The Journal of Aging Research & Lifestyle 14 (2025) 100006

Contents lists available at ScienceDirect

The Journal of Aging Research & Lifestyle

journal homepage: www.elsevier.com/locate/jarlif

Original Research

Comparison of body composition changes and nutritional status after surgery between older Japanese patients with upper and lower gastrointestinal cancer

Eiko Takano[a,*], Tsukasa Aritake[b], Kakeru Hashimoto[c], Yumi Suzuki[b], Yuichi Kitagawa[b], Ken Fujishiro[b], Yasuji Kawabata[b], Shinichirou Kobayashi[d], Izumi Kondo[a]

[a] Assistive Robotics Center, National Center for Geriatrics and Gerontology, Japan
[b] Department of Gastroenterological Surgery, National Center for Geriatrics and Gerontology, Japan
[c] Department of Rehabilitation Medicine, National Center for Geriatrics and Gerontology, Japan
[d] Department of Surgery, Kasugai Municipal Hospital, Japan

A R T I C L E I N F O

Keywords:
Upper gastrointestinal cancer
Lower gastrointestinal cancer
Body composition changes
Nutritional status
Malnutrition
Postoperative recovery

A B S T R A C T

Introduction: Postoperative changes in body composition and nutritional challenges are significant concerns for older patients undergoing gastrointestinal (GI) cancer surgery. This study compared body composition changes and nutritional outcomes between patients with upper gastrointestinal (UGI) and lower gastrointestinal (LGI) cancers over 12 months to identify tailored postoperative care needs.
Methods: This retrospective study included 55 Japanese patients (≥65 years) who underwent curative GI cancer surgery at the National Center for Geriatrics and Gerontology between 2018 and 2022. Patients were categorized as UGI (n = 17) or LGI (n = 38). Body composition parameters, including body mass index (BMI), fat-free mass (FFM), and body fat mass (BFM), were measured preoperatively and at 1, 3, 6, and 12 months postoperatively using bioelectrical impedance analysis. Two-way repeated-measures ANOVA was conducted, adjusting for age, sex, surgical method, operation time, blood loss, infection rates, and MMSE scores to minimize bias.
Results: UGI patients showed significant reductions in weight, BMI, FFM, and BFM postoperatively, indicating a higher risk of malnutrition and muscle loss. In contrast, LGI patients exhibited stable or increasing trends in these parameters. Significant time and interaction effects were observed for FFM and BFM ($p<0.05$), underscoring differential recovery patterns between groups.
Conclusions: UGI patients face a higher risk of postoperative malnutrition and muscle loss compared to LGI patients, who showed more favorable recovery trajectories. Early, intensive nutritional interventions and personalized rehabilitation strategies are essential for mitigating muscle wasting and improving outcomes in UGI patients.

1. Introduction

Surgery is the primary treatment option for patients with gastrointestinal (GI) cancer, offering the potential for curative outcomes. However, patients undergoing surgery for GI cancer are well-documented to be at elevated risk of malnutrition [1–4]. Malnutrition, often characterized by declines in both body fat mass (BFM) and lean body mass (LBM) [5], is particularly common among patients undergoing surgery for upper GI cancers, such as gastric cancer [6]. Thus, postoperative nutritional care is crucial to prevent or mitigate adverse changes in body composition, significantly impacting recovery and long-term health outcomes.

Changes in body composition, including losses in BFM and LBM, can persist long after surgery. For instance, a Polish study showed significant reductions in body weight, BFM, and visceral fat at 3 months post-colorectal surgery, while patients with esophageal and gastric cancers

Abbreviations: ANOVA, analysis of variance; BCM, body cell mass; BFM, body fat mass; BIA, bioelectrical impedance analysis; BMI, body mass index; ECW/TBW, extracellular water / total body water ratio; FFM, fat-free mass; FFMI, fat-free mass index; FMI, fat mass index; GI, gastrointestinal; GLIM, Global Leadership Initiative on Malnutrition; LBM, lean body mass; LGI, lower gastrointestinal; MMSE, Mini-Mental State Examination; NCGG, National Center for Geriatrics and Gerontology; PBF, percentage body fat; PM, protein mass; QOL, quality of life; SMI, skeletal muscle index; SMM, skeletal muscle mass; TMM, trunk muscle mass; UGI, upper gastrointestinal.

* Corresponding author.
E-mail address: eikoath@ncgg.go.jp (E. Takano).

https://doi.org/10.1016/j.jarlif.2025.100006
Received 15 November 2024; Received in revised form 17 December 2024; Accepted 22 January 2025

experienced declines in fat-free mass (FFM) up to 24 months postoperatively [7,8]. Older patients (≥ 80 years old) are particularly vulnerable to malnutrition due to the catabolic effects of cancer and potential GI side effects such as nausea, vomiting, anorexia, diarrhea, dysphagia and malabsorption [9]. These findings highlight a need for comprehensive and effective long-term nutritional interventions.

In addition to the catabolic effects and postoperative complication, the digestive and absorptive functions of the upper and lower GI tracts differ significantly, which may then influence postoperative recovery and nutritional status. The upper GI tract (comprising the esophagus, stomach, and duodenum) is primarily responsible for the initial breakdown and absorption of food, while the lower GI tract (including the small intestine, colon, and rectum) plays a critical role in the absorption of nutrients and water, as well as the formation and excretion of waste. Consequently, the impact of surgical interventions on body composition and nutritional status may vary depending on whether the surgery involves the upper or lower GI tract, as each site plays different physiological roles in digestion. Understanding these specific changes in body composition and nutritional status is essential, particularly in older adults undergoing surgery for GI cancers. Comparing these changes over a 12-month postoperative period can provide valuable insights into the distinct needs of patients with upper versus lower GI cancers, optimizing postoperative care and enhancing long-term outcomes by addressing their unique nutritional challenges.

Despite these physiological differences, few studies have directly compared body composition and nutritional status between older adults with upper and lower GI cancers, particularly in Japanese populations, who may have unique digestive characteristics. For instance, a higher prevalence of lactose intolerance and differences in gut microbiota patterns may influence nutrient absorption and the metabolism of fat and LBM following surgery [10]. Moreover, cultural factors such as dietary habits and genetic predispositions may further affect postoperative recovery and long-term nutritional status. Understanding these specific population characteristics is crucial for developing effective, culturally appropriate nutritional interventions that address the unique needs of older Japanese patients recovering from GI cancer surgery.

The Global Leadership Initiative on Malnutrition (GLIM) criteria provide a standardized framework for diagnosing malnutrition, particularly in the context of postoperative nutritional assessment [11]. The GLIM criteria involve a two-step process: initial screening with validated tools (e.g., MUST, NRS-2002) followed by diagnosis based on specific phenotypic and etiological criteria, offering a reliable method for evaluating malnutrition in clinical settings. Given the gaps in current research and the unique challenges faced by older Japanese patients with GI cancers, the present study sought to explore changes in body composition and nutritional status over a 12-month postoperative period, comparing these changes between patients with upper and lower GI cancers. The study utilized the GLIM criteria and bioelectrical impedance analysis (BIA) parameters to assess malnutrition and provide insights for optimizing postoperative nutritional interventions.

2. Methods

This study was approved by the National Center for Geriatrics and Gerontology (NCGG) Medical Ethics Committee (approval no. 1156) and conducted following the provisions of the Declaration of Helsinki (as revised in Brazil, 2013). All participants received a committee-approved explanatory document detailing the study and provided written informed consent before the study began.

2.1. Participants

This study included patients aged ≥ 65 years who underwent GI cancer surgery between 4 September 2018 and 24 January 2022 at NCGG. All participants were Japanese and resided in Aichi prefecture of Japan. Information was collected from medical records, including patient demographics (age, sex), diagnosis, surgical method (open or laparoscopic), operation time, intraoperative blood loss, length of hospital stay, presence of postoperative infection, and Mini-Mental State Examination (MMSE) scores during hospitalization.

Patients were excluded if they were < 65 years old, underwent noncurative resection (due to an inability to achieve full cancer removal, which may influence long-term nutritional outcomes) or total gastrectomy (because of the resulting significant alterations in digestion and absorption that could confound body composition results), underwent resection involving both GI tracts, had missing body composition data at any time point, or declined to participate.

2.2. Outcome measurements

Nutritional status and body composition were assessed using a comprehensive set of parameters, including body weight (kg), body mass index (BMI; kg/m^2), FFM (kg), BFM (kg), percentage body fat (PBF; %), protein mass (PM; kg), skeletal muscle mass (SMM; kg), trunk muscle mass (TMM; kg), body cell mass (BCM; kg), extracellular water/total body water ratio (ECW/TBW), skeletal muscle index (SMI; kg/m^2), fat mass index (FMI; kg/m^2), and FFM index (FFMI; kg/m^2). These assessments were performed using the InBody 720 (until May 2021; InBody Japan Inc., Tokyo, Japan) and InBody 770 (from June 2021; InBody Japan Inc.). The switch from the 720 to the 770 model was due to an upgrade in technology to ensure more accurate measurements of body composition.

All measurements were conducted with the patient standing, ensuring they were in a fasted state and had voided before the assessment to minimize fluid retention effects. Electrodes were placed on the hands and feet, and bioelectrical impedance was used to measure the body composition parameters. BMI was calculated by inputting the height, measured at the time of hospital admission, into the Inbody system. Height (cm) was measured using a calibrated stand-up scale. These assessments were conducted at five points: preoperatively (T0) and at 1 month (T1), 3 months (T2), 6 months (T3), and 12 months (T4) postoperatively.

In this study, malnutrition was evaluated in patients with GI cancer by identifying at least one phenotypic and one etiological criterion according to the GLIM criteria [11]. Weight loss (≥5% in the past 6 months or ≥10% in more than 6 months), low BMI (<18.5 kg/m^2 for patients <70 years old and <20.0 kg/m^2 for patients ≥70 years old), and reduced muscle mass (diagnosed using the Asian criteria for sarcopenia, with SMI <7.0 kg/m^2 for men and <5.7 kg/m^2 for women, as measured by BIA) [12] were used to evaluate the phenotypic criteria. The etiological criteria were applied to all subjects in this study due to GI cancer-related disease burden and inflammation. However, the severity of malnutrition was not assessed due to the lack of specific GLIM cut-off values for low BMI and reduced muscle mass in the Japanese population. The GLIM criteria were applied at four postoperative time points: T1, T2, T3, and T4.

2.3. Statistical analysis

Patients were categorized into two groups based on the location of the cancer: 1) the Upper Gastrointestinal (UGI) group, which included patients with cancer in the esophagus, stomach, or duodenum; and 2) the Lower Gastrointestinal (LGI) group, which included patients with cancer in the small intestine, colon, or cecum.

Independent *t*-tests were used to compare continuous variables between the UGI and LGI groups for baseline characteristics, and the chi-square test was used to compare the frequency of open surgery versus laparoscopic surgery between the two groups.

Data on body composition changes were analyzed using two-way repeated-measures analysis of variance (ANOVA) to assess differences

Table 1
Baseline characteristics of older Japanese patients undergoing gastrointestinal cancer surgery (n = 55).

Characteristics	UGI (n = 17)			LGI (n = 38)		
	Mean	SD		Mean	SD	P value
Age, years	76.0	5.4		76.2	5.0	0.917
Sex, n (%)						
Male	12	(70.6)		19	(50.0)	
Female	5	(29.4)		19	(50.0)	
Location of cancer, n (%)						
Stomach	11	(64.7)	**Colon**	35	(92.1)	
Esophagus	3	(17.6)	**Cecum**	3	(7.9)	
Duodenum	3	(17.6)	**Small intestine**	0	(0.0)	
Surgical method, n (%)						<0.001
Open	15	(88.2)		12	(31.6)	
Lap	2	(11.8)		26	(68.4)	
Operation time, min	335.3	182.8		256.3	101.1	0.110
Blood loss, ml	489.4	436.4		313.6	442.7	0.178
LHS, days	37.7	22.6		25.7	17.5	0.036
Infection, n (%)	6	(35.3)		4	(10.5)	
MMSE, points	(n = 8)			(n = 22)		
	25.0	7.1		24.0	6.2	0.697
Height, cm	160.3	8.3		157.4	9.5	0.273

The Upper Gastrointestinal (UGI) group included patients with cancer located in the esophagus, stomach, or duodenum. The Lower Gastrointestinal (LGI) group included patients with cancer located in the colon, cecum, or small intestine. *SD*: standard deviation; *Lap*: laparoscopic surgery; *LHS*: length of hospital stay; *MMSE*: Mini-Mental State Examination. An independent t-test was used to compare continuous variables between the UGI and LGI groups for baseline characteristics, and the chi-square test was used to compare the frequency of open surgery versus laparoscopic surgery between the two groups.

between the two groups over time. Subsequently, the analysis was conducted while controlling for potential confounding factors, including age, sex, surgical method (open or laparoscopic), operation time, blood loss, length of hospital stay, presence of infection, and MMSE scores during hospitalization.

All statistical analyses were conducted using IBM SPSS Statistics (version 29.0.0.0 (241) for Mac; IBM, Chicago, IL, USA), with the significance level set at p < 0.05.

3. Results

This study included 120 patients ≥ 65 years old who underwent GI cancer surgery between 4 September 2018 and 24 January 2022 at NCGG. Patients were excluded based on the following criteria: age <65 years (n = 7), non-curative resection (n = 4), total gastrectomy (n = 10), resections involving both the UGI and LGI tracts (n = 2), missing body composition data at any time point from T0 to T4 (n = 53), and declining to participate (n = 4). As a result, 55 patients (31 men, 24 women; mean age 76.1 ± 5.1 years) were included in the final analysis (UGI: n = 17; LGI: n = 38).

Table 1 shows the baseline characteristics. No significant difference in age was seen between the UGI group (76.0 ± 5.4 years) and LGI group (76.2 ± 5.0 years; p = 0.917). Open surgery was performed more frequently for the UGI group (88.2%) than for the LGI group (31.6%), while laparoscopic surgeries were performed more frequently for the LGI group (68.4%) than for the UGI group (11.8%; p<0.001). The UGI group had a significantly longer hospital stay (37.7 ± 22.6.4 days) than the LGI group (25.7 ± 17.5 days; p = 0.036). Operation time, blood loss, MMSE scores, and height did not differ significantly between groups.

Significant differences in body composition parameters were observed between the UGI and LGI groups over time and analyzed using two-way repeated-measures ANOVA. Significant effects were found for time, group, and interaction (p<0.05 each) across most parameters (Table 2). Weight and BMI decreased progressively in the UGI group (p<0.001), while the LGI group showed slight increases over time. FFM remained relatively stable in the LGI group but decreased in the UGI group, with significant time, group, and interaction effects (p<0.01). BFM and PBF decreased in the UGI group, while both increased in the LGI group (p<0.001 each). Similar trends were observed for other parameters, such as SMM, TMM, and BCM, reflecting more significant changes in body composition in the UGI group compared to the LGI group.

After adjusting for confounding factors, significant differences were observed between the UGI and LGI groups in body composition parameters over time (Table 3, Fig. 1). No significant time effect was evident for weight changes (p = 0.865), but the interaction was significant (p = 0.024), with the UGI group showing a steady decrease in weight while the LGI group experienced a gradual increase (Table 3, Fig. 1a). BMI changes also showed a significant group effect (p<0.001) and interaction (p = 0.015), with BMI decreasing in the UGI group and increasing in the LGI group (Table 3, Fig. 1b). FFM and BFM followed similar patterns, with no significant time effects, but significant interactions for BFM (p = 0.008) and PBF (p = 0.007) (Table 3, Figs. 1a, 1b). The UGI group showed a decrease in body fat, while that in the LGI group increased over time. TMM showed a significant interaction (p = 0.047), with the UGI group showing a decline over time compared to the relatively stable levels in the LGI group (Table 3, Fig. 1e). Similarly, FMI demonstrated a significant interaction (p = 0.007; Table 3, Fig. 1f), reflecting contrasting patterns of fat mass changes between the two groups.

To address concerns regarding the small sample size, we conducted a post hoc power analysis using G*Power 3.1, which confirmed a statistical power of over 0.80 for detecting significant differences in all body composition parameters. In Addition, a sensitivity analysis was performed to evaluate the adequacy of the sample size and statistical power of this study. The sensitivity analysis was conducted with a significance level (α) of 0.05, a target power ($1-\beta$) of 0.80, and a total sample size of n = 55. The results indicated that the detectable effect size (Cohen's f) was 0.150, demonstrating that the study is adequately powered to detect small-to-moderate effect sizes.

Malnutrition, assessed using GLIM criteria, was more prevalent in the UGI group than in the LGI group across all postoperative time points. At T1, 94% of UGI patients were malnourished, a rate that remained stable through T4. In contrast, malnutrition in the LGI group decreased from 71.1% at T1 to 50.0% at T4 (Table 4).

Table 2
Longitudinal changes in body composition parameters over a 12-month postoperative period between upper and lower gastrointestinal cancer groups (Upper Gastrointestinal group: n = 17; Lower Gastrointestinal group: n = 38).

Parameters	Group	T0		T1		T2		T3		T4		Time effect	Group effect	Interaction
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value	*P* value
Weight, kg	**UGI**	57.0	10.4	52.4	8.8	51.0	9.3	51.1	8.9	50.0	7.6	<0.001	<0.001	<0.001
	LGI	56.1	11.4	53.9	11.1	55.9	11.7	57.2	11.7	59.0	12.2			
BMI, kg/m^2	**UGI**	22.3	4.2	20.4	3.6	19.9	3.6	19.9	3.4	19.5	3.0	<0.001	<0.001	<0.001
	LGI	22.5	3.3	21.6	3.2	22.4	3.2	22.9	3.2	23.6	3.5			
FFM, kg	**UGI**	43.0	6.6	40.8	5.7	40.9	6.3	41.8	5.9	40.9	6.2	<0.001	0.010	0.001
	LGI	40.2	8.5	39.6	8.4	40.6	8.6	40.5	8.5	40.4	8.8			
BFM, kg	**UGI**	14.0	7.8	11.6	7.0	10.1	6.6	9.3	6.3	9.1	5.6	<0.001	<0.001	<0.001
	LGI	16.0	5.7	14.2	5.4	15.7	5.9	16.7	5.8	18.6	6.8			
PBF, %	**UGI**	23.6	9.9	21.3	10.0	18.9	9.9	17.2	9.4	17.6	9.2	<0.001	<0.001	<0.001
	LGI	28.1	7.0	26.1	7.1	27.1	7.1	28.9	6.8	31.1	7.8			
PM, kg	**UGI**	8.3	1.3	7.8	1.1	7.8	1.2	8.0	1.2	7.9	1.2	<0.001	<0.001	<0.001
	LGI	7.8	1.7	7.6	1.6	7.8	1.7	7.8	1.7	7.8	1.7			
SMM, kg	**UGI**	23.1	4.0	21.6	3.4	21.6	3.7	22.2	3.5	21.8	3.7	<0.001	0.002	<0.001
	LGI	21.5	5.1	21.0	4.9	21.6	5.1	21.6	5.1	21.6	5.2			
TMM, kg	**UGI**	19.7	3.6	18.4	3.1	17.8	3.6	18.5	2.9	18.0	3.3	<0.001	0.001	<0.001
	LGI	18.2	4.1	17.5	3.9	17.9	4.1	18.2	4.1	18.6	4.2			
BCM, kg	**UGI**	27.6	4.4	25.9	3.7	25.9	4.1	26.4	4.2	26.1	4.1	<0.001	0.009	<0.001
	LGI	25.8	5.6	25.2	5.4	25.9	5.6	26.0	5.6	25.9	5.7			
ECW/TBW	**UGI**	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	<0.001	<0.001	<0.001
	LGI	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0			
SMI, kg/m^2	**UGI**	6.9	0.8	6.3	0.7	6.5	0.8	6.7	0.7	6.4	0.8	<0.001	0.007	0.001
	LGI	6.4	1.2	6.3	1.2	6.4	1.2	6.4	1.2	6.5	1.2			
FMI, kg/m^2	**UGI**	5.6	3.4	4.7	3.0	4.0	2.9	3.7	2.8	3.6	2.6	<0.001	<0.001	<0.001
	LGI	6.5	2.3	5.7	2.2	6.3	2.3	6.7	2.3	7.5	2.8			
FFMI, kg/m^2	**UGI**	16.7	1.6	15.8	1.2	15.8	1.4	16.2	1.4	15.8	1.4	<0.001	0.006	<0.001
	LGI	16.1	2.1	15.9	2.0	16.2	2.0	16.2	2.0	16.1	2.0			

The Upper Gastrointestinal (UGI) group included patients with cancer located in the esophagus, stomach, or duodenum. The Lower Gastrointestinal (LGI) group included patients with cancer located in the colon, cecum, or small intestine.
T0: preoperatively (baseline); *T1*: 1 month postoperatively; *T2*: 3 months postoperatively; *T3*: 6 months postoperatively; *T4*: 12 months postoperatively; *SD*: standard deviation; *BMI*: body mass index; *FFM*: fat-free mass; *BFM*: body fat mass; *PBF*: percentage fat mass; *PM*: protein mass; *SMM*: skeletal muscle mass; *TMM*: trunk muscle mass; *BCM*: body cell mass; *ECW/TBW*: extracellular water/total body water ratio; *SMI*: skeletal muscle index; *FMI*: fat mass index; *FFMI*: fat-free mass index. Repeated-measures two-way analysis of variance (ANOVA) was used to assess differences in body composition parameters between the UGI and LGI groups over time (T1-T4).

4. Discussion

This study highlights key differences in postoperative body composition changes and nutritional status between older Japanese patients who underwent surgery for UGI and LGI cancers. The analysis, adjusted for potential confounders, revealed distinct patterns in body composition between the two groups over a 12-month postoperative period. The mean age of patients in this study (76.1 ± 5.1 years) was higher than that reported for gastric cancer surgery (51–71 years) and colorectal cancer surgery (around 70 years) [13–15]. This suggests that our study population may have faced an elevated risk of postoperative complications, including malnutrition and sarcopenia, compared to younger populations typically included in other studies.

Biological mechanisms, such as altered gut microbiota, metabolic adaptations, and inflammatory responses post-surgery, may underlie the differential recovery patterns observed between UGI and LGO patients. The gut microbiota, in particular, plays a critical role in nutrient absorption, immune modulation, and maintaining metabolic homeostasis [16,17]. Alterations in gut microbiota following gastrointestinal surgeries have been associated with impaired nutrient metabolism and increased systemic inflammation, which may exacerbate malabsorption and muscle loss, particularly in UGI surgery patients [18]. These disruptions could significantly hinder postoperative recovery, contributing to sustained inflammation and nutritional deficiencies. Exploring these mechanisms in future studies could unveil novel therapeutic targets and provide deeper insights into the physiological challenges faced by these patients.

Patients who underwent UGI surgery showed significant reductions in body weight, BMI, and BFM over the 12-month postoperative period. These declines in body weight, FFM, and BFM are clinically significant, as previous studies have demonstrated a strong association between malnutrition, sarcopenia, and increased postoperative complications, including higher rehospitalization rates and delayed recovery [19,20]. The severe reduction in muscle mass and fat reserves observed in UGI patients may impair wound healing, reduce immune function, and prolong hospitalization, thereby increasing healthcare utilization. Addressing these risks through early nutritional interventions and tailored rehabilitation strategies is critical to improving recovery outcomes and minimizing rehospitalization rates. These reductions were accompanied by concurrent declines in both BFM and PBF, indicating an elevated risk of malnutrition in this group. A previous study reported that patients experience a dietary intake reduction of approximately 10% at 1 month post-gastrectomy [21]. Postoperative gastrointestinal dysfunctions, including acid reflux, regurgitation, and anorexia, often persist after gastrectomy, contributing to continued weight loss and negatively impacting postoperative quality of life (QOL) [22]. The pronounced decreases in weight, BMI, BFM, and PBF further emphasize the physiological stress associated with UGI surgeries, which likely complicates recovery by impairing nutritional intake and fat preservation.

In contrast, the LGI group exhibited relatively stable or increasing trends in FFM, BFM, and PBF over time. This outcome suggests that LGI surgeries, which have less direct impact on the early stages of digestion and nutrient absorption, may allow for better nutritional recovery. In addition, the higher proportion of laparoscopic surgeries in the LGI group likely contributed to the better postoperative outcomes, as minimally invasive procedures are associated with faster recovery and fewer complications. Large randomized controlled trials have confirmed several short-term advantages of laparoscopic resection for colorectal cancer, such as less intraoperative blood loss, sooner return of bowel function, and shorter hospital stay [23–25], and similar long-term on-

Table 3
Adjusted longitudinal changes in body composition parameters over a 12-month postoperative period between upper and lower gastrointestinal cancer groups (Upper Gastrointestinal group: $n = 17$; Lower Gastrointestinal group: $n = 38$).

Parameters	Group	T0		T1		T2		T3		T4		Time Effect	Group Effect	Interaction
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value	*P* value
Weight, kg	**UGI**	54.4	9.0	49.9	8.3	48.3	8.8	47.3	7.8	47.7	8.3	0.865	0.120	0.024
	LGI	56.8	12.7	54.4	12.2	56.2	12.7	57.6	12.8	59.1	13.2			
BMI, kg/m²	**UGI**	22.4	3.2	20.6	3.1	19.9	3.1	19.5	3.0	19.7	3.2	0.969	<0.001	0.015
	LGI	22.4	3.5	21.5	3.4	22.2	3.3	22.7	3.3	23.3	3.6			
FFM, kg	**UGI**	40.1	6.9	37.7	6.2	38.1	6.8	38.6	5.7	38.3	7.0	0.477	0.386	0.199
	LGI	41.0	9.7	40.3	9.0	41.3	9.4	41.5	9.2	41.7	9.7			
BFM, kg	**UGI**	14.4	6.3	12.2	6.0	10.3	6.7	8.7	6.2	9.4	6.5	0.368	0.102	0.008
	LGI	15.8	5.8	14.2	5.6	14.9	6.0	16.2	5.9	17.4	6.1			
PBF, %	**UGI**	25.9	8.8	23.9	9.2	20.3	11.0	17.4	10.7	19.0	10.6	0.214	0.020	0.007
	LGI	27.6	6.9	25.6	6.7	26.2	6.8	27.8	6.7	29.2	6.6			
PM, kg	**UGI**	7.7	1.4	7.2	1.2	7.3	1.3	7.4	1.1	7.4	1.4	0.387	0.185	0.145
	LGI	7.9	1.9	7.7	1.8	8.0	1.9	8.0	1.8	8.0	1.9			
SMM, kg	**UGI**	21.3	4.1	19.8	3.7	19.9	3.9	20.4	3.4	20.2	4.1	0.445	0.343	0.162
	LGI	21.9	5.8	21.3	5.3	22.0	5.6	22.1	5.5	22.3	5.7			
TMM, kg	**UGI**	18.1	3.9	16.8	3.5	16.2	4.2	16.9	2.8	16.7	3.8	0.821	0.137	0.047
	LGI	18.7	4.7	17.9	4.2	18.2	4.6	18.6	4.4	18.8	4.5			
BCM, kg	**UGI**	25.6	4.5	24.0	4.0	24.1	4.3	24.0	4.2	24.4	4.5	0.314	0.378	0.147
	LGI	26.3	6.4	25.6	5.9	26.3	6.2	26.5	6.1	26.7	6.3			
ECW/TBW	**UGI**	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.829	0.149	0.065
	LGI	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0			
SMI, kg/m²	**UGI**	6.6	0.9	6.0	0.8	6.3	0.9	6.5	0.8	6.1	0.9	0.492	0.304	0.261
	LGI	6.4	1.4	6.2	1.3	6.5	1.3	6.5	1.3	6.5	1.3			
FMI, kg/m²	**UGI**	6.0	3.0	5.1	2.9	4.3	3.1	3.7	3.0	4.0	3.2	0.362	0.088	0.007
	LGI	6.3	2.2	5.6	2.1	5.9	2.2	6.4	2.2	6.9	2.3			
FFMI, kg/m²	**UGI**	16.4	1.1	15.5	0.9	15.6	1.0	15.9	0.8	15.9	0.8	0.362	0.267	0.133
	LGI	16.1	2.4	15.9	2.1	16.2	2.1	16.3	2.1	16.3	2.1			

The Upper Gastrointestinal (UGI) group included patients with cancer located in the esophagus, stomach, or duodenum. The Lower Gastrointestinal (LGI) group included patients with cancer located in the colon, cecum, or small intestine.
T0: preoperatively (baseline); *T1*: 1 month postoperatively; *T2*: 3 months postoperatively; *T3*: 6 months postoperatively; *T4*: 12 months postoperatively; *SD*: standard deviation; *BMI*: body mass index; *FFM*: fat-free mass; *BFM*: body fat mass; *PBF*: percentage fat mass; *PM*: protein mass; *SMM*: skeletal muscle mass; *TMM*: trunk muscle mass; *BCM*: body cell mass; *ECW/TBW*: extracellular water/total body water ratio; *SMI*: skeletal muscle index; *FMI*: fat mass index; *FFMI*: fat-free mass index. This analysis was conducted using repeated-measures two-way analysis of variance (ANOVA) while controlling for potential confounding factors, including age, sex, surgical method (open or laparoscopic), operation time, blood loss, length of hospital stay, presence of infection, and Mini-Mental State Examination (MMSE) scores during hospitalization.

cologic when compared with open surgery [26–31]. Compared with open colectomy in patients with T4 colon cancer, laparoscopic colectomy has been shown to result in less blood loss, fewer perioperative transfusions, fewer complications, lower rates of wound infection, and shorter length of hospital stay [32]. These advantages of laparoscopic surgery may have played a role in the improved recovery observed in the LGI group.

LGI patients generally tend to experience better postoperative outcomes, but tailored rehabilitation strategies are necessary to address the specific characteristics of each UGI and LGI patient, optimizing recovery and preserving or increasing muscle mass. For UGI patients, early and intensive nutritional support is critical to mitigate the more severe declines in body weight, FFM, and BFM. High-protein, calorie-dense diets that accommodate reduced digestive capacity could play a key role in preventing muscle wasting and malnutrition [33]. Nutritional supplements enriched with amino acids, such as leucine, might help stimulate muscle protein synthesis, particularly in older adults at higher risk of sarcopenia [34,35]. UGI patients are more vulnerable in early recovery, so gradual strength-building exercises should be incorporated to counteract declines in muscle mass. In contrast, LGI patients should focus on maintaining or increasing muscle mass while avoiding excessive fat gain. Monitoring of body composition is essential to ensure that weight gain does not lead to disproportionate increases in fat mass, which could result in adverse metabolic effects. Resistance training should form a central component of rehabilitation, and given the generally more favorable postoperative outcomes, LGI patients can benefit from the inclusion of standard strength-building exercises. For UGI and LGI patients, supervised physical therapy focusing on resistance and endurance training is crucial. Rehabilitation programs should be tailored to recovery stage and physical limitations of each specific patient. While UGI patients may need a slower approach, LGI patients can engage in regular, more intensive exercises to maintain lean body mass and support overall health.

The application of the GLIM criteria at multiple postoperative time points provided a comprehensive understanding of malnutrition in older patients undergoing GI cancer surgery. The first evaluation, conducted 1 month postoperatively, captured the early signs of malnutrition and revealed a particularly high prevalence in the UGI group (94.1%). This early period is critical for identifying at-risk patients as postoperative complications begin to manifest [36]. By 3 and 6 months postoperatively, the LGI group showed a decline in malnutrition indicating a more favorable recovery trajectory compared to the UGI group, where malnutrition persisted (94.1% at T4). The continued weight loss and muscle mass reduction in the UGI group align with the greater physiological burden and postoperative complications associated with UGI surgeries. The 12-month assessment further emphasized the need for ongoing nutritional interventions in UGI patients, as they remained at higher risk of long-term malnutrition and sarcopenia. These findings underscore the importance of early identification and intervention using the GLIM criteria to optimize recovery in high-risk patients. The pronounced declines in body composition among UGI patients highlight the urgent need for early and targeted nutritional interventions. Such strategies are essential to mitigate sarcopenia, enhance recovery, and improve long-term QOL by reducing hospital readmissions and fostering more efficient postoperative rehabilitation.

These findings carry important implications for clinical practice and health policy. The significant declines in weight, body fat, and muscle mass observed in UGI patients highlight the need for targeted postopera-

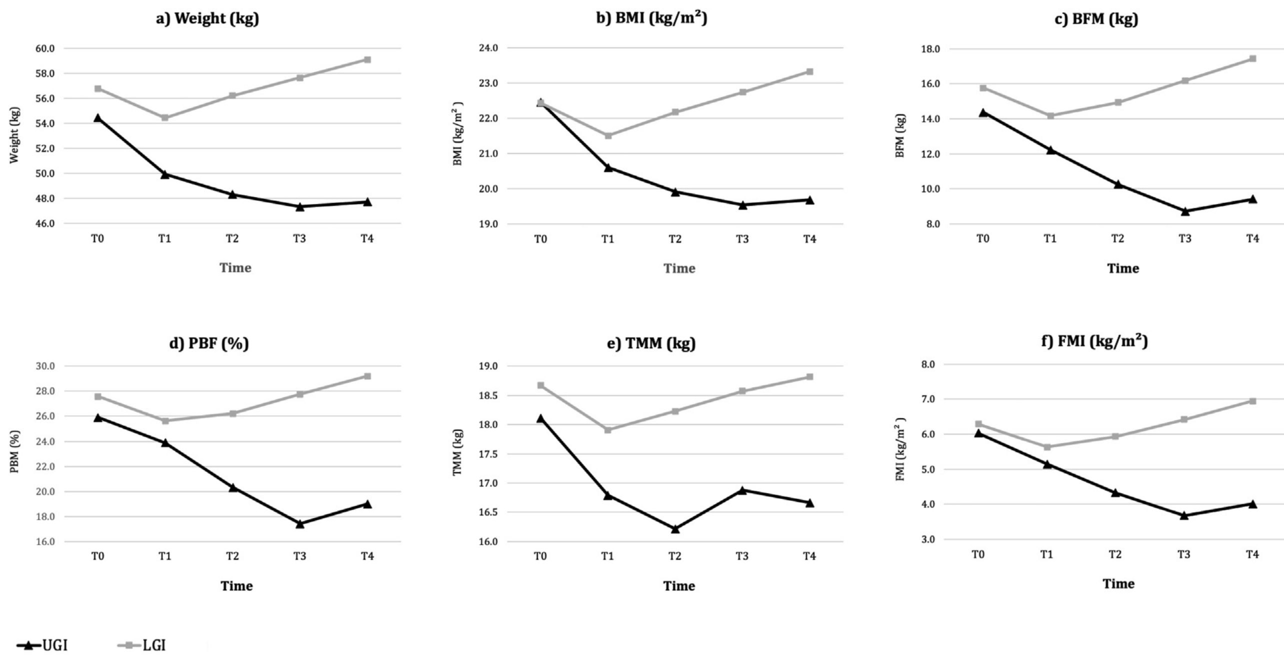

Fig. 1. Longitudinal changes in body composition parameters over 12 months after surgery in older Japanese patients with upper and lower gastrointestinal cancers.
Figure Legend:
Upper Gastrointestinal (UGI) group data are shown as black lines and lower gastrointestinal (LGI) group data are shown as gray lines.
T0: preoperatively (baseline); *T1*: 1 month postoperatively; *T2*: 3 months postoperatively; *T3*: 6 months postoperatively; *T4*: 12 months postoperatively; *BMI*: body mass index; *BFM*: body fat mass; *PBF*: percentage fat mass; *TMM*: trunk muscle mass; *FMI*: fat mass index.
a) Changes in weight (kg) over time: While no significant time effect was observed ($p = 0.865$), a significant group-by-time interaction was evident ($p = 0.024$). The UGI group showed a steady decline in weight over time, whereas the LGI group exhibited a gradual increase, highlighting the greater vulnerability of UGI patients to weight loss.
b) Changes in body mass index (BMI, kg/m^2) over time: BMI changes demonstrated a significant group effect (p<0.001) and group-by-time interaction ($p = 0.015$). BMI decreased steadily in the UGI group, reflecting the impact of surgical stress and malnutrition, while it increased in the LGI group, suggesting better postoperative recovery.
c) Changes in body fat mass (BFM, kg) over time: Significant group-by-time interaction ($p = 0.008$) was observed. The UGI group experienced a marked reduction in body fat mass, while the LGI group showed an increasing trend, indicating contrasting fat preservation abilities between the two groups.
d) Changes in percentage body fat (PBF, %) over time: PBF showed a significant interaction effect ($p = 0.007$). The decline in PBF in the UGI group compared to the relatively stable or increasing trend in the LGI group underscores the heightened risk of malnutrition and fat loss in UGI patients.
e) Changes in trunk muscle mass (TMM, kg) over time: A significant interaction effect ($p = 0.047$) was observed. TMM declined over time in the UGI group, while the LGI group maintained relatively stable levels, highlighting the need for muscle-preserving interventions in UGI patients.
f) Changes in fat mass index (FMI, kg/m^2) over time: FMI demonstrated a significant interaction effect ($p = 0.007$). The UGI group showed a decrease in FMI, indicating fat loss, while the LGI group displayed an increasing trend, reflecting better fat mass preservation.

Table 4
Longitudinal prevalence of malnutrition based on GLIM criteria in older Japanese patients undergoing upper and lower gastrointestinal cancer surgery (Upper Gastrointestinal group: $n = 17$; Lower Gastrointestinal group: $n = 38$).

Criteria	Group	T1		T2		T3		T4	
		n	%	n	%	n	%	n	%
Malnutrition	**UGI**	16	94.1	17	100.0	16	94.1	16	94.1%
	LGI	27	71.1	24	63.2	19	50.0	19	50.0%
Involuntary weight loss	**UGI**	12	70.6	14	82.4	14	82.4	11	64.7%
	LGI	15	39.5	5	13.2	4	10.5	2	5.3%
Low BMI	**UGI**	7	41.2	9	52.9	10	58.8	10	58.8%
	LGI	11	28.9	7	18.4	7	18.4	3	7.9%
Reduced muscle mass	**UGI**	13	76.5	11	64.7	9	52.9	14	82.4%
	LGI	23	60.5	22	57.9	18	47.4	18	47.4%

The Upper Gastrointestinal (UGI) group includes patients with cancer located in the esophagus, stomach, or duodenum. The Lower Gastrointestinal (LGI) group includes patients with cancer located in the colon, cecum, or small intestine.
T1: 1 month postoperatively; *T2*: 3 months postoperatively; *T3*: 6 months postoperatively; *T4*: 12 months postoperatively; *BMI*: body mass index.
GLIM criteria were used to diagnose malnutrition, with weight loss (≥5% in 6 months or ≥10% in over 6 months), low BMI (<18.5 kg/m^2 for patients <70 years old, <20.0 kg/m^2 for patients ≥70 years old), and reduced muscle mass as assessed using the Asian sarcopenia criteria (skeletal muscle index <7.0 kg/m^2 for men and <5.7 kg/m^2 for women).

tive care strategies to mitigate malnutrition and sarcopenia. Integrating personalized nutritional interventions and rehabilitation protocols into standard care pathways could improve functional recovery, reduce rehospitalization rates, and enhance long-term QOL. Furthermore, by addressing the higher healthcare costs associated with postoperative complications in malnourished patients, these strategies offer cost-effective approaches that could inform national guidelines and hospital policies for GI cancer care. Future research should evaluate the economic benefits and survival outcomes of such interventions to further justify their integration into clinical practice.

Despite these important findings, several limitations should be considered when interpreting the results. First, this study's single institution design limits the findings' generalizability to other healthcare systems or patient populations. Collaborating with multiple centers and including patients from diverse socioeconomic and cultural backgrounds would improve external validity by providing a more representative sample. Such a multicenter approach would capture patient demographics and healthcare practice variations, offering broader insights into body composition changes and postoperative recovery patterns after GI cancer surgery. Second, the small sample size ($n = 55$) raises concerns regarding the robustness of the conclusion, particularly in the UGI group ($n = 17$). To address these concerns, we conducted a post hoc power analysis, which confirmed a statistical power of over 0.80 for detecting significant differences in key body composition parameters. While this analysis supports the validity of the findings, future studies involving larger cohorts are necessary to improve the generalizability and reliability of the results. Recruiting larger cohorts, particularly for the UGI group, would not only increase statistical power and enhance the ability to detect subtle differences in body composition changes. Third, this study focused on older Japanese patients whose unique genetic, dietary, and cultural characteristics, such as specific dietary habits, a higher prevalence of lactose intolerance, and differences in gut microbiota, may influence postoperative recovery and body composition changes. This specificity limits the generalizability of the findings to other populations. Future studies aimed at addressing this limitation should include diverse ethnic groups and healthcare settings through multicenter designs that incorporate patients from varied socioeconomic and healthcare systems. Such an approach would provide broader insights into postoperative recovery patterns and allow for a deeper exploration of the influence of genetic, dietary, and healthcare system differences across diverse populations. Fourth, while BIA is a practical and non-invasive method for assessing body composition, it may introduce variability due to factors such as hydration status. We instructed patients to stand, fast, and void to minimize this variability before all measurements. However, unmeasured factors, including comorbidities and adherence to nutritional interventions, may have introduced bias, potentially influencing the accuracy and interpretation of the results. More precise techniques, such as dual-energy X-ray absorptiometry (DXA), should complement BIA in future studies to improve measurement accuracy and reduce potential variability. Finally, while this study employed robust methods, including adjustments for potential confounders such as surgical method and patient demographics, unmeasured factors may have introduced bias. Specifically, comorbidities, adherence to nutritional interventions, and other patient-specific variables should have been fully accounted for, as these factors could have influenced the results. In addition, the exclusion criteria, such as patients undergoing non-curative resection or total gastrectomy, may have introduced selection bias, potentially limiting the generalizability of the findings. A more comprehensive evaluation of these factors in future studies would enhance the validity and reliability of the results.

Future studies should address the limitations identified in this research while expanding the scope to explore long-term outcomes and underlying mechanisms driving postoperative recovery. First, extending the follow-up period beyond 12 months would provide valuable insights into the long-term impact of postoperative nutritional changes on survival, functional recovery, and QOL. Such longitudinal data could inform strategies to optimize rehabilitation and nutritional interventions. Second, investigating the biological mechanisms underlying the differential recovery patterns between UGI and LGI patients is essential. Potential focus areas include the role of gut microbiota composition, metabolic adaptations, and inflammatory responses, which may influence body composition changes and recovery trajectories. Third, targeted interventions, such as personalized nutrition plans, optimized exercise regimens, and pharmacological agents, should be explored and validated in future clinical trials to address the specific needs of UGI and LGI patients.

In addition, adopting a multicenter design with diverse ethnic groups and healthcare settings would enhance the generalizability of findings and provide broader perspectives on postoperative recovery. This approach could also facilitate the evaluation of systems-level implications, such as the impact of findings on hospital policies, rehabilitation protocols, and national guidelines for cancer care. Emerging technologies, such as artificial intelligence (AI) and machine learning, offer promising opportunities to develop predictive models for postoperative nutritional outcomes, enabling early identification of high-risk patients and more tailored interventions. Future research that builds on the current findings can contribute to improved clinical care, a deeper mechanistic understanding, and evidence-based strategies to support postoperative recovery in patients undergoing GI cancer surgery.

5. Conclusion

This study highlights distinct postoperative changes in body composition between older Japanese patients undergoing surgery for UGI and LGI cancers. UGI patients experienced significant declines in weight, body fat, and muscle mass, indicating a higher risk of malnutrition and sarcopenia. In contrast, LGI patients showed more stable or improved body composition attributable to the less invasive surgical methods. These findings stress the importance of personalized postoperative care. UGI patients require early, intensive nutritional support and resistance training to counteract muscle loss, while LGI patients need monitoring to maintain lean mass and prevent excessive fat gain. Tailored rehabilitation strategies based on cancer site and surgery type are crucial for optimizing recovery and long-term outcomes. Future research should explore the long-term impact of these interventions on survival and QOL.

These findings emphasize the clinical importance of early nutritional intervention and tailored rehabilitation strategies and highlight their potential to reduce healthcare costs by preventing rehospitalization and long-term complications. Policymakers and healthcare providers should consider integrating these evidence-based approaches into national guidelines and hospital protocols to optimize recovery outcomes and improve resource utilization in older adults undergoing gastrointestinal cancer surgery.

Funding

This research was based on data collected for a project funded by the "Aichi Digital Health Project" from the Aichi Prefectural Government.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Eiko Takano reports financial support was provided by the "Aichi Digital Health Project" from the Aichi Prefectural Government. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Eiko Takano: Writing – original draft, Funding acquisition. **Tsukasa Aritake:** Investigation, Data curation. **Kakeru Hashimoto:** Investigation, Data curation. **Yumi Suzuki:** Investigation, Data curation. **Yuichi Kitagawa:** Investigation, Data curation. **Ken Fujishiro:** Investigation, Data curation. **Yasuji Kawabata:** Supervision, Project administration. **Shinichirou Kobayashi:** Methodology, Conceptualization. **Izumi Kondo:** Writing – review & editing, Supervision.

Acknowledgments

We would like to express our sincere gratitude to the patients who participated in this study and the medical staff at NCGG for their invaluable support during the data collection process. We also appreciate the contributions of the surgical and rehabilitation teams for their dedication to patient care.

References

[1] Braga M, Gianotti L, Gentilini O, Liotta S, Di Carlo V. Feeding the gut early after digestive surgery: results of a nine-year experience. Clin Nutr 2002;21(1):59–65. doi:10.1054/clnu.2001.0504.

[2] Farreras N, Artigas V, Cardona D, Rius X, Trias M, González JA. Effect of early postoperative enteral immunonutrition on wound healing in patients undergoing surgery for gastric cancer. Clin Nutr 2005;24(1):55–65. doi:10.1016/j.clnu.2004.07.002.

[3] Fettes SB, Davidson HI, Richardson RA, Pennington CR. Nutritional status of elective gastrointestinal surgery patients pre- and post-operatively. Clin Nutr 2002;21(3):249–54. doi:10.1054/clnu.2002.0540.

[4] Rey-Ferro M, Castaño R, Orozco O, Serna A, Moreno A. Nutritional and immunologic evaluation of patients with gastric cancer before and after surgery. Nutrition 1997;13(10):878–81. doi:10.1016/s0899-9007(97)00269-4.

[5] Cai B, Luo L, Zhu C, Meng L, Shen Q, Fu Y, et al. Influence of body composition assessment with bioelectrical impedance vector analysis in cancer patients undergoing surgery. Front Oncol 2023;13:1132972. doi:10.3389/fonc.2023.1132972.

[6] Garth AK, Newsome CM, Simmance N, Crowe TC. Nutritional status, nutrition practices and post-operative complications in patients with gastrointestinal cancer. J Hum Nutr Diet 2010;23(4):393–401. doi:10.1111/j.1365-277X.2010.01058.x.

[7] Tojek K, Banaszkiewicz Z, Budzyński J. Body composition among patients undergoing surgery for colorectal cancer. Prz Gastroenterol 2021;16(1):47–55. doi:10.5114/pg.2021.104736.

[8] Heneghan HM, Zaborowski A, Fanning M, McHugh A, Doyle S, Moore J, et al. Prospective study of malabsorption and malnutrition after esophageal and gastric cancer surgery. Ann Surg 2015;262(5):803–7 discussion 7-8. doi:10.1097/sla.0000000000001445.

[9] Aoyama T, Maezawa Y, Yoshikawa T, Segami K, Kano K, Hayashi T, et al. Comparison of weight and body composition after gastrectomy between elderly and non-elderly patients with gastric cancer. In Vivo 2019;33(1):221–7. doi:10.21873/invivo.11463.

[10] J-milk (Japan Dairy Association) The investigation about eating habit trend of milk, dairy products in 2015; 2016 https://www.j-milk.jp/report/trends/f13cn00000000x9t-att/hn0mvm0000000tv1.pdf [accessed 31 March 2016].

[11] Cederholm T, Jensen GL, Correia M, Gonzalez MC, Fukushima R, Higashiguchi T, et al. GLIM criteria for the diagnosis of malnutrition - a consensus report from the global clinical nutrition community. Clin Nutr 2019;38(1):1–9. doi:10.1016/j.clnu.2018.08.002.

[12] Chen LK, Liu LK, Woo J, Assantachai P, Auyeung TW, Bahyah KS, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 2014;15(2):95–101. doi:10.1016/j.jamda.2013.11.025.

[13] Shan B, Shan L, Morris D, Golani S, Saxena A. Systematic review on quality of life outcomes after gastrectomy for gastric carcinoma. J Gastrointest Oncol 2015;6(5):544–60.

[14] Lee TH, Choo JM, Kim JS, Shin SH, Kim JS, Baek SJ, et al. Characteristics and outcomes of colorectal cancer surgery by age in a tertiary center in Korea: a retrospective review. Ann Coloproctol 2022;38(3):244–52. doi:10.3393/ac.2021.00619.0088.

[15] Widdison AL, Barnett SW, Betambeau N. The impact of age on outcome after surgery for colorectal adenocarcinoma. Ann R Coll Surg Engl 2011;93(6):445–50. doi:10.1308/003588411x587154.

[16] Sekirov I, Russell SL, Antunes LC, Finlay BB. Gut microbiota in health and disease. Physiol Rev 2010;90(3):859–904. doi:10.1152/physrev.00045.2009.

[17] Rowland I, Gibson G, Heinken A, et al. Gut microbiota functions: metabolism of nutrients and other food components. Eur J Nutr 2018;57(1):1–24. doi:10.1007/s00394-017-1445-8.

[18] Hill C, Guarner F, Reid G, et al. Expert consensus document. The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. Nat Rev Gastroenterol Hepatol 2014;11(8):506–14. doi:10.1038/nrgastro.2014.66.

[19] Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age and ageing 2019;48:16–31. doi:10.1093/ageing/afy169.

[20] Fearon KC, Voss AC, Hustead DS. Definition of cancer cachexia: effect of weight loss, reduced food intake, and systemic inflammation on functional status and prognosis. Am J Clin Nutr 2006;83:1345–50 xc. doi:10.1093/ajcn/83.6.1345.

[21] Nakazono M, Aoyama T, Hayashi T, Hara K, Segami K, Shimoda Y, et al. Comparison of the dietary intake loss between total and distal gastrectomy for gastric cancer. In Vivo 2021;35(4):2369–77. doi:10.21873/invivo.12514.

[22] Nakata K. Actual conditions and management of postgastrectomy syndrome—An introduction. Japanese Society of Gastroenterological Surgery educational gathering. 2010.

[23] Guillou PJ, Quirke P, Thorpe H, Walker J, Jayne DG, Smith AM, et al. Short-term endpoints of conventional versus laparoscopic-assisted surgery in patients with colorectal cancer (MRC CLASICC trial): multicentre, randomised controlled trial. Lancet 2005;365(9472):1718–26. doi:10.1016/s0140-6736(05)66545-2.

[24] van der Pas MH, Haglind E, Cuesta MA, Fürst A, Lacy AM, Hop WC, et al. Laparoscopic versus open surgery for rectal cancer (COLOR II): short-term outcomes of a randomised, phase 3 trial. Lancet Oncol 2013;14(3):210–18. doi:10.1016/s1470-2045(13)70016-0.

[25] Veldkamp R, Kuhry E, Hop WC, Jeekel J, Kazemier G, Bonjer HJ, et al. Laparoscopic surgery versus open surgery for colon cancer: short-term outcomes of a randomised trial. Lancet Oncol 2005;6(7):477–84. doi:10.1016/s1470-2045(05)70221-7.

[26] Bonjer HJ, Deijen CL, Abis GA, Cuesta MA, van der Pas MH, de Lange-de Klerk ES, et al. A randomized trial of laparoscopic versus open surgery for rectal cancer. New Engl J Med 2015;372(14):1324–32. doi:10.1056/NEJMoa1414882.

[27] Buunen M, Veldkamp R, Hop WC, Kuhry E, Jeekel J, Haglind E, et al. Survival after laparoscopic surgery versus open surgery for colon cancer: long-term outcome of a randomised clinical trial. Lancet Oncol 2009;10(1):44–52. doi:10.1016/s1470-2045(08)70310-3.

[28] Fleshman J, Sargent DJ, Green E, Anvari M, Stryker SJ, Beart RW Jr, et al. Laparoscopic colectomy for cancer is not inferior to open surgery based on 5-year data from the COST Study Group trial. Ann Surg 2007;246(4):655–62 discussion 62-4. doi:10.1097/SLA.0b013e318155a762.

[29] Green BL, Marshall HC, Collinson F, Quirke P, Guillou P, Jayne DG, et al. Long-term follow-up of the Medical Research Council CLASICC trial of conventional versus laparoscopically assisted resection in colorectal cancer. Br J Surg 2013;100(1):75–82. doi:10.1002/bjs.8945.

[30] Jayne DG, Thorpe HC, Copeland J, Quirke P, Brown JM, Guillou PJ. Five-year follow-up of the Medical Research Council CLASICC trial of laparoscopically assisted versus open surgery for colorectal cancer. Br J Surg 2010;97(11):1638–45. doi:10.1002/bjs.7160.

[31] Kuhry E, Schwenk W, Gaupset R, Romild U, Bonjer J. Long-term outcome of laparoscopic surgery for colorectal cancer: a Cochrane systematic review of randomised controlled trials. Cancer Treat Rev 2008;34(6):498–504. doi:10.1016/j.ctrv.2008.03.011.

[32] Chen P, Zhou H, Chen C, Qian X, Yang L, Zhou Z. Laparoscopic vs. open colectomy for T4 colon cancer: a meta-analysis and trial sequential analysis of prospective observational studies. Front Surg 2022;9:1006717. doi:10.3389/fsurg.2022.1006717.

[33] Gangadharan A, Choi SE, Hassan A, Ayoub NM, Durante G, Balwani S, et al. Protein calorie malnutrition, nutritional intervention and personalized cancer care. Oncotarget 2017;8(14):24009–30. doi:10.18632/oncotarget.15103.

[34] Martínez-Arnau FM, Fonfría-Vivas R, Cauli O. Beneficial effects of leucine supplementation on criteria for sarcopenia: a systematic review. Nutrients 2019;11(10):2504. doi:10.3390/nu11102504.

[35] Lee SY, Lee HJ, Lim J-Y. Effects of leucine-rich protein supplements in older adults with sarcopenia: a systematic review and meta-analysis of randomized controlled trials. Arch Gerontol Geriatr 2022;102:104758. doi:10.1016/j.archger.2022.104758.

[36] Huebner M, Hübner M, Cima RR, Larson DW. Timing of complications and length of stay after rectal cancer surgery. J Am Coll Surg 2014;218(5):914–19. doi:10.1016/j.jamcollsurg.2013.12.042.