The Relationship between Serum Insulin-Like Growth Factor-1 Levels and Body Composition Changes after Sleeve Gastrectomy

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\textbf{Keywords}
Laparoscopic sleeve gastrectomy · Insulin-like growth factor-1 · Obesity · Body fat · Skeletal muscle

\textbf{Abstract}
\textbf{Introduction:} We previously reported that preoperative serum insulin-like growth factor-1 (IGF-1) is a predictor of total weight loss percentage (%TWL) after laparoscopic sleeve gastrectomy (LSG). IGF-1 may suppress muscle loss after surgery. IGF-1 almost accurately reflects the growth hormone (GH) secretion status, and GH has lipolytic effects. Therefore, IGF-1 may influence both the maintenance of skeletal muscle and the reduction of adipose tissue after LSG. The identification of the relationship between preoperative serum IGF-1 levels and body composition changes after LSG can help in understanding the pathophysiology of obesity. \textbf{Methods:} We retrospectively reviewed 72 patients with obesity who underwent LSG and were followed up for 12 months. We analyzed the relationship between preoperative serum IGF-1 levels and body composition changes after LSG. A multiple regression model was used. \textbf{Results:} LSG led to a significant reduction in body weight. Both body fat mass and skeletal muscle mass decreased after LSG. Preoperative serum IGF-1 levels significantly correlated with %TWL, changes in skeletal muscle mass, and body fat mass after LSG. The multiple regression model showed that preoperative serum IGF-1 levels were related to decreased body fat mass and maintaining skeletal muscle mass after LSG. \textbf{Discussion/Conclusion:} Preoperative IGF-1 measurement helps predict not only successful weight loss but also decreases body fat mass and maintains skeletal muscle mass after LSG.

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\textbf{Introduction}
Laparoscopic sleeve gastrectomy (LSG) is among the most common and effective bariatric surgical procedures and leads to excess weight reductions of 47.2–83.3% one
year after surgery [1–4]. The effect of LSG on body weight (BW) loss is superior to that of lifestyle modification and nonsurgical treatment [5, 6]. Thus, LSG has excellent therapeutic effects against obesity. However, 18.5–46.2% of cases show insufficient weight loss 2 years after LSG [7–9]; therefore, it is important to predict successful weight loss before LSG. Some preoperative clinical parameters, including age, sex, body mass index (BMI), presence of type 2 diabetes, serum triglyceride (TG), and glycated hemoglobin (HbA1c) have been reported as preoperative predictors of weight loss after bariatric surgery [10–14].

We previously reported that low preoperative serum insulin-like growth factor-1 (IGF-1) is related to insufficient weight loss after LSG [15]. IGF-1 is an anabolic hormone that may suppress muscle mass loss after surgery and increase energy expenditure [16, 17]; hence, serum IGF-1 is associated with weight loss after surgery. Further, IGF-1 is a growth hormone (GH)-dependent polypeptide, and circulating GH stimulates its synthesis and secretion from the liver [18]. IGF-1 reflects patient GH secretion status [19], and GH has lipolytic effects [20, 21]. Therefore, serum IGF-1 levels may reflect the lipolytic action of GH. However, it remains unclear whether body composition of skeletal muscle or adipose tissue changes after LSG is associated with preoperative serum IGF-1 levels. Identifying the relationship between preoperative serum IGF-1 levels and body composition changes after LSG can help understand the pathophysiology of obesity. Therefore, this study aimed to investigate the relationship between preoperative serum IGF-1 levels and body composition changes after LSG.

**Materials and Methods**

**Study Design and Participants**

We retrospectively reviewed clinical data obtained between January 2014 and August 2019 at the Toho University Sakura Medical Center (Sakura City, Chiba, Japan) to identify patients treated for primary obesity (BMI of 32.0–34.9 kg/m² with at least 1 obesity-related comorbidity or BMI ≥35 kg/m² at first visit) who underwent LSG at our hospital) were ultimately included. Eighty-one patients underwent LSG during this period; 6 dropped out within 12 months after LSG. Body composition was not measured before and 12 months after LSG were not measured. Some preoperative clinical parameters, including age, sex, body mass index (BMI), presence of type 2 diabetes, serum triglyceride (TG), and glycated hemoglobin (HbA1c) have been reported as preoperative predictors of weight loss after bariatric surgery [10–14].

Within 1 h of blood collection, serum and plasma were separated by centrifuging the specimen at 3,000 rpm for 10 min. Serum was used to measure the levels of HbA1c, AST, ALT, blood urea nitrogen, creatinine, eGFR, lipids, and IGF-1. Serum IGF-1 levels were measured using the ECLusys® reagent IGF-1 assay kit (Roche Diagnostics, Basel, Switzerland). IGF-1 levels were measured at the LSI Medience Corporation (Tokyo, Japan). IGF-1 levels were measured using the cobas® 8000 system (Roche Diagnostics, Basel, Switzerland).

Body composition was measured with direct segmental multifrequency bioelectrical impedance analysis (BIA) using InBody 720 ( Biospace Co., Ltd. Chungcheongnam-do, Republic of Korea). The system separately measured the impedance of the participants’ right arm, left arm, trunk, right leg, and left leg at 6 different frequencies (1, 5, 50, 250, 500, and 1,000 kHz) [22, 23]. Fat mass and skeletal muscle mass were normalized for height (m) squared.

**Statistical Analyses**

Normality of the data distribution was tested using the Shapiro-Wilk test. Continuous data were expressed as median and interquartile range (IQR) because many variables were non-normally distributed. Paired sample data were analyzed using the Wilcoxon signed-rank test. Univariate analysis was performed using Spearman’s rank correlation coefficient, owing to the nonparametric nature of the data. A multivariate analysis was used to analyze independent associations of variables with preoperative serum IGF-1 levels. Covariates were selected to assess the independent contributions of age, sex, and study outcomes (change in normalized fat mass and change in normalized skeletal muscle mass). Existence of type 2 diabetes was also included in the model according to prior published literature [24]. %TWL, change in free fat mass, change in body fat mass, and change in skeletal muscle mass were excluded from the model because of influences of multicollinearity on change in normalized body fat mass and change in normalized skeletal muscle mass. p values <0.05 were considered significant. All statistical analyses were performed using JMP software (version 14.2; SAS Institute, Cary, NC, USA).

**Results**

Table 1 shows patient baseline characteristics and changes in various parameters 12 months after LSG. In total, 59.7% (n = 43) of the patients had type 2 diabetes. Median (IQR) age, BMI, HbA1c, and IGF-1 were 44.0 (37.0–51.8) years, 43.1 (38.1–49.0) kg/m², 6.3% (5.8–6.8%), and 108.5 (81.5–138.8) ng/mL, respectively.
Table 1. Baseline characteristics and change in various parameters 12 months after LSG

|                      | Baseline                  | After 12 months          | p valuea |
|----------------------|---------------------------|--------------------------|----------|
| Participants, n      | 72                        |                          |          |
| Sex (male/female), n (%) | 33 (45.8)/39 (54.2)       |                          |          |
| Type 2 diabetes, %   | 59.7 (43)                 |                          |          |
| %TWL, %              |                           | 29.3 (22.6–35.3)         |          |
| IGF-1, ng/mL         | 108.5 (81.5–138.8)        |                          |          |
| Age, years           | 44.0 (37.0–51.8)          |                          |          |
| BW, kg               | 113.2 (99.3–134.8)        | 79.8 (70.6–98.0)         | <0.0001  |
| BMI, kg/m²           | 43.1 (38.1–49.0)          | 30.6 (26.9–36.1)         | <0.0001  |
| AST, IU/L            | 26.0 (20.0–35.0)          | 18.0 (14.0–21.8)         | <0.0001  |
| ALT, IU/L            | 32.5 (20.0–53.3)          | 14.0 (11.0–22.0)         | <0.0001  |
| BUN, mg/dL           | 13.0 (10.9–16.3)          | 14.2 (10.7–16.8)         | 0.8720   |
| Serum creatinine, mg/dL | 0.67 (0.60–0.81)    | 0.66 (0.56–0.76)         | 0.0016   |
| eGFR, ml/min/1.73 m² | 84.0 (73.5–95.0)          | 86.5 (73.3–103.8)        | 0.0083   |
| TC, mg/dL            | 177.0 (158.5–203.0)       | 191.5 (171.5–213.5)      | 0.0024   |
| TG, mg/dL            | 133.5 (100.3–185.0)       | 89.5 (63.0–123.3)        | <0.0001  |
| HDL-C, mg/dL         | 42.0 (37.0–49.0)          | 62.0 (54.0–74.0)         | <0.0001  |
| LDL-C, mg/dL         | 110.0 (97.0–131.8)        | 105.0 (94.5–127.8)       | 0.0317   |
| FBG, mg/dL           | 105.0 (94.5–120.0)        | 96.5 (90.3–107.8)        | 0.0005   |
| HbA1c, %             | 6.3 (5.8–6.8)             | 5.6 (5.3–5.9)            | <0.0001  |

Data are presented as median and IQR. LSG, laparoscopic sleeve gastrectomy; TWL, total weight loss; IGF-1, insulin-like growth factor-1; BW, body weight; BMI, body mass index; AST, aspartate transaminase; ALT, alanine transaminase; BUN, blood urea nitrogen; eGFR, estimated glomerular filtration rate; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; FBG, fasting blood glucose; HbA1c, glycosylated hemoglobin; IQR, interquartile range. a Wilcoxon signed-rank test.

Table 2. Body composition at baseline and 12 months after LSG

|                      | Baseline                  | After 12 months          | Difference between before and 12 months after LSG | p valuea |
|----------------------|---------------------------|--------------------------|--------------------------------------------------|----------|
| All patients, n = 72 |                           |                          |                                                  |          |
| Free fat mass, kg    | 55.8 (48.6–70.8)          | 51.5 (43.8–65.0)         | −4.1 (−7.2–1.9)                                  | <0.0001  |
| Body fat mass, kg    | 50.3 (42.9–64.7)          | 30.6 (20.5–43.5)         | −21.8 (−29.9 to −15.1)                           | <0.0001  |
| Normalized body fat mass, kg/m² | 19.7 (16.4–24.0)  | 11.5 (7.0–15.8)          | −7.8 (−11.0 to −5.9)                             | <0.0001  |
| Skeletal muscle mass, kg | 52.7 (46.3–67.0)   | 48.4 (41.1–61.4)         | −4.1 (−7.0 to −1.8)                              | <0.0001  |
| Normalized skeletal muscle mass, kg/m² | 20.1 (18.5–23.0)  | 18.6 (16.9–21.6)         | −1.5 (−2.7 to −0.7)                              | <0.0001  |
| Male (n = 33)        |                           |                          |                                                  |          |
| Free fat mass, kg    | 71.1 (63.6–81.6)          | 67.3 (59.3–76.1)         | −3.8 (−7.4 to −1.7)                              | <0.0001  |
| Body fat mass, kg    | 54.5 (42.3–77.0)          | 31.3 (17.4–48.2)         | −25.8 (−36.4 to −16.0)                           | <0.0001  |
| Normalized body fat mass, kg/m² | 20.0 (14.3–26.6)  | 11.2 (6.0–17.1)          | −8.7 (−12.5 to −5.8)                             | <0.0001  |
| Skeletal muscle mass, kg | 67.3 (60.0–77.3)   | 63.8 (56.1–71.8)         | −3.5 (−7.2 to −1.7)                              | <0.0001  |
| Normalized skeletal muscle mass, kg/m² | 23.1 (20.7–24.3)  | 21.7 (19.7–23.1)         | −1.2 (−2.5 to −0.6)                              | <0.0001  |
| Female (n = 39)      |                           |                          |                                                  |          |
| Free fat mass, kg    | 49.7 (44.4–52.7)          | 44.4 (41.7–47.5)         | −4.8 (−7.2 to −1.8)                              | <0.0001  |
| Body fat mass, kg    | 47.8 (42.8–56.3)          | 30.6 (22.1–35.6)         | −17.6 (−26.1 to −14.2)                           | <0.0001  |
| Normalized body fat mass, kg/m² | 19.7 (16.7–22.5)  | 11.5 (8.5–14.7)          | −7.1 (−9.9 to −6.1)                              | <0.0001  |
| Skeletal muscle mass, kg | 46.9 (41.9–49.8)   | 41.7 (39.3–44.6)         | −4.6 (−7.0 to −1.8)                              | <0.0001  |
| Normalized skeletal muscle mass, kg/m² | 18.7 (17.7–20.0)  | 17.0 (16.2–17.6)         | −1.9 (−2.7 to −0.7)                              | <0.0001  |

Data are presented as median and IQR. Normalized fat mass or skeletal muscle mass was estimated as fat mass or skeletal muscle mass/height (m²). LSG, laparoscopic sleeve gastrectomy; IQR, interquartile range. a Wilcoxon signed-rank test.
Twelve months after LSG, the median (IQR) %TWL was 29.3% (22.6–35.3%). BW and BMI values significantly decreased after LSG. TG, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, fasting blood glucose, and HbA1c levels significantly improved after LSG (Table 1). Table 2 shows body composition parameters at baseline and 12 months after LSG. Free fat mass, body fat mass, normalized body fat mass, skeletal muscle mass, and normalized skeletal muscle mass significantly decreased among all, male, and female patients ($p < 0.0001$).

Table 3 shows the correlation between preoperative serum IGF-1 levels and body composition at baseline and 12 months after LSG. We included the existence of type 2 diabetes because a clinical study showed that serum IGF-1 levels are different between obese patients with and without type 2 diabetes [24]. We also included AST and ALT, which may reflect liver fat, in this analysis, because circulating IGF-1 is associated with liver fat [25]. Univariate analysis showed that serum IGF-1 level significantly negatively correlated with age ($p = 0.0491$), sex ($p = 0.0311$), and preoperative normalized body fat mass ($p = 0.0044$). Preoperative serum IGF-1 levels significantly positively correlated with %TWL ($p = 0.0425$), change in free fat mass ($p = 0.0351$), skeletal muscle mass ($p = 0.0331$), and normalized skeletal muscle mass ($p = 0.0168$). Serum IGF-1 levels significantly negatively correlated with changes in body fat mass ($p = 0.0003$).

Table 3. Correlation between the preoperative serum IGF-1 levels and body composition at baseline and 12 months after LSG

|                      | Preoperative IGF-1 | multivariate |
|----------------------|--------------------|--------------|
|                      | univariate         | standardized β | p value |
|                      | ρ                  | p value       | p value |
| Preoperative         |                    |               |         |
| Age, years           | −0.2328            | 0.0491        | −0.2698 | 0.0186 |
| Sex (male; 0, female; 1) | −0.2544          | 0.0311        | −0.0516 | 0.6466 |
| Type 2 diabetes (no; 0, yes; 1) | −0.0600       | 0.6168        | −0.1433 | 0.1826 |
| BW, kg               | −0.0429            | 0.7204        |         |         |
| BMI, kg/m²           | −0.1880            | 0.1137        |         |         |
| AST, IU/L            | 0.0969             | 0.4179        |         |         |
| ALT, IU/L            | 0.1989             | 0.0939        |         |         |
| Free fat mass, kg    | 0.1065             | 0.3732        |         |         |
| Body fat mass, kg    | −0.2197            | 0.0637        |         |         |
| Normalized body fat mass, kg/m² | −0.3321       | 0.0044        |         |         |
| Skeletal muscle mass, kg | 0.0937           | 0.4336        |         |         |
| Normalized skeletal muscle mass, kg/m² | −0.0295       | 0.8055        |         |         |
| Postoperative        |                    |               |         |
| %TWL, %              | 0.2398             | 0.0425        |         |         |
| ΔBW, kg              | −0.1595            | 0.1807        |         |         |
| ΔBMI, kg/m²          | −0.1413            | 0.2366        |         |         |
| ΔAST, IU/L           | −0.0338            | 0.7782        |         |         |
| ΔALT, IU/L           | −0.1072            | 0.3701        |         |         |
| ΔFree fat mass, kg   | 0.2488             | 0.0351        |         |         |
| ΔBody fat mass, kg   | −0.2764            | 0.0187        |         |         |
| ΔNormalized body fat mass, kg/m² | −0.2436        | 0.0392        | −0.2405 | 0.0400 |
| ΔSkeletal muscle mass, kg | 0.2515           | 0.0331        |         |         |
| ΔNormalized skeletal muscle mass, kg/m² | 0.2809           | 0.0168        | 0.4399  | 0.0003 |

Univariate analysis was performed using Spearman’s rank correlation coefficient, owing to the nonparametric nature of a large volume of data. The multivariate analysis model was $r^2 = 0.2753$ and $p = 0.0006$. Δ is the difference between the baseline value and the value after 12 months. Normalized fat mass or skeletal muscle mass was estimated as fat mass or skeletal muscle mass/height (m²). IGF-1, insulin-like growth factor-1; LSG, laparoscopic sleeve gastrectomy; BW, body weight; BMI, body mass index; AST, aspartate transaminase; ALT, alanine transaminase; TWL, total weight loss.
0.0187) and change in normalized body fat mass ($p = 0.0392$) after LSG.

In the multivariate analysis, the change in normalized skeletal muscle mass was a major independent predictor of preoperative serum IGF-1 levels ($p = 0.0003$). Age ($p = 0.0186$) and change in normalized body fat mass ($p = 0.0400$) were also independent predictors of preoperative serum IGF-1 levels. Sex and existence of type 2 diabetes were not independent predictors (Table 3).

We also analyzed the relationship between preoperative serum IGF-1 levels and body composition at baseline and 12 months after LSG in men and women because body composition differs between men and women [26]. There was a significant negative correlation of preoperative serum IGF-1 levels with BMI, body fat mass, normalized body fat mass, and normalized skeletal muscle mass at baseline and a positive correlation with change in free fat mass, skeletal muscle mass, and normalized skeletal muscle after LSG in men (Table 4). On the other hand, although correlation coefficients between body fat mass or normalized body fat mass and preoperative serum IGF-1 levels were about −0.25, there was no significant correlation between preoperative serum IGF-1 levels and body composition changes in women (Table 4).

### Discussion/Conclusion

In this study, LSG led to significant reductions in BW and BMI. LSG also decreased body fat mass, normalized body fat mass, skeletal muscle mass, and normalized skeletal muscle mass significantly. In the univariate analysis,
preoperative serum IGF-1 levels were significantly correlated with preoperative normalized body fat mass, %TWL, changes in body fat mass, normalized body fat mass, skeletal muscle mass, and normalized skeletal muscle mass after LSG. The multiple regression model showed that age, change in normalized body fat mass, and change in normalized skeletal muscle mass were independent predictors of preoperative serum IGF-1 levels, and change in normalized skeletal muscle mass was the major independent predictor. Preoperative serum IGF-1 levels were significantly correlated with change in normalized skeletal muscle mass in male patients; however, they were not significantly correlated with preoperative serum IGF-1 levels and body composition change in female patients.

IGF-1 reflects patient GH secretion status [19]. GH exerts lipolytic action through extracellular signal-regulated kinases and signal transducer and activator of transcription 5-dependent mechanisms to control peroxisome proliferator-activated receptor-γ-mediated transcription of fat-specific protein 27. However, the lipolytic action of GH is direct and not associated with IGF-1 [27–30]. Serum IGF-1 levels were related to decreased body fat mass in this study, suggesting that IGF-1 reflects GH secretion and lipolytic action. Other studies have also shown a relationship between serum or plasma IGF-1 levels and body fat [31–33]. Fat mass is significantly higher [31], and the degree of fat mass change was significantly lower [32] in patients with IGF-1 deficiency or insufficiency than in those with IGF-1 normalcy after laparoscopic adjustable gastric banding. Plasma IGF-1 levels significantly negatively correlated with body fat percentage [33]. The results of previous studies and our study indicate that serum IGF-1 levels reflect the lipolytic effect of GH. Patients with sufficient serum IGF-1 levels are considered to adequately maintain GH secretion.

A previous study showed that serum IGF-1 level was related to preoperative BMI and %TWL after LSG, rather than serum GH [15]. This can be attributed to 3 factors. First, the acute effect of lipolysis by GH is weaker, but its chronic effects are stronger in humans [34]. Second, GH has circadian changes, and a reduced mean 24-h GH secretion value strongly correlates with an increased truncal fat mass [35]. Third, GH peaks after GH-releasing hormone + arginine were found to significantly correlate with the percentage of excess weight loss [28]. GH does not lipolyze immediately and its serum concentration changes easily; therefore, serum IGF-1 levels may be a better marker of body fat than GH.

The multiple regression analysis showed that preoperative serum IGF-1 levels were related to changes in skeletal muscle mass. IGF-1 promotes myoblast proliferation and skeletal muscle growth via the PI3K/Akt signaling pathway [36, 37]. Serum IGF-1 levels are significantly correlated with skeletal muscle mass [38]. In a mouse model, serum IGF-1 maintained skeletal muscle volume by activating Akt, extracellular signal-regulated kinases, Eif4e, and p70S6K [39]. In patients with acromegaly whose serum IGF-1 levels are quite high, skeletal muscle mass is significantly higher than in controls, and it significantly decreases 1 year after pituitary tumor resection [40]. Thus, serum IGF-1 levels are associated with changes in skeletal muscle mass.

Our study showed that preoperative serum IGF-1 levels were correlated with change in skeletal muscle mass after LSG in male patients; however, there was no correlation between preoperative serum IGF-1 levels and change in body composition after LSG in female patients. A clinical study showed that changes in body compositions after GH therapy in GH-deficient adults are different between men and women [41]. Baseline serum IGF-1 levels are related to increase in lean body mass and decrease in body fat in all patients; this was similar to our findings; however, lean body mass and body fat do not change significantly after GH therapy in female patients, despite the significant increase in IGF-1 levels [41]. This study and our study suggest that reactions of GH or/and IGF-1 may be different between men and women, but further study is needed to clarify this suggestion.

We showed that higher preoperative serum IGF-1 levels were significantly correlated with decreasing body fat mass and maintaining skeletal muscle mass after LSG. Age was significantly correlated with preoperative IGF-1 levels in both univariate and multivariate analyses. Although sex was also significantly correlated with IGF-1 levels only in the univariate analysis, age was significantly higher in women than in men. The correlation between IGF-1 levels and sex reflected the difference in age between men and women. Other variants such as BMI, liver enzymes, eGFR, and the existence of type 2 diabetes were not significantly correlated with preoperative serum IGF-1 levels. Therefore, age is an important determinant of preoperative IGF-1 levels. However, age was not significantly correlated with change in normalized body fat mass and normalized skeletal muscle mass after LSG (Δnormalized body fat mass, ρ = 0.2179, p = 0.0660; Δnormalized skeletal muscle mass, ρ = 0.2034, p = 0.0866). Therefore, we considered that there are other determinants of preoperative serum IGF-1 levels. Except for age, we could not identify the other determinants in this study. Furthermore, IGF-1 has an effect on skeletal muscle hypertrophy and reflects the se-
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cretion of GH, which has a lipolytic action, but we did not measure postoperative serum IGF-1 levels in this study. If we measured postoperative serum IGF-1 levels, we would have clarified the effect of IGF-1 on body fat mass and skeletal muscle mass after LSG. Therefore, we considered that we showed 1 cause of a decrease in body fat and maintenance of skeletal muscle mass after LSG.

Body composition is generally measured using dual energy X-ray absorptiometry (DXA) for obese patients in clinical settings. We evaluated body composition by BIA using InBody device in this study. Although InBody is not acceptable for individual estimates of body composition in an obese patient, like DXA, InBody could be used for estimating group body composition (body fat percent and free fat mass) [42]. Furthermore, like DXA, InBody can predict changes in body composition between pre- and post-treatment of energy reduction and exercise [43]. However, InBody shows the systematic bias and proportional bias when estimating fat mass in women and free fat mass in men [44]. We used the same device before and 12 months after LSG. We considered that these biases were similar for both measurements in this study. The reported coefficient of variation of InBody is 1.8% [45]. Thus, we considered that BIA using InBody could be used to evaluate body composition in this study.

This study has some limitations. First, we did not measure IGF-1 levels after LSG. Hormone level measurements, including GH and IGF-1, were performed only at the preoperative stage as it was aimed at the discrimination of secondary obesity. Therefore, we could not evaluate the relationship between changes in body composition and IGF-1 levels after LSG. Second, the physiological decrease in IGF-1 among patients with obesity without GH deficiency usually increases after weight loss or bariatric surgery. In this study, in some participants with lower preoperative IGF-1 levels, IGF-1 levels might not have increased after LSG. However, we did not measure the serum IGF-1 levels 12 months after LSG. Hence, we could not ascertain the degree of change in IGF-1 levels after LSG. Finally, since this was a single-center retrospective study, the sample size was limited. Future studies are needed that include a larger number of patients with obesity, the addition of a control group, and the use of multiple medical centers in Japan and possibly other Asian countries. Despite these limitations, we were able to show that preoperative serum IGF-1 level was associated with maintaining skeletal muscle mass and a decrease in body fat after LSG.

In conclusion, preoperative serum IGF-1 level is related to maintaining skeletal muscle mass and decreasing body fat mass. IGF-1 measurement in the preoperative state helps predict not only successful weight loss but also the maintenance of skeletal muscle mass and a decrease in body fat after LSG.

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Statement of Ethics
This study was performed in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Toho University Sakura Medical Center (approval date: November 28, 2018; approval No. S18061). Although this was a retrospective study, we individually explained the issue of use and release of study data before the operation, and written consent was obtained in each case.

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

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Author Contributions
M.O. contributed to the research concept and design, collection and/or assembly of data, data analysis, and writing of the article. Y.W. contributed to collection and/or assembly of data. T.Y. contributed to collection and/or assembly of data. H.O. contributed to collection and/or assembly of data. S.Y. contributed to collection and/or assembly of data. K.A. contributed to collection and/or assembly of data. S.N. contributed to collection and/or assembly of data. N.K contributed to collection and/or assembly of data. D.N. contributed to collection and/or assembly of data. A.S. contributed to collection and/or assembly of data. T.O. contributed to collection and/or assembly of data. I.T. contributed to data interpretation and critical revision of the manuscript. All authors approved the version to be published.

Data Availability Statement
Data generated and/or analyzed during this research are available from the corresponding author on reasonable request.
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