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RESEARCH

Insufficient weight loss after bariatric surgery and its predictors: Tehran Obesity Treatment Study (TOTS)

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Abstract

Background This study aimed to determine the factors related to insufficient weight loss (IWL) following bariatric surgery.

Methods The data for 3456 individuals who had bariatric surgery were obtained prospectively. A bioelectrical impedance analyzer was used to measure body composition changes and compare them between the sufficient (SWL) and IWL groups. The generalized estimated equation approach was used to assess changes in fat mass (FM), fat-free mass (FFM), FFM loss/weight loss percentage (FFML/WL%), and excess weight loss percentage (EWL%). Multivariate logistic regression models were used for IWL to establish independent baseline factors.

Results IWL was recorded in 8% of the cases. The data analysis revealed substantial differences in the changes in FM%, FFM%, FFML/WL%, and EWL% between the SWL and IWL groups after six months of follow-up. The IWL group demonstrated a greater FFML/WL% (Ptime before & after 6 months < 0.05). An older age, a higher baseline BMI, diabetes mellitus (DM), non-smoking, and sleeve gastrectomy (SG) were the predictors of IWL.

Conclusion the significant predictors of IWL included older age, a higher baseline BMI, DM, SG, and non-smoking.

Keywords Insufficient weight loss · Bariatric surgery · Sleeve gastrectomy · Gastric bypass · Excess weight loss

Introduction

Insufficient weight loss (IWL) is a serious clinical concern following bariatric surgery. Approximately 15–30% of bariatric surgery patients experience significant IWL (defined as less than 50% excess weight reduction). There are multiple definitions for weight regain (WR) and IWL, which possibly explain their varying prevalence reported in different research [1–4].

IWL predictions have been shown to play an important influence on patient satisfaction with bariatric surgery. Cottam et al. found that the baseline BMI was strongly associated with IWL [5]. Age, gender, type of surgery, and obesity-related comorbidities including hypertension (HTN) and diabetes mellitus (DM) have already been reported as predictors of IWL; however, research findings are inconsistent, and there are currently arguments about the effects of demographic characteristics, obesity-related comorbidities, and type of surgery on the risk of IWL [4].

Studies, most of which have been conducted following sleeve gastrectomy (SG) or gastric bypass (GB), have shown gaps in modifiable and non-modifiable determinants of IWL, and there are a few reports on the role of one-anastomosis gastric bypass (OAGB). Moreover, WR and IWL have different definitions and probably different predictors, so they should be investigated separately [4, 6]. Identifying the major predictors of IWL after bariatric surgery can help provide better counseling, more efficient screening of potential candidates who may benefit the most from surgery, and create specific guidelines to prevent IWL. Thus, this study aimed to determine whether patients' clinical characteristics could be used as early predictors of IWL.

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Materials and methods

Study protocol

This study was performed within the framework of the Tehran Obesity Treatment Study (TOTS), in which individuals undergo bariatric surgery in specialized centers based on particular characteristics, whose details are available elsewhere [7]. The participants of this prospective study were aged 18–70 years old and were recruited from March 1, 2013, to February 31, 2019. Out of 4025 patients who underwent sleeve gastrectomy (SG) or GB, 569 individuals were excluded (patients with a history of previous bariatric surgery [$n=66$], other few non-standardized or non-common types of surgery [$n=17$], BMI < 35 [$n=51$], various physical or mental disabilities such as severe depression ($n=5$), severe spine deformities ($n=5$), depending on a cane ($n=14$) or wheelchair ($n=8$), [total $n=32$]). So, the study involved 3456 individuals. Follow-up rates at 1, 3, 6, 12, and 24 months were 84.8%, 75.1%, 82.0%, 72.7%, and 64.8% for sufficient weight loss (SWL) and 85%, 73.3%, 77.0%, 64.7%, and 59.4% for IWL, respectively.

Surgical procedures

The surgeon informed patients via numerous individual consultations that included extensive explanations of surgical techniques, expected results, and probable complications, along with an all-encompassing review for every candidate. Individuals having a family record of gastric cancer were recommended to choose SG owing to the necessity of endoscopic screening, whereas individuals who had substantial hiatal hernias or significant gastroesophageal reflux were warned about the reflexogenic nature of SG. Patients with diabetes were advised that GB provides a greater remission or improvement of diabetes than SG.

The study is organized into three distinct phases, each representing the most common form of malabsorptive gastric bypass (GB) treatment at the time. During the first six months, only Roux-en-Y gastric bypass (RYGB) was used. However, starting in September 2013, OAGB has become the recommended approach. Initially, all OAGB patients received a 200 cm biliopancreatic limb (BPL) for up to three years. Unfortunately, after a patient expired due to severe protein-calorie deprivation and liver failure [8], the BPL length was reduced to 160 cm. Importantly, the decision to change the BPL length in OAGB was unaffected by the patient's age, gender, preoperative BMI, comorbidities, or dietary habits. Additionally, since September 2013, RYGB has been rarely used, reserved mainly for patients with severe hiatal hernia, significant gastroesophageal reflux, or based on individual patient preference. Of a total of 3456 patients, 2352 (68.1%) underwent SG, and 1104 (31.9%) underwent GB (986: OAGB, 118: RYGB).

Measurements

Data were obtained following the study protocol. To assess obesity status and key health parameters, all patients underwent a physical examination and regular medical history assessment, which included systolic and diastolic blood pressure (BP) measurements. Baseline data, including age and gender, as well as anthropometric measurements (height, weight, and BMI), were collected in accordance with World Health Organization (WHO) criteria [9]. Body composition was measured with a portable bioelectrical impedance analyzer (BIA) (InBody 370, Biospace, Seoul, South Korea).

To ensure accurate results, participants were asked to follow several guidelines before the impedance analysis: fasting overnight or for at least 4–5 h, refraining from exercise for at least 12 h, avoiding alcohol for at least 24 h, staying hydrated, and resting in a supine position for at least 5 min. The patient's resistance to alternating current (500 µA at 50/60 kHz) was measured while standing on the analyzer platform. The results were interpreted using the manufacturer-provided software's "standard" setting. The measurements included fat mass (FM in kg and%) and fat-free mass (FFM in kg and%). These body composition assessments have demonstrated good concordance with the gold-standard dual-energy X-ray absorptiometry (DXA) and are safe for routine clinical use [10, 11]. Data were collected at baseline and at 1, 3, 6, 9, 12, 18, and 24 months post-surgery.

After 12–14 h of fasting, blood samples were collected and sent for biochemical analysis, which included the lipid profile (total cholesterol [TC], high-density lipoprotein cholesterol [HDL-C], and serum triglycerides [TG]) and fasting plasma glucose (FPG). FPG, TG, and TC were evaluated using enzymatic colorimetric techniques, whereas HDL-C was quantified using a specialized kit after precipitating apolipoprotein B-containing lipoproteins with phosphotungstic acid. Internal quality control was carried out to guarantee accuracy, and all tests met the necessary standards. The inter- and intra-assay coefficients of variation at baseline were 2.2% for FPG, 2% and 0.5% for HDL-C, and 1.6% and 0.6% for TG, respectively.

Definitions

Elevated triglycerides (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), and reduced high-density lipoprotein cholesterol (HDL-C) were defined as follows: TG levels ≥ 150 mg/dL or use of lipid-lowering medications, TC levels ≥ 200 mg/dL, LDL-C levels ≥ 130 mg/dL, and HDL-C levels < 50 mg/dL for women or < 40 mg/dL for men. Hypertension was categorized by a systolic blood pressure (SBP) of ≥ 140 mmHg, diastolic blood pressure (DBP) of ≥90 mmHg, or the use of antihypertensive medication. Diabetes mellitus was defined by either a fasting plasma glucose (FPG) level ≥ 126 mg/dL, HbA1c ≥ 6.5%, or the use of diabetes medications. Additionally, behavioral and psychological factors, including current or past smoking (as defined by the US Centers for Disease Control and Prevention) [12], alcohol consumption, and a history of psychological disorders, were also assessed at the baseline. Alcohol consumption and a history of psychological disorders were also evaluated at baseline. Depression was assessed using the Persian version of the Beck Depression Inventory (BDI), version I, a 21-item questionnaire designed to identify and measure the severity of depressive symptoms. Scores were categorized as follows: 0–9 (normal), 10–18 (mild to moderate depression), 19–29 (moderate to severe depression), and 30–63 (severe depression) [13]. Serum creatinine (Cr) levels were measured using the Jaffe kinetic method. The preoperative glomerular filtration rate (GFR) was estimated using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) formula) [14], while insulin resistance (IR) was calculated using the homeostatic model assessment-insulin resistance (HOMA-IR) formula: HOMA-IR = [fasting insulin (μU/mL) × fasting glucose (mmol/L)]/22.5. Insulin resistance was defined as HOMA-IR ≥ 2.6 for both sexes [15]. Diabetes mellitus (DM), hypertension (HTN), and dyslipidemia remission were defined as follows: DM remission was indicated by HbA1c levels < 6.5% and fasting blood glucose (FBG) < 126 mg/dL without the use of antidiabetic medications. Hypertension remission was defined as systolic blood pressure (SBP) < 140 mmHg and diastolic blood pressure (DBP) < 90 mmHg without antihypertensive medications. Dyslipidemia remission was considered a normal lipid profile without lipid-lowering medications, with LDL < 100 mg/dL, HDL ≥ 40 mg/dL, total cholesterol < 200 mg/dL, and triglycerides < 150 mg/dL.

To assess weight loss, the percentage of excess weight loss (EWL%) was calculated as:

$$\text{EWL\%} = \frac{\text{Initial Weight} - \text{PostoperativeWeight}}{\text{Initial weight} - \text{Ideal weight}} \times 100 \quad (1)$$

where the ideal weight was based on a body mass index (BMI) of 25 kg/m².

Fat-free mass loss relative to total weight loss (FFML/WL%) was calculated as:

$$FFML/WL\% = \frac{FFM\,(post-operative) - FFM\,(preoperative)}{weight\,(post-operative) - weight\,(preoperative} \times 100 \quad (2)$$

Insufficient weight loss (IWL) was defined as not achieving 50% of EWL during a median follow-up of 18 months (range: 12–24 months) after surgery in all of our analyses, or the less popular definition < 20% TWL [4, 16]. The individuals who did not fall into the IWL category were considered to achieve sufficient weight loss (SWL).

Follow-up and postoperative care

Patients underwent comprehensive evaluations following a strict post-operative protocol at 1, 3, 6, 9, 12, 18, and 24 months after surgery to ensure compliance. Our post-op care team consisted of an obesity specialist, a nutritionist, and a sports and exercise medicine physician. Patients were placed on a calorie-restricted diet, consisting of 10–35% protein, and were prescribed daily vitamin and mineral supplements for up to one year. Their diets were continually adjusted based on individualized clinical and biochemical assessments. Additionally, all patients were instructed to follow a physical activity regimen, incorporating a combination of aerobic and resistance exercises for at least 30 min per day post-surgery.

Statistical analysis

Categorical variables were summarized and presented by frequencies and percentages, while normally distributed continuous variables were reported as means and standard deviations (SD), and non-normally distributed data as median [25–75 interquartile range (IQR)]. Normally distributed variables were analyzed by the two-tailed independent sample t-test, and non-normally distributed variables were analyzed using the Mann–Whitney test. The Chi-square and Fisher's exact tests were used to compare qualitative variables between groups when appropriate. The generalized estimating equation (GEE) method, using an auto-regressive working correlation structure and a log-link function with binomial errors, was employed to evaluate changes in fat mass (FM), fat-free mass (FFM), fat-free mass loss relative to weight loss (FFML/WL%), and excess weight loss percentage (EWL%) over 24 months following bariatric surgery. Time-trend analysis models were applied to both the IWL and SWL groups, with P values for trends reported separately for each group. Interactions between the groups at each phase of the study were assessed using various models. To identify significant independent baseline predictors for IWL, multivariate logistic regression models were constructed. Variables with a P value of < 0.2 in the univariate regression analysis were included in the multivariate analysis, and stepwise regression was applied to identify risk factors associated with IWL. All analyses were conducted using IBM SPSS Version 20 (SPSS, Chicago, IL, USA), with statistical significance set at $P<0.05$ (two-tailed).

Results

A total of 3456 individuals (78.2% women) participated in the study. The medians of age and BMI were 39.9 ± 11.3 years and 44.8 ± 5.6 kg/m^2, respectively. Most of the participants were categorized in the obesity class III (BMI: 40-44.9). After a median follow-up of 18 months post-surgery, 3190 (92.3%) individuals achieved 50% or more EWL (i.e., the SWL group), and 266 (8%) failed to achieve this parameter (categorized as IWL). The members of the IWL group were older and had a higher mean baseline BMI (47.6 ±6.3 vs. 44.6 ±5.5 $P<0.001$), as well as higher baseline FM% (51.3 ±4.4 vs. 49.9 ±4.7 $P<0.001$), and lower baseline FFM% (48.5±4.1 vs. 49.9±4.7% $P<0.001$). In the IWL group compared to the SWL group, a significantly higher ratio of patients underwent SG compared to GB (9.7% vs. 3.4%, $P<0.001$). All metabolic parameters and obesity-related comorbidities (WC, TG, FPG, HbA1C, SBP, DBP, dyslipidemia, HTN, DM, and insulin resistance) were higher or more frequent in the IWL group compared to the SWL group ($P<0.05$) (Table 1).

Figure 1 shows changes in FM%, FFM%, FFML/WL%, and EWL% in the SWL and IWL groups throughout a median of 18 months of follow-up. The means of FM%, FFM%, and FFML/WL% significantly decreased, and EWL% significantly increased in both the SWL and IWL groups ($P_{trend} < 0.05$). There were significant differences in FM%, FFM%, FFML/WL%, and EWL% between the two groups over time, with the IWL group showing a higher FFM/WL% loss and a lower FM loss after six months of follow-up (P time before & after 6 months < 0.05) (Fig. 1).

Table 2 shows univariate and multivariate logistic regression and stepwise regression analysis of the factors associated with IWL with two popular definitions of it. With defining IWL < 50% EWL at 18 months post-surgery, An older age, suffering from DM, undergoing SG, a higher baseline BMI, and non-smoking were associated with a greater likelihood of IWL, so these parameters were the main negative predictors of achieving a satisfactory outcome after bariatric surgery ($P<0.05$). Moreover, by defining IWL as < 20% TWL, the prevalence of IWL and SWL was 2.9% ($n=100$) and 85% ($n=2938$), respectively. Predictors of IWL, associated with a higher risk of IWL with this definition were: an older age, suffering from DM and HTN, undergoing SG, a higher baseline BMI, and non-smoking. However, significant results of HTN and non-significant BMI of 40–44.9 kg/m^2 and age of 40–59 in the multivariate analysis were different in comparison to the former definition (EWL < 50%).

Table 3 shows obesity-related co-morbidities resolution in each study group. Regarding the remission of co-morbidities, our analysis revealed a significantly greater remission rate of HTN and DM in the SWL group compared to the IWL. However, there weren't any significant differences in dyslipidemia resolution between the two groups.

Discussion

In the present study, after a median follow-up of 18 months (range: 12–24 months), data analysis showed that 8% of the participants fell into the IWL group. Significant differences were seen in the changes of FM%, FFM %, FFML/WL%, and EWL% between the SWL and IWL groups after six months of follow-up. Also, FFML/WL% was significantly higher in the IWL group. An older age, a higher baseline BMI, having DM, and undergoing SG and non-smoking were the main independent predictors of IWL.

Currently, there is no standardized definition for the success or failure of bariatric surgery. Additionally, in the literature, IWL is often confused with WR, but these terms should not be used interchangeably [4, 17]. WR and IWL are distinct issues, and patients experiencing them require different treatment approaches [18]. Patients with IWL may experience early negative outcomes or may have biological or genetic factors that limit the beneficial effects of bariatric surgery. In contrast, patients who experience WR typically respond well to the initial metabolic effects of surgery but struggle with long-term weight management, which may be due to behavioral, metabolic, or genetic factors.

The Reinhold classification has been most acceptable used to determine unsuccessful weight loss as EWL < 50% [19]. Although, the ability of this definition to correlate with clinical outcomes such as resolution or recurrence of co-morbidities, quality of life, and patient satisfaction is limited. A recent review in 2022 suggests that for obesity treatment, the term "*surgical nonresponse*" would be appropriate as a replacement for IWL [17]. It is still unclear to which extent cardiometabolic improvements after bariatric surgery depend on the degree of weight loss. In addition, many surgeons use projections based on EWL% to provide their patients with expectations of successful surgery. Our results showed that individuals with SWL had a greater improvement in cardio-metabolic comorbidities such as DM and HTN compared to the IWL group. There is a big knowledge gap about this issue and no previous study is available regarding the comparison of cardio-metabolic comorbidities resolution between IWL and SWL groups. With this investigation, the authors try to get the attention of elites and researchers to the knowledge gap in this field and to discuss it more.

Table 1 Baseline characteristics of studied groups prior to bariatric surgery

Variables	Total (3456)	Insufficient weight loss (IWL) (*N*=266)	Sufficient weight loss (SWL) (*N*=3190)	*P* value
Sex women, n (%)	2701 (78.2)	221 (83.1)	2480 (77.7)	**0.043**
Age group, n (%)	39.9 ± 11.3			
18–39	1790 (51.8)	74 (27.8)	1716 (53.8)	**<0.001**
40–59	1508 (43.6)	156 (58.6)	1352 (42.4)	
60 <	158 (4.6)	36 (13.5)	122 (3.8)	
BMI (kg/m^2)`	44.8 ± 5.6	47.6±6.3	44.6±5.5	**<0.001**
BMI group, n (%)				**<0.001**
35-39.9	566 (16.3)	19 (7.1)	547 (17.2)	
40-44.9	1419 (41.0)	87 (32.7)	1332 (41.8)	
45-49.9	910 (26.3)	78 (29.3)	832 (26.1)	
≥50	560 (16.2)	82 (30.8)	478 (15)	
WC (cm)	124.5 ± 23.9	127.9±14.9	124.3±24.5	**0.023**
TG (mg/dl),	143 (105–191)	157 (114-204.75)	142 (105–189)	**0.011**
Dyslipidemia, n (%)	2835 (85.2)	230 (88.5)	2605 (84.9)	**0.119**
HDL (mg/dl)	47.0 ± 11.8	47.9±12.7	47.0±11.8	0.232
LDL (mg/dl)	110.9 ± 31.9	108.4±34.4	111.1±31.7	0.195
Cholesterol (mg/dl)	188.9 ± 37.6	187.6±39.9	189.0±37.5	0.567
SBP (mmhg)	123.8 ± 12.3	126.1±12.8	123.7±12.3	**0.003**
DBP (mmhg)	79.8 ± 7.4	80.9±8.0	79.8±7.4	**0.030**
HTN, n (%)	975 (28.2)	118 (45.7)	857 (28.1)	**<0.001**
FPG (mg/dl)	110.25 ± 37.4	123.6±46.0	109.1±36.4	**<0.001**
HbA1c	5.9 ± 1.41	6.3±1.5	5.9±1.4	**<0.001**
DM, n (%)	892 (25.8)	119 (45.9)	773 (25.7)	**<0.001**
Serum Creatinine (mg/dl)	0.9 ± 0.4	0.9±0.1	0.9±0.4	0.397
eGFR (ml/min)	240.6 ± 87.9	83.277 ± 19.874	88.371 ± 19.720	<0.001
eGFR group, n (%)				<0.001
eGFR≥60	3229 (93.4)	238 (89.5)	2991 (93.8)	
eGFR 30–60	212 (6.1)	28 (10.5)	184 (5.8)	
eGFR<30	15 (0.4)	0 (0.0)	15 (0.5)	
FM, kg	60.2 ± 11.1	63.4±12.5	59.9±10.9	**<0.001**
FM (%)	50.0 ± 4.7	51.3±4.4	49.9±4.7	**<0.001**
FFM, kg	60.1 ± 12.0	59.8 ± 11.2	60.1 ± 12.0	0.709
FFM, (%)	49.7 ± 4.6	48.5 ± 4.1	49.90 ± 4.7	**<0.001**
Surgery type, n (%)				**<0.001**
SG	2352 (68.1)	228 (85.7)	2124 (66.6)	
GB (RYBG and OAGB)	1104 (31.9)	38 (14.3)	1066 (33.4)	
Insulin (µU/mL)	18.7 (12.4–26.9)	18.3 (12.6–25.9)	18.8 (12.4–27.0)	0.711
Insulin resistance, n (%)	2905 (84.1)	199 (87.7)	2185 (81.6)	**0.022**
Alcohol consumption, n (%)	440 (12.7)	15 (5.9)	425 (13.9)	**<0.001**
Depressive disorders	107 (3.1)	17 (6.4)	90 (2.8)	**0.001**
Smoking status n, (%)				**<0.001**
Smoker	369 (10.7)	9 (3.6)	360 (11.9)	
Non-smoker	2898 (83.9)	243 (96.4)	2655 (88.1)	

IWL, insufficient weight loss (<50% EWL at 18 months post surgery), BMI, body mass index; WC, waist circumference; High TG, triglyceride≥150 or using lipid-lowering medication; Low HDL, HDL-C<40 in men and <50 in women or using lipid-lowering medication; HTN, hypertension (Systolic blood pressure (SBP)≥140 mmHg and/or diastolic blood pressure (DBP)≥90 mmHg or taking antihypertensive medication, FPG, DM, dibetes mellitus, FPG≥126 mg/dl or HBA1C≥6.5 anti-diabetic medication use; FM, fat mass; FFM, fat free mass; SG, sleeve gastrectomy; RYGB, Roux-en-Y, gastric bypass; OAGB, one-anastomosis gastric bypass; Insulin resistance, HOMA-IR, fasting glucose (mg/dL) X fasting insulin (µU/mL) / 405. *IR was defined as HOMA-IR≥2.6 in both sexes.* Data are presented as mean±SD or n (%) except for TG and Insuline, which has been presented as median (IQ 25–75)

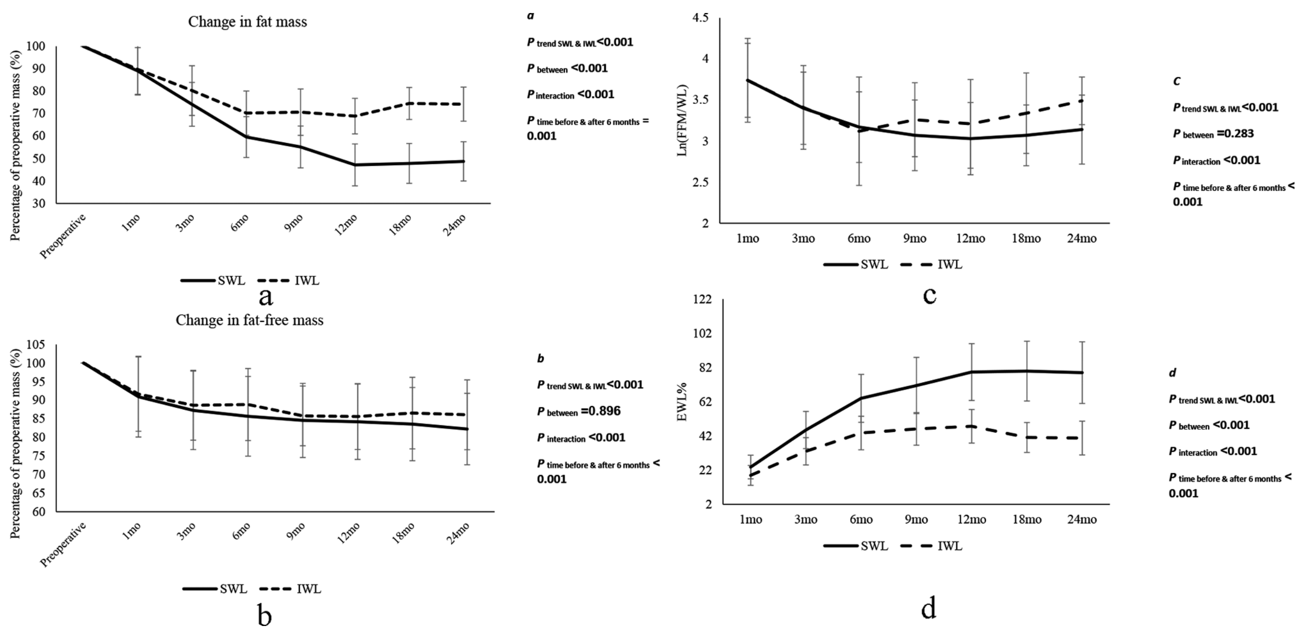

Fig. 1 Trend of different characteristics of IWL and SWl individuals during 24 months of follow-up. **a**) Fat mass percentage (FM%). **b**) Fat-free mass percentage (FFM%). **c**) fat-free mass loss/weight loss (FFML/WL). **d**) excess weight loss (EWL%)

With the lack of an accurate definition of IWL, the true incidence is not known. According to current definitions, about 15–35% of the patients undergoing bariatric surgery may lose weight inadequately and are considered to have IWL [2, 20]. Moreover, some studies have not reported separate frequencies for IWL and WR [4, 20]. Al-Khayatt et al.. conducted a study on 227 patients undergoing GB to determine the predictors of IWL (defined as <50% EWL after 12 months) and reported an incidence rate of 14% for IWL [1]. Lower mean age and baseline BMI in our study population compared to the population studied by Al-Khayatt et al. (39.9 ± 11.3, 44.8 ± 5.6 vs. 48.60 ± 11, 53.6 ± 7.1), as well as different surgical techniques and our strict exclusion criteria, may have caused the different incidence rates of IWL (8% vs. 14%). Using different bariatric techniques, multiple IWL definitions, and different study populations have been noted to result in different IWL frequencies [3, 20].

The factors associated with IWL and their impacts have been a matter of debate [1, 3, 21]. Identifying the factors associated with IWL may help reduce its incidence by employing specific strategies and additional supportive therapies for at-risk groups. In line with our results, older age has been noted as a predictor of IWL after GB [1] and SG [3]. As we know, aging is accompanied by a decrease in the basal metabolic rate and lipolytic activities [1]. However, Cadena-Obando reported that age alone might not significantly affect weight loss because of the dominant effects of intensive exercise programs and diet [2]. Needless to say, many old individuals may undergo bariatric surgery to manage their comorbidities better rather than achieve SWL. Altogether, it seems better to perform bariatric surgery at a younger age for optimal outcomes.

Multiple reports have demonstrated that a higher baseline BMI can be associated with IWL [1, 3, 22–24]. Consistent with our findings, El-Moussaoui et al. concluded that a higher baseline BMI (BMI > 50 kg/m^2) was a significant predictor of weight loss failure [24]. However, Gil–Rendo et al. reported that, according to multivariate regression analysis, baseline BMI did not affect SWL four years after SG [25]. Patients with super obesity (BMI > 50 kg/m^2) generally have reduced physical activity, lower calorie intake, and an intrinsic metabolic pattern [26], demanding adequate dietary regimens pre-operative to promote acceptable weight loss after surgery.

Consistent with our results, one of the most significant predictors of IWL has been noted to be the type of bariatric surgery [4]. In agreement with our observation, previous studies demonstrated that SG was a negative predictor of IWL [21]. This may be explained by more extended malabsorptive areas in GB and more significant changes in ghrelin and other appetite-regulating hormones after SG [2, 27]. As reported in previous studies, GB was associated with better FFM preservation compared to SG [28], which may be due to lower ghrelin levels after SG compared to GB. Ghrelin is an important anabolic agent for skeletal muscles, and during SG, the major source of ghrelin is removed [29]. Altogether, malabsorptive bariatric surgeries may be offered to high-risk candidates.

We found that obesity-related comorbidities such as DM negatively influenced weight loss, which is in line with other

Table 2 univariate, multivariate and Stepwise logistic regression of factors associated with two different definitions for IWL*

IWL (< 50% EWL at 18 months post surgery)				IWL (< 20% TWL)	
Variables	Univariate		Stepwise	Univariate	stepwise
	OR(95% CI)	*P* value	OR(95% CI) *P* value	OR(95% CI) *P* value	OR(95% CI) *P* value
Age					
18–39 (ref)	1		1	1	1
40–59	2.676 (2.011–3.560)	**< 0.001**	**2.277 (1.633–3.118) <0.001**	**2.121 (1.399–3.360) <0.001**	1.530 (0.891–2.627) 0.123
≥ 60	6.843 (4.413–10.610)	**0.006**	**3.728 (2.265–6.134) <0.001**	**8.337 (4.541–15.307) < 0.001**	**3.330 (1.560–7.110) 0.002**
sex					
Women (ref)	1	**-**	-	1	-
Men	0.711 (0.511-0.991)	**0.044**	-	0.733 (0.432–1.243) 0.249	-
Baseline BMI					
35-39.9 (ref)	1			1	
40-44.9	1.884 (1.136–3.125)	**0.014**	**2.023 (1.191–3.438) 0.009**	0.784 (0.483–1.273) 0.325	0.865 (0.497–1.508) 0.610
45-49.9	2.704 (1.619–4.516)	**< 0.001**	**2.832 (1.651–4.857) <0.001**	0.305 (0.155–0.599) 0.305	**0.315 (0.150–0.661) 0.002**
≥ 50	4.948 (2.960–8.272)	**< 0.001**	**5.265 (3.047–9.098) 0.001**	0.387 (0.185–0.811). 0.387	**0.322 (0.137–0.758) 0.009**
Type of surgery					
Gastric bypass (RYBG and OAGB) (ref)	1			**1**	**1**
SG	3.011 (2.119–4.278)	**< 0.001**	**3.847 (2.640–5.606) <0.001**	**3.576 (1.947–6.568) <0.001**	**3.844 (1.992–7.416) <0.001**
HTN (ref = no)	2.162 (1.671–2.796)	**< 0.001**	-	2.566 (1.702–3.868) **<0.001**	**1.820 (1.107–2.990) 0.018**
DM (ref = no)	2.452 (1.895–3.173)	**< 0.001**	**2.06 (1.549–2.765) <0.001**	3.074 (2.041–4.630) **<0.001**	**2.563 (1.577–4.166) <0.001**
Dyslipidemia (ref = no)	1.366 (0.922–2.023)	**0.120**	-	1.601 (0.826–3.102) 0.163	-
FM%	1.084 (1.047–1.122)	**< 0.001**	**-**	0.984 (0.944–1.026) 0.469	**-**
FFM%	0.001 (0.000-0.014)	**< 0.001**	**0.001 (0.000-0.183) 0.010**	1.023 (0.982–1.066) 0.270	**-**
eGFR (ref≥60)	1.76 (1.165–2.683)	**0.007**	**-**	1.580 (0.809–3.087) 0.180	
Alcohol consumption (ref = no)	0.388 (0.228–0.661)	**< 0.001**	**-**	**0.373 (0.151–0.926) 0.033**	**-**
Smoking status (ref = non-smoker)	0.273 (0.139–0.536)	**< 0.001**	**0.363 (0.183–0.723) 0.004**	**3.946 (1.242–12.540) 0.020**	**0.223 (0.054–0.922) 0.038**
Insulin resistance (ref = no)	1.604 (1.067–2.410)	**0.023**	**-**	**2.518 (1.155–5.494) 0.02**	**-**
Depressive disorders (ref = no)	2.352 (1.378–4.012)	**0.002**	**1.813 (0.994–3.305) 0.052**	0.968 (0.301–3.111) 0.956	**-**

IWL, insufficient weight loss (< 50% EWL at 18 months post surgery* and < 20% TWL), BMI, body mass index; HTN, hypertension (Systolic blood pressure (SBP) ≥ 140 mmHg and/or diastolic blood pressure (DBP) ≥ 90 mmHg or taking antihypertensive medication, DM, dibetes mellitus, FPG ≥ 126 mg/dl or HBA1C ≥ 6.5 anti-diabetic medication use; FM, fat mass; FFM, fat free mass; SG, sleeve gastrectomy; RYGB, Roux-en-Y, gastric bypass; OAGB, one-anastomosis gastric bypass; Insulin resistance, HOMA-IR, fasting glucose (mg/dL) X fasting insulin (µU/mL) / 405. *IR was defined as HOMA-IR ≥ 2.6 in both sexes*

Table 3 Cardiovascular risk factors and co-morbidities in each study group

Variables		IWL	SWL	*P*-value
Hypertension, n (%)	Pre-operation	118 (45.7)	857 (28.1)	0.001
	Remission Post-operation	45 (48.9)	438 (66.5)	
Diabetes mellitus, n (%)	Pre-operation	119 (45.9)	773 (25.7)	0.005
	Remission Post-operation	49 (60.5)	409 (75.3)	
Dyslipidemia, n (%)	Pre-operation	230 (88.5)	2605 (84.9)	0.143
	Remission Post-operation	28 (20.0)	454 (25.6)	

IWL, insufficient weight loss (< 50% EWL at 18 months post surgery), HTN, hypertension (Systolic blood pressure (SBP) ≥ 140 mmHg and/or diastolic blood pressure (DBP) ≥ 90 mmHg or taking antihypertensive medication, DM, diabetes mellitus, FPG ≥ 126 mg/dl or HBA1C ≥ 6.5 anti-diabetic medication use; Dyslipidemia: High TG, triglyceride ≥ 150 or using lipid-lowering medication; Low HDL, HDL-C < 40 in men and < 50 in women or using lipid-lowering medication

Diabetes mellitus Remission, (HbA1c < 6.5%, FBG < 126 mg/dL) in the absence of antidiabetic medications; hypertension Remission, Defined as SBP < 140 mmHg and DBP < 90 mmHg off antihypertensive medication; Dyslipidemia Remission, Normal lipid panel off medication. (LDL < 100 mg/dL and HDL < 40 mg/dL, total cholesterol < 200 mg/dL and triglyceride < 150 mg/dL

reports [1, 3, 4]. This may be due to the impact of some antidiabetic agents that can increase circulating insulin levels and promote lipogenesis, reducing weight loss. Nevertheless, GB has been noted to improve insulin sensitivity, and the benefits of bariatric surgeries are well-established in diabetic patients [1]. Overall, our findings suggest regular follow-up and post-surgery monitoring of weight loss in patients with DM.

The etiology of IWL post-surgery is multifactorial, and the factors contributing to this phenomenon considerably overlap with each other. In agreement with our previous report, we also observed here a non-significant independent link between eGFR ≥ 60 mL/ min and IWL in multivariate regression analysis, reflecting that IWL may be partly caused by DM or older age in individuals with eGFR higher than this threshold [30].

This study had some limitations. First of all, our study had a relatively short follow-up time and we inevitably had missing data at some points, which were managed by GEE analysis and matching the characteristics of people in the IWL and SWL groups at the baseline. We did not evaluate participants' physical activity and dietary habits, which could have had notable effects on weight loss and body composition. We evaluated variables only at the baseline, and no data were available post-bariatric surgery and throughout the follow-up. Addressing the strengths of this study, our study was conducted on a large population; we defined IWL as a separate entity from WR, and we also assessed the effects of OAGB, which has been described in a few reports.

Conclusion

In conclusion, this study showed that after a median follow-up of 18 months after bariatric surgery, the incidence of IWL was 8%. The factors associated with IWL included older age, higher baseline BMI, having DM, undergoing SG, and non-smoking. Malabsorptive bariatric procedures may be offered to high-risk individuals; however, this requires identifying the risk factors associated with IWL so that at-risk individuals can benefit from appropriate support plans preoperatively and during follow-up to improve their clinical outcomes.

In order to get to the goal of effective treatment after bariatric surgery there is a dire need for a standardized definition of IWL. This makes it difficult to define how much EWL% is significant to achieve improvement of co-morbidities. Therefore, there is a need to address the IWL definitions knowledge gaps including the exact cutoff points predicting cardiometabolic outcomes. Moreover, for obesity treatment, the term *surgical nonresponse* would be appropriate as a replacement for IWL. Further studies will be needed to elucidate all preoperative and post-operative modifiable predictors of IWL, including physical activity and dietary regimen, to achieve the best outcomes possible.

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Author contributions MB: Study design, data collection, coordination of patients' issues, manuscript preparation, and the final approval of the manuscript. 'MHA': Data collection, literature review, and manuscript preparation. 'DE': Data collection, literature review, and manuscript preparation. 'AK': Study design, performing surgeries, and the final approval of the manuscript. 'MM': Data analysis, data interpretation, and manuscript preparation, 'MV': Final approval of the manuscript. 'FH': Study design, revising the manuscript, and final approval of the manuscript: All authors reviewed and approved the final draft.

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Declarations

Ethical approval and consent to participate All the procedures performed in the study were approved by the Research Ethics Committee of the Research Institute for Endocrine Sciences of Shahid Beheshti University of Medical Sciences and followed the ethical standards of the institutional Human Research Review Committee and the 1964 Helsinki declaration and its later amendments. Informed written consent was obtained from all participants.

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References

1. Al-Khyatt W, Ryall R, Leeder P, Ahmed J, Awad S (2017) Predictors of inadequate weight loss after laparoscopic gastric bypass for morbid obesity. Obes Surg 27(6):1446–1452
2. Cadena-Obando D, Ramírez-Rentería C, Ferreira-Hermosillo A, Albarrán-Sanchez A, Sosa-Eroza E, Molina-Ayala M et al (2020) Are there really any predictive factors for a successful weight loss after bariatric surgery? BMC Endocr Disord 20(1):20
3. Almezaien O Predictors of inadequate weight loss after laparoscopic sleeve gastrectomy YR– 2022/4/1. Al-Azhar Assiut medical journal. (2 UL-http://www.azmj.eg.net/article.asp?issn=1687-1693;year=2022;volume=20;issue=2;spage=225;epage=231;aulast=Almezaien;t=5):225 OP-231 VO– 20.
4. El Ansari W, Elhag W (2021) Weight regain and insufficient weight loss after bariatric surgery: definitions, prevalence, mechanisms, predictors, prevention and management strategies, and knowledge Gaps-a scoping review. Obes Surg 31(4):1755–1766
5. Cottam S, Cottam D, Cottam A (2019) Sleeve gastrectomy weight loss and the preoperative and postoperative predictors: a systematic review. Obes Surg 29(4):1388–1396
6. Dharmaratnam VM, Lim E, Eng A, Chan WH, Tan HC, Ho E et al (2022) Revisional surgery or pharmacotherapy for insufficient weight loss and weight regain after primary bariatric procedure: a descriptive study. Obes Surg 32(10):3298–3304
7. Barzin M, Hosseinpanah F, Motamedi MA, Shapoori P, Arian P, Daneshpour MA et al (2016) Bariatric surgery for morbid obesity: Tehran Obesity Treatment Study (TOTS) Rationale and Study Design. JMIR Res Protoc. 5(1):e8
8. Motamedi MAK, Barzin M, Ebrahimi M, Ebrahimi R, Khalaj A (2017) Severe fatal protein malnutrition and liver failure in a morbidly obese patient after mini-gastric bypass surgery: case report. Int J Surg Case Rep 33:71–74
9. Physical status (1995) the use and interpretation of anthropometry. Report of a WHO Expert Committee. Vol. 854, World Health Organization technical report series. Switzerland
10. Achamrah N, Colange G, Delay J, Rimbert A, Folope V, Petit A et al (2018) Comparison of body composition assessment by DXA and BIA according to the body mass index: A retrospective study on 3655 measures. PLoS ONE 13(7):e0200465
11. Marra M, Sammarco R, de Lorenzo A, Iellamo F, Siervo M, Pietrobelli A et al (2019) Assessment of body composition in health and disease using bioelectrical impedance analysis (BIA) and dual energy X-Ray absorptiometry (DXA): A critical overview. Contrast Media Mol Imaging 2019:3548284
12. Schoenborn CA, Adams PE (2010) Health behaviors of adults: united States, 2005–2007. Vital Health Stat 10(245):1–132
13. Barzin M, Khalaj A, Tasdighi E, Samiei Nasr D, Mahdavi M, Banihashem S et al (2020) Sleeve gastrectomy vs gastric bypass in improvement of depressive symptoms following one year from bariatric surgery, Tehran obesity treatment study (TOTS). Obes Res Clin Pract 14(1):73–79
14. Levey AS, Stevens LA, Schmid CH, Zhang YL, Castro AF 3rd, Feldman HI et al (2009) A new equation to estimate glomerular filtration rate. Ann Intern Med 150(9):604–612
15. Tohidi M, Ghasemi A, Hadaegh F, Derakhshan A, Chary A, Azizi F (2014) Age- and sex-specific reference values for fasting serum insulin levels and insulin resistance/sensitivity indices in healthy Iranian adults: Tehran lipid and glucose study. Clin Biochem 47(6):432–438
16. Corcelles R, Boules M, Froylich D, Hag A, Daigle CR, Aminian A et al (2016) Total weight loss as the outcome measure of choice after Roux-en-Y gastric bypass. Obes Surg 26(8):1794–1798
17. Majid SF, Davis MJ, Ajmal S, Podkameni D, Jain-Spangler K, Guerron AD et al (2022) Current state of the definition and terminology related to weight recurrence after metabolic surgery: review by the POWER task force of the American society for metabolic and bariatric surgery. Surg Obes Relat Dis 18(7):957–963
18. Sarwer DB, Allison KC, Wadden TA, Ashare R, Spitzer JC, McCuen-Wurst C et al (2019) Psychopathology, disordered eating, and impulsivity as predictors of outcomes of bariatric surgery. Surg Obes Relat Dis 15(4):650–655
19. Reinhold RB (1982) Critical analysis of long term weight loss following gastric bypass. Surg Gynecol Obstet 155(3):385–394
20. Brissman M, Beamish AJ, Olbers T, Marcus C (2021) Prevalence of insufficient weight loss 5 years after Roux-en-Y gastric bypass: metabolic consequences and prediction estimates: a prospective registry study. BMJ Open 11(3):e046407
21. Chang WW, Hawkins DN, Brockmeyer JR, Faler BJ, Hoppe SW, Prasad BM (2019) Factors influencing long-term weight loss after bariatric surgery. Surg Obes Relat Dis 15(3):456–461
22. Mazri FH, Shahar S, Kosai NR, Omar MA, Ramilis N, Rajan R (2019) A retrospective study of weight-loss predictors following bariatric surgery in Malaysian patients with obesity. Malays J Nutr.;25(3)
23. Nickel F, de la Garza JR, Werthmann FS, Benner L, Tapking C, Karadza E et al (2019) Predictors of risk and success of obesity surgery. Obes Facts 12(4):427–439
24. El Moussaoui I, Van Vyve E, Johanet H, Dabrowski A, Piquard A, Delaunay T et al (2021) Laparoscopic sleeve gastrectomy for morbid obesity in a Belgian-French prospective multicenter study: outcomes and predictors weight loss failure. Acta Chir Belg 121(6):413–419
25. Gil-Rendo A, Muñoz-Rodríguez JR, Domper Bardají F, Menchén Trujillo B, Martínez-de Paz F, Caro González MDP et al (2019) Laparoscopic sleeve gastrectomy for High-Risk patients in a monocentric series: Long-Term outcomes and predictors of success. Obes Surg 29(11):3629–3637

26. Melton GB, Steele KE, Schweitzer MA, Lidor AO, Magnuson TH (2008) Suboptimal weight loss after gastric bypass surgery: correlation of demographics, comorbidities, and insurance status with outcomes. J Gastrointest Surg 12(2):250–255
27. Takiguchi S, Takata A, Murakami K, Miyazaki Y, Yanagimoto Y, Kurokawa Y et al (2014) Clinical application of Ghrelin administration for gastric cancer patients undergoing gastrectomy. Gastric Cancer 17(2):200–205
28. Barzin M, Heidari Almasi M, Mahdavi M, Khalaj A, Valizadeh M, Hosseinpanah F (2021) Body composition changes following sleeve gastrectomy vs. One-Anastomosis gastric bypass: Tehran obesity treatment study (TOTS). Obes Surg.;31(12)
29. Tuero C, Valenti V, Rotellar F, Landecho MF, Cienfuegos JA, Frühbeck G (2020) Revisiting the Ghrelin changes following bariatric and metabolic surgery. Obes Surg 30(7):2763–2780
30. Barzin M, Mousapour P, Khalaj A, Mahdavi M, Valizadeh M, Hosseinpanah F (2020) The relationship between preoperative kidney function and weight loss after bariatric surgery in patients with estimated glomerular filtration rate≥30 mL/min: Tehran obesity treatment study. Obes Surg 30(5):1859–1865