectrum of vitamins, minerals, antioxidants, and fiber. Adopting the dietary pattern may result in decreased gastric emptying, decreased postprandial blood glucose levels, decreased insulin secretion, and an effect on satiety and energy balance via the production of short-chain fatty acids [25–27]. These factors may potentially lead to greater TWL and reduce the odds of a suboptimal clinical response. High-quality protein sources, such as dairy, eggs, and animal meats, also make it easier to meet the necessary postoperative protein requirements within this dietary pattern, lowering the risk of inadequate protein intake. Changes in the macronutrient composition of the diet in favor of increasing protein intake early after bariatric surgery (≤ 0.5 years) have been linked to greater weight loss in previous research [21, 28].

Prior research on the relationship between post-operative dietary patterns and weight and body composition outcomes after bariatric surgery was limited to HEI [10–12]. PCA is an exploratory technique that identifies common food consumption patterns based on the correlations between food groups [29]. Our review of the literature indicates that no previous study has examined the major dietary patterns following bariatric surgery and their associations with weight loss and variations in body composition. The study's strengths include taking into consideration both %TWL and FM and FFM loss relative to weight loss as outcomes, as well as multiple confounding factors for each outcome. The study's limitations should also be discussed. First, the study's cross-sectional design cannot establish a cause-and-effect relationship. Second, misreporting dietary data is a concern due to recall bias and social desirability bias [30]. Individuals with suboptimal clinical responses may be more likely to report inaccurate information. Third, the lack of a standard definition for suboptimal clinical response or excessive FFM increases the likelihood of misclassifying participants. However, we used the 25% TWL cutoff for suboptimal clinical response based on findings of the more recent studies suggesting that the cut-off is more efficient to assess clinical response to bariatric surgery than the other criteria [17, 18, 31]. Fourth, even though our analyses account for a large number of covariates, residual confounding remains a possibility.

Conclusion

This exploratory dietary analysis revealed increased odds of suboptimal clinical response and excessive FFM loss in patients who more adhered to a diet high in fast foods, soft drinks, processed meats, sugar confectionary, salty snacks, grains, and organ meats at midterm after bariatric surgery. In contrast, more adherence to a diet characterized by a high intake of fruits, dairy, vegetables, legumes, eggs, nuts, red meats, poultry, and fish was associated with lower odds of suboptimal clinical response. The associations were observed independent of energy intake. The findings of this study highlight the importance of post-surgery diet on the outcomes of bariatric surgery in terms of %TWL and the proportion of weight loss as FM and FFM. To achieve the best postoperative outcome, the study recommends encouraging patients undergoing bariatric surgery to modify their dietary habits by reducing their intake of ultra-processed foods and increasing their consumption of high-quality protein sources, fruits, and vegetables.

Abbreviations

%FFML	Percentage fat-free mass loss relative to total weight loss
FFQ	Food frequency questionnaire
%FML	Percentage fat mass loss relative to total weight loss
HEI	The healthy eating index
IPAQ	International Physical Activity Questionnaire
PCA	Principal component analysis
SG	Sleeve gastrectomy
TOTS	Tehran Obesity Treatment Study
TWL	Total weight loss

Supplementary Information

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Supplementary Material 1.

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Author contributions

Conceived and designed the study: NM, ZK, PM, MB; Data collection: ZK; Helped in data collection: NM, MB, AK; analyzed and interpreted the data: NM, ZK; Wrote the first draft of the manuscript: NM, ZK. All authors read and approved the final manuscript.

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Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The Research Ethics Committees of the National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, approved this investigation (approval number: IR.SBMU.NNFTRI.REC.1401.004).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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