J Metab Bariatr Surg. 2024 Jun;13(1):8-16
https://doi.org/10.17476/jmbs.2024.13.1.8
pISSN 2287-2930·eISSN 2508-5956

Journal of Metabolic and Bariatric Surgery JMBS

Original Article

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Prediction Model for Chronological Weight Loss After Bariatric Surgery in Korean Patients

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Received: Dec 27, 2023
Revised: Mar 22, 2024
Accepted: Mar 25, 2024
Published online: Jun 4, 2024

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ABSTRACT

Purpose: This study aimed to develop a predictive model for monitoring chronological weight loss during the early postoperative period following bariatric surgery in Korean patients with morbid obesity.
Materials and Methods: The baseline characteristics and postoperative weight loss outcomes were collected for up to 24 months after surgery in patients who underwent sleeve gastrectomy (SG) or Roux-en-Y gastric bypass (RYGB). The factors influencing weight loss outcomes were analyzed, and longitudinal percentile charts were plotted using quantile regression models adjusted for the identified independent factors.
Results: The analysis included 491 and 274 patients who underwent SG and RYGB, respectively, of whom 225 (29.4%) were men. A positive association was found between the maximum percentage of total weight loss (%TWL) and female sex, body mass index (BMI) ≥40, and age <40 years. Among patients who reached nadir BMI or had at least 12 months of follow-up data (n=304), 7.6% exhibited inadequate weight loss (TWL <20%). The predictors of insufficient weight loss were older age (>40 years), male sex, and psychological problems. Centile charts were generated for the entire cohort, incorporating age, sex, and the type of procedure as covariates.
Conclusion: The percentile charts proposed in the present study can assist surgeons and healthcare providers in gauging patients' progress toward their weight loss goals and determining the timing of adjunctive intervention in poor responders during early postoperative follow-up.

Keywords: Morbid obesity; Bariatric surgery; Weight loss; Body weight trajectory

INTRODUCTION

Bariatric and metabolic surgeries result in remarkable weight loss and often lead to the improvement or resolution of obesity-related comorbidities in patients with morbid obesity. Several outcome measures can be used to determine the efficacy of metabolic and bariatric surgery, including weight loss, the resolution of obesity-related comorbidities, improved

Funding
This study was supported by a research grant from the Korean Society of Metabolism and Bariatric Society (KSMBS-2021-04).

Conflict of Interest
None of the authors have any conflict of interest.

Author Contributions
Conceptualization: Park JY; Data curation: Park JY, Chung Y, Kim YJ; Formal analysis: Park JY, Shin J, Shin JY: Funding acquisition: Park JY; Investigation: Park JY, Chung Y, Kim YJ; Methodology: Park JY, Shin J, Shin JY; Project administration: Park JY; Resources: Park JY, Kim YJ; Supervision: Park JY; Visualization: Park JY, Shin J, Shin JY; Writing - original draft: Park JY; Writing - review & editing: Park JY, Chung Y, Shin J, Shin JY, Kim YJ.

quality of life, and prolonged life expectancy [1-3]. Weight loss is one of the most commonly used parameters for evaluating outcomes among surgical patients, procedures, and studies. Enhanced weight loss following bariatric surgery is typically associated with heightened metabolic benefits and consequent reductions in comorbidity-associated medical costs [4]. Therefore, weight loss serves as a prominent endpoint frequently utilized in scholarly literature.

However, weight loss outcomes are difficult to predict precisely due to the multifaceted influences, including demographic factors, comorbidities, and the surgical approach employed. Moreover, these outcomes are not simply binary or categorical but are continuous and prone to variation over time following surgery. Additionally, patient adherence to healthier lifestyles or unforeseen events during the postoperative period can have an impact on these outcomes. Previous literature has predominantly focused on documenting outcomes, often centered on weight loss measurements at 1 year post-surgery or at the point of achieving the lowest body weight. Consequently, the specific weight loss journey within the first year after bariatric surgery in each patient remains unclear, posing a significant challenge in providing guidance toward achieving weight loss goals [5].

The present study aimed to suggest a chronological prediction model for weight loss after bariatric surgery in Korean patients with morbid obesity. It also aimed to propose selection criteria for identifying poor responders to bariatric surgery who may benefit from adjunctive intervention in the early postoperative phase of weight loss.

MATERIALS AND METHODS

1. Patients

A retrospective review of a prospectively established bariatric database at two Korean bariatric centers, Kyungpook National University Chilgok Hospital, Daegu and Yanji H+ Hospital, Seoul, identified all consecutive patients who underwent primary sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB) between January 2017 and December 2020. Patients who underwent revision or conversion surgery after the primary bariatric surgery were excluded from the study. The patients' baseline demographics and obesity-related comorbidities were retrospectively reviewed. This retrospective study was approved by the institutional review board of each hospital (KNUCH 2021-04-018 and HYJ 2021-06-001), and the need for informed consent was waived.

The eligibility for bariatric surgery in Korea is determined based on the national insurance reimbursement policy: those with a body mass index (BMI) of ≥35 kg/m^2 or a BMI of ≥30 kg/m^2 and inadequately controlled obesity-related comorbidities (e.g., type 2 diabetes [T2D], dyslipidemia, hypertension, obstructive sleep apnea, and non-alcoholic steatohepatitis) [6]. The procedure type was determined on an individual basis through discussions with each patient, taking into account their metabolic status, surgical risks, and potential long-term complications.

The patients were scheduled for follow-up appointments at the outpatient clinic 2–3 weeks after surgery, every 3 months after the first year of surgery, and annually thereafter. The anthropometric data were collected at each follow-up visit. If the patients were unable to visit the clinic, data regarding changes in body weight were obtained via telephone.

 https://doi.org/10.17476/jmbs.2024.13.1.8

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The efficacy of the surgical procedures and the amount of weight loss were expressed as percentages of total weight loss (%TWL). The %TWL was calculated based on the body weight measured at the time of surgery: %TWL = (weight at surgery − postoperative weight)/weight at surgery × 100%. The nadir body weight was defined as the lowest recorded body weight during a follow-up period of at least 12 months. Patients whose weight continued to decrease and had not yet completed the 12-month follow-up were regarded as not having reached their nadir weight and were consequently excluded from the analysis involving nadir weight or nadir BMI. The maximum %TWL was calculated based on the nadir BMI after surgery. Insufficient weight loss was defined as a %TWL of less than 20% at the nadir BMI.

2. Statistical analysis

Data analysis was performed using SPSS (version 26.0; IBM Corporation, Armonk, NY, USA) and SAS 9.4. (SAS Institute Inc., Cary, NC, USA). To utilize the available data, missing data were excluded at the individual data point level, rather than at the patient level, in the final analysis. Continuous variables were compared using the Student's t-test, while categorical variables were compared using the Pearson's χ^2 test or Fisher's exact test, as appropriate. The prediction model for the maximum %TWL was developed using a linear regression model. The predictors of insufficient weight loss were identified using the Cox proportional hazards regression model, and the variables for the multivariate analysis were selected using the backward conditional elimination method. Longitudinal centile lines were plotted using the estimation predictions of the quantile regression models adjusted for age, sex, the type of procedure, and postoperative months. A P value of <0.05 was considered significant.

RESULTS

A total of 765 patients were deemed eligible for this study and included in the analyses. Among them, 491 (64.2%) underwent SG, while 274 (35.8%) underwent RYGB. Additionally, five patients who underwent resectional RYGB, where the excluded stomach was resected, were included in the RYGB group.

The initial mean BMI of these patients was 39.4±13.6 kg/m^2, while the mean age was 35.3±10.4 years. The study population comprised 225 (29.4%) men and 540 (70.6%) women. At baseline, 30.5% of the patients presented with T2D. The baseline BMI was significantly higher in RYGB patients (42.1±21.4 kg/m^2) than in SG patients (37.9±5.6 kg/m^2, P<0.001). More than half of the RYGB patients presented with T2D at baseline compared with SG patients (53.8% vs. 23.9%; P<0.001). The patient's baseline characteristics are outlined in **Table 1**.

The mean follow-up duration was 9.0 ± 6.9 months (median: 7.4, range: 0–31.6 months) in all patients. The attrition rates were 15.4%, 22.1%, 40.0%, 62.5%, 65.0%, 81.2%, and 92.9% at 3, 6, 9, 12, 18 and 24 months after surgery, respectively.

Of the 765 patients, 311 (40.7%) either reached their nadir BMI or had at least 12 months of follow-up data. The mean time to reach the nadir BMI was 12.3±4.7 months. The time to reach their nadir BMI varied among patients: 14.5% at 9 months, 46.0% at 12 months, and 19.9% at 18 months. A significant difference was observed in the distribution of time to reach the nadir BMI between SG and RYGB patients (P=0.014): 81.4% of the SG patients reached their nadir BMI within 12 months, while only 63.4% of RYGB patients reached this milestone within the same timeframe. Furthermore, 36.6% of RYGB patients showed a tendency for

https://doi.org/10.17476/jmbs.2024.13.1.8

Table 1. Clinical characteristics of all study patients

Variables	SG (n=491)	RYGB (n=274)	P value
Age (years)	34.9±10.5	36.0±10.1	0.155
Sex			0.993
Male	145 (29.5)	81 (29.6)	
Female	346 (70.5)	193 (70.4)	
Body weight (kg)	106.7±21.1	113.9±26.6	<0.001
BMI (kg/m^2)	37.9±5.6	42.1±21.4	<0.001
Comorbidities			
Diabetes	111 (23.9)	127 (53.8)	<0.001
Hypertension	137 (29.5)	87 (36.9)	0.049
Dyslipidemia	235 (50.6)	117 (49.8)	0.830
OSA	122 (26.3)	64 (27.1)	0.815
GERD	83 (18.0)	43 (18.3)	0.924
Psychological disorder	26 (5.6)	16 (6.8)	0.531

Values are presented as mean ± standard deviation or number (%).
SG = sleeve gastrectomy, RYGB = Roux-en-Y gastric bypass, BMI = body mass index, OSA = obstructive sleep apnea, GERD = gastroesophageal reflux disease.

Table 2. Predictors of the maximal percentage of total weight loss (%TWL) at nadir BMI after bariatric surgery

Variables	Unstandardized coefficient		Standardized coefficient	t-value	P value	95% CI of B	
	B	SE	β			Lower	Upper
Constant	23.657	3.845	-	6.153	<0.001	16.092	31.223
Age	−0.167	0.042	−0.218	−3.980	<0.001	−0.250	−0.085
Female	4.151	0.938	0.237	4.426	<0.001	2.306	5.997
Preoperative BMI	0.193	0.078	0.139	2.482	0.014	0.040	0.346
RYGB	3.023	0.934	0.174	3.239	0.001	1.186	4.860
Psychological disorder	−2.675	1.513	−0.093	−1.768	0.078	−5.652	0.303
Adjusted R^2				0.153			

Maximum %TWL = 23.657 − 0.167 (age) + 4.151 (female) + 0.193 (preop BMI) + 3.023 (RYGB) − 2.675 (psychological disorder).
TWL = total weight loss, BMI = body mass index, SE = standard error, CI = confidence interval, RYGB = Roux-en-Y gastric bypass.

continued weight loss beyond 12 months. Although the mean BMI at nadir was similar between the SG and RYGB groups, the maximum %TWL at nadir BMI was significantly higher in RYGB patients (31.3±8.4%) than in SG patients (27.8±7.8%, P<0.001).

The predictors of maximum %TWL at nadir BMI included younger age, female sex, procedure type (RYGB), and higher preoperative BMI at baseline (**Table 2**). Of these predictors, female sex exerted the greatest influence on the maximum %TWL outcome, followed by age and procedure type. The regression equation used for calculating the maximum %TWL at the nadir BMI was as follows:

Maximum %TWL = 23.657 − 0.167 (age) + 4.151 (female) + 0.193 (preoperative BMI) + 3.023 RYGB – 2.675 (psychological disorder)

Insufficient weight loss, defined as a maximum %TWL of <20% at nadir BMI, was independently associated with age >40 years (hazard ratio [HR] 2.991, 95% confidence interval [CI] 1.540–5.809), male sex (HR 2.420, 95% CI 1.249–4.689), and the presence of psychological disorders at baseline (HR 3.203, 95% CI 1.287–7.969) in the present cohort (**Table 3**).

The %TWL as early as 3 and 6 months after surgery was strongly correlated with the maximum %TWL after surgery. Upon categorizing the cohort into subgroups using the cutoff values of 10% and 15% at 3 and 6 months, respectively, 57.1% of the patients with a TWL of <10% at 3 months failed to achieve 20% of the %TWL at their nadir BMI. This proportion increased to 80% in those with a TWL of <15% at 6 months (**Table 4**). In patients who failed to achieve a

Table 3. Predictors of insufficient weight loss (maximum %TWL <20%)

Variables	Univariate analysis			Multivariate analysis		
	HR	95% CI	P value	HR	95% CI	P value
Age >40 years	2.564	1.348–4.875	0.004	2.991	1.540–5.809	0.001
Male	2.071	1.093–3.925	0.026	2.420	1.249–4.689	0.009
BMI >40	0.946	0.494–1.811	0.867			
Operative procedure						
SG	Ref					
RYGB	0.709	0.354–1.421	0.333			
Diabetes	1.094	0.565–2.115	0.790			
Hypertension	2.169	1.149–4.095	0.017			
Dyslipidemia	0.851	0.451–1.604	0.618			
OSA	1.496	0.771–2.904	0.234			
Psychological disorder	2.826	1.161–6.878	0.022	3.203	1.287–7.969	0.012

TWL = total weight loss, HR = hazard ratio, CI = confidence interval, BMI = body mass index, SG = sleeve gastrectomy, RYGB = Roux-en-Y gastric bypass, OSA = obstructive sleep apnea.

Table 4. Correlation between early weight loss at 3 and 6 months and maximum percentage of total weight loss (%TWL)

Variables	Total (prevalence, %)	Max TWL ≥20%	Max TWL <20%	P value
At 3 months (n=471)				<0.001
TWL <10%	21 (4.5%)	9 (42.9%)	12 (57.1%)	
TWL 10–15%	92 (19.5%)	72 (78.3%)	20 (21.7%)	
TWL ≥15%	358 (76.0%)	354 (98.9%)	4 (1.1%)	
At 6 months (n=414)				<0.001
TWL <15%	15 (3.6%)	3 (20.0%)	12 (80.0%)	
TWL ≥15%	399 (96.4%)	384 (96.2%)	15 (3.8%)	

TWL = total weight loss.

TWL of ≥10% at 3 months and a TWL of ≥15% at 6 months, the average max %TWL was 12.6% on average. None of these patients achieved a maximum %TWL of >20% (**Fig. 1**).

A longitudinal %TWL percentile chart was created for the entire cohort, incorporating relevant predictors (age, sex, and the type of procedure) as covariates (**Fig. 2**). The presence of diabetes and baseline BMI were excluded from the model due to their lack of significance in predicting the %TWL. Additionally, variables with substantial missing data or uncertain reliability, such as %TWL at 24 months and the presence of psychological disorders, were excluded from the modelling process. The coefficients for age, sex, and the type of procedure across various quantiles (5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles) are presented in **Table 5**, indicating their respective effects on %TWL at these quantiles. SG demonstrated a significantly lower %TWL compared with RYGB beyond the 25th percentile (**Supplementary Fig. 1**). Age exhibited a negative correlation beyond the 10th percentile, suggesting a decrease in %TWL with increasing age. Male patients consistently showed lower %TWL values compared with female patients at quantiles below the 75th percentile.

DISCUSSION

Researchers have proposed various predictive models for weight loss after bariatric surgery in the previous literature [5,7-11]. The specific outcome measures varied among studies, including final BMI, the percentage of excess weight loss (%EWL), and %TWL, while the common predictors for weight loss outcomes after bariatric surgery included baseline BMI, age, sex, the presence of diabetes or other comorbidities, and the type of surgical procedure performed. Consistent with earlier findings, this study reinforces the positive association of

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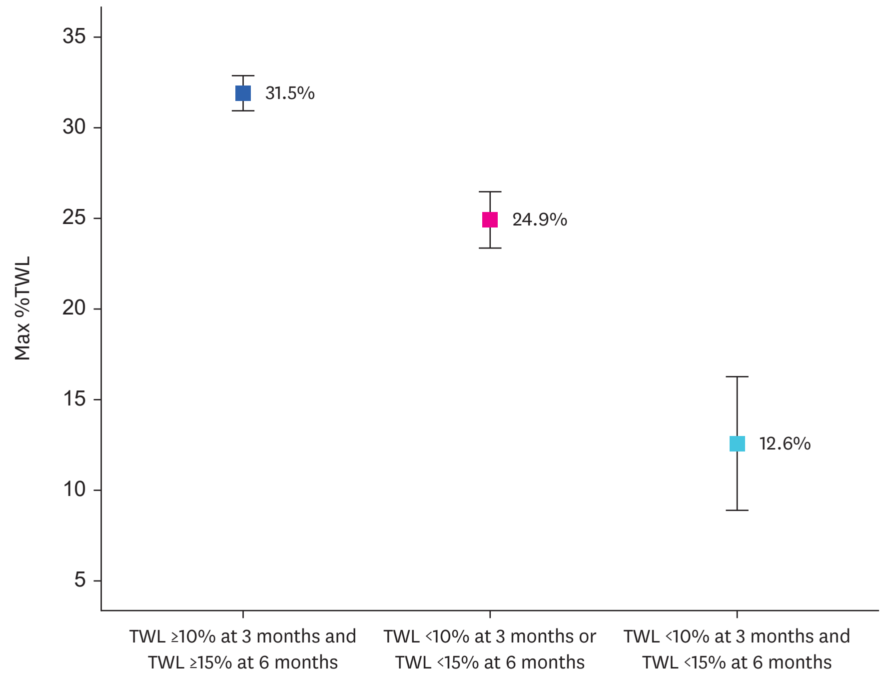
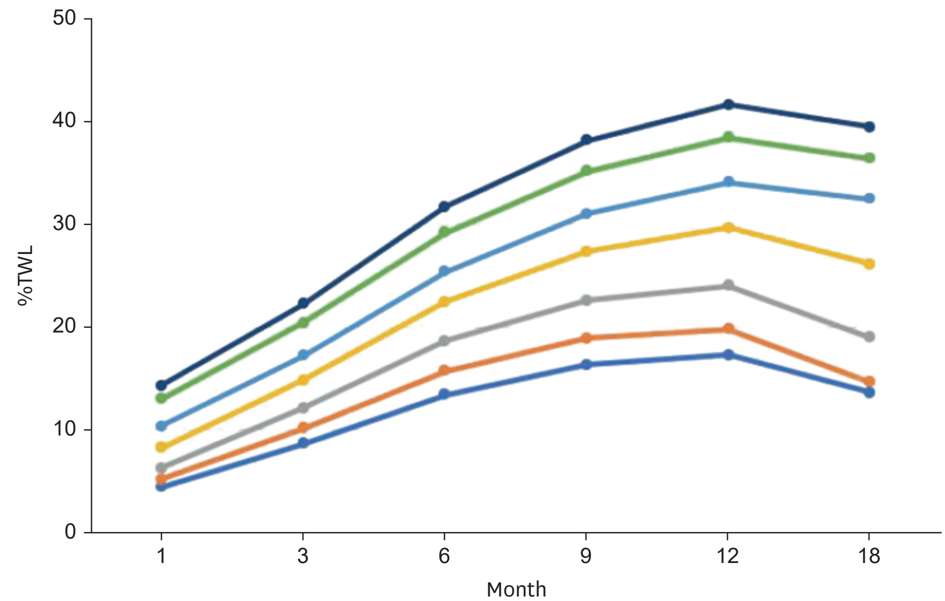


Fig. 1. Maximal percentage of total weight loss (%TWL) at the nadir body mass index in the subgroups classified based on the %TWL at 3 and 6 months. Error bars indicate the 95% confidence intervals.
TWL = total weight loss.

female sex, younger age, higher baseline BMI, and RYGB procedures with achieving a higher max %TWL following bariatric surgery. Notably, this study revealed that female sex and age exhibited the strongest correlation with the %TWL achievable by patients, while baseline BMI and procedure type showed relatively weaker predictability for max %TWL or insufficient weight loss compared with the findings in previous literature. This discrepancy may stem from variations in the targeted predictive metrics or ethnic disparities among Korean patients. Several studies have suggested that ethnicity can influence weight loss outcomes after bariatric surgery, even in Asian populations [12-15]. In particular, the preoperative BMI distribution among Korean patients eligible for bariatric surgery tends to be more evenly spread around a lower average BMI compared with the Western populations, which has predominantly influenced previous prediction models. Additionally, the distinct dietary habits of Korean patients may moderate the effects of different surgical procedures. This potential variability in the response to bariatric surgery across ethnic groups underscores the necessity for tailored prediction models specifically designed for Korean patients.

As previously observed, most previous studies primarily focused on predicting static weight loss outcomes rather than delineating the chronological trajectories of weight reduction throughout the postoperative follow-up period. Although these models are beneficial in forecasting and discussing the final goal, they often fail to identify poor responders early in the postoperative course and provide insights for timely adjunctive interventions to improve overall clinical outcomes in real-world clinical practice. Weight loss observed as early as 3 months postoperatively serves as a reliable predictor of insufficient weight loss, evidenced by a significant gradual increase in the proportion of patients with a max %TWL of <20%, coupled with a lower TWL at 3 months. This predictive capability was further strengthened when supplemented with additional information on %TWL at 6 months. Similar findings were reported in a previous study conducted by Silveira et al., which indicated that the

https://doi.org/10.17476/jmbs.2024.13.1.8



Quantile level						
0.05	4.5	8.7	13.5	16.3	17.3	13.6
0.1	5.2	10.2	15.7	19.0	19.9	14.6
0.25	6.3	12.1	18.7	22.6	24.0	19.0
0.5	8.3	14.8	22.5	27.4	29.7	26.1
0.75	10.4	17.3	25.4	31.0	34.1	32.5
0.9	13.0	20.4	29.2	35.2	38.4	36.4
0.95	14.3	22.3	31.8	38.2	41.6	39.5

Fig. 2. Longitudinal centile curves depicting the percentage of total weight loss (%TWL) up to 18 months after bariatric surgery in Korean patients. The model was generated using age, sex, and the type of procedure as covariates.
TWL = total weight loss.

%TWL values at 1 month and 3 months were highly predictive of achieving a %TWL of >20% at 1 year after RYGB [16]. Varban et al. [17] also demonstrated that significant differences in weight loss trajectories, distinguishing between those who met their 1-year weight loss targets and those who did not, could be identified as early as 2–3 months after surgery, based on temporal achievement [18]. Hence, the prompt identification of individuals showing inadequate weight loss in the early postoperative phase is crucial, necessitating the implementation of adjunctive measures to optimize final weight loss outcomes.

This study presents centile charts of weight loss trajectories using a quantile regression model. It provides an intuitive method of evaluating patients at each postoperative visit and determining whether they are progressing adequately toward achieving sufficient weight loss during early postoperative follow-ups. Moreover, this approach can enhance communication with patients who often seek a relative assessment of their progress. Employing percentile charts in clinical practice can guide patients by establishing realistic and tangible weight loss goals at each visit and motivating them to improve their lifestyle or adhere to adjunctive measures to achieve better weight loss outcomes. The quantile regression model revealed that post-bariatric patients situated within the lower 5th percentile of the %TWL were less influenced by baseline characteristics or the type of procedure undertaken. Conversely, among those exceeding the 25th percentile, representing those with fair or good responses to surgery, the %TWL was significantly influenced by age, sex, and the type of procedure conducted.

Table 5. Quantile regression models for the percentage of total weight loss (%TWL) across various quantiles

Parameter	5th percentile			10th percentile			25th percentile			50th percentile			75th percentile			90th percentile			95th percentile		
	Estimate	SE	P value	Estimate	SE	P value	Estimate	SE	P value	Estimate	SE	P value	Estimate	SE	P value	Estimate	SE	P value	Estimate	SE	P value
Intercept	3.49	0.88	<0.0001	4.95	0.58	<0.0001	6.69	0.48	<0.0001	8.45	0.50	<0.0001	11.33	0.65	<0.0001	14.96	0.90	<0.0001	16.16	1.30	<0.0001
Month	2.53	0.19	<0.0001	3.02	0.10	<0.0001	3.48	0.10	<0.0001	3.88	0.09	<0.0001	4.00	0.12	<0.0001	4.33	0.16	<0.0001	4.66	0.19	<0.0001
Month*month	−0.11	0.01	<0.0001	−0.13	0.01	<0.0001	−0.14	0.01	<0.0001	−0.15	0.01	<0.0001	−0.14	0.01	<0.0001	−0.16	0.01	<0.0001	−0.17	0.01	<0.0001
SG (Ref: RYGB)	0.02	0.46	0.972	−0.38	0.35	0.265	−0.97	0.25	0.000	−1.04	0.25	<0.0001	−1.15	0.33	0.001	−1.16	0.42	0.006	−1.37	0.59	0.020
Age	−0.03	0.02	0.105	−0.05	0.01	<0.0001	−0.06	0.01	<0.0001	−0.06	0.01	<0.0001	−0.08	0.01	<0.0001	−0.11	0.02	<0.0001	−0.11	0.03	0.001
Male (Ref: female)	−1.67	0.39	<0.0001	−1.43	0.33	<0.0001	−1.56	0.26	<0.0001	−1.69	0.27	<0.0001	−1.01	0.37	0.007	−0.68	0.45	0.131	−0.28	0.59	0.632

TWL = total weight loss, SE = standard error, SG = sleeve gastrectomy, RYGB = Roux-en-Y gastric bypass.

However, determining the specific percentile that serves as an appropriate cutoff to define insufficient weight loss or ascertain the need for adjunct treatment, such as behavioral therapy or anti-obesity medications, remains unclear. The definition of insufficient weight loss varied across previous studies. The most commonly used threshold is a %EWL of <50%, while the less frequently adopted threshold is a %TWL of <10–20% at nadir body weight [5,19,20]. The current study observed that the 12–13 percentile at the nadir BMI roughly corresponded to the %EWL of 50% (with reference BMI of 23 in Asians) or %TWL of 20%. Nevertheless, these definitions primarily rely on expert opinions rather than concrete evidence, and the use of centile charts to define insufficient weight loss during a weight reduction process lacks substantial supporting literature. Therefore, a consensus among experts needs to be reached to define and report insufficient weight loss using percentile charts, and further studies should be conducted to refine these thresholds. On rare occasions, some patients may require nutritional support or behavioral therapy for extreme weight loss caused by postoperative anatomic problems or incorrect eating behaviors. This percentile chart is expected not only to identify those with insufficient weight loss but also to detect patients experiencing undesirable extreme weight loss after surgery.

The current study has several limitations. First, this study is retrospective in nature with a relatively high attrition rate of patients and a relatively short follow-up. This may introduce selection bias as only available data were used in the analyses. Ideally, following all patients at every visit would yield a more precise prediction model. However, in actual clinical practice, bariatric patients often become lost to follow-up without prior notification. Considering the reports of previous studies indicating superior weight loss outcomes among patients who adhered to postoperative follow-up visits compared with those who did not, the weight loss prediction model in this study may exhibit bias, showing more favorable outcomes than the actual outcomes observed in the overall patient population. Second, the results may not be generalizable as the data were obtained from only two bariatric centers in Korea. Additionally, it remains unclear whether this model is applicable to patients from other ethnic groups. Hence, further external validation using a larger cohort from Korea and other ethnicities is warranted. Lastly, some patients received adjuvant medications after surgery to enhance weight loss; however, this was not appropriately reflected in the analysis of weight loss outcomes.

CONCLUSION

In conclusion, it is imperative to identify patients with insufficient weight loss in the early postoperative course to optimize weight loss after bariatric surgery, which is eventually associated with the long-term sustained success of the procedure. The percentile charts proposed in this study can aid surgeons and healthcare providers in assessing patients' progress toward weight loss goals and determining the timing of adjunctive intervention in poor responders during the early postoperative follow-up before reaching the nadir body weight.

SUPPLEMENTARY MATERIAL

Supplementary Fig. 1

Respective longitudinal centile curves of percentage of total weight loss (%TWL) up to 18 months following SG and RYGB in Korean patients, with age and sex as covariates.

https://doi.org/10.17476/jmbs.2024.13.1.8

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