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ORIGINAL CONTRIBUTIONS

# Reference Values for Weight Loss During 1 Year After Sleeve Gastrectomy: a Multicenter Retrospective Study in Japan

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## Abstract

**Introduction** This study aimed to provide reference values for the percentage total weight loss during 1 year after laparoscopic sleeve gastrectomy associated with primary response in Japan.

**Methods** This multicenter retrospective study comprised 248 patients with severe obesity who underwent laparoscopic sleeve gastrectomy at five institutions in Japan. A percentage total weight loss < 20% at 1 year was defined as primary non-response. Parsimonious predictive models were developed based on the results of multiple regression analyses. A receiver operating characteristic curve analysis was used to assess the discriminative performance for primary non-response.

**Results** The median age, initial body mass index, and percentage total weight loss at 1 year were 41 years, 41.4 kg/m$^2$, and 30.1%, respectively. There were 28 (11.3%) primary non-responders. For discriminating primary non-responders, the areas under the receiver operating characteristic curve of the parsimonious model and actual percentage of total weight loss at 3 months after laparoscopic sleeve gastrectomy were 0.846 and 0.803, respectively. Cutoffs for the predicted percentage total weight loss using the model and actual value of percentage total weight loss at 3 months attaining 80% sensitivity were 30% and 22%, and those attaining 98% specificity were 22% and 15%, respectively.

**Conclusions** Reference values for the percentage total weight loss at 3 months were obtained using the predictive model and actual value of percentage total weight loss at 3 months. Patients at risk for primary non-response can be determined at 3 months with these values, which can help in considering earlier interventions.

**Keywords** Prediction model · Primary non-responder · Reference value · Sleeve gastrectomy · Weight loss failure

Key Points.
- Predictive model based on %TWL to discriminate primary non-responder was developed.
- Reference values for %TWL at 3 months can be set with the predictive model.
- Reference values for %TWL at 3 months can also be set with the actual %TWL3M.

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## Introduction

Laparoscopic sleeve gastrectomy (LSG) has contributed to the treatment of extreme obesity [1–3], and the number of LSG cases is increasing worldwide [4]. Weight loss after

LSG generally takes approximately 1 to 1.5 years to reach maximum, after which, the body weight (BW) increases slightly or plateaus [5–7]. Therefore, postoperative follow-up is recommended at 1, 3, 6, and 12 months after surgery [8].

Nevertheless, some patients have insufficient weight loss or weight loss failure after LSG (primary non-responders [PNRs]) [9]. There are various definitions of primary non-response [9–14]; the most widely used is the percentage excess weight loss (%EWL) of < 50% at ≥ 1 year after surgery [9–11, 13]. However, the use of %EWL for evaluating the postoperative weight loss effect can be disadvantageous because the %EWL tends to be high in cases with a low body mass index (BMI) [15, 16]. Another definition of primary non-response is the percentage total weight loss (%TWL) of < 20% [14]. Recently, it has been recommended that weight loss outcomes after bariatric surgery should be evaluated by %TWL, as the ideal BW does not need to be determined and %TWL does not tend to be low in cases with a high BMI [15, 16].

The rate of revisional surgery has increased to 7.4% for all bariatric surgeries, including LSG [4]. The incidence of revisional surgery after LSG is reported to be 10.4% at ≥ 3 years after LSG and 22.6% at ≥ 10 years [17]. Postoperative weight loss issues, including primary and secondary non-response (so-called weight regain), are the most common reasons for revisional surgery after LSG [17].

Currently, as a clinical problem, even if clinicians follow up patients at 1, 3, 6, and 12 months after surgery in accordance with the guidelines, there are no reference values for weight loss at < 1 year after surgery [8]. Although there are a few reports on post-LSG weight prediction models [12, 18], none of these is based on %TWL. Therefore, the aim of this multicenter study was to find the reference values for weight loss during 1 year after LSG based on %TWL by developing predictive models in Japan.

## Patients and Methods

This multicenter retrospective study was conducted at five bariatric institutions in Japan, which were certified by the Japanese Society for Treatment of Obesity. Although this study is retrospective, all data, including demographic characteristics, weight metrics, and comorbidities, were prospectively recorded. Data were collected from each institution for analysis. The institutional ethical review boards of each hospital approved the study (approval number of the principal institutional ethical review board: R2017-030). All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee, and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The need for written informed consent was waived because of the retrospective nature of the study.

In total, 248 patients who underwent LSG between January 2011 and December 2015 at the five participating institutions and had complete follow-up weight metric data at 1, 3, 6, and 12 months after LSG were enrolled in this study. The criteria for LSG, based on the guidelines for bariatric surgery in Japan [19, 20], were as follows: patients with primary obesity; aged 18–65 years; and who met any of the following conditions, BMI ≥ 35 kg/m$^2$, BMI ≥ 32 kg/m$^2$ with type 2 diabetes mellitus (T2DM), or BMI ≥ 32 kg/m$^2$ with more than 2 comorbidities other than T2DM. Our surgical method for LSG generally followed global standard techniques [2]: five to seven laparoscopic trocars were placed in the upper abdomen, establishing pneumoperitoneum at 12–15 mmHg. The greater omentum was dissected along the greater curvature of the stomach with an ultrasonic energy device or a vessel sealing device. After mobilizing the fundus and exposing the angle of His, the stomach wall was dissected using a 36–45 Fr. bougie with endoscopic linear staplers. The dissection was started 4–5 cm from the oral side of the pylorus up to 1–1.5 cm on the distal side of the gastroesophageal junction. All patients underwent preoperative and postoperative educational programs conducted by a multidisciplinary bariatric surgical team at each institution.

The data collected prospectively were as follows: preoperative comorbidities, including T2DM, hypertension, dyslipidemia, obstructive sleep apnea syndrome (OSAS), mental disorder (MD), and gastroesophageal reflux disease (GERD); insulin use at time of the first visit; Los Angeles classification of GERD [21] before LSG; and anthropometric measurements immediately before surgery, and at 1, 3, and 6 months, 1 year, and 2 years after LSG. Postoperative weight loss was assessed by %TWL (baseline: BW at the first visit) and %EWL (baseline: BW at the first visit; BMI at the ideal BW: 25 kg/m$^2$), and patients with a %TWL < 20% [14] at 1 year after LSG were defined as PNRs.

Descriptive statistics were used to summarize patient characteristics and clinical outcomes. Categorical data are expressed as numbers (proportion), and numerical data are expressed as means ± standard deviation or medians (interquartile range). The comparison between primary responders and PNRs was performed using a Mann–Whitney *U* or chi-square tests. The relationships among %EWL at 1 year (%EWL1Y), %TWL at 1 year (%TWL1Y), and BMI at the first visit were evaluated by Pearson correlation coefficients. The relationships between %TWL1Y and %TWL at 1 month (%TWL1M), %TWL at 3 months (%TWL3M), and %TWL at 6 months (%TWL6M) were also investigated using Pearson correlation coefficients.

Seven prognostic models for predicting the %TWL1Y were created using multiple regression analyses. Ten preoperative factors, which were previously reported as the factors influencing weight loss or co-morbidities of obesity, were included as independent variables in some models: sex [10], age [10, 11, 22], BMI [11, 22], T2DM [10–12], OSAS [11, 12], MD [14, 23], hypertension, dyslipidemia, and GERD. Insulin use [24] was also included because it is the influencing factor for diabetes remission after LSG and Cramer's $V$ statistic ($V=0.268$) indicated a relatively weak association between insulin use and T2DM. In addition to these factors, weight metrics in the early postoperative period (%TWL1/3/6 M) were included as independent variables in some models. The seven models were as follows: model 1, 10 preoperative factors; model 2, %TWL1M only; model 3, 10 preoperative factors + %TWL1M; model 4, %TWL3M only; model 5,

**Table 1** Patient characteristics and clinical outcomes; comparison between primary responders and primary non-responders

| | Total patients ($N=248$) | Primary responders (%TWL≥20%, $N=220$) | Primary non-responders (%TWL < 20%, $N=28$) | $p$ value |
|---|---|---|---|---|
| Age[a], years | 43 ± 11, 41 (35, 51) | 43 ± 11, 41 (35, 50) | 44 ± 12, 43 (38, 52) | 0.430 |
| Female[b], % | 141 (56.9%) | 125 (56.8%) | 16 (57.1%) | 0.974 |
| Height[a], cm | 165 ± 9, 164 (159, 172) | 165 ± 9, 164 (159, 172) | 164 ± 10, 165 (156, 170) | 0.537 |
| Body weight at the first visit[a], kg | 118 ± 28, 113 (98, 131) | 119 ± 28, 114 (100, 131) | 110 ± 28, 106 (88, 122) | 0.072 |
| BMI at the first visit[a], kg/m$^2$ | 43.1 ± 8.4, 41.4 (37.0, 46.7) | 43.5 ± 8.4, 41.9 (37.3, 46.8) | 40.5 ± 7.8, 38.3 (35.9, 44.0) | 0.031 |
| Body weight before surgery[a], kg | 111 ± 25, 107 (93, 123) | 111 ± 25, 107 (93, 123) | 106 ± 27, 101 (87, 125) | 0.172 |
| BMI before surgery[a], kg/m$^2$ | 40.4 ± 7.3, 39.1 (35.3, 43.9) | 40.6 ± 7.2, 39.6 (35.3, 44.5) | 38.8 ± 7.6, 36.5 (33.3, 42.1) | 0.103 |
| Period from the first visit to LSG[a], months | 4.7 ± 3.9, 3 (2, 6) | 4.8 ± 4.0, 3 (2, 6) | 4.3 ± 2.3, 4 (3, 5) | 0.618 |
| Type 2 diabetes mellitus[b], % | 103 (41.5%) | 90 (40.9%) | 13 (46.4%) | 0.577 |
| Insulin use before LSG[b], % | 12 (4.8%) | 9 (4.3%) | 3 (10.7%) | 0.124 |
| Preoperative HbA1c[a], % | 6.5 ± 1.6, 6.0 (5.7, 6.9) | 6.5 ± 1.6, 6.0 (5.6, 6.9) | 6.6 ± 1.5, 6.0 (5.7, 7.1) | 0.989 |
| Hypertension[b], % | 156 (62.9%) | 138 (62.7%) | 18 (64.3%) | 0.872 |
| Dyslipidemia[b], % | 170 (68.5%) | 152 (69.1%) | 18 (64.3%) | 0.606 |
| OSAS[b], % | 212 (85.8%) | 189 (86.3%) | 23 (82.1%) | 0.552 |
| Joint disorder[b], % | 146 (66.7%) | 132 (67.3%) | 14 (60.9%) | 0.533 |
| Use of walking aid[b], % | 5 (2.0%) | 5 (2.3%) | 0 (0.0%) | 0.420 |
| Mental disorder[b], % | 56 (22.6%) | 47 (21.4%) | 9 (32.1%) | 0.199 |
| GERD LA Classification: Grade N/M/A/B/C/D [b] | 128/69/37/12/0/0 | 111/63/32/12/0/0 | 17/6/5/0/0/0 | 0.447 |
| %EWL at 1 year[a], % | 77.7 ± 30.2, 76.4 (57.1, 92.9) | 82.0 ± 28.5, 78.1 (63.1, 95.3) | 44.1 ± 20.3, 42.7 (32.8, 57.4) | < 0.001 |
| %TWL at 1 month[a], % | 14.8 ± 5.0, 14.1 (11.8, 17.2) | 15.2 ± 5.0, 14.5 (12.0, 17.3) | 12.5 ± 4.3, 11.9 (10.0, 13.7) | 0.002 |
| %TWL at 3 months[a], % | 22.2 ± 5.3, 21.8 (19.0, 25.5) | 22.9 ± 5.0, 22.6 (19.4, 26.0) | 17.0 ± 5.0, 16.7 (14.0, 21.1) | < 0.001 |
| %TWL at 6 months[a], % | 28.0 ± 6.8, 27.8 (23.2,32.6) | 29.2 ± 5.9, 28.8 (25.2,33.0) | 18.3 ± 5.6, 18.2 (14.3,20.2) | < 0.001 |
| %TWL at 1 year[a], % | 30.9 ± 9.0, 30.1 (24.3, 37.6) | 32.8 ± 7.6, 32.0 (26.8, 38.2) | 16.4 ± 3.6, 18.0 (13.9, 19.2) | < 0.001 |
| %TWL < 20%[b], % | 28 (11.3%) | 0 (0%) | 28 (100%) | Not performed |
| %TWL≥20%[b], % | 220 (88.7%) | 220 (100%) | 0 (0%) | Not performed |
| %TWL at 2 years[a], % ($N=230$) | 30.5 ± 11.8, 29.8 (22.2, 37.9) | 32.4 ± 9.2, 31.7 (25.0, 39.3) | 13.5 ± 6.8, 16.7 (9.6, 18.3) | < 0.001 |
| Revisional surgery[b], % | 3 (1.2%) | 1 (0.5%) | 2 (7.1%) | 0.002 |
| Morbidity (CD grade≥3)[b], % | 8 (3.2%) | 7 (3.2%) | 1 (3.6%) | 0.919 |
| Mortality[b], % | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | Not performed |

[a]Values are mean ± standard deviation, median (interquartile range); [b]values are number (%); *%TWL*, percentage total weight loss; *BMI*, body mass index; *LSG*, laparoscopic sleeve gastrectomy; *OSAS*, obstructive sleep apnea syndrome; *GERD*, gastroesophageal reflux disease; *LA Classification*, Los Angeles Classification; *%EWL*, percentage excess weight loss; *CD*, Clavien-Dindo Classification[25]

10 preoperative factors + %TWL3M; model 6, %TWL6M only; and model 7, 10 preoperative factors + %TWL6M.

These models were compared based on the adjusted R-squared, as a goodness-of-fit measure, and the area under the receiver operating characteristic (ROC) curve (AUC) for discriminating PNRs from responders, as a measure of discriminative performance. The most satisfactory model was used to create a parsimonious model. The parsimonious model was the model with the smallest corrected Akaike's information criterion value among models with all possible combinations of the independent variables from the original model.

Finally, the parsimonious model was submitted to a ROC curve analysis to determine appropriate cutoff values for %TWL during 1 year after surgery. Four cutoff values were calculated for predicted %TWL1Y, for discriminating PNRs from responders. Specifically, one based on Youden's index, one attaining 80% sensitivity, one attaining 95% specificity, and one attaining 98% specificity were calculated. In addition, a ROC analysis was performed to determine cutoffs of the actual value of %TWL3M (rather than the predictive value of %TWL1Y).

All statistical analyses were performed using SPSS version 25.0, for Windows (IBM Corp., Armonk, NY, USA). $p < 0.05$ was considered statistically significant.

## Results

Patient characteristics and clinical outcomes are shown in Table 1. The median age, BW, and BMI at the first visit were 41 years, 113 kg, and 41.4 kg/m$^2$, respectively. Median %EWL1Y and %TWL1Y were 76.4% and 30.1%, respectively. There were 28 (11.3%) PNRs: PNRs had significantly lower BMI at the first visit and lower %TWL at each time point than did primary responders (Table 1). Three patients (1.2%) underwent revisional surgery; one was a primary responder and two were PNRs. The intervals between LSG and revisional surgery in these patients were 6.7, 7.2, and 7.3 years, respectively.

The %EWL1Y and %TWL1Y were positively correlated ($r = 0.606$) (Fig. 1a). The %EWL1Y and BMI at the first visit were negatively correlated ($r = -0.516$) (Fig. 1b), while the %TWL1Y and BMI at the first visit were positively correlated ($r = 0.263$) (Fig. 1c). The %TWL after LSG gradually increased over 1 year (Fig. 2a). Positive correlations were found between %TWL1Y and %TWL1/3/6 M, with gradually increasing correlation coefficients ($r = 0.277$/ 0.545/ 0.831, respectively) (Fig. 2b–d).

Fitted multiple regression models 1–7 and AUCs of ROC curves representing performance of the predicted values of each model in discriminating PNRs from responders are shown in Table 2. For models 1–3, the best adjusted $R$-squared was 0.148 and the best AUC was 0.725. The %TWL3M was significant in both 3-month models (models 4 and 5), and sex, BMI, T2DM, MD, and OSAS were significant in model 5. Adjusted $R$-squared of

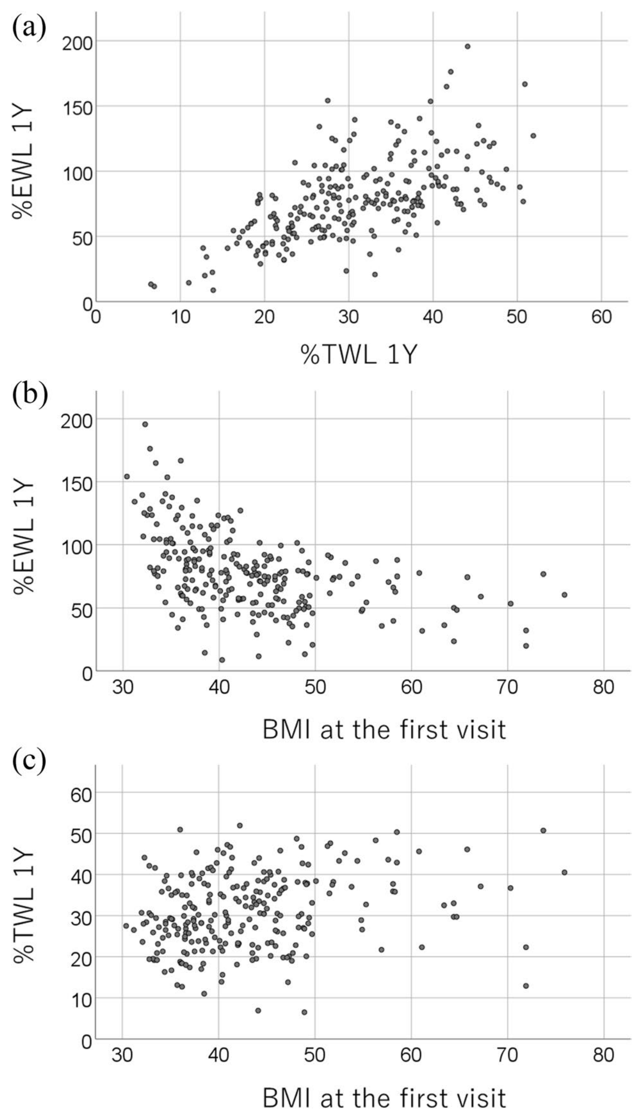



**Fig. 1** **a** Relationship between %TWL1Y and %EWL1Y ($r = 0.606$, 95% CI: 0.521, 0.679). **b** Relationship between BMI at the first visit and %EWL1Y ($r = -0.516$, 95% CI: −0.602, −0.419). **c** Relationship between BMI at the first visit and %TWL1Y ($r = 0.263$, 95% CI: 0.143, 0.375). %TWL 1Y, percentage total weight loss at 1 year; %EWL 1Y, percentage excess weight loss at 1 year; BMI, body mass index; $r$, correlation coefficient; CI, confidence interval

models 4–7 were 0.295, 0.385, 0.690, and 0.718, respectively, and AUCs were 0.803, 0.858, 0.919, and 0.934, respectively.

Models 6 and 7 (models including %TWL6M) had high AUCs, but could not be used until the sixth month. Therefore, model 5, which could be used earlier and had a reasonable discrimination performance, was determined to be the most satisfactory. Thus, model 8 was created as a parsimonious model based on model 5; model 8 included seven independent variables, with adjusted $R$-squared of 0.375 and AUC of 0.846 (Table 2 and Fig. 3a–b). The formula for model 8 is:

$$Y = -2.4 \times Sex + 0.2 \times BMI - 2.5 \times T2DM - 3.2 \times OSAS - 2.0 \times MD - 3.8 \times Insulinuse + 0.9 \times \%TWL3M + 5.8$$

where $Y$ = the predicted %TWL1Y, $Sex$ = 0 for female, 1 for male; $BMI$ = BMI at the first visit in kg/m$^2$; $T2DM$ = 1 if positive, and 0 if negative, for T2DM; $OSAS$ = 1 if positive, and 0 if negative, for OSAS; $MD$ = 1 if positive, and 0 if negative, for a MD; *Insulin use* = 1 if positive and 0 if negative.

The ROC curves of model 8 (7 preoperative factors + %TWL3M) and model 4 (%TWL3M only) are shown in Fig. 3b–c. The AUC of model 4 was inferior, but comparable, to that of model 8 (Table 3). In model 8, the cutoff values of the predicted %TWL1Y were 26% (using Youden's index), 30% (attaining 80% sensitivity), 25% (attaining 95% specificity), and 22% (attaining 98% specificity) (Table 3). The cutoff values of the actual %TWL3M values were 18% (using Youden's index), 22% (attaining 80% sensitivity), 16% (attaining 95% specificity), and 15% (attaining 98% specificity) (Table 3).

## Discussion

Although primary non-response after LSG is known to occur [9, 12], there are currently no reference values to predict PNR in the early postoperative period. In the present study, we identified factors that affect postoperative weight loss and developed a model to predict primary non-response. Using this model, patients at risk for primary non-response can be determined at 3 months after LSG. In addition, the AUC for discriminating PNRs from responders using the actual value of %TWL3M (rather than the predictive value of %TWL1Y) was comparable to that of the parsimonious model at 3 months. Therefore, the actual %TWL3M value may be useful for discriminating PNRs from responders in clinical settings.

Although there are numerous reports on models for predicting weight loss after bariatric surgery [12, 18, 26–28], there are only a few models for predicting weight loss after LSG [12, 18]. For example, Cottam et al. [12] developed a chart that predicts a primary response, defined as an %EWL > 55%, using %EWL at 1 and 3 months. Another study by Cottam et al. [18] developed models that

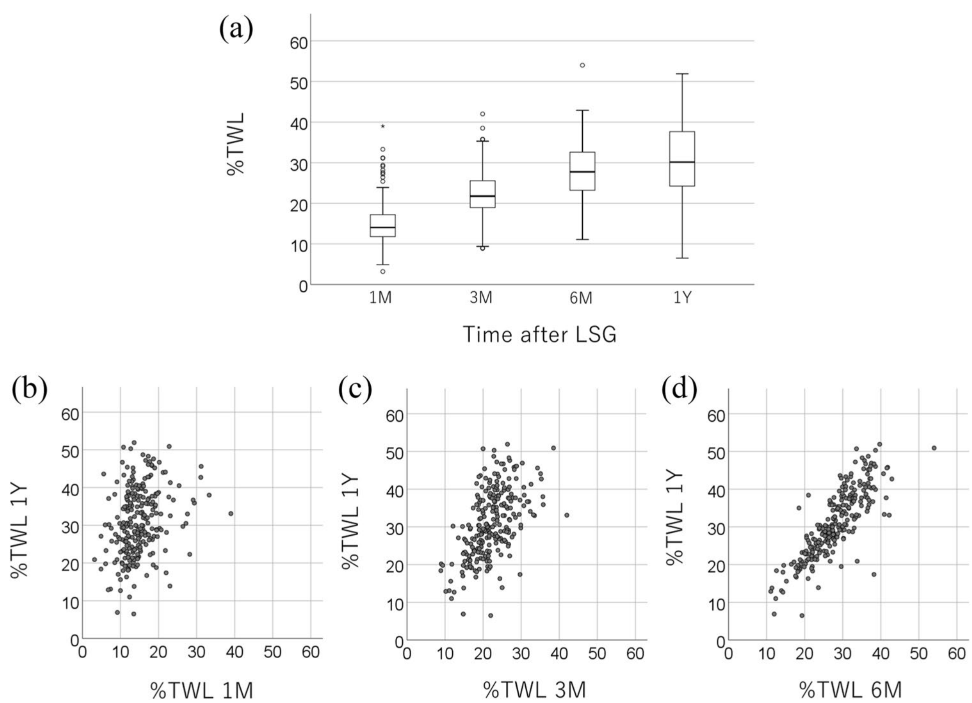



**Fig. 2** **a** Change in the %TWL after LSG. **b** Relationship between %TWL1Y and %TWL1M ($r$ = 0.277, 95% CI: 0.158, 0.389). **c** Relationship between %TWL1Y and %TWL3M ($r$ = 0.545, 95% CI: 0.451, 0.627). **d** Relationship between %TWL1Y and %TWL6M ($r$ = 0.831, 95% CI: 0.789, 0.866). %TWL, percentage total weight loss; 1 M, 1 month; 3 M, 3 months; 6 M, 6 months; 1Y, 1 year; LSG, laparoscopic sleeve gastrectomy; $r$, correlation coefficient; CI, confidence interval

**Table 2** Eight models for predicting primary non-response after LSG

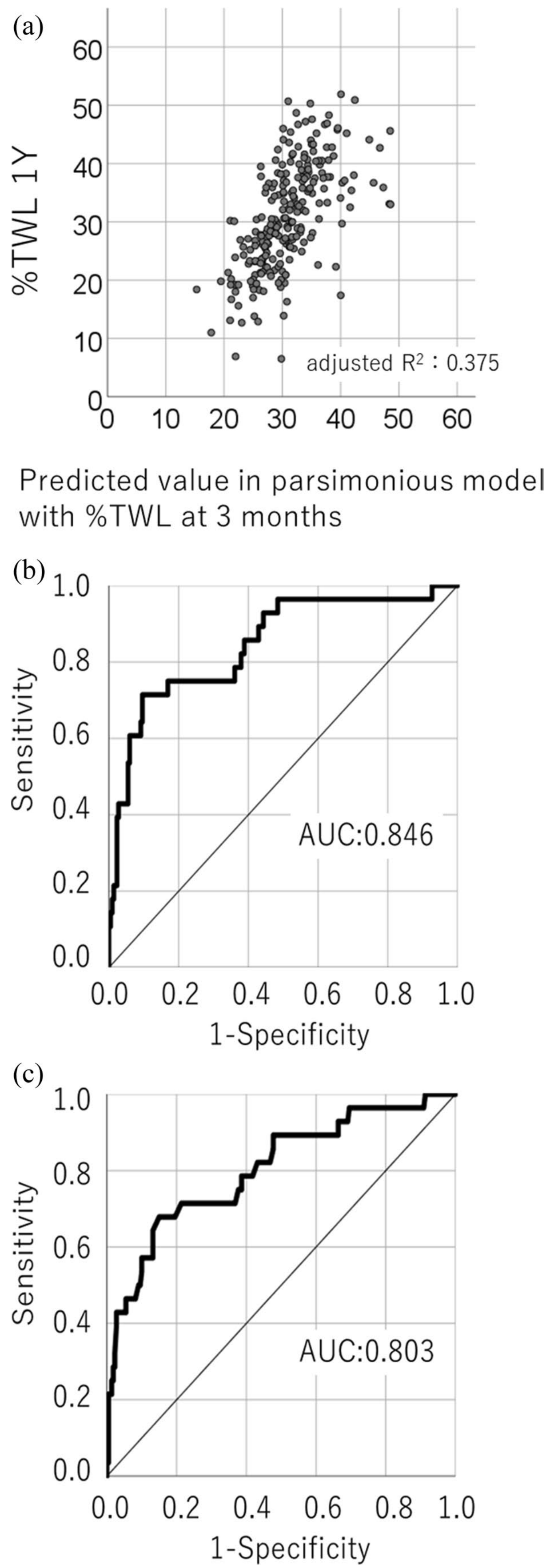
| | | Model 1<br>10 Preop. factors | Model 2<br>%TWL1M | Model 3<br>10 Preop. factors + %TWL1M | Model 4<br>%TWL3M | Model 5<br>10 Preop. factors + %TWL3M | Model 6<br>%TWL6M | Model 7<br>10 Preop. factors + %TWL6M | Model 8<br>Parsimonious model with %TWL3M |
|---|---|---|---|---|---|---|---|---|---|
| Number of cases | | 248 | 248 | 248 | 248 | 248 | 248 | 248 | 248 |
| Number of defects | | 3 | 0 | 3 | 0 | 3 | 0 | 3 | 1 |
| Adjusted $R^2$ | | 0.076 | 0.073 | 0.148 | 0.295 | 0.385 | 0.690 | 0.718 | 0.375 |
| AUC | | 0.646 | 0.679 | 0.725 | 0.803 | 0.858 | 0.919 | 0.934 | 0.846 |
| Intercept | | 23.72 | 23.52 | 20.77 | 10.49 | 6.51 | 0.32 | −2.54 | 5.76 |
| | (95%CI) | (14.59, 32.84) | (20.12, 26.92) | (11.92, 29.62) | (6.44, 14.54) | (−1.56, 14.58) | (−2.33, 2.96) | (−8.06, 2.98) | (−0.03, 11.54) |
| | *p* value | <0.001 | <0.001 | <0.001 | <0.001 | 0.113 | 0.812 | 0.365 | 0.051 |
| Male 1, female 0 | Coefficient | −2.68 | | −3.06 | | −2.96 | | −1.24 | −2.43 |
| | (95%CI) | (−5.13, −0.24) | | (−5.41, −0.71) | | (−4.96, −0.97) | | (−2.59, 0.12) | (−4.34, −0.53) |
| | *p* value | 0.032 | | 0.011 | | 0.004 | | 0.074 | 0.013 |
| Age | Coefficient | −0.06 | | −0.08 | | −0.06 | | −0.01 | |
| | (95%CI) | (−0.18, 0.06) | | (−0.19, 0.04) | | (−0.15, 0.04) | | (−0.08, 0.06) | |
| | *p* value | 0.358 | | 0.190 | | 0.273 | | 0.791 | |
| BMI at the first visit | Coefficient | 0.32 | | 0.25 | | 0.25 | | 0.15 | 0.22 |
| | (95%CI) | (0.17, 0.47) | | (0.10, 0.39) | | (0.12, 0.37) | | (0.07, 0.24) | (0.11, 0.34) |
| | *p* value | <0.001 | | 0.001 | | <0.001 | | 0.001 | <0.001 |
| T2DM | Coefficient | −0.47 | | −1.33 | | −2.23 | | −1.76 | −2.49 |
| (Yes 1, no 0) | (95%CI) | (−2.95, 2.00) | | (−3.74, 1.07) | | (−4.27, −0.19) | | (−3.13, −0.39) | (−4.41, −0.56) |
| | *p* value | 0.706 | | 0.276 | | 0.033 | | 0.012 | 0.012 |
| OSAS | Coefficient | −2.06 | | −2.85 | | −3.08 | | −1.80 | −3.16 |
| (Yes 1, no 0) | (95%CI) | (−5.37, 1.24) | | (−6.04, 0.34) | | (−5.78, −0.38) | | (−3.63, 0.02) | (−5.82, −0.49) |
| | *p* value | 0.220 | | 0.080 | | 0.026 | | 0.053 | 0.021 |
| MD | Coefficient | −2.01 | | −2.55 | | −2.46 | | −1.55 | −1.99 |
| (Yes 1, no 0) | (95%CI) | (−4.78, 0.75) | | (−5.22, 0.12) | | (−4.71, −0.20) | | (−3.07, −0.02) | (−4.18, 0.21) |
| | *p* value | 0.153 | | 0.061 | | 0.033 | | 0.048 | 0.076 |
| Insulin use | Coefficient | −3.52 | | −3.47 | | −3.69 | | −0.89 | −3.76 |
| (Yes 1, no 0) | (95%CI) | (−8.83, 1.79) | | (−8.57, 1.63) | | (−8.03, 0.65) | | (−3.83, 2.06) | (−8.11, 0.60) |
| | *p* value | 0.193 | | 0.181 | | 0.095 | | 0.554 | 0.090 |
| GERD:LA Classification | Coefficient | 0.05 | | 0.25 | | 0.40 | | 0.00 | |
| (N 0, M 1, A 2, B 3, C 4, D 5) | (95%CI) | (−1.23, 1.34) | | (−0.99, 1.48) | | (−0.66, 1.44) | | (−0.71, 0.71) | |
| | *p* value | 0.936 | | 0.696 | | 0.460 | | 0.992 | |
| Hypertension | Coefficient | −1.61 | | −1.02 | | −0.43 | | 0.80 | |

**Table 2** (continued)

| | | Model 1<br>10 Preop. factors | Model 2<br>%TWL1M | Model 3<br>10 Preop. factors + %TWL1M | Model 4<br>%TWL3M | Model 5<br>10 Preop. factors + %TWL3M | Model 6<br>%TWL6M | Model 7<br>10 Preop. factors + %TWL6M | Model 8<br>Parsimonious model with %TWL3M |
|---|---|---|---|---|---|---|---|---|---|
| Number of cases | | 248 | 248 | 248 | 248 | 248 | 248 | 248 | 248 |
| Number of defects | | 3 | 0 | 3 | 0 | 3 | 0 | 3 | 1 |
| Adjusted $R^2$ | | 0.076 | 0.073 | 0.148 | 0.295 | 0.385 | 0.690 | 0.718 | 0.375 |
| AUC | | 0.646 | 0.679 | 0.725 | 0.803 | 0.858 | 0.919 | 0.934 | 0.846 |
| (Yes 1, no 0) | (95%CI) | (−4.26, 1.04) | | (−3.58, 1.54) | | (−2.60, 1.75) | | (−0.68, 2.28) | |
| | *p* value | 0.231 | | 0.433 | | 0.700 | | 0.288 | |
| Dyslipidemia | Coefficient | 1.05 | | 0.81 | | 0.49 | | −0.07 | |
| (Yes 1, no 0) | (95%CI) | (−1.48, 3.57) | | (−1.62, 3.23) | | (−1.57, 2.55) | | (−1.47, 1.33) | |
| | *p* value | 0.415 | | 0.513 | | 0.642 | | 0.922 | |
| %TWL1M | Coefficient | | 0.50 | 0.53 | | | | | |
| | (95%CI) | | (0.28, 0.72) | (0.30, 0.76) | | | | | |
| | *p* value | | <0.001 | <0.001 | | | | | |
| %TWL3M | Coefficient | | | | 0.92 | 0.97 | | | 0.94 |
| | (95%CI) | | | | (0.74, 1.10) | (0.79, 1.14) | | | (0.77, 1.11) |
| | *p* value | | | | <0.001 | <0.001 | | | <0.001 |
| %TWL6M | Coefficient | | | | | | 1.10 | 1.08 | |
| | (95%CI) | | | | | | (1.00, 1.19) | (0.99, 1.17) | |
| | *p* value | | | | | | <0.001 | <0.001 | |

*LSG*, laparoscopic sleeve gastrectomy; *Preop. factors*, preoperative factors; *%TWL*, percentage total weight loss; *AUC*, area under the curve; *CI*, confidence interval; *BMI*, body mass index; *T2DM*, type 2 diabetes mellitus; *OSAS*, obstructive sleep apnea syndrome; *MD*, mental disorder; *GERD*, gastroesophageal reflux disease; *LA Classification*, Los Angeles Classification; *%TWL1M*, %TWL at 1 month; *%TWL3M*, %TWL at 3 months; *%TWL6M*, %TWL at 6 months

**Fig. 3** **a** Relationship between %TWL at 1 year and predicted value in model 8 (parsimonious model with %TWL at 3 months). **b** ROC curve of model 8. **c** ROC curve of model 4, with %TWL at 3 months only. %TWL, percentage total weight loss; Y, year; ROC, receiver operating characteristic; $R.^2$, coefficient of determination; AUC, area under the curve




predicted %EWL and BMI decrease at 1 year after surgery using four preoperative factors (age, BMI, diabetes mellitus, and hypertension). However, these models are based on %EWL, not %TWL. The models developed in the present study used %TWL to predict a primary non-response. To the best of our knowledge, there are no reports on models developed for predicting primary non-response after LSG using %TWL.

In this study, the parsimonious model at 3 months after LSG can determine patients at risk for primary non-response using the optimally set cutoff values. However, we found the actual %TWL3M value predicted %TWL1Y, which was inferior to, but comparable to, the developed model. Actual %TWL3M value has the advantage of easier prediction in clinical settings.

Postoperative weight loss issues are the most common reasons for revisional surgery after LSG [17]. The model created here does not discriminate patients with revisional surgery. It was difficult to create such a model because only three cases underwent revisional surgery in our cohort. However, since PNR can be predicted at 3 months using our model, it is expected that interventions such as strengthening patient education for avoiding revisional surgery or considering revisional surgery can be implemented from an early stage.

The present study has several limitations, including its retrospective nature, lack of validation for the models, and short duration of observation. Therefore, we developed parsimonious models to prevent overfitting in our cohort. However, further studies are needed to validate the models in the longer term. Another limitation was that the study cohort had median preoperative BMI of 41 kg/m$^2$ and therefore this may not have relevance to populations worldwide with higher BMI. A further limitation was the discrepancy between predicted values of the models and actual %TWL values at 1 year. A possible reason for this discrepancy may be that other factors should be included as independent factors in the multiple regression analysis to predict more accurately %TWL1Y, such as psychological factors [14, 23], surgical factors [29], endocrine factors [30], and lifestyle habits [22]. Although the predicted values of the model in the present study deviated from the actual value, the cutoffs were considered useful reference values for predicting primary non-response in the early period after LSG.

**Table 3** Cutoffs for predicted value using parsimonious models, and actual value of %TWL at 3 months

| | Parsimonious model with %TWL at 3 months (model 8) | Actual value of %TWL at 3 months only |
|---|---|---|
| Number of cases | 248 | 248 |
| Number of defects | 1 | 0 |
| AUC | 0.846 | 0.803 |
| Cutoff value (Youden's index) | 26.1 | 18.4 |
| Sensitivity (%) | 71.4 | 67.9 |
| Specificity (%) | 90.4 | 85.0 |
| Number of patients (< cutoff value) (a) | 41 | 52 |
| Number of PNR patients (b) | 20 | 19 |
| (b)/(a) (%) | 48.8 | 36.5 |
| Cutoff value (sensitivity ≥ 80%) | 29.7 | 21.7 |
| Sensitivity (%) | 82.1 | 82.1 |
| Specificity (%) | 62.1 | 56.8 |
| Number of patients (< cutoff value) (a) | 107 | 124 |
| Number of PNR patients (b) | 23 | 23 |
| (b)/(a) (%) | 21.5 | 18.5 |
| Cutoff value (specificity ≥ 95%) | 24.5 | 15.5 |
| Sensitivity (%) | 42.9 | 42.9 |
| Specificity (%) | 95.0 | 95.0 |
| Number of patients (< cutoff value) (a) | 24 | 23 |
| Number of PNR patients (b) | 12 | 12 |
| (b)/(a) (%) | 50.0 | 52.2 |
| Cutoff value (specificity ≥ 98%) | 21.8 | 14.6 |
| Sensitivity (%) | 21.4 | 28.6 |
| Specificity (%) | 98.2 | 98.2 |
| Number of patients (< cutoff value) (a) | 10 | 13 |
| Number of PNR patients (b) | 6 | 8 |
| (b)/(a) (%) | 60.0 | 61.5 |

*%TWL*, percentage total weight loss; *AUC*, area under the curve; *PNR*, primary non-responder

## Conclusions

We developed a predictive model based on %TWL to determine patients at high risk for primary non-response at 1 year after LSG. We found that actual %TWL3M value predicts %TWL1Y comparable to the developed predictive model. Using the model and actual %TWL3M, appropriate reference values for %TWL during 1 year can be set so patients who may be PNRs can be determined at 3 months after LSG, which can aid medical staff and patients in considering medical or intense interventions such as revisional surgery.

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## Declarations

**Conflict of Interest** The authors declare no competing interests.

**Ethics Approval** All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The institutional ethical review board of each institution approved the study (approval number from the ethical review board of the principal institution: R2017-030). The need for written informed consent was waived because of the retrospective nature of the study. The opt-out method for obtaining patient consent was used at each institution.

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