BMC Gastroenterology

RESEARCH

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The impact of probiotic supplementation on gastric motility and nutrient absorption in elderly patients with Gastrointestinal disorders

Pingting Gong[1] and Xuehong Tang[2*]

Abstract

Background Gastrointestinal disorders (GIDs) in the elderly often lead to impaired gastric motility and nutrient absorption, exacerbating malnutrition. Probiotics, particularly Lactobacillus rhamnosus GG (LGG), may enhance gastric motility and nutrient absorption. This study evaluates the impact of LGG supplementation on gastric motility and nutrient absorption in elderly patients with GIDs.

Methods A retrospective analysis was conducted on 231 elderly patients with GIDs, divided into a probiotic supplementation (PS) group ($n=110$) and a NPS group ($n=121$). The PS group received LGG (1×10^{10} CFU, twice daily) for at least 7 days. Baseline and post-treatment measurements included gastric motility via ultrasonography, gastrointestinal hormone levels using radioimmunoassay, and nutrient absorption markers through ELISA and calorimetry.

Results Post-treatment, the PS group exhibited significantly improved gastric motility, with increased antral contraction amplitude (58.65 mm vs. 56.53 mm; $P=0.004$), frequency (4.06 vs. 3.81 times/min; $P=0.009$), and reduced gastric half-emptying time (28.15 min vs. 29.77 min; $P=0.007$). Hormone analyses showed elevated motilin and neuropeptide Y levels and decreased vasoactive intestinal peptide levels in the PS group ($P<0.05$). Nutrient absorption markers indicated decreased stool fat, protein, and carbohydrate content, enhanced intestinal permeability, increased weight and digestibility of energy, fat, and protein in the PS group ($P<0.05$).

Conclusion PS with LGG significantly enhances gastric motility and nutrient absorption in elderly patients with GIDs, indicating potential therapeutic benefits for addressing digestive dysfunction and malnutrition in this demographic.

Keywords Gastrointestinal disorders, Elderly, Probiotics, Lactobacillus rhamnosus GG, Gastric motility, Nutrient absorption

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Introduction

Gastrointestinal disorders (GIDs) represent a significant health concern among the elderly population, with an estimated prevalence of 45% in individuals aged 65 and older. Manifesting as a complex interplay of symptoms such as chronic gastritis, functional dyspepsia, and irritable bowel syndrome. These conditions not only significantly undermine nutritional status due to impaired gastric motility and nutrient absorption but also contribute to a 20% increase in the risk of developing other age-related diseases. Moreover, the impact of GIDs extends beyond morbidity, contributing to a reduction in life expectancy by approximately 3 years on average. Exacerbating age-related declines in physiological functions and increasing vulnerability to malnutrition, identifying therapeutic strategies that can effectively enhance gastric motility and optimize nutrient absorption is paramount in managing GIDs to improve quality of life and maintain the overall health of elderly individuals [1–3].

Probiotics, particularly strains like Lactobacillus rhamnosus GG (LGG), have garnered attention for their potential role in modulating gut health. LGG is renowned for its ability to enhance gut health, boost immune function, and prevent or treat conditions such as antibiotic-associated diarrhea and respiratory infections. Its applications span from dairy products to dietary supplements, making it accessible globally. In China, LGG has been approved by the National Health Commission for use in food production, highlighting its safety and efficacy. These microorganisms, when administered in adequate amounts, confer health benefits to the host by interacting with the gut microbiota, enhancing barrier functions, and modulating immune responses. Beyond their well-documented role in maintaining microbiota balance, probiotics were gaining recognition for their ability to influence gastrointestinal motility and nutrient absorption. Existing literature suggests that probiotics can enhance gastric motility through various mechanisms, including altering the gut microbiota to favor the secretion of motility-stimulating hormones such as motilin (MTL) and neuropeptide Y (NPY). These hormones were integral to gastrointestinal function, affecting smooth muscle contractions and gastrointestinal transit time. Moreover, probiotics may also impact intestinal permeability and nutrient absorption by modulating the integrity of the intestinal epithelium and facilitating the uptake of nutrients [4–6].

While the effects of probiotics on gastric motility and nutrient absorption have been investigated in various populations, research specifically targeting elderly patients with GIDs remains sparse. This demographic presents unique challenges due to the natural decline in digestive system efficacy and increased prevalence of comorbidities affecting gut health [7–9]. Consequently, understanding the potential benefits of probiotics in this group could provide a valuable therapeutic avenue for enhancing nutritional status and overall health. This retrospective analysis investigates the impact of probiotic supplementation (PS) with LGG on gastric motility and nutrient absorption in elderly patients with GIDs.

Materials and methods

Study design and ethics statement

This retrospective analysis examined 231 elderly patients with GIDs treated at our hospital between January 2019 and December 2023. Patients were categorized based on their PS status: the PS group consisted of 110 individuals who received probiotics, while the NPS group included 121 individuals who did not. The study received approval from the Institutional Review Board and Ethics Committee of our institution.

Inclusion and exclusion criteria

The inclusion criteria for this study were as follows: patients aged 60 years or older; a diagnosis of GIDs such as chronic gastritis [10], functional dyspepsia [11], or irritable bowel syndrome [12]; probiotic supplementation intervention duration exceeding 7 days; all patients underwent examinations of gastric and intestinal function, and the availability of comprehensive medical records.

The exclusion criteria comprised: any contraindications to treatment, such as allergies; having received other forms of gastrointestinal treatment or surgery within two weeks prior to admission; undergoing dietary modifications that could influence the study outcomes; initiation of new medications during the study period; existing severe cardiovascular, infectious, hematological, or autoimmune diseases; diagnosis of malignant tumors; and the presence of psychiatric or neurological disorders.

Intervention approach and data collection

Patients in the PS group underwent at least 7 days of oral probiotic therapy. The probiotic administered was LGG (Culturelle®, I-Health Inc., USA), given at a dosage of 1×10^{10} colony-forming units (CFU) twice daily—this represents a modified dosing regimen specifically chosen for this elderly population based on unpublished preliminary data suggesting enhanced efficacy with increased frequency of administration in patients with GI disorders.

All patients had a total daily energy intake ranging from 1800 to 2400 calories, as determined using the methodology outlined in reference [13]. The probiotic administered was LGG (Culturelle®, I-Health Inc., USA), given at a dosage of 1×1010 CFU twice daily, which represents a modified dosing regimen specifically chosen for this elderly population based on previous clinical evidence

suggesting enhanced efficacy with increased frequency of administration in patients with GI disorders.

Data were retrieved from the medical record system and included demographic information, Gastrointestinal Symptom Rating Scale (GSRS) scores, gastric motility, gastrointestinal hormone levels, intestinal permeability markers, and gastrointestinal digestion rates. The GSRS questionnaire was employed at baseline to evaluate the presence and severity of gastrointestinal symptoms, with each item rated on a scale from 0 to 7, where 0 represents no symptoms and 7 indicates the most severe intensity. The GSRS demonstrated internal consistency reliability ranging from 0.43 to 0.87 and test-retest reliability from 0.36 to 0.75 [14]. Energy content from the diet, stool, and urine was measured using bomb calorimetry to calculate intestinal energy absorption [15].

Detection of gastric motility

Ultrasonography (CX-970D, Mianyang Sonic Electronics Co., China) was conducted to assess gastric motility both before and 7 days after treatment. Patients were instructed to refrain from drinking for 2 to 3 h and eating for 4 to 8 h prior to the examination. Once the antrum was visualized using ultrasound, patients consumed a predetermined amount of orange water. Six minutes following ingestion, measurements of antral contraction amplitude, antral contraction frequency, and gastric half-emptying time were taken.

Detection of Gastrointestinal hormone levels

Fasting venous blood samples (3 ml) were collected from each patient in the morning, both before treatment and 7 days post-treatment. These samples were centrifuged at 4000 rpm for 10 min using a low-temperature (4 °C) high-speed centrifuge (Mini1524, Zhuhai Hema Medical Instrument Co., Ltd., China) and subsequently stored at low temperatures (− 80 °C) for future analysis. The concentrations of MTL, serum NPY, and vasoactive intestinal peptide (VIP) were determined using an automated radioimmunoassay analyzer (CN20, Beijing Zhongxi Yuanda Technology Co., Ltd., China).

Detection of intestinal permeability markers

Venous blood samples, anticoagulated with citrate, were collected from patients in the early morning, both before and 7 days after treatment, using sodium citrate vacuum collection tubes. These samples (3 ml each) were centrifuged at 3000 rpm for 5 min using a low-temperature (4 °C) high-speed centrifuge (Mini1524, Zhuhai Hema Medical Instrument Co., Ltd., China). The plasma levels of zonulin, occludin, and lipopolysaccharide-binding protein (LBP) were assessed using enzyme-linked immunosorbent assay (ELISA). The specific ELISA kits employed included: the human zonulin kit (EKC 36091, Biomatik USA, LLC; Wilmington, DE, USA), the human occludin kit (NBP2-80305, Novus Biologicals, LLC; Centennial, CO, USA), and the human LBP kit (DY870-05, R&D Systems, Inc.; Minneapolis, MN, USA).

Statistical analysis

Data analysis was performed using SPSS 29.0 statistical software (SPSS Inc., Chicago, IL, USA). Categorical data were reported as frequencies and percentages [n (%)]. Chi-square tests were applied for sample sizes of 40 or more with a theoretical frequency (T) of 5 or greater, using the standard χ^2 test statistic. For sample sizes of 40 or more but with theoretical frequencies between 1 and less than 5 ($1 \le T < 5$), a corrected chi-square formula was used. In instances where the sample size was less than 40 or the theoretical frequency was less than 1 ($T < 1$), Fisher's exact test was employed for statistical analysis. Continuous variables were initially assessed for normal distribution using the Shapiro-Wilk test. Normally distributed continuous data were presented as means and standard deviations ($X \pm s$). A P Value of less than 0.05 was considered indicative of statistical significance. Pearson correlation analysis was applied to continuous variables, while Spearman correlation analysis was utilized for categorical variables.

Results

Basic data

The mean age in the NPS group was 67.17 ± 3.04 years compared to 66.97 ± 3.12 years in the PS group ($P = 0.610$) (Table 1). The average weight was 65.93 ± 10.87 kg for the NPS group versus 64.65 ± 9.46 kg for the PS group ($P = 0.344$), while the body mass index (BMI) was 22.54 ± 6.14 kg/m² compared to 23.35 ± 5.62 kg/m², respectively ($P = 0.297$). Gender distribution was comparable, with females comprising 61.98% in the NPS group and 66.36% in the PS group ($P = 0.488$). Fasting glucose levels, smoking status, alcohol consumption, hypertension, diabetes, residence distribution, marital status, dietary preferences and disease type showed no significant differences between the groups (all $P > 0.05$). These findings indicate no significant demographic differences between the groups, suggesting a well-matched cohort for further analysis of gastric motility and nutrient absorption outcomes.

At baseline, the mean indigestion score was 3.54 ± 1.17 for the NPS group compared to 3.66 ± 1.07 for the PS group ($P = 0.414$) (Table 2). Diarrhea scores were similarly comparable, at 2.78 ± 0.78 in the NPS group and 2.74 ± 0.79 in the PS group ($P = 0.735$). Constipation scores were 2.45 ± 0.97 for the NPS group and 2.36 ± 0.82 for the PS group ($P = 0.417$). Abdominal pain scores were also close, with the NPS group at 3.07 ± 1.04 and the PS group at 3.27 ± 1.01 ($P = 0.129$). Finally, scores for reflux

Table 1 Comparison of demographic characteristics between two groups

Parameters	NPS group ($n=121$)	PS group ($n=110$)	t/χ^2	*P*
Age (years)	67.17 ± 3.04	66.97 ± 3.12	0.511	0.610
Weight (kg)	65.93 ± 10.87	64.65 ± 9.46	0.947	0.344
BMI (kg/m^2)	22.54 ± 6.14	23.35 ± 5.62	1.046	0.297
Fasting glucose (mg/dL)	94.63 ± 9.65	93.35 ± 7.36	1.133	0.258
Female/Male [n (%)]	75 (61.98%) / 46 (38.02%)	73 (66.36%) / 37 (33.64%)	0.480	0.488
Current smokers [n (%)]	15 (12.4%)	11 (10%)	0.331	0.565
Alcohol drinkers [n (%)]	36 (29.75%)	37 (33.64%)	0.402	0.526
Hypertension [n (%)]	45 (37.19%)	47 (42.73%)	0.737	0.391
Diabetes [n (%)]	20 (16.53%)	23 (20.91%)	0.730	0.393
Residence (Urban/Town) [n (%)]	85 (70.25%) / 36 (29.75%)	81 (73.64%) / 29 (26.36%)	0.327	0.567
Marital Status (Married/ Unmarried or Divorced) [n (%)]	104 (85.95%) / 17 (14.05%)	89 (80.91%) / 21 (19.09%)	1.065	0.302
Food preference (Omnivore/ Vegetarian/ Vegan) [n (%)]	85 (70.25%)/30 (24.79%)/6 (4.96%)	82 (74.55%)/22 (20%)/6 (5.45%)	0.763	0.683
Disease type (chronic gastritis/ functional dyspepsia/ irritable bowel syndrome/others) [n (%)]	36 (29.75%)/48 (39.67%)/ 12 (9.92%)/25 (20.66%)	36 (32.73%)/ 47 (42.73%)/14 (12.73%)/13 (11.82%)	3.438	0.329

Continuous variables were analyzed by independent t-tests between NPS and PS groups, and categorical variables were analyzed by chi-square or Fisher's exact test as appropriate.BMI: Body Mass Index

Table 2 Comparison of baseline GSRS scores between two groups

Parameters	NPS group ($n=121$)	PS group ($n=110$)	t	*P*
Indigestion	3.54 ± 1.17	3.66 ± 1.07	0.818	0.414
Diarrhea	2.78 ± 0.78	2.74 ± 0.79	0.338	0.735
Constipation	2.45 ± 0.97	2.36 ± 0.82	0.814	0.417
Abdominal pain	3.07 ± 1.04	3.27 ± 1.01	1.525	0.129
Reflux	2.46 ± 0.76	2.48 ± 0.99	0.205	0.838

Independent t-tests were used to compare GSRS subscale scores between groups at baseline.GSRS: Gastrointestinal Symptom Rating Scale

Table 3 Comparison of gastric motility between two groups (before treatment)

Parameters	NPS group ($n=121$)	PS group ($n=110$)	t	*P*
Antral Contraction Amplitude (mm)	37.53 ± 5.19	37.42 ± 4.56	0.161	0.872
Antral Contraction Frequency (times/min)	1.76 ± 0.46	1.86 ± 0.52	1.523	0.129
Gastric Half-Emptying Time (min)	53.64 ± 8.24	52.56 ± 7.83	1.014	0.312

Independent t-tests were used to compare pre-treatment gastric motility parameters between NPS and PS groups

symptoms showed no difference, recorded at 2.46 ± 0.76 in the NPS group and 2.48 ± 0.99 in the PS group ($P=0.838$). These findings indicate that baseline gastrointestinal symptoms were similar in both groups prior to treatment commencement.

Gastric motility

The antral contraction amplitude was 37.53 ± 5.19 mm in the NPS group compared to 37.42 ± 4.56 mm in the PS group ($P=0.872$) (Table 3). The frequency of antral contractions was measured at 1.76 ± 0.46 times per minute for the NPS group and 1.86 ± 0.52 times per minute for the PS group ($P=0.129$). Regarding gastric half-emptying time, participants in the NPS group had an average time of 53.64 ± 8.24 min, while those in the PS group had a time of 52.56 ± 7.83 min ($P=0.312$). These findings indicate that initial gastric motility measures were comparable between the two groups prior to intervention.

After 7 days of treatment, the PS group exhibited significantly improved gastric motility, with increased antral contraction amplitude (from 37.42 ± 4.56 mm to 58.65 ± 5.67 mm; $P<0.001$), frequency (from 1.86 ± 0.52 times/min to 4.06 ± 0.75 times/min; $P<0.001$), and reduced gastric half-emptying time (from 52.56 ± 7.83 min to 28.15 ± 4.53 min; $P<0.001$) compared to the NPS group (from 37.53 ± 5.19 mm to 56.53 ± 5.36 mm; $P=0.004$) (Fig. 1). Similarly, antral contraction frequency was greater in the PS group, with a mean of 4.06 ± 0.75 times per minute, compared to 3.81 ± 0.68 times per minute in the NPS group ($P=0.009$). Additionally, the gastric half-emptying time was significantly shorter in the PS group at 28.15 ± 4.53 min, versus 29.77 ± 4.56 min in the NPS group ($P=0.007$). Unexpectedly, the NPS group also showed significant improvements in gastric motility parameters without probiotic intervention, which requires further investigation. These results suggest that PS effectively enhances gastric motility in elderly patients with GIDs over a short-term treatment period.

Gastrointestinal hormone levels

The levels of MTL were similar, with the NPS group reporting 208.35 ± 26.35 pg/ml and the PS group at 206.46 ± 25.36 pg/ml ($P=0.582$) (Table 4). NPY levels were 1.43 ± 0.26 pg/ml for the NPS group and 1.45 ± 0.29 pg/ml for the PS group ($P=0.580$). Additionally, VIP levels were 24.64 ± 3.65 pg/ml in the NPS group compared to 24.55 ± 3.71 pg/ml in the PS group ($P=0.859$). These results indicate that baseline gastrointestinal hormone levels were comparable between the two groups prior to intervention.

After 7 days of treatment, MTL levels increased significantly in the PS group from 206.46 ± 25.36 pg/ml to 312.35 ± 38.55 pg/ml ($P<0.001$), compared to a modest

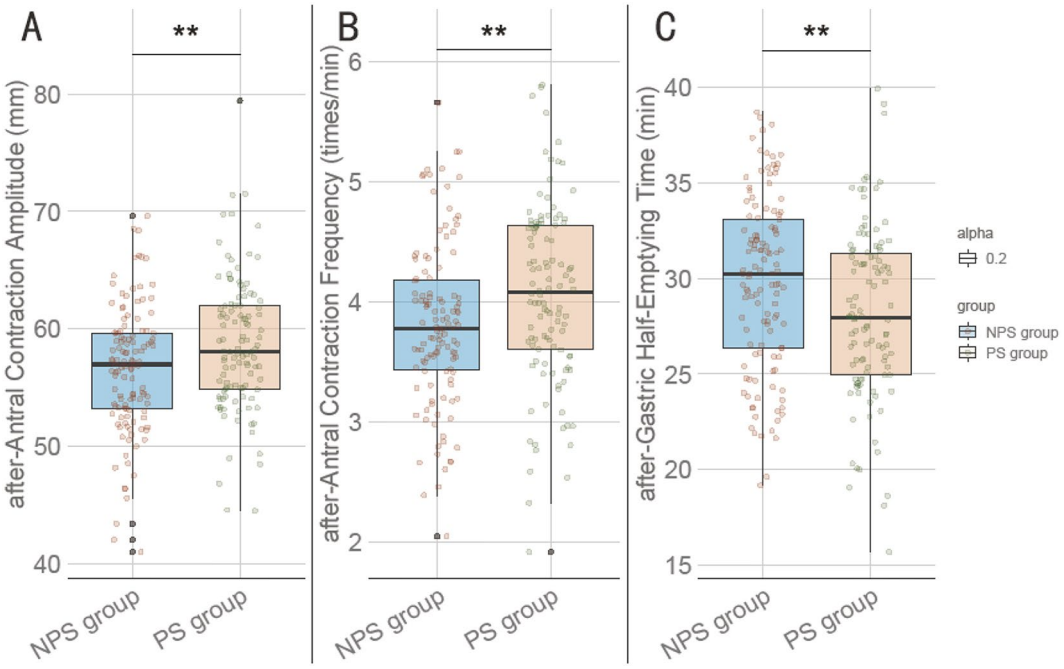

Fig. 1 Comparison of gastric motility between two groups (after treatment 7d). (**A**) Antral Contraction Amplitude; (**B**) Antral Contraction Frequency; (**C**) Gastric Half-Emptying Time. **: $P < 0.01$.Paired t-tests were used for within-group comparisons (pre- vs. post-treatment), and independent t-tests for between-group comparisons at day 7

Table 4 Comparison of Gastrointestinal hormone levels between two groups (before treatment)

Parameters	NPS group ($n=121$)	PS group ($n=110$)	t	*P*
MLT (pg/ml)	208.35 ± 26.35	206.46 ± 25.36	0.552	0.582
NPY (pg/ml)	1.43 ± 0.26	1.45 ± 0.29	0.555	0.580
VIP (pg/ml)	24.64 ± 3.65	24.55 ± 3.71	0.178	0.859

Independent t-tests were used to compare baseline hormone levels between NPS and PS groups.MLT: Motilin; NPY: Neuropeptide Y; VIP: Vasoactive Intestinal Peptide

increase in the NPS group from 208.35 ± 26.35 pg/ml to 298.76 ± 35.22 pg/ml ($P = 0.006$) (Fig. 2). Similarly, NPY levels rose in the PS group from 1.45 ± 0.29 pg/ml to 2.13 ± 0.42 pg/ml ($P < 0.001$), while the NPS group experienced a slight increase from 1.43 ± 0.26 pg/ml to 2.01 ± 0.37 pg/ml ($P = 0.025$). Conversely, VIP levels decreased in the PS group from 24.55 ± 3.71 pg/ml to 11.52 ± 2.16 pg/ml ($P < 0.01$), compared to the NPS group which showed a minor reduction from 24.64 ± 3.65 pg/ml to 12.34 ± 2.65 pg/ml ($P = 0.011$) (Fig. 2). Notably, the NPS group also demonstrated changes in hormone levels without probiotic intervention, suggesting potential confounders or natural variations. These findings suggest that PS notably affects gastrointestinal hormone levels, potentially contributing to alterations in gastric motility and nutrient absorption in elderly patients with GIDs.

Nutrient absorption

Occludin levels were 0.31 ± 0.11 ng/mL in the NPS group and 0.29 ± 0.10 ng/mL in the PS group ($P = 0.157$) (Table 5). Zonulin levels were comparable between groups, with the NPS group at 1.41 ± 0.34 ng/mL and the PS group at 1.39 ± 0.31 ng/mL ($P = 0.616$). Additionally, LBP levels were 30.24 ± 7.54 ng/mL in the NPS group compared to 30.96 ± 7.62 ng/mL in the PS group ($P = 0.473$). These data indicate that baseline levels of intestinal permeability markers were similar across both groups prior to the initiation of treatment.

Occludin levels were lower in the PS group, at 0.29 ± 0.09 ng/mL, compared to 0.32 ± 0.09 ng/mL in the NPS group ($P = 0.015$) (Fig. 3). Zonulin levels also decreased significantly in the PS group, measured at 1.29 ± 0.22 ng/mL versus 1.39 ± 0.39 ng/mL in the NPS group ($P = 0.009$). Conversely, LBP levels were higher in the PS group at 33.87 ± 7.77 ng/mL compared to 31.53 ± 7.21 ng/mL in the NPS group ($P = 0.018$). (Fig. 3). Unexpected changes in the NPS group's intestinal permeability markers without probiotic intervention suggest potential confounders or natural variations. These findings suggest that PS can notably influence intestinal permeability markers, potentially enhancing barrier integrity in elderly patients with GIDs.

In the comparison of weight and fecal parameters between the NPS (no probiotic supplementation) and PS (probiotic supplementation) groups after 7 days of treatment, significant differences were observed in all measured parameters (Table 6). In the PS group, the mean weight increased from 64.00 ± 9.50 kg before treatment to 69.33 ± 10.55 kg after treatment (t = 2.210, $P = 0.028$),

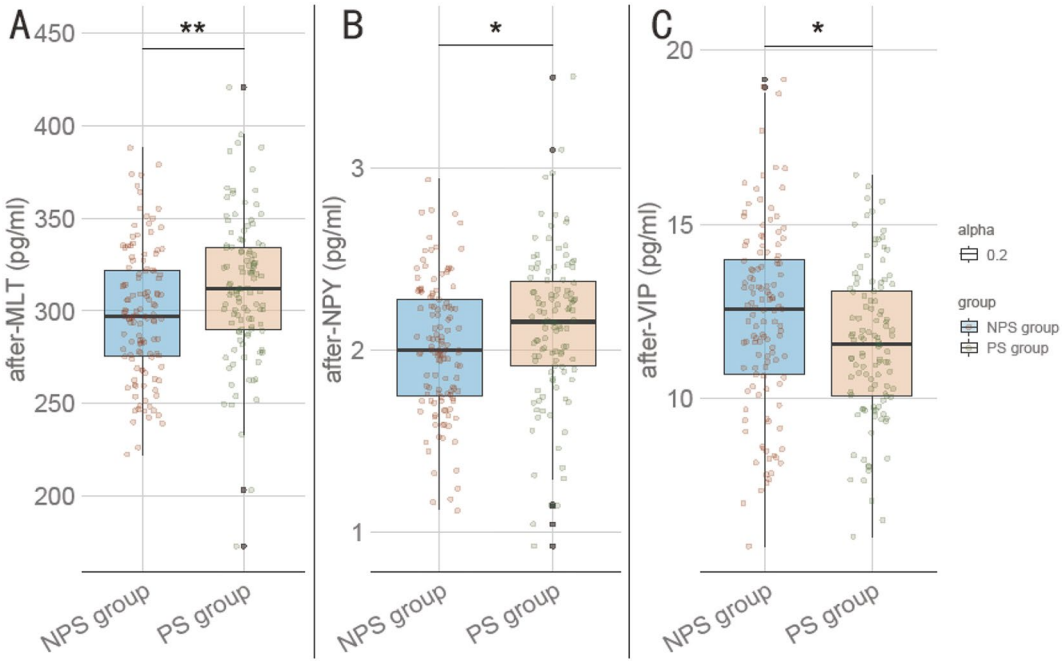

Fig. 2 Comparison of gastrointestinal hormone levels between two groups (after treatment 7d). (**A**) MLT; (**B**) NPY; (**C**) VIP. MLT: Motilin; NPY: Neuropeptide Y; VIP: Vasoactive Intestinal Peptide. *: $P < 0.05$; **: $P < 0.01$.Paired t-tests were used for pre- vs. post-treatment comparisons, and independent t-tests for between-group comparisons at day 7

Table 5 Comparison of intestinal permeability markers levels between two groups (before treatment)

Parameters	NPS group ($n = 121$)	PS group ($n = 110$)	t	*P*
Occludin (ng/mL)	0.31 ± 0.11	0.29 ± 0.10	1.419	0.157
Zonulin (ng/mL)	1.41 ± 0.34	1.39 ± 0.31	0.503	0.616
LBP (ng/mL)	30.24 ± 7.54	30.96 ± 7.62	0.719	0.473

LBP: Lipopolysaccharide Binding Protein

whereas the NPS group showed a smaller increase from 65.50 ± 10.00 kg to 66.37 ± 9.79 kg (t = 2.210, $P = 0.028$). Stool fat content decreased significantly in the PS group from 3.90 ± 0.50 g/day before treatment to 3.93 ± 0.36 g/day after treatment (t = 2.200, $P = 0.029$), indicating improved fat absorption, while the NPS group exhibited a slight increase from 4.10 ± 0.80 g/day to 4.12 ± 0.84 g/day. Additionally, stool protein content was significantly reduced in the PS group from 17.50 ± 2.00 g/day before treatment to 17.54 ± 2.11 g/day after treatment (t = 3.284, $P = 0.001$), suggesting better protein absorption, compared to the NPS group which showed minimal change from 18.70 ± 3.30 g/day to 18.75 ± 3.36 g/day. Stool carbohydrate content also decreased in the PS group from 15.70 ± 3.40 g/day before treatment to 15.76 ± 3.64 g/day after treatment (t = 2.075, $P = 0.039$), indicating enhanced carbohydrate absorption, whereas the NPS group remained largely unchanged from 16.70 ± 3.50 g/day to 16.74 ± 3.51 g/day. These findings suggest that probiotic supplementation in elderly patients with gastrointestinal disorders can lead to significant improvements in weight gain and nutrient absorption compared to the non-supplemented group.

Energy digestibility was higher in the PS group at 67.63 ± 10.86%, compared to 63.33 ± 12.44% in the NPS group ($P = 0.006$) (Fig. 4). Fat digestibility also improved in the PS group, reaching 80.83 ± 6.96%, as opposed to 77.44 ± 5.67% in the NPS group ($P < 0.001$). Similarly, protein digestibility was superior in the PS group at 91.54 ± 2.53%, compared to 90.56 ± 2.41% in the NPS group ($P = 0.003$). In contrast, carbohydrate digestibility was similar between the groups, with the NPS group at 93.25 ± 1.55% and the PS group at 93.12 ± 1.68% ($P = 0.565$). These findings suggest that PS significantly enhances the digestibility of energy, fat, and protein in elderly patients with GIDs.

Discussion

In the present study, we explored the impact of PS on gastric motility and nutrient absorption in elderly patients with GIDs. The observed increase in gastric motility, highlighted by the significant differences in antral contraction amplitude and frequency post-treatment, points to potential mechanisms wherein probiotics exert their motility-enhancing effects [16, 17]. One hypothesis was that probiotics like LGG alter the intestinal microbiota in a way that boosts the secretion of motility-stimulating hormones such as MTL and NPY. Our findings support this hypothesis, given the notable increases in MTL and

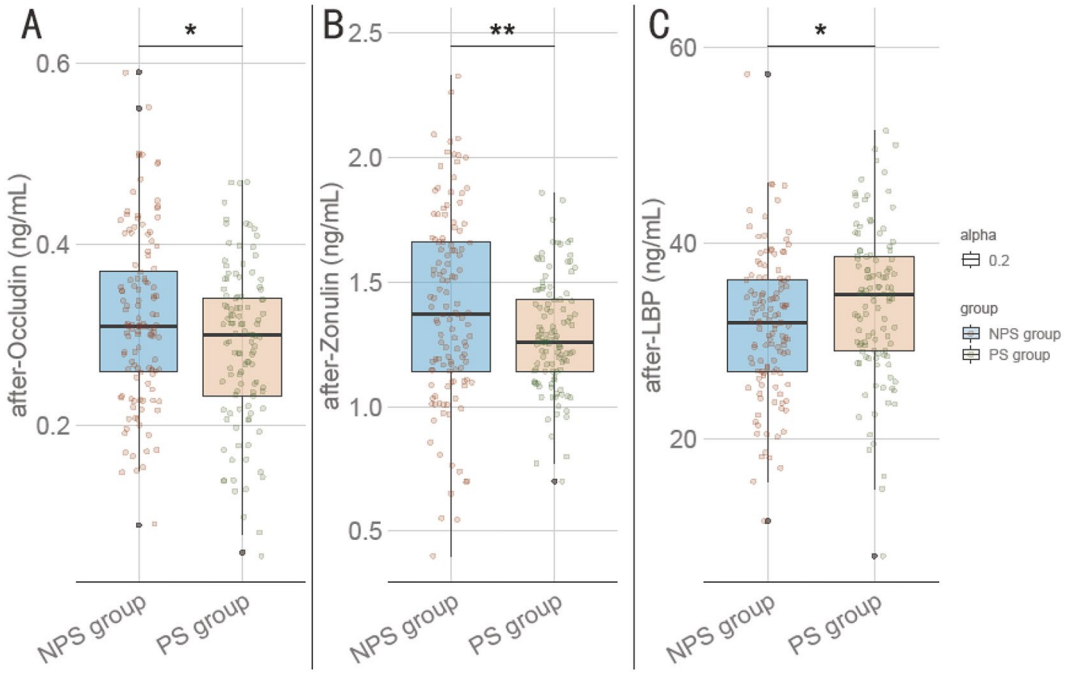

Fig. 3 Comparison of intestinal permeability markers levels between two groups (after treatment 7d). (**A**) Occludin; (**B**) Zonulin; (**C**) LBP. LBP: Lipopolysaccharide Binding Protein. *: $P < 0.05$; **: $P < 0.01$.Paired t-tests were used to compare pre- vs. post-treatment values within each group; independent t-tests were used for between-group comparisons at day 7

Table 6 Comparison of weight and fecal parameters between two groups before and after treatment

Parameters	NPS group Before Treatment ($n = 121$)	NPS group After Treatment ($n = 121$)	PS group Before Treatment ($n = 110$)	PS group After Treatment ($n = 110$)	t	*P*
Weight (kg)	65.50 ± 10.00	66.37 ± 9.79	64.00 ± 9.50	69.33 ± 10.55	2.210	0.028
Stool fat (g/day)	4.10 ± 0.80	4.12 ± 0.84	3.90 ± 0.50	3.93 ± 0.36	2.200	0.029
Stool protein (g/day)	18.70 ± 3.30	18.75 ± 3.36	17.50 ± 2.00	17.54 ± 2.11	3.284	0.001
Stool carbohydrate (g/day)	16.70 ± 3.50	16.74 ± 3.51	15.70 ± 3.40	15.76 ± 3.64	2.075	0.039

Paired t-tests (within-group comparisons pre- vs. post-treatment) and independent t-tests (between-group comparisons) were performed for each parameter

NPY levels observed in the PS group. These hormones were known to play pivotal roles in gastrointestinal motility by stimulating muscle contractions in the gut. Notably, MTL acts upon the smooth muscle of the gastrointestinal tract to enhance contractions, while NPY has been associated with autonomic regulation of gut motility [18, 19].

Moreover, the decrease in VIP levels following probiotic treatment offers additional insight. VIP generally functions as a relaxant for intestinal smooth muscles, demonstrating opposing effects to MTL and NPY. The reduction in VIP levels among the PS group could thus contribute to enhanced motility by decreasing the inhibitory signals that typically slow gastrointestinal transit [20, 21].

The mechanisms by which probiotics affect nutrient absorption appear related both to direct effects on the intestinal epithelium and indirect modulation via the gut microbiota. Our study noted significant improvements in the digestibility of energy, fats, and proteins, which could be attributed to enhanced intestinal permeability and subsequent nutrient uptake. This was supported by the changes observed in intestinal permeability markers such as occludin and zonulin. These markers were critical components of tight junctions in intestinal epithelial cells, and their decreased levels post-treatment indicate increased tight junction integrity. Probiotics may engage with the mucosal lining directly or through microbiota-elicited secondary metabolites, thereby bolstering barrier function and facilitating improved nutrient absorption [22–24].

The changes in LBP levels highlight another important aspect of probiotic influence. The elevation in LBP levels post-treatment might reflect heightened systemic responses to the altered microbial environment induced by probiotics. LBP was a critical component of the immune system, binding lipopolysaccharides from Gram-negative bacteria and facilitating their recognition by immune cells. The elevated levels imply an enhanced alert to bacterial constituents, perhaps indicative of a

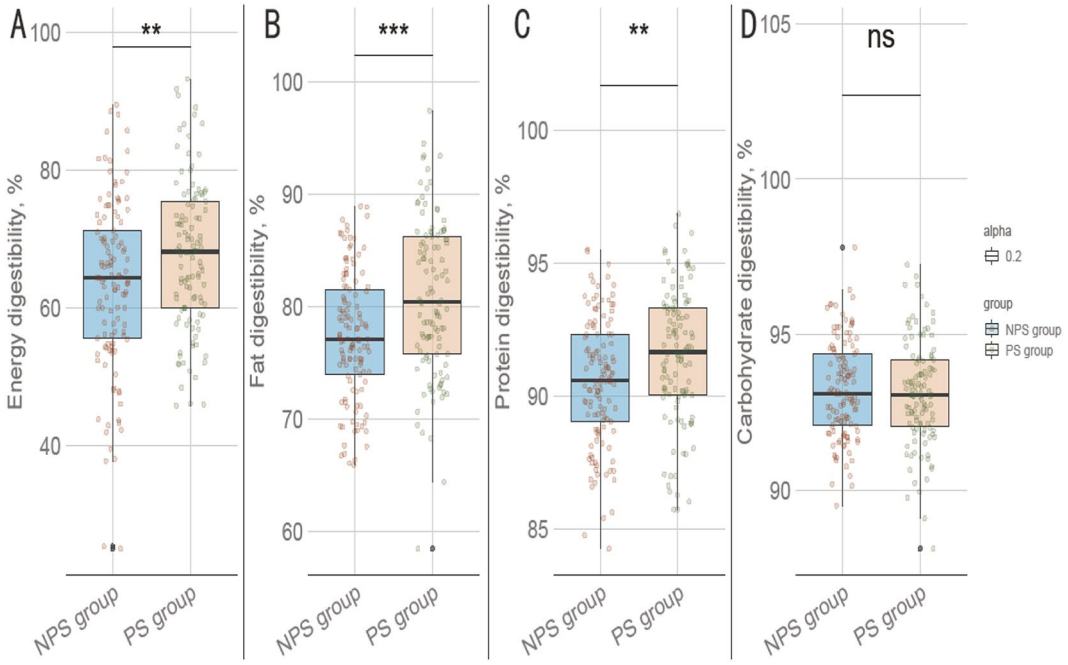

Fig. 4 Comparison of gastrointestinal digestion rate between two groups. (**A**) Energy digestibility; (**B**) Fat digestibility; (**C**) Protein digestibility; (**D**) Carbohydrate digestibility. ns: no statistically significant difference; **: $P < 0.01$; ***: $P < 0.001$.Independent t-tests for between-group comparisons at day 7. ns: no statistically significant difference

healthier, more responsive intestinal immune environment [25–27].

Furthermore, Gastrointestinal Disorders (GIDs) encompass a broad range of conditions with varying pathophysiologies, and our study did not stratify patients based on specific disease types or syndromes. This lack of stratification may mask differential responses to probiotic supplementation across distinct subgroups. Future research should consider disease and syndrome-specific analyses to better understand the nuanced effects of probiotics.Additionally, the use of probiotics can result in variable and individualized responses among patients due to factors such as baseline microbiota composition and host genetics. While our sample size was sufficient to detect general trends, it may not be adequate for capturing the diversity of probiotic effects across different patient profiles. Future studies with larger sample sizes and stratified patient groups would provide more robust and personalized insights into the efficacy of probiotic interventions.

The potential benefits gleaned from PS were of particular interest in the elderly population afflicted with GIDs, who often experience a decline in nutrient absorption efficiency due to decreased gastric motility and compromised intestinal barrier function. By addressing these deficits, probiotics compose a therapeutic strategy that not only improves quality of life by reducing gastrointestinal symptomology but also mitigates broader health risks associated with malnutrition and nutrient deficiencies [28–30].

It was worth considering that probiotics may also modulate gut-brain axis mechanisms, with implications for both enteric nervous system activity and central neurohormonal signaling. While these effects were not directly assessed in the present study, existing literature provides a basis for further exploration. Probiotic-induced alterations in gut microbiota composition could influence the production of neuroactive compounds, which in turn might affect intestinal motility and systemic nutrient handling through neural pathways [31–33].

Despite the promising findings, the mechanisms through which probiotics exert these effects were complex and multifactorial, involving intricate interactions between microbiota, host epithelium, and immune responses. Our results underscore the importance of considering each of these systems holistically, recognizing that changes to one facet of this ecosystem may reverberate throughout others. Future studies should aim to delineate these pathways with greater specificity, potentially leveraging advanced omics technologies and integrative systems biology approaches to capture the dynamism of probiotic actions in vivo.

Additionally, the study's retrospective design presents inherent limitations, as causality cannot be definitively established. The broad categorization of GIDs without disease-specific stratification may limit the applicability of the findings to specific patient subgroups. Randomized

controlled trials with longer follow-up periods and stratified patient populations would be advantageous in confirming these findings and determining the sustainability of benefits conferred by PS. Investigation into differential responses based on specific patient subgroups, such as those differing in baseline microbiota composition or specific GID diagnoses, would also lend further insight into personalized applications of probiotics in clinical practice.Additionally, concurrent consumption of other probiotics or prebiotics was not specifically monitored during the study period, which could potentially influence the outcomes and represents a limitation of the current study. Future research should incorporate monitoring of other probiotic and prebiotic intakes to better isolate and understand the specific effects of LGG supplementation.

Importantly, the safety profile of probiotics should not be overlooked. While generally regarded as safe for most individuals, specific patient populations, particularly those with compromised immune systems, may experience adverse effects [34]. Continuous monitoring and documentation of any such events were beyond the scope of this retrospective analysis; however, prospective studies could address this by implementing robust safety monitoring protocols.

Natural improvements observed in the NPS group highlight several potential confounding factors in assessing treatment efficacy. Disease severity may naturally fluctuate over time, while subtle changes in diet, lifestyle [35], and stress levels can impact symptoms despite protocol restrictions. Additionally, the heightened clinical attention during the study period may enhance patients' adherence to existing medical guidelines, creating a placebo effect. Some patients might also experience lingering benefits from previous treatments. These complexities emphasize the need for more rigorous prospective randomized controlled trials that carefully monitor confounding variables.

Conclusion

In conclusion, our study supports the hypothesis that PS with LGG effectively enhances gastric motility and nutrient absorption in elderly patients with GIDs. These findings provide compelling rationale for incorporating probiotics into therapeutic regimens aimed at ameliorating digestive dysfunctions inherent to GIDs, ultimately contributing to improved nutritional status and overall health in this vulnerable demographic. Moving forward, expanded research efforts was essential to optimize dosing strategies, identify responder profiles, and elucidate the long-term implications of sustained probiotic use in clinical settings.

Abbreviations

GIDs	Gastrointestinal disorders
LGG	Lactobacillus rhamnosus GG
MTL	motility-stimulating hormones such as motilin
NPY	neuropeptide Y
CFU	colony-forming units
PS	probiotic supplementation
GSRS	Gastrointestinal Symptom Rating Scale
VIP	vasoactive intestinal peptide
LBP	lipopolysaccharide-binding protein
ELISA	Enzyme-linked immunosorbent assay
BMI	Body Mass Index
NPS	No probiotic supplementation
PS	Probiotic supplementation
MLT	Motilin
LBP	Lipopolysaccharide Binding Protein

Acknowledgements

Not Applicable.

Author contributions

PTG and XHT were involved in the conception and design, or analysis and interpretation of the data; PTG the drafting of the paper, revising it critically for intellectual content; XHT the final approval of the version to be published; and that all authors agree to be accountable for all aspects of the work.

Funding

No funding was received.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Second People's Hospital of Banan District (CQ-CN-23). Written informed consent was obtained from all participants. This waiver was granted by the Institutional Review Board and Ethics Committee in accordance with regulatory and ethical guidelines governing retrospective research.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

Received: 14 November 2024 / Accepted: 27 February 2025
Published online: 20 March 2025

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