Impact of Preoperative Frailty on Postoperative Functional Recovery and Quality of Life in Elderly Patients With Gastrointestinal Tumors

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AIM: To examine the impact of preoperative frailty levels on postoperative functional recovery and quality of life in elderly individuals with gastrointestinal tumors, thereby providing evidence to inform perioperative clinical management.

METHODS: A total of 198 individuals aged ≥60 years who underwent radical resection of gastrointestinal tumors in the Department of General Surgery, The First Affiliated Hospital of Kunming Medical University from January 2019 to January 2024 were retrospectively analyzed. The Tilburg Frailty Indicator (TFI) was utilized to assess preoperative frailty; the Barthel Index was used to evaluate functional recovery at 30 and 90 days postoperatively; and the 12-Item Short-Form Health Survey (SF-12) was adopted to assess quality of life at 90 days postoperatively. Statistical analyses, such as chi-square test, logistic regression, and repeated measures analysis of variance, were performed.

RESULTS: The incidence of preoperative frailty was 19.2%, mainly manifested in the physical domain. Age, severe comorbidity (Charlson Comorbidity Index ≥6 points), operative duration ≥180 minutes, and preoperative depression were identified as independent risk factors for preoperative frailty, while habit of regular exercise was a protective factor ($p < 0.05$). Postoperatively, both the Barthel Index and SF-12 scores in the frailty group were significantly lower compared to the non-frailty group ($p < 0.001$).

CONCLUSIONS: Preoperative frailty delays postoperative functional recovery and reduces quality of life in elderly individuals with gastrointestinal tumors. Our findings support the inclusion of TFI in routine preoperative assessment, coupled with the implementation of targeted interventions.

Keywords: elderly gastrointestinal tumors; preoperative frailty; postoperative functional recovery; quality of life

Introduction

In China, the elderly individuals account for over 18.9% of the population. Gastrointestinal tumors in elderly individuals—predominantly gastric cancer and colorectal cancer—rank among the leading malignant tumors, with radical surgical resection serving as the primary therapeutic approach [1–3]. Age-related declines in physiological reserve significantly increase the incidence of frailty among older adults, making preoperative frailty a key risk factor for postoperative frailty in elderly patients with gastrointestinal tumors. Moreover, frailty is often accompanied by muscle mass loss and multisystem dysfunction, which not only increase the risk of postoperative complications but also may affect postoperative functional independence and quality of life [4–6].

At present, preoperative clinical evaluation of elderly patients with gastrointestinal tumors hinges on the assessments of the American Society of Anesthesiologists (ASA) classification and organ function, without taking frailty status into account [7,8]. Most of the existing studies focused on the assessments of postoperative frailty and short-term prognosis, in terms of complications and length of hospital stay [9]; however, targeted analyses on how preoperative frailty levels affect postoperative functional recovery (e.g., self-care ability) and quality of life (physical–psychological domains) remain scarce. Therefore, the objective of this research is to examine the impact of preoperative frailty on postoperative functional recovery and quality of life in elderly patients with gastrointestinal tumors, and analyze influencing factors of preoperative frailty, thereby providing an evidentiary basis for informing the perioperative management for this particular clinical population.

Methods

Study Subjects

Elderly patients aged ≥60 years who underwent radical resection of gastrointestinal tumors (open or laparoscopic surgery) under general anesthesia in the Department of General Surgery, The First Affiliated Hospital of Kunming Medical University from January 2019 to January 2024

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were retrospectively included. This research was conducted in compliance with the ethical principles outlined in the Declaration of Helsinki [10] and was granted ethical approval by the Ethics Committee of The First Affiliated Hospital of Kunming Medical University (2025-12). All participating patients provided written informed consent after having been briefed about the study's objective.

Inclusion criteria of this study are as follows: (1) patients aged ≥60 years, with gastric cancer, colon cancer, or rectal cancer confirmed by pathological examination; (2) patients who had undergone radical resection of gastrointestinal tumors (excluding palliative surgery and simple endoscopic stent placement); (3) patients with complete electronic medical record data, including preoperative Tilburg Frailty Indicator (TFI) scores, postoperative Barthel Index scores, 12-Item Short-Form Health Survey (SF-12) scores, Charlson Comorbidity Index (CCI) scores, and 15-Item Geriatric Depression Scale (GDS-15) scores; and (4) patients who agreed to participate in postoperative follow-up and completed the 90-day follow-up assessment.

Exclusion criteria of the current investigation are as follows: (1) patients who underwent emergency surgery for acute gastrointestinal tumors (e.g., emergency surgery for tumor rupture or massive bleeding); (2) patients with terminal-stage disease, evident by documentation of extensive tumor metastasis and expected survival of <3 months in medical records; (3) patients suffering from preoperative severe functional impairment (e.g., long-term bed rest, Barthel Index <30 points); (4) individuals with cognitive impairment or psychiatric disorders that preclude cooperation with study assessment, as documented in the medical records; (5) patients who lost to follow-up after surgery or failed to complete the 90-day Barthel Index assessment.

This retrospective study ultimately included 198 patients. According to a common rule of thumb in logistic regression analysis, the sample size should be commensurate with the number of independent variables to ensure the adequacy of the analysis. This study included 8 key independent variables, corresponding to a minimum recommended sample size of 80 cases. Therefore, the sample size of 198 patients is sufficient to meet the planned multivariate analysis. In addition, the study population included patients with different tumor locations and surgical methods, which may help improve the representativeness of the sample.

Observation Indicators

General Data and Disease Characteristics

Data were retrieved from the hospital's electronic medical record system, encompassing age, gender, regular exercise habits (engaging in light-to-moderate physical activity such as walking or *tai chi*, ≥3 times per week, with each session lasting ≥30 minutes in the six months prior to cancer diagnosis. This definition refers to the physical activity assessment standards commonly used for the elderly), tumor site (stomach/colon/rectum), history of neoadjuvant therapy, surgical approach (laparoscopic/open surgery), and operative duration.

Preoperative Frailty Assessment

The Chinese version of the TFI was utilized to evaluate preoperative frailty (data collected within 24 hours before surgery) [11]. This scale covers 3 domains: physical (8 items), psychological (3 items), and social (4 items), with a total of 15 items. It uses a binary scoring system (reverse scoring for some items), with a total score ranging from 0 to 15. Frailty was defined as a total score of ≥5 points. The scale demonstrated acceptable internal consistency (Cronbach's α = 0.686) and moderate test–retest reliability (0.620), supporting its overall psychometric adequacy.

Postoperative Functional Recovery Assessment

The Barthel Index was used to evaluate postoperative functional recovery (data at 30 and 90 days after surgery) [12]. This scale includes 10 items (e.g., eating, dressing, using the toilet), with a total score ranging from 0 to 100. Higher scores indicate enhanced self-care ability, signifying superior functional recovery outcomes. The scale demonstrated good internal consistency, with a Cronbach's α coefficient greater than 0.8, indicating reliable psychometric performance.

Postoperative Quality of Life Assessment

The SF-12 was used to assess postoperative quality of life (data at 90 days after surgery) [13]. This scale includes two domains: physical component summary (PCS, 4 subdomains) and mental component summary (MCS, 4 subdomains), with a total score ranging from 0 to 100. Higher scores reflect a better quality of life. Among elderly individuals, the Chinese-adapted SF-12 demonstrated good internal consistency (Cronbach's α = 0.828), indicating acceptable applicability and reliable psychometric performance. Nutritional status was indirectly reflected by preoperative hemoglobin and albumin levels in this study, and no specific nutritional risk assessment tools (e.g., Nutrition Risk Screening (NRS)-2002) were integrated into the frailty evaluation, which may limit the comprehensiveness of frailty assessment.

Other Key Indicators

Other key indicators include the following:

(1) Comorbidity status: The CCI was used [14]. Scoring was based on comorbid conditions documented in the medical records (e.g., cardiovascular disease, diabetes). A CCI score ≥6 was defined as an indicator for severe comorbidity, consistent with the cutoff value validated by Fernández-Cortiñas AB *et al*. [14] in patients with proximal humerus fractures.

(2) Mental status: Preoperative GDS-15 scores [15] and 20-Item Geriatric Anxiety Inventory (GAI-20) scores [16] were gleaned from the medical records. A GDS-15 score $\geq$8 indicates depression, whereas a GAI-20 score $\geq$9 indicates anxiety.
(3) Nutritional and laboratory indicators: Preoperative hemoglobin (a value $<$120 g/L was considered abnormal) and albumin (a value $<$35 g/L was considered abnormal) were extracted.
(4) Postoperative complications: The occurrence of early complications (e.g., bleeding, intestinal obstruction) within 5 days after surgery was recorded.

Data Collection Method

Two trained researchers (gastrointestinal surgery nurses) independently extracted data from the inpatient medical records and postoperative follow-up records, which are available in the hospital's electronic medical record system. For variables with discrepancies, such as tumor staging and TFI score determination, the data were reviewed and confirmed by a chief physician in the Department of Gastrointestinal Surgery.

Statistical Analysis

SPSS 25.0 statistical software (IBM Corporation, Armonk, NY, USA) was utilized for data analysis. Categorical data, such as gender and preoperative frailty, are expressed as frequency (percentage). The normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous data, including age and Barthel Index scores, that adhered to a normal distribution are presented as mean $\pm$ standard deviation (SD), while those deviating from a normal distribution are expressed as median (quartile) [M (Q1, Q3)]. The chi-square test was employed to compare variations in the proportion of preoperative frailty across patients with distinct characteristics and used Fisher's exact test where appropriate. For intergroup comparisons of continuous data, the *t*-test was utilized for normally distributed data, while the rank-sum test was applied to non-normally distributed data. Taking the presence of preoperative frailty as the dependent variable and indicators with $p < 0.05$ in univariate analysis and clinical relevance as independent variables, binary logistic regression (forward stepwise method) was used to identify independent influencing factors. Repeated measures analysis of variance (ANOVA) was used to compare the time effect, group effect, and interaction effect of Barthel Index scores at 30 and 90 days postoperatively between the frailty group and the non-frailty group. The *t*-test was used to compare the difference in postoperative SF-12 scores between the two groups, separately for PCS and MCS domains. Statistical significance was defined as a $p < 0.05$.

Results

General Data

The 198 enrolled patients had a mean age of 68.5 $\pm$ 5.7 years (age range 60–87 years). The cohort consisted of 132 males (66.7%) and 66 females (33.3%). In terms of tumor location, 40 cases (20.2%) had gastric tumors, 76 cases (38.4%) had colon tumors, and 82 cases (41.4%) had rectal tumors. Regarding surgical methods, 110 cases (55.6%) underwent laparoscopic surgery, and 88 cases (44.4%) underwent open surgery. Seventy-eight cases (39.4%) had a CCI score $\geq$6 (severe comorbidity); 45 cases (22.7%) had the habit of regular exercise; 23 cases (11.6%) had preoperative depression (GDS-15 score $\geq$8). Postoperative complications occurred in 13 cases (34.2%) in the preoperative frailty group and 20 cases (12.5%) in the non-frailty group (Table 1).

Postoperative Outcomes

A total of 33 cases (16.7%) of postoperative complications occurred. Among these, the incidence of complications in the preoperative frail group was 34.2% (13/38), which was significantly higher than the 12.5% (20/160) observed in the non-frail group; this difference was statistically significant ($\chi^2 = 10.421$, $p = 0.001$).

Preoperative Frailty Status in Elderly Patients With Gastrointestinal Tumors

Overall Incidence of Preoperative Frailty

Among the 198 patients, 38 cases (19.2%) suffered from preoperative frailty (TFI score $\geq$5), 62 cases (31.3%) were in the pre-frailty stage (TFI score 1–4), and 98 cases (49.5%) were non-frail (TFI score 0). The median total TFI score in patients with preoperative frailty was 6 (5, 8) points. Median scores by domain were 4 (3, 5) points for the physical domain, 2 (1, 3) points for the psychological domain, and 0 (0, 1) points for the social domain, indicating that physical frailty was the predominant manifestation.

Univariate Analysis of Preoperative Frailty

The univariate analysis revealed that the proportion of preoperative frailty was substantially elevated in patients with the following attributes ($p < 0.05$) (Table 2): (1) Age: the 80–87 years group (42.9%) $>$ the 70–79 years group (41.2%) $>$ the 60–69 years group (10.1%) ($\chi^2 = 26.049$, $p < 0.001$); (2) CCI score: the $\geq$6 group (38.5%) vs. the $<$6 group (6.7%) ($\chi^2 = 30.814$, $p < 0.001$); (3) Operative duration: the $\geq$180 min group (29.4%) vs. the $<$180 min group (8.3%) ($\chi^2 = 14.168$, $p < 0.001$); (4) Preoperative depression: yes (65.2%) vs. no (13.1%) ($\chi^2 = 35.545$, $p < 0.001$); (5) Regular exercise: no (23.5%) vs. yes (4.4%) ($p = 0.003$); (6) Hemoglobin: abnormal (34.0%) vs. normal (13.8%) ($\chi^2 = 10.181$, $p = 0.001$).

Table 1. General data of elderly individuals with gastrointestinal tumors (n = 198).

Items	Categories	Number of cases (n)	Percentage (%)
Age (years)	60–69	140	70.7
	70–79	51	25.8
	80–87	7	3.5
Gender	Male	132	66.7
	Female	66	33.3
Tumor location	Stomach	40	20.2
	Colon	76	38.4
	Rectum	82	41.4
Surgical method	Laparoscopy	110	55.6
	Laparotomy	88	44.4
CCI score (points)	<6	120	60.6
	≥6	78	39.4
Regular exercise	Yes	45	22.7
	No	153	77.3
Preoperative depression (GDS-15)	Yes	23	11.6
	No	175	88.4

CCI, Charlson Comorbidity Index; GDS-15, 15-Item Geriatric Depression Scale.

Table 2. Univariate analysis of influencing factors of preoperative frailty (n = 198).

Items	Categories	Non-frailty group (n = 160)	Frailty group (n = 38)	χ^2	p-value
Age (years)	60–69	126 (89.9)	14 (10.1)	26.049	<0.001
	70–79	30 (58.8)	21 (41.2)		
	80–87	4 (57.1)	3 (42.9)		
CCI score (points)	<6	112 (93.3)	8 (6.7)	30.814	<0.001
	≥6	48 (61.5)	30 (38.5)		
Operative duration (min)	<180	88 (91.7)	8 (8.3)	14.168	<0.001
	≥180	72 (70.6)	30 (29.4)		
Preoperative depression	Yes	8 (34.8)	15 (65.2)	35.545	<0.001
	No	152 (86.9)	23 (13.1)		
Regular exercise habit	Yes	43 (95.6)	2 (4.4)	-	0.003
	No	117 (76.5)	36 (23.5)		
Hemoglobin	Normal	125 (86.2)	20 (13.8)	10.181	0.001
	Abnormal	35 (66.0)	18 (34.0)		

Note: "-" indicates that only the p-value from the Fisher's exact test is reported.

Table 3. Binary logistic regression analysis of risk factors of preoperative frailty.

Variables	B	SE	Wald	p-value	OR	95% CI
Age	0.198	0.052	14.76	<0.001	1.218	1.105–1.342
CCI score (≥6 points)	1.140	0.325	12.31	<0.001	3.125	1.568–6.228
Operative duration (≥180 min)	1.064	0.368	8.35	0.004	2.897	1.403–5.978
Preoperative depression	0.831	0.385	4.68	0.031	2.293	1.035–5.087
Habit of Regular exercise	−0.794	0.362	4.87	0.027	0.452	0.231–0.884
Constant	−8.652	2.147	16.19	<0.001	0.000	-

SE, Standard Error; OR, Odds Ratio; CI, Confidence Interval.

Binary Logistic Regression Analysis of Influencing Factors for Preoperative Frailty

All variables with $p < 0.05$ from the univariate analysis, namely age, CCI score, operative duration, preoperative depression, regular exercise, and hemoglobin, were fed into the binary logistic regression model. The analysis showed that age, severe comorbidity (CCI score ≥6), operative duration ≥180 minutes, and preoperative depression were independent risk factors for preoperative frailty, whereas the habit of regular exercise was an independent protective fac-

Table 4. Comparison of postoperative barthel index scores between groups.

Group	Barthel Index scores (points), mean ± SD	
	30 days postoperatively	90 days postoperatively
Frailty group (n = 38)	51.2 ± 9.3	69.8 ± 8.5
Non-frailty group (n = 160)	68.5 ± 8.1	93.8 ± 7.3
Time	F = 246.351, $p < 0.001$	
Group	F = 108.724, $p < 0.001$	
Time × Group	F = 12.467, $p < 0.001$	

SD, standard deviation.

Table 5. Comparison of postoperative SF-12 scores between groups.

Domain	Group	Score at 90 days postoperatively (points), mean ± SD	t-value	p-value
Physical health (PCS)	Frailty group (n = 38)	32.1 ± 3.5	15.62	<0.001
	Non-frailty group (n = 160)	54.9 ± 4.1		
Mental health (MCS)	Frailty group (n = 38)	45.8 ± 4.2	10.37	<0.001
	Non-frailty group (n = 160)	56.5 ± 3.8		

MCS, mental component summary; PCS, physical component summary; SF-12, 12-Item Short-Form Health Survey.

tor (Table 3). The model demonstrated good fit (Hosmer–Lemeshow test: $\chi^2 = 6.890$, $p = 0.552$).

Impact of Preoperative Frailty on Postoperative Functional Recovery (Barthel Index)

The repeated measures ANOVA revealed a significant main effect of time on postoperative functional recovery (F = 246.351, $p < 0.001$), indicating that the postoperative function of patients in both groups exhibited a continuous recovery trend as time elapsed. A significant intergroup main effect was also observed (F = 108.724, $p < 0.001$), suggesting that preoperative frailty status exerted a notable impact on postoperative functional recovery. The interaction effect was statistically significant (F = 12.467, $p < 0.001$), implying that the two groups differed in the rate of functional recovery (Table 4).

Impact of Preoperative Frailty on Postoperative Quality of Life (SF-12)

The SF-12 assessment at 90 days after surgery showed that both PCS and MCS scores in the frailty group were significantly lower compared to the non-frailty group ($p < 0.001$). This indicates that the subjects in the frailty group experienced a worse quality of life (Table 5).

Discussion

In conjunction with the accelerated trend of aging, China saw an ever-increasing incidence of gastrointestinal tumors—mainly gastric cancer and colorectal cancer—in the elderly population aged 60 years, with radical surgical resection as the primary treatment mode for this demographic group [17–19]. Nevertheless, inherent age-related declines in physiological reserve resulted in a notably higher prevalence of frailty syndrome in elderly people than in younger populations. Frailty not only manifests as a decline in physical functions measured in terms of muscle strength and exercise endurance, but also is accompanied by multiple dysfunctions reflected in the psychological and social dimensions. By affecting surgical tolerance, postoperative inflammatory response, and tissue repair processes, frailty contributes to an indirect, adverse impact on patients' prognosis [20,21]. Currently, preoperative clinical evaluation for elderly patients with gastrointestinal tumors relies heavily on assessments of traditional indicators such as ASA classification and organ function, without including frailty within its evaluation framework. Despite a predominant focus on exploring the association of postoperative frailty with short-term complications and length of hospital stay, targeted analyses on the impact of preoperative frailty on postoperative functional independence (e.g., self-care ability) and quality of life (dual physical–psychological domains) are lacking in existing studies. Therefore, this research employed an analysis of retrospective data by using the Chinese version of the TFI, Barthel Index, and SF-12 scale to systematically examine the severity of preoperative frailty, identify its influencing factors, and analyze its effect on postoperative functional recovery and quality of life, thereby providing empirical evidence for optimizing perioperative management of elderly patients with gastrointestinal tumors and filling the gap in regionalized research.

This study showed that the incidence of preoperative frailty (TFI score ≥5) among 198 individuals was 19.2%, which was significantly lower than the rate reported in a previous study (about 40.3%) [21]. This difference is mainly attributed to the implementation of assessment at different time points and the stress states: surgery, as a traumatic stressor, can trigger the body to release pro-inflammatory factors such as interleukin 6 (IL-6) and C-reactive protein (CRP), and disrupt the body's homeostasis, thereby augmenting the risk for postoperative frailty. Preoperative as-

sessment is not affected by surgical stress, providing a better or more accurate indicator of the frailty level in patients. From the perspective of frailty dimension distribution, patients with preoperative frailty in this study exhibited the highest score in the physical domain [4 (3, 5) points], followed by the psychological domain [2 (1, 3) points], and the lowest score in the social domain [0 (0, 1) points]. This pattern aligns with the findings of Maeda *et al*. [22] in elderly patients with colorectal cancer. Individuals with gastrointestinal tumors often experience muscle mass loss and reduced exercise endurance due to tumor-related metabolic consumption and impaired nutrient absorption, making physical frailty the main manifestation. The relatively low scores in the social domain may be attributable to strong family support, which could help buffer against the development of social frailty. Furthermore, the prevalence of preoperative frailty in the present study was lower compared to that in Zhang *et al*.'s research (43.8%) [23], where the Groningen Frailty Indicator (GFI) was adopted as the evaluation tool. In addition to the differences in assessment tools, this finding may also be related to the baseline characteristics of patients in this study. Notably, 22.7% of patients reported engaging in regular exercise. Such activity can help delay the progression of physical frailty by improving muscle strength and enhancing cardiopulmonary reserve, thereby indirectly reducing the incidence of preoperative frailty.

In this study, binary logistic regression analysis identified age as an independent risk factor for preoperative frailty (Odds Ratio [OR] = 1.218, 95% Confidence Interval [CI]: 1.105–1.342) and revealed that the incidence of frailty among patients aged 80–87 years (42.9%) was approximately four times that observed in those aged 60–69 years (10.1%), with the 70–79 years group showing a similarly high frailty prevalence (41.2%). With advancing age, skeletal muscle mass in older adults decreases at an annual rate of approximately 1% [24]. At the same time, declines in digestive and absorption functions common in this age group contribute to malnutrition, which is a key factor of physical frailty [25]. In this study, patients with a CCI score $\geq$6 (indicating severe comorbidity) had a markedly elevated risk of preoperative frailty (OR = 3.125). This finding is consistent with Han *et al*. [26], who reported similar results in elderly patients undergoing thoracic and abdominal surgery. Severe comorbidities, such as hypertension and diabetes, aggravate frailty through polypharmacy and organ dysfunction (e.g., abnormal protein metabolism associated with renal insufficiency), thereby creating a vicious cycle of "comorbidity–polypharmacy–malnutrition–frailty".

The risk of preoperative frailty in patients with operative duration $\geq$180 min increased by 2.897 times. Although operative duration is an intraoperative variable, the preoperative expectation of prolonged surgical trauma may induce psychological stress and sleep disorders, which are associated with preoperative frailty. Therefore, operative duration is regarded as an associated factor rather than a causal determinant. This may be accounted for by the "pre-effect" of surgical stress: although the assessment was conducted preoperatively, anticipation of a prolonged surgical procedure (such as concerns about surgical difficulty and trauma) may provoke preoperative anxiety, leading to sleep disturbances. Inadequate sleep may, in turn, suppress the secretion of growth hormone and accelerate muscle protein hydrolysis [27]. At the same time, a prolonged surgical procedure is associated with increased intraoperative release of inflammatory factors. Even without having undergone surgery prior to the assessment, psychological stress related to surgical trauma may activate the hypothalamic–pituitary–adrenal axis, resulting in elevated cortisol levels and thereby indirectly promoting the development of frailty. In the present study, patients with preoperative frailty had a 2.293-fold higher risk of preoperative depression (defined as GDS-15 score $\geq$8). Depressive symptoms may reduce appetite, contributing to abnormal hemoglobin levels, and also diminish physical activity, thereby further compromising functional reserve and ultimately increasing the risk of frailty.

Regular exercise—defined as $\geq$3 sessions per week, each lasting $\geq$30 minutes—was found to be associated with a reduced risk of preoperative frailty by 54.8% (OR = 0.452), consistent with previous research findings on elderly patients with gastric cancer [23]. Resistance exercise, such as elastic band training, can increase the mitochondrial content of skeletal muscle and improve muscle strength [28], whereas aerobic exercise, such as brisk walking, can enhance cardiopulmonary endurance and improve the body's stress resistance, providing a physiological basis for coping with tumor consumption and surgical trauma before surgery. In addition, exercise may improve mood by promoting the secretion of endorphins, thereby indirectly reducing the likelihood of depression and further reducing the risk of frailty.

Our repeated measures ANOVA examined the impact of preoperative frailty on postoperative functional recovery across three dimensions: the main effect of time, the main effect between groups, and the interaction effect. Compared with the single-time-point analysis, this statistical test offers a more comprehensive analysis of the joint effect of "time" and "group" on the outcome. From the perspective of the main effect of time ($F = 246.351$, $p < 0.001$), the Barthel Index of patients in both groups increased significantly from 30 days to 90 days after surgery. This aligns with the typical trajectory of postoperative functional recovery in elderly patients with gastrointestinal tumors, presented as the resolution of postoperative inflammation, improvement in gastrointestinal function, gradual restoration of the ability to perform activities, and gradual improvement in self-care ability. From the perspective of the main effect between groups ($F = 108.724$, $p < 0.001$), the Barthel Index of the frailty group at 30 days and 90 days

post-surgery was substantially lower than that of the non-frailty group, suggesting that preoperative frailty is associated with a "lower starting point" for postoperative functional recovery. This is primarily attributed to pre-existing muscle mass loss, reduced muscle strength, and diminished multisystem reserve in this patient group, which are further aggravated by surgical trauma. Furthermore, the interaction effect ($F = 12.467$, $p < 0.001$) indicated a significantly slower functional recovery rate in the frailty group compared with the non-frailty group, which was reflected by the smaller increase in Barthel Index scores from 30 to 90 days postoperatively in the frailty group (18.6 points) than in the non-frailty group (25.3 points). Delayed postoperative ambulation due to poor muscle strength impairs gastrointestinal peristalsis and limits nutrient intake, creating a vicious cycle that hinders functional recovery. On the other hand, the chronic inflammatory state, characterized by the increased levels of IL-6 and CRP, may delay wound healing and tissue repair under the circumstances of frailty, and elevate the risk of complications such as infection and intestinal obstruction [29]. In this study, the incidence of postoperative complications was significantly higher in the frailty group compared with the non-frailty group (34.2% vs. 12.5%). These complications may further impede recovery by occupying patients' recovery time, thereby hampering the process of functional restoration.

At 90 days post-surgery, the frailty group had a significantly lower SF-12 PCS score (32.1 $\pm$ 3.5 points) compared with the non-frailty group (54.9 $\pm$ 4.1 points). This difference was mainly due to physical pain, such as more pronounced incision pain, and reduced vitality, including fatigue stemming from diminished muscle mass, both of which are characteristic consequences of frailty. Meanwhile, the MCS score of the frailty group (45.8 $\pm$ 4.2 points) was lower than that of the non-frailty group (56.5 $\pm$ 3.8 points), reflecting the adverse impact of functional impairments on emotions. Individuals with preoperative frailty often experience reduced self-efficacy due to challenges in independently performing activities such as dressing and using the toilet, which exacerbates anxiety and depressive symptoms, thereby setting up a vicious cycle of "impaired function $\rightarrow$ negative emotions $\rightarrow$ decreased quality of life" [30].

Several limitations of this study should be acknowledged. First, due to the single-center nature of this retrospective study, the demographic attributes of the participating subjects in our sample lack diversity. The cohort included a high proportion of males (66.7%) and patients reporting regular exercise habits (22.7%), which may exceed the average levels observed in similar populations in other primary medical institutions or in rural areas. This may introduce potential selection bias and limit the generalizability of the findings. Second, postoperative quality of life was measured with only one instrument, i.e., SF-12, and tools oriented toward gauging postoperative recovery experience were not included. Third, preoperative biological indicators such as inflammatory factors and muscle mass were not detected, thus hampering more in-depth analyses of the mechanism of preoperative frailty affecting postoperative outcomes. Fourth, follow-up was limited to 90 days post-surgery, precluding the assessment of the long-term impact of preoperative frailty on functional recovery and quality of life. Additionally, participation in postoperative rehabilitation programs was not recorded, potentially overlooking important confounding factors. Fifth, this study utilized retrospectively collected data, which were archived in the electronic medical records. Unfortunately, data from several indicators lack specificity (such as details of regular exercise and the degree of sleep disorders) and may be vague or biased. Furthermore, the accuracy of our results could be further affected since the history of preoperative pre-rehabilitation intervention was not collected and analyzed. Sixth, frailty evaluation was limited by a lack of specific nutritional risk assessment tools adopted in this study. Seventh, the Barthel Index used to evaluate functional recovery may exhibit a ceiling effect in the non-frailty group, potentially limiting its sensitivity in distinguishing the degree of functional recovery. Eighth, TNM staging and history of neoadjuvant therapy were not included in the multivariate regression model, and there may be unrecognized confounding effects. Ninth, the potential influence of surgical approach (laparoscopic vs. open surgery) on postoperative recovery was not analyzed, yet this variable could affect the recovery trajectory of patients. Tenth, regular exercise was assessed based on self-reported data, which may be subject to recall and information biases.

In light of the aforementioned limitations, multicenter prospective investigations are recommended for future work by using an expanded sample size and harmonizing patients' baseline attributes to enhance the generalizability of the results obtained. The evaluation system should be optimized by integrating supplementary tools for postoperative recovery assessment and detection of biological indicators (e.g., IL-6, CRP, muscle mass). In addition, the follow-up period should be extended to 6 months and 1 year post-surgery to explore the long-term effects. At the same time, based on the high-risk and protective factors identified in this study, preoperative pre-rehabilitation programs should be developed and their effectiveness evaluated. Ultimately, a clinical screening and intervention pathway for preoperative frailty in elderly individuals with gastrointestinal tumors should be established to provide more precise guidance for clinical practice.

Conclusions

In the present study, preoperative frailty was observed in 19.2% of elderly patients with gastrointestinal tumors, with the physical domain being the most prominent manifestation. Independent risk factors for preoperative frailty included advanced age, severe comorbidity (CCI score $\geq$6), operative duration $\geq$180 min, and preoperative depression

(GDS-15 score ≥8), whereas regular exercise habit (≥3 times/week, ≥30 minutes per session in the first half year before surgery) served as an independent protective factor. Our study also found that preoperative frailty significantly delayed the functional recovery in patients at 30 days and 90 days postoperatively and reduced their quality of life at 90 days post-surgery. To better assess the frailty level, the Chinese version of TFI is recommended to be included in the routine preoperative evaluation of elderly patients with gastrointestinal tumors. Meanwhile, targeted interventions for high-risk groups, along with the promotion of regular exercise, should be implemented to improve postoperative outcomes.

Availability of Data and Materials

All data included in this study can be obtained by contacting the corresponding author if needed.

Author Contributions

FJX conceived and designed the study and drafted the original manuscript. CX and GQB contributed to the study design, participated in clinical data extraction and verification. BY and XYZ conducted postoperative patient follow-up, collated and organized all observation indicator data. BWF contributed to the data acquisition and interpretation of research results. ZBZ supervised and guided the entire study and contributed to the study design and statistical data analysis. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This research complied with the ethical principles outlined in the Declaration of Helsinki and was granted ethical approval by the Ethics Committee of The First Affiliated Hospital of Kunming Medical University (2025-12). All participating patients provided written informed consent after understanding the purpose of the study.

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Conflict of Interest

The authors declare no conflict of interest.

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