Acta Med. Okayama, 2025
Vol. 79, No. 1, pp. 9-19

Acta Medica
Okayama

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Original Article

Gastrectomy Causes an Imbalance in the Trunk Muscles

Nanami Ikeya[a,b§], Atsushi Okita[b], Shinsuke Hashida[b], Sumiharu Yamamoto[b], Hirokuni Ikeda[b], Kazunori Tsukuda[b*], and Shinichi Toyooka[a]

[a]*Department of General Thoracic Surgery and Breast and Endocrinological Surgery, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama 700-8558, Japan,*
[b]*Department of Surgery, Okayama City Hospital, Okayama 700-8557, Japan*

Muscle loss negatively affects gastrectomy prognosis. However, muscle loss is recognized as a systemic change, and individual muscle function is often overlooked. We investigated changes in the muscle volume of individual muscles after gastrectomy to identify clues for prognostic factors and optimal rehabilitation programs. Patients who underwent R0 gastrectomy for Stage I gastric cancer at our hospital from 2015 to 2021 were retrospectively selected to minimize the effects of malignancy and chemotherapy. Trunk muscle volume was measured by computed tomography to analyze body composition changes. Statistical analysis was performed to identify risk factors related to body composition changes. We compared the preoperative and 6-month postoperative conditions of 59 patients after gastrectomy. There was no difference in the psoas major muscle, a conventional surrogate marker of sarcopenia. There were significant decreases in the erector spinae ($p = 0.01$) and lateral abdominal ($p = 0.01$) muscles, and a significant increase in the rectus abdominis muscle ($p = 0.02$). No significant correlation was found between these muscle changes and nutritional status. Body composition imbalance may serve as a new indicator of the general condition of patients after gastrectomy. Rehabilitation to correct this imbalance may improve prognosis after gastrectomy.

Key words: sarcopenia, skeletal muscle, gastric cancer, gastrectomy, erector spinae muscle

Gastric cancer is the fifth most diagnosed cancer and the third leading cause of cancer-related death according to global cancer statistics [1]. The primary treatment for non-metastatic gastric cancer is gastrectomy, although it can lead to postoperative muscle catabolism and post-gastrectomy syndrome, resulting in body weight loss (BWL) and skeletal muscle loss (SML) [2, 3]. Preoperative and postoperative SML and BWL have been associated with an increase in postoperative complications in various solid tumors [4-8], including gastric cancer. Furthermore, postoperative SML/BWL has been shown to impact quality of life and cancer prognosis [9, 10]. Therefore, preventing SML/BWL after gastric cancer surgery is crucial to improve gastric cancer prognosis.

The poor prognosis of patients with severe BWL after gastrectomy is thought to be due to poor adherence to adjuvant chemotherapy for advanced gastric cancer [11, 12]. However, it should be noted that gastrectomy itself may worsen prognosis, irrespective of chemotherapy or malignancy. As suggestive evidence, national data in Japan have suggested that more than 20% of older patients die from other diseases within 5 years after gastrectomy, with lower survival rates compared

Received November 24, 2023; accepted October 7, 2024.
*Corresponding author. Phone : +81-86-737-3000; Fax : +81-86-737-3019
E-mail : kazunori_tukuda@okayama-gmc.or.jp (K. Tsukuda)
§Current affiliation: National Hospital Organization Shikoku Cancer Center, Ehime, Japan

Conflict of Interest Disclosures: No potential conflict of interest relevant to this article was reported.

with the expected natural course [13]. From this observation, it can be inferred that gastrectomy might independently increase the risk of other diseases and worsen patient prognosis, independent of malignancy and chemotherapy.

Currently, various interventions, including perioperative nutritional therapy and rehabilitation, are being attempted to suppress SML in patients undergoing gastrectomy, with the expectation of improving gastric cancer prognosis. Several exercise programs have shown promise for suppressing SML in patients with gastric cancer, and several randomized controlled trials on post-gastrectomy rehabilitation exercise programs have been performed [14, 15].

Until now, post-gastrectomy SML has been considered a systemic condition. Therefore, the specific changes and functions of individual muscles have not been investigated. We hypothesized that the impact of gastrectomy on the muscles may differ among individual muscles. If gastrectomy affects individual muscles differently, the imbalance of these muscles could be a novel indicator of the general condition of patients after gastrectomy, and it would be beneficial in developing rehabilitation programs targeting those specific muscles and creating optimal supportive therapies for patients who undergo gastrectomy.

Based on these considerations, we analyzed the changes in trunk muscle mass in patients undergoing gastrectomy while minimizing the effects of malignancy and chemotherapy. Additionally, we examined the relationship between changes in nutritional status after gastrectomy and SML to identify the risk factors associated with these changes.

Materials and Methods

Patient selection. We selected patients with early-stage gastric cancer to evaluate the impact of gastrectomy alone on body composition while excluding the effects of chemotherapy and malignancy. Specifically, patients with pathologically confirmed Stage IA/IB gastric cancer (The Union for International Cancer Control [UICC]/American Joint Committee on Cancer [AJCC] tumor–node–metastasis [TNM] classification, 8th edition) who underwent curative gastrectomy at Okayama City Hospital between August 2015 and March 2021 were selected. Clinical and radiological findings were retrospectively extracted from the patients' medical records. The following exclusion criteria were applied: Eastern Cooperative Oncology Group Performance Status Scale (ECOG-PS) of 3 or 4, a history of other malignant tumors within the past 5 years, gastrectomy for remnant gastric cancer, combined resection of organs other than the gallbladder, administration of adjuvant chemotherapy, and unavailability of computed tomography (CT) images within 2 months before surgery or 5-7 months after surgery. All patients who did not meet these exclusion criteria were included.

Patient characteristics and clinicopathological factors. We compared the preoperative and 6-month postoperative condition of each patient. Data on age, sex, height, body weight, ECOG-PS, age-adjusted Charlson comorbidity index, and surgical approach were collected. Additionally, nutritional parameters, such as body mass index, serum albumin concentration, and prognostic nutritional index (PNI), were recorded. Finally, short-term outcomes, including operation time, blood loss volume, and postoperative hospital stay, were documented.

Body composition analysis. We estimated the skeletal muscle volume of each patient by examining CT images acquired during preoperative staging and postoperative analysis for recurrence evaluation. The CT images were obtained using a CT scanner (SOMATOM Force; Siemens Healthineers, Forchheim, Germany). The skeletal muscle volume was measured using the Volume Analyzer Synapse Vincent 3D analysis system (version 4.6; Fujifilm Medical, Tokyo, Japan).

At the horizontal level of the lower margin of the third lumbar vertebra, we measured the cross-sectional area of each individual skeletal muscle (psoas major, rectus abdominis muscle [RAM], lateral abdominal muscles [LAM], quadratus lumborum, erector spinae muscle [ESM], and multifidus) separately (Fig. 1A). The measurements were performed using manual tracing, referencing past reports [16]. The sum of these individual muscle areas was used to calculate the overall skeletal muscle area (Fig. 1A). The reference range for the skeletal muscle area was −29 to 150 Hounsfield units (HU). To standardize the measurements, we calculated the skeletal muscle index (SMI; cm^2/m^2) by dividing each individual muscle area (cm^2) by the square of the patient's height. For each patient, the percentage change in SMI was calculated, and the mean value was used to assess the change in skeletal muscle mass [17].

We also measured the subcutaneous fat area (refer-

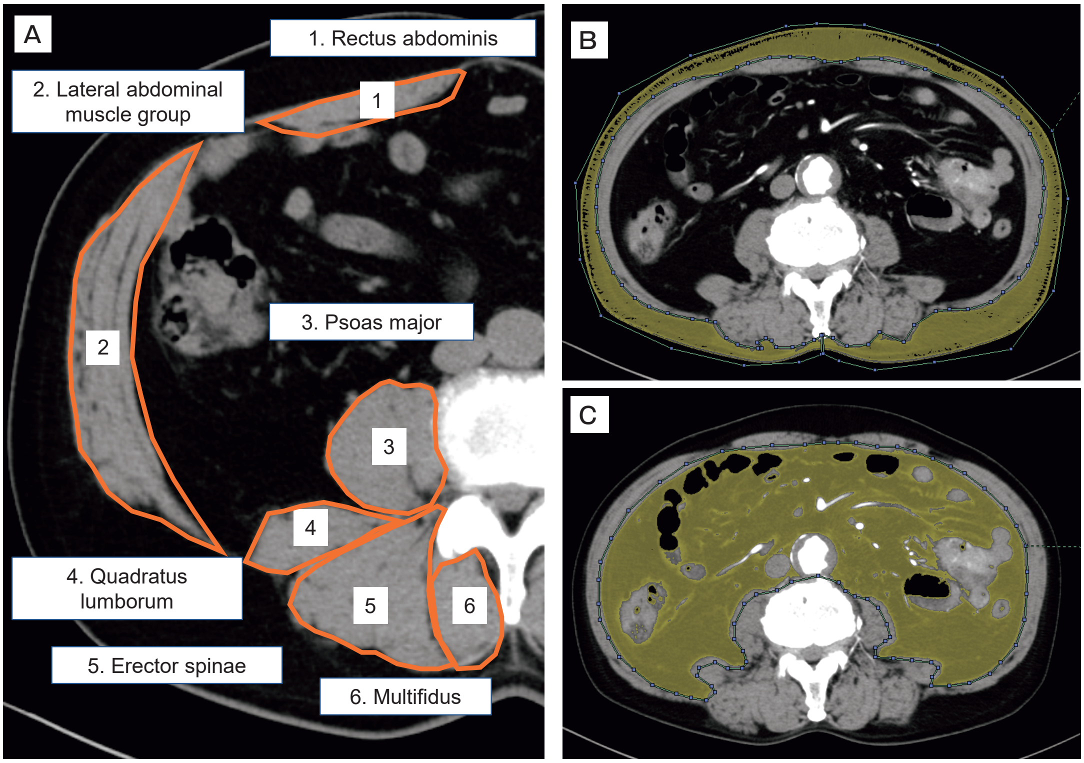

Fig. 1 Representive images of muscle-mass and fat-volume measurement. A, Each muscle is illustrated in the figure. The area of each muscle was measured in Hounsfield units (HU) (reference interval: −29 to 150 HU); B, The yellow shaded area in the figure represents subcutaneous fat (reference interval: −150 to −50 HU); C, The yellow shaded area in the figure represents visceral fat (reference interval: −29 to 150 HU).

ence range: −190 to −30 HU) and visceral fat area (reference range: −150 to −50 HU) and expressed them as indices, namely the subcutaneous fat index (SFI; cm^2/m^2) and visceral fat index (VFI; cm^2/m^2), respectively (Fig. 1B, C). Using these indices, we evaluated the rates of change in subcutaneous and visceral fat [17].

Statistical analysis. The statistical analysis was performed using JMP version 13.0 for Windows (SAS Institute, Cary, NC, USA). The Shapiro–Wilk test was used to assess the normality of the data distribution. For the analysis of paired data, such as changes in nutritional indices and muscle mass at both preoperative and postoperative six-month intervals, we employed the paired t-test for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed variables. A significance level of $p < 0.05$ was considered statistically significant. To investigate factors contributing to changes in muscle mass, we conducted univariate analyses for each factor, considering those with a p-value of < 0.05 as statistically significant. Additionally, in a multivariate analysis, factors with p-values < 0.1 in the univariate analysis were included, along with age and sex, in a multiple linear regression analysis.

Ethical committee approval. This study was performed in accordance with the principles of the Declaration of Helsinki, and the study protocol was approved by the institutional review board of Okayama City Hospital (No. 2-137). The requirement for written informed consent was waived owing to the retrospective observational (non-interventional) nature of the study.

Results

Eligible patients. Figure 2 presents a flow chart of the patient selection. During the study period, a total of 89 patients with pathologically confirmed Stage IA/IB gastric cancer based on the AJCC/UICC TNM classification, 8th edition, underwent curative gastrectomy. However, after applying the exclusion criteria, 30 patients were excluded from the analysis. The reasons for exclusion were as follows: 3 patients underwent gastrectomy for remnant gastric cancer, 9 patients had other malignant diseases, and 1 patient underwent adjuvant chemotherapy. The remaining 17 exclusions were patients who did not undergo CT scans during the specified period. Two of these 17 patients died due to postoperative pneumonia and exacerbation of liver cirrhosis after discharge, respectively. As a result, the final analysis included 59 patients.

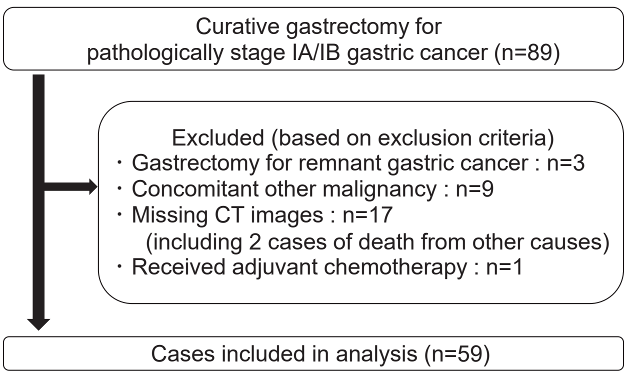

Fig. 2 Flow chart of the patient selection.

The characteristics of the patients are presented in Table 1. The mean age of the patients was 69.6 years, and 35 patients (59%) were male. Fifty-eight of 59 patients (98%) had an ECOG-PS of 0 or 1, indicating a good performance status. The numbers of cases for each extent of gastric resection were as follows: 6 cases of total gastrectomy and 53 cases of partial gastrectomy (including 50 cases of distal gastrectomy and 3 cases of proximal gastrectomy). Laparoscopic surgery was performed in 58 patients (98%), indicating that the majority of patients underwent minimally invasive surgery. Next, postoperative complications were documented according to the Clavien-Dindo Grade (C-D Grade). There were no complications classified as C-D Grade 3b or higher. There were two C-D Grade 3a complications: 1 case of intra-abdominal abscess and 1 case of intestinal obstruction. There were eight C-D Grade 2 complications, including 2 cases of pancreatic fistula, 2 cases requiring blood transfusions due to severe anemia, 1 case of intestinal obstruction, 1 case of gastroesopha-

Table 1 Patients' characteristics

Variables		B-I	R-Y	DFT	All patients (n=59)
Age, years					69.6 ± 8.04*
Male/Female					35/24
BMI, kg/m^{2} †					23.2 ± 3.81*
ECOG-PS †	0/1/2				43/15/1
ASA-PS †	1/2/3				4/41/14
Main tumor location					
U/M/L/U+M/M+L					6/33/15/1/4
Surgical procedure and reconstruction					
Open distal gastrectomy		1	0	−	1
Laparoscopic distal gastrectomy		37	12	−	49
Laparoscopic proximal gastrectomy		−	−	3	3
Laparoscopic total gastrectomy		−	6	−	6
Operation time, min					355 ± 89.1*
Blood loss, mL					119 ± 317*
Morbidity					
C-D Grade ≧3/≧2/≧1					2/10/14
Postoperative hospital stay, days					16 ± 7.0*
Pathological stage IA/IB					51/8

*Mean ± standard deviation.
†Preoperative data.
ASA-PS, American Society of Anesthesiologists Physical Status; B-I, Billroth-I; BMI, body mass index; ECOG-PS, Eastern Cooperative Oncology Group Performance Status Scale; R-Y, Roux-en-Y; DFT, double flap technique; C-D Grade, Clavien-Dindo classification grade.

geal reflux disease, 1 case of pneumonia, and 1 case of skin burn. There were four C-D Grade 1 complications: 1 case of pancreatic fistula, 1 case of pancreatitis, 1 case of dysphagia, and 1 case of delayed healing of the drainage site due to ascitic fluid.

Nutritional parameters. The changes in various nutritional parameters are shown in Table 2. The body weight and BMI declined significantly ($p < 0.01$, respectively). During the study, 90% of the patients experienced BWL, with 43% of the patients losing >10% of their body weight. The remaining 2 patients showed an increase in body weight, and data on weight changes were missing for 3 patients. There were no significant changes in the nutritional indicators measured through blood tests, such as serum albumin concentration and PNI ($p = 0.50$ and 0.78).

Change in body composition. The SMI was calculated based on the CT image data analysis shown in Table 3. The overall SMI, referred to as Total-SMI, tended to decrease after surgery, but the change was not statistically significant (−1.03%, $p = 0.08$). In the following, we present the results of our measurement of the individual muscle indices. The ESM showed a significant decrease (−2.23%, $p = 0.01$), and the LAM also decreased significantly (−3.12%, $p = 0.01$). Conversely, the RAM increased significantly (+9.39%, $p = 0.02$). There was little change in the psoas major muscle (+0.49%, $p = 0.93$). These results indicate that the impact of gastrectomy varies among the different muscles. Figure 3 visually represents these results through

Table 2 Nutritional parameters

	Before surgery	6 Months after surgery	*P*-value
Body weight, kg	58.6 ± 11.8	53.4 ± 11.6	<0.01*
BMI, kg/m^2	23.2 ± 3.8	21.2 ± 3.76	<0.01*
Serum albumin, mg/dL	4.0 ± 0.5	4.0 ± 0.4	0.50
PNI	48.4 ± 6.08	48.7 ± 5.6	0.78

Values are presented as the mean ± standard deviation.
BMI, body mass index; PNI, prognostic nutritional index.
The paired *t*-test was conducted for body weight and PNI, while the Wilcoxon signed-rank test was performed for BMI and serum albumin. Mark * on items with statistical significance.

Table 3 SMI at various points and fat index

	Index, cm^2/height^2			
	Before surgery	6 Months after surgery	Change (%)	*P*-value
Total muscles	43.5 ± 8.56	42.7 ± 7.52	−1.03	0.08
Psoas major	5.70 ± 1.56	5.70 ± 1.57	0.49	0.93
Rectus abdominis	3.27 ± 1.08	3.43 ± 0.98	9.39	0.02*
Lateral abdominal	15.7 ± 3.34	15.2 ± 3.15	−3.12	0.01*
Quadratus lumborum	3.06 ± 1.07	2.99 ± 0.90	0.76	0.24
Erector spinae	11.8 ± 2.65	11.4 ± 2.31	−2.23	0.01*
Multifidus	3.91 ± 1.13	4.04 ± 1.06	5.95	0.19
Total fat	98.5 ± 44.4	59.1 ± 40.8	−40	<0.01*
Subcutaneous fat	43.3 ± 17.6	28.0 ± 17.4	−35.3	<0.01*
Visceral fat	55.2 ± 32.9	31.0 ± 25.2	−43.8	<0.01*

The indices are presented as the mean ± standard deviation.
SMI, skeletal muscle index.
For total muscles, psoas major, rectus abdominis, lateral abdominal, quadratus lumborum, erector spinae, and multifidus, the paired *t*-test was conducted. For total fat, subcutaneous fat, and visceral fat, the Wilcoxon signed-rank test was performed. Mark * on items with statistical significance.

bar graphs. Additionally, with regard to changes in adipose tissue, both the SFI and VFI declined significantly, with decreases of −35.3% ($p<0.01$) and −43.8% ($p<0.01$), respectively, as shown in Table 3. We also investigated the factors contributing to the decrease in Total-SMI, including preoperative nutritional indices and their changes (Table 4). In the univariate analysis, being male ($p=0.03$), having a high serum albumin level ($p=0.03$), a high PNI ($p=0.01$), or a high preoperative Total-SMI ($p<0.01$), and the presence of postoperative complications of C-D Grade 2 or higher ($p=0.04$) were found to be significantly associated with a decrease in Total-SMI. We conducted a multiple linear regression analysis by including age as an additional variable alongside the significant factors identified in the univariate analysis. Although not statistically signifi-

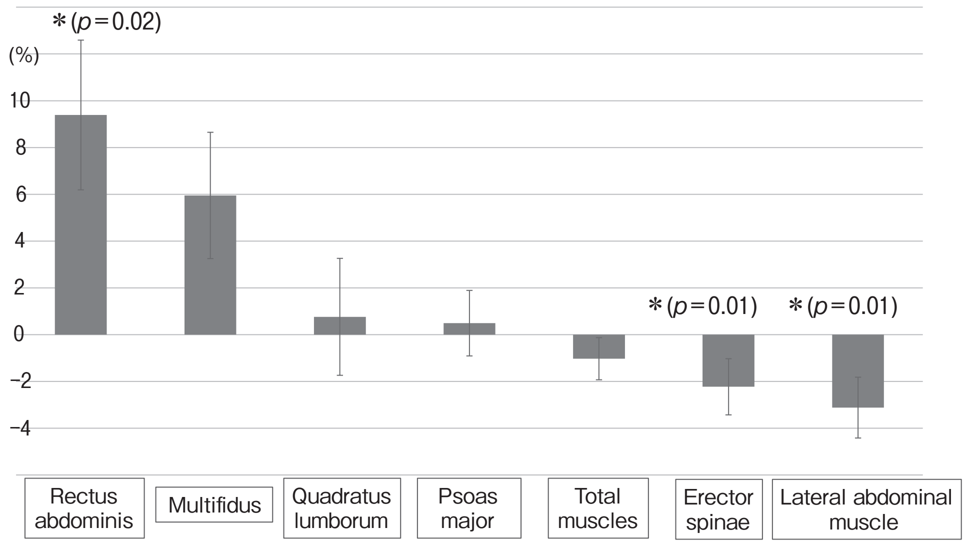

Fig. 3 Changes in skeletal muscle index. The values on the vertical axis and the error bars indicate the mean and standard error values.

Table 4 Simple and multiple linear regression analysis for predicting changes in total muscles

	Simple linear regression analysis					Multiple linear regression analysis				
	B	SE B	95% CI	β	*P*-value	B	SE B	95% CI	β	*P*-value
Age	0.19	0.11	−0.04 to 0.42	0.21	0.10	0.14	0.11	−0.08 to 0.35	0.15	0.21
Sex [female]	1.98	0.91	0.16 to 3.79	0.28	0.03	0.54	1.11	−1.69 to 2.76	0.07	0.63
BW	−0.12	0.08	−0.28 to 0.03	−0.21	0.10					
BMI	0.45	0.33	−0.21 to 1.10	0.18	0.17					
albumin	−4.05	1.86	−7.77 to −0.33	−0.28	0.03	0.80	3.93	−7.10 to 8.70	0.05	0.84
PNI	−0.40	0.15	−0.70 to −0.10	−0.34	0.01	−0.20	0.33	−0.86 to 0.46	−0.17	0.55
Total-SMI	−0.39	0.10	−0.58 to −0.20	−0.48	<0.01	−0.27	0.14	−0.56 to 0.01	−0.32	0.06
SFI	0.05	0.05	−0.06 to 0.15	0.12	0.39					
VFI	−0.01	0.03	−0.06 to 0.05	−0.04	0.79					
TFI	0.00	0.02	−0.04 to 0.05	0.02	0.88					
Procedure [DG/PG]	0.84	1.53	−2.22 to 3.91	0.07	0.58					
C-D Grade ≧ 1	2.12	1.05	0.02 to 4.23	0.26	0.05	1.10	1.67	−2.26 to 4.47	0.13	0.51
C-D Grade ≧ 2	2.52	1.19	0.14 to 4.90	0.27	0.04	1.46	1.91	−2.38 to 5.30	0.15	0.45
C-D Grade ≧ 3	2.67	2.54	−2.42 to 7.75	0.14	0.30					
IAIC	1.95	1.83	−1.71 to 5.61	0.14	0.29					

BW, body weight; BMI, body mass index; PNI, prognostic nutritional index; Total-SMI, total skeletal muscle index; SFI, subcutaneous fat index; VFI, visceral fat index; TFI, total fat index; Procedure [DG/PG], Surgical procedures [distal gastrectomy or proximal gastrectomy] for total gastrectomy; C-D Grade, Clavien-Dindo classification grade; IAIC, intra-abdominal infectious complications which includes anastomotic leakage, pancreatic fistula, and intra-abdominal abscess.
B, partial regression coefficient; SE B, standard error of partial regression coefficient; 95%CI, 95% Confidence Interval; β, standardized partial regression coefficient.

cant, a trend was observed indicating an association between the decrease in Total-SMI and preoperative Total-SMI ($p = 0.06$). This outcome suggests that patients with higher preoperative muscle mass experienced a more pronounced rate of decrease.

We also explored the factors contributing to the significant changes observed in individual muscles. Regarding the decrease in ESM (Table 5), univariate analysis revealed a significant association with both Total-SMI ($p = 0.03$) and SFI ($p = 0.02$), and in the multivariate regression analysis, low SFI ($p = 0.02$) was identified as a contributing factor to the decrease in ESM. In the analysis of LAM decrease (Table 6), univariate analysis showed associations with Total-SMI ($p = 0.04$), C-D Grade 1 or higher ($p < 0.01$), C-D Grade 2 or higher ($p < 0.01$), and the presence of intra-abdom-

Table 5 Simple and multiple linear regression analysis for predicting changes in erector spinae muscle

	Univariate linear regression analysis					Multiple linear regression analysis				
	B	SE B	95% CI	β	*P*-value	B	SE B	95% CI	β	*P*-value
Age	−0.03	0.16	−0.35 to 0.28	−0.03	0.84	−0.12	0.15	−0.42 to 0.18	−0.10	0.43
Sex [female]	2.05	1.25	−0.45 to 4.56	0.21	0.11	−1.16	1.68	−4.53 to 2.21	−0.12	0.49
BW	−0.02	0.11	−0.23 to 0.20	−0.02	0.86					
BMI	0.45	0.33	−0.21 to 1.10	0.18	0.17					
albumin	−4.86	2.54	−9.95 to 0.23	−0.25	0.06	−1.82	2.71	−7.26 to 3.62	−0.09	0.51
PNI	−0.31	0.21	−0.74 to 0.12	−0.19	0.15					
Total-SMI	−0.32	0.14	−0.61 to −0.04	−0.29	0.03	−0.39	0.20	−0.79 to 0.01	−0.34	0.06
SFI	0.17	0.07	0.03 to 0.31	0.31	0.02	0.19	0.08	0.04 to 0.34	0.34	0.02
VFI	0.02	0.04	−0.05 to 0.10	0.08	0.55					
TFI	0.04	0.03	−0.02 to 0.10	0.18	0.17					
Procedure [DG/PG]	−2.41	2.06	−6.52 to 1.71	−0.15	0.25					
C-D Grade ≧ 1	0.84	1.47	−2.11 to 3.79	0.08	0.57					
C-D Grade ≧ 2	−0.45	1.67	−3.81 to 2.90	−0.04	0.79					
C-D Grade ≧ 3	0.90	3.47	−6.06 to 7.85	0.03	0.79					
IAIC	−3.12	2.47	−8.05 to 1.82	−0.17	0.21					

BW, body weight; BMI, body mass index; PNI, prognostic nutritional index; Total-SMI, total skeletal muscle index; SFI, subcutaneous fat index; VFI, visceral fat index; TFI, total fat index; Procedure [DG/PG], Surgical procedures [distal gastrectomy or proximal gastrectomy] for total gastrectomy; C-D Grade, Clavien-Dindo classification grade; IAIC, intra-abdominal infectious complications which includes anastomotic leakage, pancreatic fistula, and intra-abdominal abscess.
B, partial regression coefficient; SE B, standard error of partial regression coefficient; 95%CI, 95% Confidence Interval; β, standardized partial regression coefficient.

Table 6 Simple and multiple linear regression analysis for predicting changes in lateral abdominal muscle group

	Univariate linear regression analysis					Multiple linear regression analysis				
	B	SE B	95% CI	β	*P*-value	B	SE B	95% CI	β	*P*-value
Age	0.25	0.16	−0.06 to 0.56	0.21	0.11	0.13	0.14	−0.16 to 0.42	0.10	0.39
Sex [female]	0.34	1.29	−2.25 to 2.92	0.03	0.80	−1.09	1.50	−4.09 to 1.92	−0.11	0.47
BW	−0.13	0.11	−0.35 to 0.08	−0.16	0.21					
BMI	−0.31	0.33	−0.97 to 0.36	−0.12	0.36					
albumin	−1.50	2.64	−6.78 to 3.79	−0.07	0.57					
PNI	−0.26	0.22	−0.67 to 0.18	−0.16	0.24					
Total-SMI	−0.30	0.14	−0.59 to −0.02	−0.27	0.04	−0.37	0.17	−0.71 to −0.02	−0.32	0.04
SFI	−0.04	0.07	−0.18 to 0.11	−0.07	0.62					
VFI	−0.01	0.04	−0.09 to 0.07	−0.03	0.82					
TFI	−0.01	0.03	−0.07 to 0.05	−0.05	0.72					
Procedure [DG/PG]	2.88	2.06	−1.26 to 7.01	0.18	0.17					
C-D Grade ≧ 1	4.39	1.37	1.64 to 7.14	0.39	<0.01	0.15	2.36	−4.59 to 4.89	0.01	0.95
C-D Grade ≧ 2	5.72	1.51	2.70 to 8.75	0.45	<0.01	4.08	2.67	−1.28 to 9.43	0.32	0.13
C-D Grade ≧ 3	6.55	3.40	−0.25 to 13.4	0.25	0.06	1.36	3.49	−5.64 to 8.36	0.05	0.70
IAIC	5.65	2.41	0.82 to 10.5	0.30	0.02	2.54	2.59	−2.66 to 7.74	0.13	0.33

BW, body weight; BMI, body mass index; PNI, prognostic nutritional index; Total-SMI, total skeletal muscle index; SFI, subcutaneous fat index; VFI, visceral fat index; TFI, total fat index; Procedure [DG/PG], Surgical procedures [distal gastrectomy or proximal gastrectomy] for total gastrectomy; C-D Grade, Clavien-Dindo classification grade; IAIC, intra-abdominal infectious complications which includes anastomotic leakage, pancreatic fistula, and intra-abdominal abscess.
B, partial regression coefficient; SE B, standard error of partial regression coefficient; 95%CI, 95% Confidence Interval; β, standardized partial regression coefficient.

inal infectious complications ($p=0.02$). However, in the multivariate regression analysis, only Total-SMI was found to be significantly associated with a decrease in LAM ($p=0.04$). Finally, the factors contributing to the increase in RAM were as follows (Table 7). In univariate analysis, multiple factors were identified, including older age ($p<0.01$), lower albumin levels ($p<0.01$), lower PNI ($p<0.01$), and lower Total-SMI ($p<0.01$). However, in the multivariate regression analysis, only age remained a significant factor ($p<0.01$).

Discussion

In this study, we investigated the impact of gastrectomy alone on the volume changes of various trunk muscles. To achieve this, we evaluated the data of patients with early-stage gastric cancer who did not undergo adjuvant therapy. The study included mostly patients who underwent laparoscopic surgery (98%), thereby minimizing the impact of surgical invasion due to abdominal wall damage or organ exposure.

The measurement of muscle volume was conducted at two time points: preoperatively and at 6 months postoperatively. The peak BWL is typically observed between 6 and 12 months after surgery, whereas the peak SML is believed to occur earlier [18]. In the early postoperative period, metabolic changes related to postoperative inflammation and nutritional deficits result in a greater loss of muscle mass compared to fat tissue. However, from 1 week to 1 month after surgery, the decrease in fat tissue exceeds SML [2]. Nonetheless, it has been reported that SML persists until 3-6 months after surgery [19]. Therefore, the testing period (6 months after gastrectomy) was considered to be both the peak of BWL and the late phase of SML. This is expected to be the time when the differences in body composition are most significant and thus most suitable for detecting changes.

As a result, while fat mass was significantly decreased with gastrectomy alone, the reduction in muscle mass was not significant. Moreover, preoperative nutritional indices and the decline in nutritional indices at 6 months after surgery did not emerge as predictors of muscle mass reduction. However, a closer examination of individual muscle masses revealed a decrease in ESM/LAM and an increase in RAM.

In previous studies, including those involving advanced cancer, a correlation has been observed between nutritional indices and sarcopenia [20]. Therefore, we hypothesized that these nutritional indices would serve as predictors of skeletal muscle loss (SML) even in the context of gastric resection alone. To test this hypothesis, we evaluated several nutritional indicators (body weight, BMI, albumin, and PNI). However, contrary to our expectations, there were no significant declines in these indicators at 6 months after

Table 7 Simple and multiple linear regression analysis for predicting changes in rectus abdominis

	Univariate linear regression analysis					Multiple linear regression analysis				
	B	SE B	95% CI	β	P-value	B	SE B	95% CI	β	P-value
Age	1.26	0.37	0.51 to 2.01	0.41	<0.01	1.08	0.36	0.36 to 1.81	0.34	<0.01
Sex [female]	5.20	3.25	−1.31 to 11.7	0.21	0.12	1.90	3.68	−5.49 to 9.29	0.07	0.61
BW	−0.34	0.28	−0.89 to 0.21	−0.16	0.22					
BMI	−0.11	0.86	−1.84 to 1.62	−0.02	0.90					
albumin	−23.3	6.07	−35.5 to −11.2	−0.45	<0.01	−21.9	13.3	−48.7 to 4.86	−0.43	0.11
PNI	−1.73	0.52	−2.77 to−0.69	−0.41	<0.01	0.43	1.11	−1.81 to 2.66	0.10	0.70
Total-SMI	−0.10	0.36	−1.72 to −0.27	−0.34	<0.01	−0.47	0.47	−1.42 to 0.47	−0.16	0.32
SFI	0.23	0.18	−0.14 to 0.60	0.17	0.21					
VFI	−0.03	0.10	−0.23 to 0.17	−0.04	0.74					
TFI	0.02	0.07	−0.13 to 0.17	0.03	0.81					
Procedure [DG/PG]	−1.96	5.40	−12.8 to 8.84	−0.05	0.72					
C-D Grade ≧ 1	5.47	3.77	−2.07 to 13.0	0.19	0.15					
C-D Grade ≧ 2	5.63	4.29	−2.95 to 14.2	0.17	0.19					
C-D Grade ≧ 3	1.86	9.02	−16.2 to 19.9	0.03	0.84					
IAIC	5.85	6.45	−7.07 to 18.8	0.12	0.37					

BW, body weight; BMI, body mass index; PNI, prognostic nutritional index; Total-SMI, total skeletal muscle index; SFI, subcutaneous fat index; VFI, visceral fat index; TFI, total fat index; Procedure [DG/PG], Surgical procedures [distal gastrectomy or proximal gastrectomy] for total gastrectomy; C-D Grade, Clavien-Dindo classification grade; IAIC, intra-abdominal infectious complications which includes anastomotic leakage, pancreatic fistula, and intra-abdominal abscess.
B, partial regression coefficient; SE B, standard error of partial regression coefficient; 95%CI, 95% Confidence Interval; β, standardized partial regression coefficient.

gastrectomy. We considered that the impact of gastric resection alone was not sufficient to worsen these nutritional indices at the 6-month postoperative time point. Furthermore, preoperative nutritional indices and the changes in these indices did not exhibit any significant correlation with the degree of SML or alterations in trunk muscle composition. This suggests that factors beyond nutritional status may play a role in SML following gastrectomy. Potential contributors may include postoperative inflammation, hormonal changes, rehabilitation efforts, and other factors [21-23]. Therefore, assessing the impact of gastrectomy solely based on parameters such as albumin or PNI might be challenging, indicating the need for additional evaluation criteria. Although the multivariate analysis did not identify any significant risk factors for postoperative SML, there was a tendency for a higher preoperative Total-SMI to contribute to a reduction in Total-SMI ($p = 0.06$, Table 4). It appears challenging to avoid muscle loss following gastrectomy regardless of preoperative total muscle mass. Rather, cases with higher preoperative Total-SMI may require a higher energy intake to maintain basal metabolism and muscle mass, and a decrease in caloric intake due to gastrectomy may lead to a reduction in muscle mass.

The analysis of individual muscle volume changes revealed that there was little change in the area of the psoas major muscle. The psoas major muscle has been widely used as a surrogate marker for sarcopenia, reflecting overall muscle mass in previous studies [17, 24]. However, our results indicate that the methods that have been used to evaluate sarcopenia in the past cannot assess the physical impact caused solely by gastrectomy. In the present study, no significant change was observed in the psoas major muscle, while there was a significant decrease in the LAM and the ESM. In contrast, the RAM showed an increase. The lack of a change in the psoas major as a surrogate marker and the significant changes in other individual muscles provide novel insights for the evaluation of the effects of gastrectomy and, consequently, the invasiveness of other surgical procedures with novel evaluation methods.

In this study, a significant decrease in the volumes of the LAM and ESM was observed after gastrectomy. The LAM and ESM are involved in respiratory function, and weakening of these respiratory muscles can lead to respiratory disability, especially during exhalation, which has been found to be associated with the prognosis of patients with pneumonia [25-28]. There have also been reports of long-term pneumonia after gastrectomy being associated with a worsened prognosis in patients with gastric cancer [29]. From these points, it is anticipated that the decrease in the ESM may worsen the prognosis of patients after gastrectomy.

The observation that the RAM volume increased is intriguing. The exact reasons for the increase in RAM volume are not clear, but it may be related to conditions such as kyphosis posture due to osteoporosis, surgical site pain, or organ support from surgery. This study revealed an imbalance between the ESM and the RAM after gastrectomy. The decrease in the ESM and the increase in the RAM can lead to kyphosis, and reports have suggested that kyphosis decreases lung capacity, maximum expiratory pressure, and maximum inspiratory pressure [30, 31]. There is a possibility that the muscle imbalance that occurs after gastrectomy may potentially worsen prognosis by impairing respiratory function and increasing pneumonia risk. Furthermore, the imbalance in the trunk muscles leading to impaired postural control increases the risk of falls and fractures [32]. Gastrectomy has been associated with an increased risk of fractures, which in turn can have a negative impact on prognosis [33, 34]. Considering all these factors, a rehabilitation program with a focus on maintaining trunk muscle balance and promoting good posture, such as "Lumbar Stabilization Exercises" [35] and "Combined Motor Control and Isolated Extensor Strengthening" [36], could potentially enhance the postoperative prognosis after gastrectomy.

To investigate the factors contributing to such imbalances in muscle mass, we explored various preoperative factors. The reduced preoperative SFI emerged as a significant risk factor contributing to the postoperative decline in ESM ($p = 0.02$, Table 5). While adipose tissue quantity was not the primary focus of analysis in this study, it warrants attention given the various discussions surrounding sarcopenic obesity [37]. Obesity has been reported as both a risk and protective factor for muscle mass reduction. Specifically, there is one report indicating that visceral fat is a risk factor for low muscle mass, while subcutaneous fat serves as a protective factor, indicating different effects based on the distribution of adipose tissue [38]. In this study as well, the scarcity of subcutaneous fat, a protective factor for low muscle mass, may have contributed to the decline in muscle mass.

Preoperative high SMI emerged as a significant risk factor for postoperative reduction in lateral abdominal muscle ($p = 0.04$, Table 6). As mentioned earlier, individuals with greater total muscle mass are likely to require a higher energy expenditure to maintain that muscle mass, which may be one contributing factor.

Regarding postoperative RAM increase, advancing age emerged as a significant predictor ($p < 0.01$, Table 7). Generally, as age increases, posture maintenance tends to become less stable, leading to a higher likelihood of cane walking and compression fractures. Amidst the predisposition to muscle mass reduction following gastrectomy, an increase in RAM volume associated with changes in posture is anticipated. Implementing various measures, such as exercises targeting muscle mass changes, particularly in older patients, may potentially contribute to improved prognosis for gastric cancer through enhanced posture maintenance.

This study has some notable limitations. First, it was a retrospective small-cohort study conducted at a single facility. Second, there was a lack of information on postoperative pain, oral intake and the progress of rehabilitation. In general, minimally invasive surgeries performed under laparoscopy or robot assistance tend to result in less postoperative pain compared to open surgeries, which typically involve more extensive abdominal wall disruption. This may facilitate easier pain management, promote early mobilization and rehabilitation, and potentially lead to increased oral intake. Consequently, it could also be effective in addressing the imbalance in muscle mass changes following gastrectomy. However, it should be noted that the lack of pain assessment tools such as the Visual Analog Scale (VAS) in this study represents one of its limitations. Third, regarding the measurement of muscle mass, reproducibility may be enhanced through the creation of measurement programs using computer-assisted methods rather than relying solely on freehand measurements. Fourth, the clinical significance in terms of long-term morbidity and mortality was not established. Therefore, large-scale prospective interventional studies are needed in the future.

In conclusion, this study demonstrated that gastrectomy alone causes an imbalance in the trunk muscle group. This imbalance may serve as an indicator of the overall condition of patients after gastrectomy. Moreover, a rehabilitation program focusing on correcting such imbalances and emphasizing postural control may potentially contribute to an improvement in patient prognosis after gastrectomy.

Acknowledgments. The authors would like to thank the radiology technicians involved in this study. We thank KN international (https://www.kninter.co.jp/) and Emily Woodhouse, PhD, from Edanz (https://jp.edanz.com/ac) for editing a draft of this manuscript.

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