Langenbeck's Archives of Surgery (2026) 411:23
https://doi.org/10.1007/s00423-025-03910-6

RESEARCH

Effects of enhanced recovery after surgery nursing combined with early enteral nutrition on Gastrointestinal function recovery after radical gastrectomy

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Received: 14 August 2025 / Accepted: 19 October 2025
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Abstract

Objective This study explored the effects of enhanced recovery after surgery (ERAS) nursing combined with early enteral nutrition support on postoperative gastrointestinal function in patients undergoing radical gastrectomy for gastric cancer.

Methods Ninety-six patients were randomly assigned to either an experimental group, which received ERAS nursing plus early enteral nutrition, or a routine group, which received conventional perioperative nursing with standard nutritional support. Postoperative gastrointestinal recovery, intraoperative indicators, nutritional markers [transferrin (TRF), albumin (ALB), prealbumin (PAB)], immune indicators [CD3+, CD4+, CD8+, CD4+/CD8+, IgA, IgM, IgG], quality of life (EORTC QLQ-C30), and complication rates were compared between the two groups.

Results The experimental group showed significantly shorter times to first flatus (2.45 vs. 3.84 days), first bowel movement (3.39 vs. 5.61 days), and hospital stay (8.75 vs. 12.50 days) than the routine group ($P<0.05$). On postoperative day 7, TRF, ALB, PAB, CD3+, CD4+, CD4+/CD8+, IgA, IgM, and IgG levels were significantly higher in the experimental group than in the routine group ($P<0.05$). The experimental group also achieved higher quality-of-life scores across somatic, role, cognitive, social, emotional, and global health domains, and had a lower complication rate compared to the routine group (6.25% vs. 31.25%) ($P<0.05$).

Conclusion ERAS nursing combined with early enteral nutrition accelerates gastrointestinal recovery, enhances nutritional and immune status, improves quality of life, and reduces postoperative complications in patients undergoing radical gastrectomy for gastric cancer.

Keywords Fast track surgery nursing · Gastric cancer · Early enteral nutrition support · Radical gastrectomy · Gastrointestinal function · Immune function · Nutritional status · Postoperative complications

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Introduction

Gastric cancer (GC) is one of the most prevalent malignancies worldwide and remains a major global health concern due to its high incidence and mortality rates [1]. As a highly heterogeneous tumor [2], early-stage GC can often be effectively treated with endoscopic resection [2], while advanced GC typically requires radical gastrectomy [3]. However, radical gastrectomy is a highly invasive abdominal procedure that inevitably causes damage to the gastrointestinal tract, leading to complications, and adversely affecting postoperative recovery and quality of life [4, 5].

To improve perioperative management, the "Enhanced Recovery After Surgery (ERAS) Study Group" issued a series of evidence-based recommendations in 2012,

Published online: 27 November 2025

aiming at reducing complications, improving outcomes, and shortening hospital stays [6]. Through multidisciplinary collaboration, the ERAS pathway has since been widely implemented in the perioperative management of GC patients. Core elements include comprehensive preoperative education, effective analgesia, avoidance of bowel preparation, early oral intake, minimal use of drains and nasogastric tubes, and early mobilization [7]. Current ERAS guidelines [8, 9] demonstrate that ERAS protocols improve outcomes after laparoscopic radical gastrectomy. In particular, ERAS-based multimodal analgesia has been shown to reduce postoperative pain and mitigate surgical stress responses, ultimately facilitating recovery [10].

Meanwhile, nutritional support plays a crucial role in postoperative recovery following radical gastrectomy for GC [11]. Preoperative enteral nutrition has been reported to enhance postoperative immune function and nutritional status, attenuate inflammatory responses, and promote recovery [12]. Moreover, early postoperative enteral nutrition has demonstrated benefits in patients with GC and comorbid diabetes, contributing to improved nutritional status, fewer complications, and stable glycemic control [13].

Despite the growing application of ERAS, high-quality evidence on the combined effects of ERAS and nutritional support on gastrointestinal functional recovery remains limited. Therefore, this study integrated an early enteral nutrition protocol into ERAS-based nursing to systematically evaluate its impact on patients undergoing radical gastrectomy for GC. Perioperative management was conducted in strict accordance with international ERAS guidelines, while nutritional support was delivered using a stepwise intervention strategy. The ultimate aim was to establish an individualized and precise perioperative management model and provide a novel strategy for enhancing postoperative recovery in GC patients.

Methods and materials

Ethics statement

This study was approved by the Ethics Committee of the Cancer Hospital Affiliated to Harbin Medical University and followed the principles of the Declaration of Helsinki. Written informed consent was obtained from all patients prior to participation.

Study subjects

Patients admitted to the Cancer Hospital Affiliated to Harbin Medical University who required laparoscopic-assisted radical gastrectomy were recruited. Inclusion criteria: (1) Pathologically confirmed GC suitable for laparoscopic-assisted radical gastrectomy; (2) No surgical contraindications and voluntary agreement to undergo surgery; (3) No preoperative radiotherapy, chemotherapy, immunotherapy, or hormone therapy; (4) Expected survival > 6 months; (5) Normal cognitive function and ability to communicate; (6) Complete medical records; (7) Signed consent forms for surgery. Exclusion criteria: (1) Concurrent malignancies; (2) Coagulation or immune dysfunction; (3) Severe cardiopulmonary dysfunction; (4) Mental disorders; (5) Participation in other research studies; (6) Intestinal obstruction; (7) Stage IV GC.

After screening, 96 eligible patients were enrolled and randomly assigned to the experimental group ($n=48$) or the routine group ($n=48$) using a lottery method. The experimental group received perioperative management based on ERAS nursing principles combined with early enteral nutrition support, whereas the routine group received conventional perioperative nursing and nutritional support.

Intervention methods

All surgeries were performed by the same surgical team to minimize operator-related bias.

Perioperative management

In the experimental group, ERAS-based nursing interventions were implemented [14]. A multidisciplinary nursing team composed of nurses, surgeons, anesthesiologists, nutritionists, and psychological counselors developed and delivered a patient-centered, individualized care plan. Specific measures are summarized i Table 1.

The routine group received standard perioperative care, with details also outlined Table 1.

Nutritional support

The experimental group received early enteral nutrition interventions [15]: ① Parenteral nutrition: On postoperative day 1, patients with severe preoperative malnutrition, intolerance to enteral nutrition, or anticipated inadequate intake (< 50% of requirements for >7 days) were provided with total parenteral nutrition. ② Enteral nutrition and parenteral nutrition: Beginning on postoperative day 2, patients were placed in a 30° semi-recumbent position. A nasojejunal feeding tube (Freka Tube, Fresenius Kabi AG, Germany) was used to administer 250 mL of 5% glucose-sodium chloride solution at an initial rate of 20–30 mL/h, with gradual advancement according to tolerance. Short peptide formulas were introduced on days 2–3, followed by whole-protein formulas from day 4, starting at 0–15 kcal/kg/day (1 kcal

Table 1 Comparison of perioperative measures between the two groups of patients

Measures	Routine group	Experimental group
Preoperative education	Routine education, introducing treatment methods, perioperative procedures, etc.	Conducting preoperative education through multiple means to enable patients to fully understand disease knowledge and treatment methods; providing psychological care through peer support, relaxation training, family care, etc.
Risk assessment	Not addressed	Conducting nutritional screening before surgery using the Nutritional Risk Screening 2002 (NRS2002) and providing corresponding nutritional support based on the nutritional risk level; simultaneously conducting thrombus risk assessment, and administering subcutaneous low-molecular-weight heparin calcium when the Caprini score > 3 as per doctor's advice.
Preoperative fasting and water restriction	Solid diet 3 days before surgery, fasting 12 h before surgery, and water restriction 8 h before surgery.	Fasting from solid food 6 h before surgery, and oral intake of 400 mL of 10% glucose solution 2 h before surgery.
Antibiotic use	Regular antibiotic use postoperatively until 3–4 days after surgery.	Prophylactic antibiotic use before surgery, administering broad-spectrum antibiotics 30 min before surgery, and continuing until 2 days postoperatively.
Anesthesia and analgesia	No prophylactic analgesia before surgery; general anesthesia or epidural combined with blockade anesthesia used during surgery, with no particular avoidance of opioids; conventional analgesics administered postoperatively, with no particular avoidance of opioids.	Prophylactic analgesia administered; epidural combined with blockade anesthesia used during surgery, with avoidance of opioids; non-opioid analgesics administered as needed postoperatively rather than following routine methods.
Intraoperative warming	No special warming measures	Providing warming measures such as electric blankets, warming the infusion fluid before use, and using heated air hoods to avoid hypothermia.
Incision management	Not emphasized	Minimizing the size of the incision as much as possible.
Drainage tube	Routine indwelling	Not routinely indwelling
Postoperative diet	Not emphasized	Early enteral nutrition
Postoperative extubation	Indwelling before surgery, removed 2–4 days postoperatively.	Indwelling after anesthesia, removed 1–2 days postoperatively.
Ambulation after surgery	According to patient's will	Increasing postoperative activity, with ambulation on the second day after surgery.
Fluid resuscitation	Starting fluid resuscitation 1 day postoperatively and continuing until 2–3 days postoperatively.	Administering fluid resuscitation for 1 day on the day of surgery, and reducing the fluid volume based on the patient's intake on the next postoperative day.

= 4.186 kJ) and progressively increased. The solution was warmed to body temperature, with infusion rates titrated from 20 mL/h up to a maximum of 80 mL/h. Parenteral nutrition was reduced as enteral intake increased. ③ Dietary guidance: Patients with normal preoperative nutritional status and no severe postoperative gastrointestinal reactions were encouraged to drink warm water 6 h after surgery, advance to a full liquid diet on postoperative day 1, and transition to a semi-liquid diet on day 2. Patients failing to meet nutritional goals received supplemental enteral or parenteral nutrition.

The routine group received conventional nutritional support consisting of postoperative parenteral nutrition, with oral intake resumed after the first passage of flatus. A gradual transition from liquid to semi-liquid diets was followed, with parenteral supplementation provided when caloric intake was insufficient.

Evaluation indicators

The primary outcomes of this study were postoperative gastrointestinal functional recovery, including time to first flatus, time to first bowel movement, and length of hospital

stay. Secondary outcomes included intraoperative parameters (operation time and intraoperative blood loss), nutritional markers [transferrin (TRF), albumin (ALB), and prealbumin (PAB)], immune indicators [CD3+, CD4+, CD8+, IgA, IgM, and IgG], quality of life assessed with the Cancer Quality of Life Questionnaire Core 30 (QLQ-C30), and postoperative complications.

1. (1) Postoperative gastrointestinal recovery and intraoperative related indicators: The times to first flatus, first bowel movement, and hospital stay, as well as operation duration and intraoperative blood loss, were recorded for both groups.
2. (2) Nutritional indicators: TRF, ALB, and PAB levels were measured before surgery and on postoperative day 7 using commercial assay kits (Shenzhen Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China).
3. (3) Immune indicators: Cellular immune markers (CD3+, CD4+, and CD8+) and humoral immune markers (IgA, IgM, and IgG) were assessed preoperatively and on postoperative day 7. T-lymphocyte subsets were measured by flow cytometry, and immunoglobulins were quantified using an immunoturbidimetric assay.
4. (4) Quality of life: Quality of life was evaluated by telephone follow-up and outpatient review within 2 months postoperatively, using the validated Chinese version of the EORTC QLQ-C30 [16]. The scale assesses somatic, emotional, cognitive, and social functions, with total scores ranging from 0 to 100; higher scores indicate better quality of life.
5. (5) Complications: Postoperative complications were monitored by nurses, including gastrointestinal symptoms (nausea, vomiting, bloating), wound infection, intestinal obstruction, anastomotic leakage, and pulmonary infection.

Table 2 The general data between the two groups of patients [(mean ± SD), *n* (%)]

General data	Routine group (*n* = 48)	Experimental group (*n* = 48)	*P* value
Age (years)	70.58 ± 2.58	69.88 ± 2.19	0.158[a]
Body mass index (kg/m^2)	22.63 ± 2.94	22.86 ± 2.85	0.698[a]
NRS2002 score	3.01 ± 0.39	3.09 ± 0.43	0.342[a]
Gender			0.650[b]
Male	36 (75.00)	33 (68.75)	
Female	12 (25.00)	15 (31.25)	
TNM stage			0.881[b]
I	16 (33.33)	17 (35.42)	
II	21 (43.75)	22 (45.83)	
III	11 (22.92)	9 (18.75)	
Histological type			0.950[b]
Adenocarcinoma	28 (58.33)	27 (56.25)	
Mucinous adenocarcinoma	16 (33.33)	16 (33.33)	
Indocellular carcinoma	3 (6.25)	3 (6.25)	
Others	1 (2.08)	2 (4.17)	
Tumor site			0.682[b]
Gastric sinus	28 (58.33)	24 (50.00)	
Gastric body	15 (31.25)	17 (35.42)	
Gastric base	5 (10.42)	7 (14.58)	

Note: *NRS2002* Nutritional Risk Screening 2002, *TNM* tumor node metastasis. P^a was analyzed using an independent samples t-test, P^b was analyzed using the chi-square test

Sample size calculation

Based on data from a previous study [17], the mean ± SD time to first flatus was 2.63 ± 1.07 days in the ERAS group and 3.35 ± 1.32 days in the control group. Using G*Power software (version 3.1.9.7), a sample size of 45 patients per group was calculated to achieve a statistical power of 0.8 with a two-sided α of 0.05. To account for an anticipated dropout rate of 6–7%, the final required sample size was 96 patients.

Statistical analysis

Data analysis was performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Continuous variables with normal distribution were expressed as mean ± SD and compared using independent-samples t-tests. Categorical variables were expressed as counts and compared using the chi-square (χ^2) test. A P value < 0.05 was considered statistically significant.

Results

General data

There were no significant differences between the two groups in age, body mass index, NRS2002 scores, gender, TNM stage, histological type, or tumor location($P > 0.05$), indicating comparability between groups (Table 2).

Postoperative gastrointestinal recovery and intraoperative indicators

Compared with the routine group, patients in the experimental group had shorter times to first flatus and first bowel movement, as well as a reduced length of hospital stay ($P < 0.05$). There were no significant differences in operation duration or intraoperative blood loss between the two groups ($P > 0.05$) (Table 3).

Nutritional indicators

Preoperatively, serum TRF, ALB, and PAB levels did not differ significantly between the two groups ($P>0.05$). On postoperative day 7, levels of TRF, ALB, and PAB were significantly higher in the experimental group than in the routine group ($P<0.05$) (Table 4).

Immune function indicators

No significant differences in immune parameters were observed between groups before surgery ($P>0.05$). On postoperative day 7, levels of CD3+, CD4+, CD4+/CD8+, IgA, IgM, and IgG were significantly higher in the experimental group compared with the routine group ($P<0.05$) (Table 5).

Quality of life

Postoperatively, patients in the experimental group achieved significantly higher QLQ-C30 scores in somatic, role, cognitive, social, and emotional functioning, as well as overall health, compared with those in the routine group ($P<0.05$) (Table 6).

Postoperative complications

In the routine group, 9 patients experienced gastrointestinal symptoms, 3 had incision infections, 2 developed intestinal obstruction (which was resolved after treatment with gastrointestinal decompression and medication), and 1 presented with an anastomotic fistula (which healed after adequate drainage and anti-infective treatment), totaling 15 cases. In the experimental group, there were 2 cases of gastrointestinal symptoms and 1 case of incision infection, totaling 3 cases. The incidence of postoperative complications was significantly lower in the experimental group (6.25%) compared with the routine group (31.25%) ($P<0.05$) (Table 7).

Discussion

This study investigated the impact of ERAS nursing combined with early enteral nutrition support on postoperative gastrointestinal recovery in patients with GC undergoing radical gastrectomy. The results indicated that this combined approach accelerated gastrointestinal function recovery, improved nutritional and immune status, and reduced postoperative complications.

Specifically, compared with the routine group, patients in the experimental group had earlier first flatus and first bowel movement, as well as a shorter hospital stay. hese results suggest that ERAS nursing, when integrated with early enteral nutrition, effectively stimulates intestinal peristalsis and facilitates earlier restoration of gastrointestinal physiological function. This is consistent with the findings of Huang et al., who reported that ERAS protocols in radical gastrectomy significantly accelerated recovery, shortened hospital stays, and reduced the time to first defecation and flatulence [18]. Other studies also support that ERAS interventions, with minimal complications and low readmission

Table 3 The postoperative Gastrointestinal recovery and intraoperative related indicators between the two groups of patients (mean ± SD)

Indicators	Routine group ($n=48$)	Experimental group ($n=48$)	P value
Postoperative gastrointestinal recovery			
Time to first flatus (d)	3.84 ± 0.65	2.45 ± 0.86	<0.001[a]
Time to first bowel movement (d)	5.61 ± 0.93	3.39 ± 0.51	<0.001[a]
Postoperative hospital stay (d)	12.50 ± 2.03	8.75 ± 1.27	<0.001[a]
Intraoperative related indicators			
Surgery duration (min)	216.56 ± 40.62	208.54 ± 37.13	0.315[a]
Intraoperative bleeding (mL)	80.72 ± 27.15	76.28 ± 24.34	0.401[a]

Note: P^a was analyzed using an independent samples t-test

Table 4 Nutritional indicators between the two groups of patients before and 7 d after the surgery (mean ± SD)

Indicators	Routine group ($n=48$)		Experimental group ($n=48$)	
	Preoperative	Postoperative	Preoperative	Postoperative
TRF (g/L)	2.35 ± 0.27	1.63 ± 0.17	2.31 ± 0.31	1.98 ± 0.18*
ALB (g/L)	39.49 ± 1.98	34.54 ± 0.86	39.26 ± 1.96	37.72 ± 1.55*
PAB (g/L)	0.29 ± 0.08	0.12 ± 0.03	0.30 ± 0.06	0.24 ± 0.05*

Note: *TRF* transferrin, *ALB* albumin, *PAB* prealbumin. *$P<0.05$ vs. routine group postoperatively, as analyzed by an independent samples t-test

Table 5 Immune function indicators between the two groups of patients before and 7 d after the surgery (mean ± SD)

Indicators	Routine group ($n=48$)		Experimental group ($n=48$)	
	Preoperative	Postoperative	Preoperative	Postoperative
CD3+(%)	60.31 ± 3.23	53.05 ± 2.11	60.16 ± 3.81	57.38 ± 2.31*
CD4+(%)	38.39 ± 1.59	32.79 ± 1.46	38.51 ± 1.63	35.29 ± 1.30*
CD4+/CD8+	1.66 ± 0.12	1.07 ± 0.08	1.61 ± 0.17	1.29 ± 0.11*
IgA (g/L)	2.34 ± 0.46	1.77 ± 0.36	2.31 ± 0.48	1.97 ± 0.32*
IgM (g/L)	1.19 ± 0.15	0.69 ± 0.09	1.16 ± 0.16	0.87 ± 0.11*
IgG (g/L)	14.42 ± 2.88	9.79 ± 1.34	14.57 ± 2.61	11.34 ± 1.62*

Note: Immunoglobulin A, IgA. *$P<0.05$ vs. routine group postoperatively, as analyzed by an independent samples t-test

Table 6 Postoperative quality of life between the two groups of patients (mean ± SD)

	Routine group (n=48)	Experimental group (n=48)	P value
Somatic function	41.35 ± 7.45	46.56 ± 7.35	<0.001[a]
Role function	52.33 ± 8.42	57.27 ± 8.52	0.005[a]
Cognitive function	65.27 ± 8.22	69.40 ± 8.53	0.018[a]
Social function	42.08 ± 7.98	47.94 ± 8.04	<0.001[a]
Emotional function	62.65 ± 8.64	68.52 ± 9.80	0.002[a]
Overall health	65.79 ± 7.39	78.33 ± 8.33	<0.001[a]

Note: P^a was analyzed using an independent samples t-test

Table 7 Postoperative complications between the two groups of patients [n (%)]

Postoperative complications	Routine group (n=48)	Experimental group (n=48)	P value
Mild			
Digestive system symptoms	9 (18.75)	2 (4.17)	
Incision infection	3 (6.25)	1 (2.08)	
Severe			
Anastomotic fistula	1 (2.08)	0 (0.00)	
Intestinal obstruction	2 (4.17)	0 (0.00)	
Pulmonary infection	0 (0.00)	0 (0.00)	
Total	15 (31.25)	3 (6.25)	0.004[b]

Note: P^b was analyzed using the chi-square test

rates, can promote postoperative gastrointestinal recovery [19]. Furthermore, enteral nutrition itself has been shown to improve clinical outcomes, gastrointestinal function, and prognosis in various patient populations, such as elderly patients with cerebral infarction [20].

On postoperative day 7, serum TRF, ALB, and PAB levels in the experimental group were significantly higher than those in the routine group. These parameters are widely regarded as indicators of nutritional status [21]. Their elevation in the experimental group suggests that ERAS nursing combined with early enteral nutrition provided a more appropriate route and formulation for nutrient intake, better meeting postoperative nutritional demands and supporting physical recovery. ALB, the most abundant plasma protein synthesized by the liver, plays key roles in substance transport, maintenance of osmotic pressure, and nutrition supply [17]. PAB, with a half-life of about two days, functions as a transport protein for vitamins and promotes lymphocyte maturation, making it sensitive to short-term changes in nutritional status [17]. TRF, with a similarly short half-life, is valuable for monitoring rapid shifts in visceral protein levels and assessing the effects of nutritional interventions [22]. However, it is important to note that the interpretation of visceral protein levels as nutritional markers remains debated. Serum ALB and PAB concentrations can be influenced not only by nutritional intake but also by non-nutritional factors such as acute inflammation and hepatic function [23–25]. Therefore, the elevated visceral protein levels observed in the experimental group may reflect not only enhanced nutritional support but also the broader benefits of ERAS in attenuating systemic inflammatory responses. Previous research has shown that enteral nutrition can improve nutritional indicators such as ALB and TP, while also enhancing survival and quality of life in patients with chronic conditions [20]. At the same time, ERAS protocols facilitate the effective implementation of early enteral nutrition by avoiding preoperative bowel preparation, encouraging early oral intake, and adopting other measures that create favorable conditions for gastrointestinal recovery [7]. Moreover, several studies have confirmed that ERAS-based nursing can improve the postoperative nutritional status of GC patients [17, 26, 27].

Furthermore, postoperative levels of cellular immune markers (CD3+, CD4+, and CD4+/CD8+) and humoral immune markers (IgA, IgM, and IgG) were significantly higher in the experimental group compared with the routine group. This finding suggests that ERAS nursing combined with early enteral nutrition support enhances immune function in patients undergoing radical gastrectomy for GC, thereby reducing the risk of postoperative complications such as infection. This is in line with the findings of Shougen Cao et al., who reported that ERAS protocols are clinically feasible in elderly cancer patients undergoing laparoscopic total gastrectomy, with benefits closely associated with enhanced immune function and reduced inflammatory responses [28]. Similarly, adequate nutritional support has been shown to improve immune and nutritional status, lower postoperative complication rates, and facilitate recovery [29].

In addition, patients in the experimental group achieved higher postoperative QLQ-C30 scores in somatic, role, cognitive, social, and emotional functions, as well as overall health. These results indicate that ERAS nursing combined with early enteral nutrition not only promotes physiological recovery but also exerts a positive effect on patients' overall quality of life. Optimized perioperative care and nutritional support accelerate functional recovery, enabling patients to resume daily and social activities sooner. This finding is supported by Nathan et al., who reported improved patient-reported quality of life following ERAS implementation in radical cystectomy and laparoscopic nephrectomy [30], and by Wei Wu et al., who demonstrated significant quality-of-life improvements in postoperative lung cancer patients, particularly in physical and role functions [31]. Likewise, standardized early enteral nutrition has been shown to improve nutritional status, accelerate recovery, enhance quality of life, and reduce complications in patients undergoing laparoscopic hepatectomy [32]. In the present study, the postoperative complication rate in the experimental

group was significantly lower than that in the routine group, further confirming the value of ERAS combined with early enteral nutrition in mitigating complications such as infection and intestinal obstruction, alleviating surgical stress responses, and promoting faster postoperative recovery.

Conclusion

In summary, this study demonstrates that ERAS nursing combined with early enteral nutrition support accelerates gastrointestinal functional recovery, improves nutritional and immune status, enhances quality of life, and reduces postoperative complications in patients undergoing radical gastrectomy for GC. Unlike previous studies that focused on isolated indicators, our investigation comprehensively evaluated outcomes across nutritional, immune, functional, and quality-of-life domains, thereby highlighting the multidimensional benefits of this integrated approach. This comprehensive intervention model may provide unique clinical advantages and offer new strategies for perioperative nursing of GC patients undergoing radical gastrectomy.

Several limitations should be acknowledged. First, this was a single-center study with a relatively small sample size, which may introduce bias. Second, we primarily focused on short-term postoperative outcomes and lacked long-term follow-up data, limiting assessment of sustained benefits and complication correlations. Third, nutritional status was evaluated using conventional visceral proteins such as ALB and PAB, which are influenced not only by nutritional intake but also by factors such as inflammation and stress. Future studies should incorporate more robust nutritional assessment tools for a comprehensive evaluation. To strengthen the evidence base, future research should include multicenter, large-sample randomized controlled trials with extended follow-up, expanded outcome dimensions, and mechanistic investigations to further validate our findings and provide stronger support for clinical application.

Author contributions L.M.Z. and J.W. finished study design, Y.J.J. and X.Y.Z. finished experimental studies, H.H. L. and J.W. finished data analysis, Y.J.J. and L.X.L. finished manuscript editing. All authors read and approved the final version of the manuscript.

Funding No funds, grants, or other support was received.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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