Clinical Interventions in Aging

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CLINICAL TRIAL REPORT

Effect of Continuous Perioperative Transcutaneous Electrical Acupoint Stimulation on Postoperative Delirium in Elderly Patients Undergoing Laparoscopic Gastrointestinal Surgery: A Randomized Controlled Trial

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Purpose: To investigate the effect of perioperative continuous TEAS on the incidence of POD in elderly patients undergoing laparoscopic gastrointestinal surgery.

Patients and methods: In this prospective, double-blind, randomized controlled trial, 180 elderly patients (age ≥65 years, ASA I–III) scheduled for laparoscopic gastrointestinal surgery were randomized into three groups: Group A received continuous TEAS (n=60), Group B received twice TEAS (n=60), and Group C received sham TEAS (n=60). Groups A and B received TEAS at Yintang (EX-HN 3), bilateral Shenmen (HT 7), Neiguan (PC 6), and Zusanli (ST 36) 30 min before anesthesia induction and 30 min before the end of surgery. After the operation, Group A received electrical stimulation every 8 hours for 72 hours, Group B received no electrical stimulation after the operation, and Group C received only electrodes without current output. The primary outcome was the incidence of POD within 72 hours after surgery.

Results: Group A had a significantly lower POD incidence (11.9%) than Group B (31.0%, $P'<0.017$) and Group C (53.6%, $P'<0.017$), with Group B also lower than Group C ($P'<0.017$); Groups A (15.3%) and B (25.9%) had a lower postoperative nausea and vomiting (PONV) incidence than Group C (51.8%) ($P'<0.017$), as well as lower dizziness incidence (A: 6.8%, B: 12.1% vs C: 32.1%, A vs C: $P'<0.017$; B vs C: $P'<0.017$). Compared with Group C (first flatus: 71.91±10.59h; first defecation: 97.80±10.26h), Groups A and B had earlier first flatus (61.22±11.09h, 65.53±11.73h) and defecation (86.47±11.07h, 90.79±11.85h) ($P'<0.017$), and Group A had lower Pittsburgh Sleep Quality Index (PSQI) scores at 2 weeks and 1 month postoperatively than Group B ($P'<0.017$). No significant difference in skin injury incidence was observed among the three groups ($P>0.05$).

Conclusion: Perioperative continuous TEAS significantly reduces the incidences of POD, PONV, and postoperative dizziness, effectively improves postoperative sleep quality, and accelerates the recovery of gastrointestinal function in elderly patients undergoing laparoscopic gastrointestinal surgery. Patients receiving TEAS did not experience an increased incidence of adverse events such as skin injury.

Keywords: transcutaneous electrical acupoint stimulation, postoperative delirium, sleep quality, postoperative nausea and vomiting, neuroinflammation

https://doi.org/10.2147/CIA.S581811
Received: 15 November 2025
Accepted: 13 February 2026
Published: 23 February 2026

Introduction

With the increasing aging of the global population, laparoscopic surgery has been increasingly widely used in the field of surgical treatment for elderly patients because of its advantages of minimal trauma and rapid recovery.[1] However, elderly patients are often complicated with hypertension, diabetes, coronary heart disease and other underlying diseases, the organ compensatory capacity is impaired, and tolerance to surgical trauma is reduced. During major laparoscopic surgery, long-term CO_2 pneumoperitoneum and the Trendelenburg position may cause a series of changes, such as CO_2 retention, acid–base disorders, hemodynamic fluctuations and increased permeability of the blood–cerebrospinal fluid barrier, which can promote the entry of inflammatory factors into the central nervous system and subsequently increase the risk of postoperative delirium (POD).[2–5] POD is a common perioperative complication characterized by acute, fluctuating changes in consciousness, attention, and cognition.[6] Studies have shown that the incidence of POD in elderly patients undergoing gastrointestinal surgery can reach 13% to 50%.[7] PODs mostly occur in the first 3 days after surgery in elderly patients and are closely related to adverse outcomes such as prolonged hospital stays, increased costs, and increased postoperative mortality.[8–10]

Transcutaneous electrical acupoint stimulation (TEAS) is a therapy that combines acupoint and transcutaneous electrical nerve stimulation, which has effects similar to those of acupuncture and can regulate neuroinflammation, improve sleep, and reduce the occurrence of POD.[11,12] The potential mechanisms of TEAS in reducing POD are multifaceted. First, TEAS can regulate the balance of pro-inflammatory and anti-inflammatory cytokines. Surgical trauma induces the release of proinflammatory cytokines, which disrupt the blood-brain barrier (BBB) and infiltrate the central nervous system, leading to neuroinflammation and cognitive dysfunction. A meta-analysis showed that TEAS can activate the cholinergic anti-inflammatory pathway by stimulating acupoints such as Neiguan (PC 6) and Zusanli (ST 36), inhibiting the overexpression of nuclear factor-κB (NF-κB) in immune cells, thereby reducing the secretion of pro-inflammatory cytokines and alleviating neuroinflammation.[12] Second, TEAS can improve cerebral blood flow and oxygen supply. Long-term CO_2 pneumoperitoneum during laparoscopic surgery can cause cerebral vasoconstriction and reduced cerebral perfusion. A study confirmed that TEAS can dilate cerebral blood vessels by regulating the autonomic nervous system, increasing cerebral blood flow velocity, and improving cerebral oxygenation, which is beneficial to maintaining neuronal function.[13] Third, TEAS can regulate neurotransmitter release. A study showed that TEAS can increase the levels of γ-aminobutyric acid (GABA) and serotonin in the brain, which have sedative and anxiolytic effects, and reduce the levels of glutamate, an excitatory neurotransmitter, thereby stabilizing neuronal activity and reducing the risk of delirium.[9]

However, previous studies mostly focused on verifying whether TEAS can prevent and treat POD, but whether the duration of intervention has a difference in efficacy is unknown. Although the potential value of continuous TEAS after surgery was mentioned in the two meta-analyses, the programs of continuous intervention and short-term intervention were scattered in different surgical types (such as orthopedics and thoracic surgery).[12,14] At the same time, TEAS studies on digestive surgery (including laparoscopic gastrointestinal surgery) were few. Moreover, there is no study to directly compare the effects of continuous TEAS and short-term TEAS in the same elderly population undergoing laparoscopic gastrointestinal surgery, resulting in the lack of consistency of the existing evidence in specific populations. In addition to POD, elderly patients with laparoscopic gastrointestinal surgery often have adverse reactions such as postoperative nausea and vomiting, dizziness, sleep disorders, and gastrointestinal dysfunction,[15–17] and the incidence of PONV can reach 20%-60%.[18] Many studies have shown that TEAS can also reduce the risk of the above-mentioned adverse reactions,[11,19–21] but it remains unclear whether the duration of TEAS treatment can enhance its therapeutic effect.

Therefore, this study aims to observe the effect of continuous transcutaneous electrical acupoint stimulation on the incidence of postoperative delirium and other adverse reactions in elderly patients undergoing laparoscopic gastrointestinal surgery, with the expectation of providing reference and optimization strategies for perioperative management of elderly patients.

Methods

Study

This prospective, double-blind, randomized controlled trial was conducted at the Affiliated Hospital of Jiaxing University. The study protocol was approved by the Ethics Committee of the Affiliated Hospital of Jiaxing University on June 27, 2023 (2023-KY-354). The trial was registered at clinicaltrials.gov (ChiCTR2300077309, 03/11/2023). This study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all the patients before randomization.

Patients

A total of 180 patients scheduled to undergo elective laparoscopic gastrointestinal surgery under general anesthesia were recruited from December 2023 to July 2025 and randomly divided into three groups: Group A received continuous TEAS (n=60), Group B received twice TEAS (n=60), and Group C received sham TEAS (n=60).

The inclusion criteria were as follows: (1) patients of both sexes, aged ≥65 years, ASA I–III; (2) expected operation time >1 hour; and (3) ability of normal communication, Chinese Mini Mental Status score(CMMS): illiterate ≥17 points, primary school education ≥20 points, secondary school and above education ≥24 points.

The exclusion criteria were as follows: (1) previous central nervous system diseases, mental disorders or mental abnormalities, or dependence on sedative, analgesic, hypnotic and other drugs; (2) severe systemic diseases or pacemaker implantation; (3) ulcers, infections or injuries in the local skin of acupoints; (4) refusal to participate or inability to cooperate.

The elimination criteria were as follows: (1) patients were asked to withdraw from the study; (2) had an operation time of less than 1 hour or conversion to open surgery; (3) patients whose condition deteriorated significantly after surgery or needed reoperation.

Randomization, Grouping and Blinding

The sample size was calculated on the basis of the results of the pilot study. After all patients provided informed consent and completed baseline assessments, randomization was performed via a sequence generated by SPSS 25.0, with the assignment concealed in opaque envelopes until the start of the intervention. A researcher who was not involved in patient recruitment, anesthesia management, or outcome assessment opened the envelope and performed the corresponding TEAS intervention. The TEAS stimulator was covered with opaque cloth throughout the experiment. The surgeons, anesthesiologists, outcome assessors, and statisticians were blinded to the group assignments. All postoperative assessments and follow-up procedures were conducted by trained study personnel masked to the group assignments.

TEAS Procedure

The acupoint selection in this study was based on TCM acupoint theory and previous studies, and TEAS manipulation was performed by researchers who received unified training.[12,19,22,23] The acupoint position referred to the Chinese national standard “Name and Location of Meridian Points” (GB/T 12346–2021).[24] The instrument used in the study was a Yingdi® KWD-808I pulse acupuncture therapeutic apparatus (Changzhou Yingdi Electronic Medical Instrument Co., Ltd).

TEAS manipulation was performed by researchers who received unified training. Groups A and B received TEAS at Yintang (EX-HN 3, midway between the medial ends of the eyebrows, on the glabella), bilateral Shenmen (HT 7, at the wrist, on the ulnar end of the transverse crease of the wrist, in the depression between the pisiform bone and the ulnar artery), Neiguan (PC 6, located on the palmar side of the forearm, 2 cun above the transverse crease of the wrist) and Zusanli (ST 36, on the anterior aspect of the lower leg, 3 cun below the patella base and one finger-width lateral from the anterior border of the tibia) 30 min before anesthesia induction and 30 min before the end of surgery.[21,25] The stimulation parameters were as follows: disperse-dense wave (2/100 Hz), pulse width 0.25 ms, current intensity 5–30 mA (adjusted to patient’s “tingling but comfortable” sensation), 30 min per session. In Group C, only the electrode patch was pasted during the whole process without current output. After the operation, electrical stimulation was stopped in Group B (the electrode patch was retained). In Group A, electrical stimulation at the same acupoints was repeated for 30 minutes every 8 hours within 72 hours postoperatively (total of 9 sessions).The selected acupoints and their locations are shown in Figure 1.

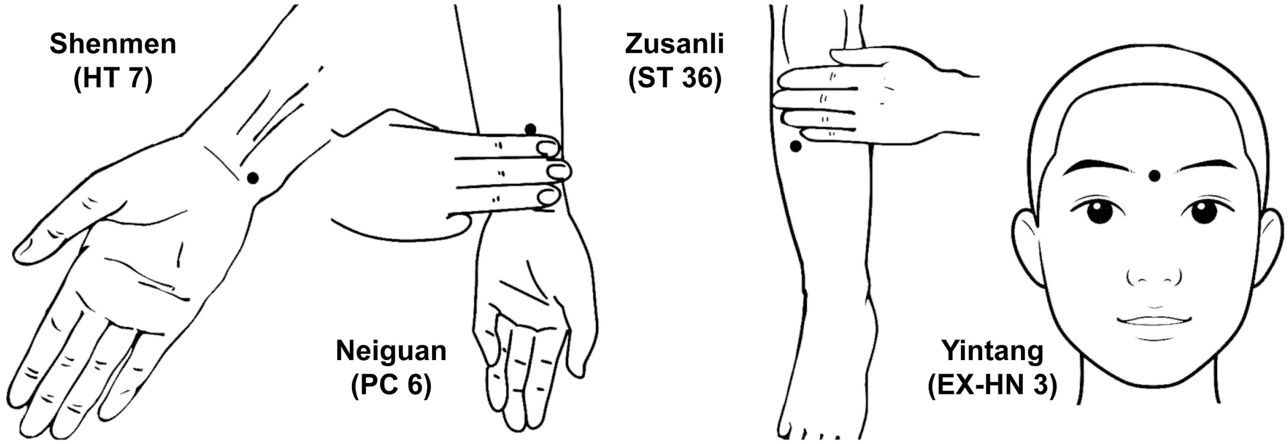

Figure 1 Location of the acupoints used in the study.
Notes: The acupoints (from left to right) are Shenmen (HT 7,at the wrist, on the ulnar end of the transverse crease of the wrist, in the depression between the pisiform bone and the ulnar artery), Neiguan (PC 6, located on the palmar side of the forearm, 2 cun above the transverse crease of the wrist), Zusanli (ST 36, on the anterior aspect of the lower leg, 3 cun below the patella base and one finger-width lateral from the anterior border of the tibia), and Yintang (EX-HN 3, midway between the medial ends of the eyebrows, on the glabella). The convenient measurement method of "cun" (Chinese acupoint measurement unit): 2 cun = the width of the patient's index finger, middle finger, ring finger, and little finger at the proximal interphalangeal joints; 3 cun = the width of the patient's four fingers (index to little finger) plus the width of the thumb.

Anesthesia and Perioperative Management

All patients routinely fasted before surgery, and upon entering the operating room, venous access was immediately established. ECG, oxygen saturation, heart rate, and noninvasive blood pressure were routinely monitored. Invasive blood pressure was monitored via transradial puncture under local anesthesia. Before induction of general anesthesia, 0.5 μg/kg dexmedetomidine was infused intravenously, followed by 1–2 mg/kg propofol, 0.5 μg/kg sufentanil, and 0.6 mg/kg rocuronium. After loss of consciousness, the patient was intubated and mechanically ventilated in volume control mode (tidal volume, 6–8 mL/kg; respiratory rate, 10–16 breaths/min; fraction of inspired oxygen, 60%), and the partial pressure of end-tidal carbon dioxide was maintained at 35–50 mm Hg. Anesthesia was maintained via the combined intravenous-inhalation technique: 2.0% sevoflurane was inhaled, and 0.1–0.2 μg/(kg·min) remifentanil was infused intravenously. The dose was titrated to maintain the bispectral index (BIS) between 40 and 60. Postoperative analgesia was performed via a patient-controlled intravenous analgesia (PCA) pump containing 100 μg of sufentanil and 8 mg of ondansetron diluted to 100 mL with normal saline. The PCA parameters were as follows: background infusion, 0 mL; single dose, 2.0 mL; and lock time, 10 min. Parecoxib sodium (40 mg) was injected intravenously as rescue analgesia if the visual analog scale (VAS) score was greater than 4 after continuously pressing PCA more than 3 times. Other treatments were performed according to the usual protocol.

Evaluations

After enrollment, all assessments were performed by trained research staff who were unaware of group assignments. The baseline cognitive function of the patients was assessed via the Chinese Mini Mental Status (CMMS) before surgery, and the Pittsburgh Sleep Quality Index (PSQI) was used to evaluate sleep quality 1 night before surgery. The primary outcome was the incidence of POD within 72 hours after surgery. POD was assessed every 8 hours via the intensive care unit delirium assessment method (CAM-ICU). The secondary outcomes included sleep quality scores at 1 week, 2 weeks and 1 month after surgery; the incidence of PONV; dizziness; skin injury; and the time to first flatus and first defecation postoperatively.

Statistical Analysis

Sample Size Calculation

In this study, the sample size was estimated by a preliminary pilot test. The same grouping and intervention measures were used, with POD incidence as the primary outcome measure. The results of pre-test showed that the incidence of

POD in continuous TEAS group (Group A, n=30), twice TEAS group (Group B, n=30) and sham TEAS group (Group C, n=30) was 9.2%, 25.0% and 38.8%, respectively. Using PASS 15.0 software, set bilateral α=0.05, 1-β = 0.9, and calculate the need for 54 cases in each group. Considering a 10% dropout rate, 60 patients were finally included in each group, with a total sample size of 180.

Primary and secondary outcomes in patients in the three groups were analyzed. All analyses were performed in SPSS 25.0. Continuous variables with a normal distribution are presented as the means ± SDs. Categorical variables are reported as case numbers or percentages. ANOVA or the Kruskal–Wallis test was used to analyze continuous variables, and Pearson's chi-square test or Fisher's exact test was used to assess the associations between outcomes and groups. All tests were two-sided, and $P<0.05$ or $P'<0.017$ ($P'=0.05/3$, with Bonferroni correction) was considered to indicate statistical significance.

Results

Between December 2023 and July 2025, the eligibility of 289 elderly patients scheduled for laparoscopic gastrointestinal surgery was assessed at the Affiliated Hospital of Jiaxing University. A total of 109 patients were excluded (65 did not meet the inclusion criteria, 28 refused to participate, and 16 did so for other reasons). As a result, 180 patients were randomly assigned 1:1:1 to Group A (continuous TEAS group), Group B (twice TEAS group), and Group C (sham TEAS group). Seven patients were lost to follow-up after discharge (4 refused postdischarge evaluation, and 3 had incorrect follow-up data) (Figure 2). A total of 173 patients were included in this analysis. There were no significant differences ($P>0.05$) among the three groups in terms of demographic or intraoperative characteristics (Table 1).

The Incidence of POD

Compared with that in Group C (53.6%), the incidence of POD in Group A (11.9%, $P'<0.017$) and Group B (31.0%, $P'<0.017$) was lower, and the incidence of POD in Group A was lower than that in Group B ($P'<0.017$) (Table 2; Table 3).

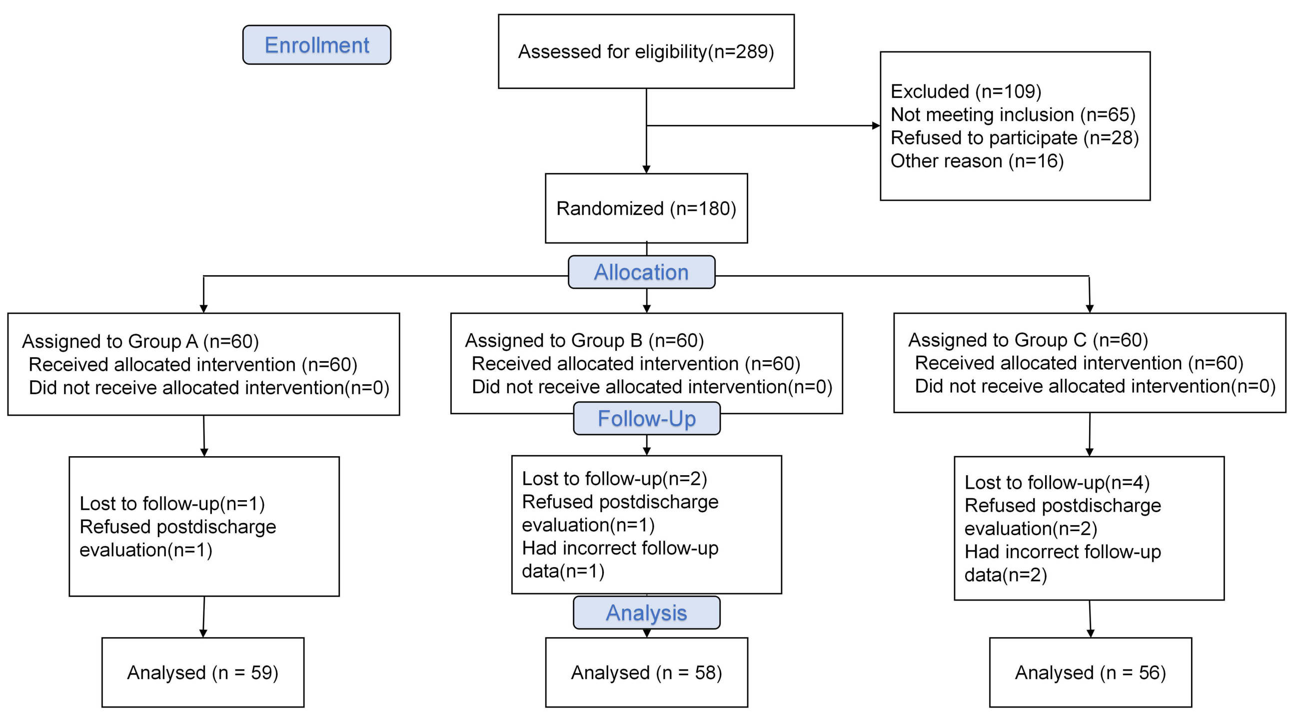

Figure 2 CONSORT flow diagram of the entire research process.

https://doi.org/10.2147/CIA.S581811

Table 1 Baseline Demographic and Clinical Characteristics of the Study Patients

Characteristics	Group A (n=59)	Group B (n=58)	Group C (n=56)	*P*-value
Age(years)	74.08±6.55	75.93±5.62	74.07±6.11	0.173
Sex				
Male, n (%)	36(61.0)	34(58.6)	35(62.5)	0.912
Female, n (%)	23(39.0)	24(41.4)	21(37.5)	0.912
Height (cm)	162.56±7.79	162.02±7.31	161.52±6.50	0.742
Weight (kg)	59.91±12.02	59.32±9.65	59.85±11.44	0.952
BMI (kg/m^2)	22.55±3.48	22.59±3.44	22.88±3.90	0.869
ASA physical status				
I, n (%)	0(0.0)	0(0.0)	0(0.0)	
II, n (%)	12(20.3)	18(31.0)	23(41.1)	0.055
III, n (%)	47(79.7)	40(69.0)	33(58.9)	0.055
Mini-Mental State Examination score	22.46±3.59	21.88±3.14	22.36±3.21	0.605
Education years(years)	4.95±2.84	4.60±2.70	5.05±2.62	0.651
History of hypertension, n (%)	36(61.0)	34(58.6)	34(60.7)	0.960
History of diabetes, n (%)	12(20.3)	15(25.9)	12(21.4)	0.752
History of coronary heart disease, n (%)	2(3.4)	0(0.0)	5(8.9)	0.051
History of cerebral infarction, n (%)	3(5.1)	0(0.0)	2(3.6)	0.243
Operative time (min)	227.92±107.77	219.57±102.20	219.70±92.60	0.878
Anesthesia time (min)	230.54±105.58	224.22±96.71	223.30±91.09	0.910
Intraoperative fluid intake (mL)	2136.80±851.60	2199.86±889.95	2151.70±769.47	0.914
Intraoperative hemorrhagic volume (mL)	142.20±111.45	116.55±80.99	110.36±89.08	0.165
Propofol dose (mg)	104.24±25.20	102.96±21.76	104.44±22.68	0.934
Remifentanil dose (mg)	1.95±0.59	1.98±0.83	1.88±0.65	0.764
Sufentanil dose (ug)	24.75±6.05	25.09±5.81	26.07±5.62	0.453

Notes: The data are presented as the means ± SD or numbers (%).
Abbreviations: BMI, Body mass index; ASA, American Society of Anesthesiologists.

Table 2 Comparison of Primary and Secondary Outcomes Among the Study Groups

Outcomes	Group A (n=59)	Group B (n=58)	Group C (n=56)	*P*-value
Primary outcome				
POD, n (%)	7(11.9)	18(31.0)	30(53.6)	<0.001
Secondary outcomes				
PONV, n (%)	9(15.3)	15(25.9)	29(51.8)	<0.001
Dizziness, n (%)	4(6.8)	7(12.1)	18(32.1)	0.001
Time to first flatus (h)	61.22±11.09	65.53±11.73	71.91±10.59	<0.001
Time to first defecation (h)	86.47±11.07	90.79±11.85	97.80±10.26	<0.001
Adverse Events				
Skin injury, n (%)	1(1.7)	1(1.7)	1(1.8)	0.999

Notes: The data are presented as the means ± SD or numbers (%).
Abbreviations: POD, Postoperative delirium; PONV, Postoperative nausea and vomiting.

Secondary Outcome

The Incidence of PONV and Dizziness

Compared with Group C (PONV: 51.8%, postoperative dizziness: 32.1%), there was significant difference in PONV and postoperative dizziness between Group A (PONV: 15.3%,$P'<0.017$;postoperative dizziness: 6.8%,$P'<0.017$) and Group B (PONV: 25.9%,$P<0.05$; postoperative dizziness:12.1%,$P<0.05$), but there was no significant difference between Group A and Group B ($P'>0.017$ and $P>0.05$) (Table 2; Table 3).

Table 3 Post Hoc Comparisons of the Three Outcome Indicator Sets

Outcomes	Group A vs Group B		Group A vs Group C		Group B vs Group C	
	P	***P'***	***P***	***P'***	***P***	***P'***
Incidence of POD	0.011[a]	0.011[b]	<0.001[a]	<0.001[b]	0.015[a]	0.015[b]
Incidence of PONV	0.155	0.155	<0.001[a]	<0.001[b]	0.010[a]	0.010[b]
Incidence of Dizziness	0.327	0.327	0.001[a]	0.001[b]	0.010[a]	0.010[b]
Time to first flatus (h)	0.038[a]	0.114	<0.001[a]	<0.001[b]	0.003[a]	0.008[b]
Time to first defecation (h)	0.037[a]	0.110	<0.001[a]	<0.001[b]	0.001[a]	0.003[b]
PSQI at 1 Week Postoperatively(points)	0.096	0.287	0.003[a]	0.008[b]	0.170	0.509
PSQI at 2 Weeks Postoperatively(points)	0.004[a]	0.011[b]	<0.001[a]	<0.001[b]	0.091	0.272
PSQI at 1 month Postoperatively(points)	<0.001[a]	<0.001[b]	<0.001[a]	<0.001[b]	0.460	>0.999

Notes: *P*: Uncorrected *P*-value; *P'*: Bonferroni-corrected *P*-value; [a]$P < 0.05$. [b]$P < 0.017$.
Abbreviation: PSQI, Pittsburgh Sleep Quality Index.

Table 4 Postoperative Sleep Quality Assessed by the Pittsburgh Sleep Quality Index (PSQI)

Time	PSQI Score (Points) - Group A	PSQI Score (Points) - Group B	PSQI Score (Points) - Group C	*P value*
1 night before surgery	12.97±5.29	12.95±5.06	12.57±5.08	0.899
1 week after surgery	9.26±3.72	10.57±4.00	11.66±4.90	<0.001
2 weeks after surgery	7.10±2.89	8.96±3.43	10.05±3.91	<0.001
1 month after surgery	5.03±1.71	7.60±2.91	7.98±3.36	<0.001

Notes: Data are presented as mean ± SD deviation.

Time to First Flatus and Time to First Defecation

Compared with those in Group C, the time to first postoperative flatus and defecation times in Group A and Group B were significantly earlier (P'<0.017), and there was difference between Group A and Group B (P<0.05) (Table 2; Table 3).

Sleep Quality

Compared with those of Group C, the PSQI scores of Group A were lower at 1 week, 2 weeks and 1 month after surgery (P'<0.017). Compared with those of Group B, the PSQI scores of Group A were lower at 2 weeks and 1 month after the operation (P'<0.017). There was no significant difference between Group B and Group C (P >0.017) (Table 4; Table 3). The trends in the changes in the PSQI scores across the three groups are shown in Figure 3.

Discussion

In this study, continuous electrical stimulation, two rounds of electrical stimulation and sham electrical stimulation were given at Yintang (EX-HN 3), Neiguan (PC 6), Shenmen (HT 7) and Zusanli (ST 36), respectively, during the perioperative period for elderly patients undergoing laparoscopic gastrointestinal surgery. The results revealed that the incidence of postoperative delirium in Group A (7/59, 11.9%) was significantly lower than that in Group B (18/58, 31.0%) (P'<0.017) and Group C (30/56, 53.6%) (P'<0.017), while Group B also had a significantly lower POD incidence than Group C (P'<0.017). This indicates that both continuous and twice TEAS can reduce POD incidence, but continuous TEAS has a more pronounced effect. The incidence of POD in Group A was significantly lower than that in Group B (P'<0.017). One of the important pathophysiological mechanisms of POD is neuroinflammation. Studies have shown that postoperative elevation of proinflammatory cytokines such as IL-6 and TNF-α in peripheral blood can lead to increased permeability and dysfunction of the blood–brain barrier (BBB), accelerate the migration and accumulation of inflammatory cells and mediators to the central nervous system, and then cause a loss of synaptic plasticity and neuronal apoptosis, which can cause nerve damage and lead to a significant increase in the risk of POD.[26,27] The inflammatory response induced by surgical trauma is triggered by tissue damage signals through immune cell activation, cytokine release and the vascular response. After trauma, the body rapidly activates the mononuclear-macrophage system and neutrophils to secrete proinflammatory cytokines, which are maintained at high levels

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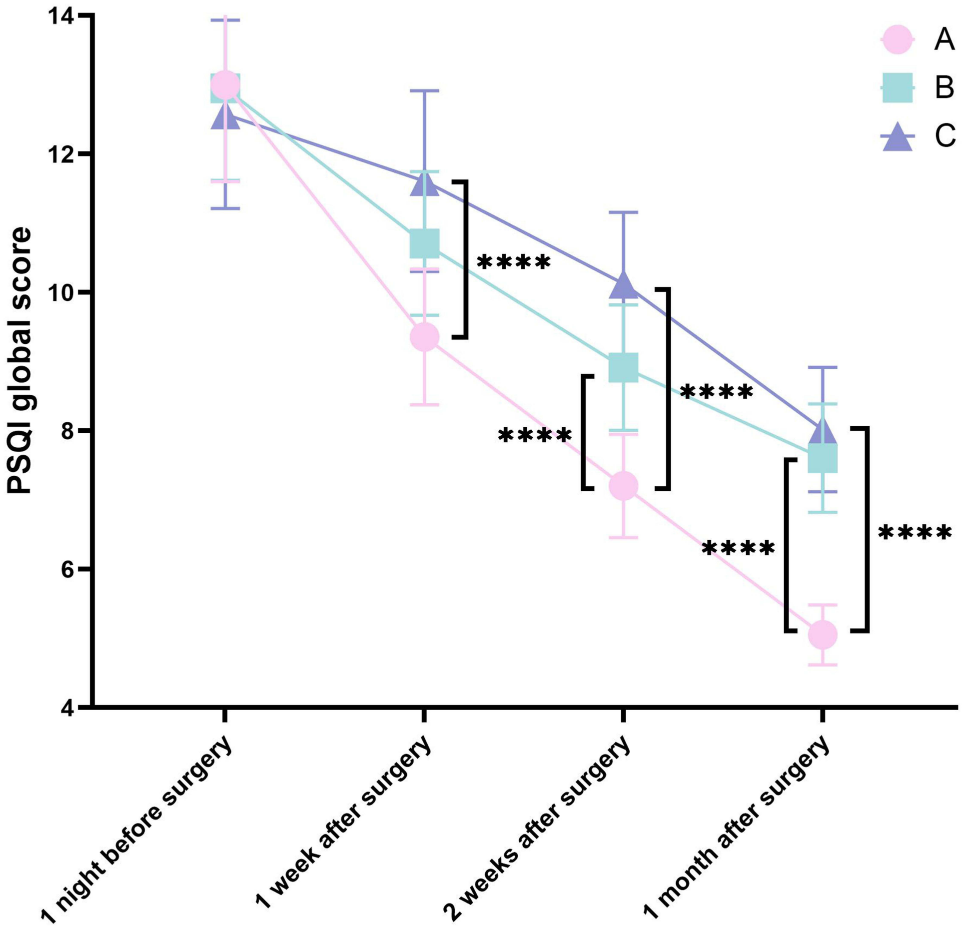

Figure 3 Trends in postoperative sleep quality.
Notes: Changes (mean ± 95% CI) in Pittsburgh Sleep Quality Index (PSQI) scores from 1 night before surgery to 1 month after surgery in the three groups. ****$P' < 0.017$.

for 1–3 days after surgery.[28] Modern studies have shown that TEAS can deliver specific low-frequency pulse currents into the human body through skin acupoints and then exert effects analogous to electroacupuncture. TEAS has demonstrated beneficial effects in labor analgesia, anti-inflammation, immune regulation, and organ function protection.[29–31] In Group A, TEAS was continued at 72 hours after surgery, which was beneficial for providing a certain anti-inflammatory effect at the peak of the postoperative inflammatory response; reducing the levels of inflammatory factors such as IL-6, CRP, and TNF-α; and reducing the occurrence of POD.[13,32–34] In addition, functional magnetic resonance imaging (fMRI) studies have shown abnormal functional connectivity within the default mode network (DMN) in POD patients.[12] Therefore, we speculate that the connectivity between the prefrontal–limbic system and the DMN may be normalized by electrical stimulation of acupoints such as Yintang (EX-HN 3) and Shenmen (HT 7). This central modulatory effect may help reduce postoperative stress and maintain cognitive stability, providing a complementary neural mechanism to reduce the risk of POD.

Our study revealed that patients in Group A had better postoperative sleep quality than did those in Groups B and C ($P' < 0.017$) (Table 3). In this study, electrical stimulation was performed at Yintang (EX-HN 3) and Neiguan (PC 6). Studies have shown that stimulation of these two acupoints may improve sleep quality and the circadian rhythm by regulating the secretion of melatonin.[22,35] An animal electrophysiological study has also shown that stimulation of the Yintang (EX-HN 3) acupoint in mice can increase θ wave activity in the prefrontal cortex and promote nonrapid eye movement sleep (NREM).[36] Moreover, TEAS can regulate the function of the hypothalamic–pituitary–adrenal (HPA) axis and reduce cortisol levels, thus improving sleep.[23] NREM sleep is essential for maintaining synaptic homeostasis and clearing neurotoxic waste through the glymphatic system.[37] Disturbed sleep can block this clearance process and exacerbate neuroinflammation, forming a vicious cycle that induces POD.[38] In this study, compared with the two TEAS group, the continuous TEAS group had a greater effect on improving the postoperative sleep quality of patients. We hypothesize that a single stimulation may only induce transient changes in neurotransmitter levels, while continuous or multiple sessions of acupoint TEAS may lead to sustained accumulation of neurotransmitters, thereby producing a more obvious effect on sleep regulation.[39] The above cumulative effect may also be an important reason why the incidence of POD can be further reduced in patients receiving multiple sessions of TEAS.

Compared with patients in the C group who did not receive TEAS, patients in the A and B groups who received TEAS had a lower incidence of PONV and postoperative dizziness and a faster recovery of gastrointestinal function ($P' < 0.017$). A meta-analysis that included 14 RCTs revealed that TEAS was effective in preventing PONV and dizziness.[19,40] A number of studies have shown that stimulation of Neiguan (PC 6) and Zusanli (ST 36) can improve intestinal peristalsis and regulate endocrine function, thereby reducing gastric acid levels and helping to regulate gastrointestinal function.[21,41] This may be the reason for the more rapid recovery of gastrointestinal function in patients undergoing consecutive TEAS procedures after surgery, which will be more conducive to achieving the goal of rapid recovery after surgery.

In addition to the short-term effects on POD incidence and postoperative recovery, TEAS may have potential long-term benefits in preventing postoperative cognitive dysfunction (POCD) and delirium-related complications. POCD is a common long-term complication in elderly surgical patients, characterized by persistent cognitive impairment lasting more than 3 months after surgery. POCD is a kind of postoperative multi-domain cognitive dysfunction, which usually occurs 2 weeks or 2 months after surgery, lasts for a long time, and is more common in the elderly. Studies have shown that neuroinflammation is a common pathophysiological mechanism of POD and POCD.[27] Continuous TEAS can reduce the levels of pro-inflammatory cytokines (IL-6, TNF-α) during the acute postoperative period, which may alleviate long-term neuronal damage and reduce the risk of POCD. However, the long-term effects of TEAS on POCD and delirium-related complications require further verification by prospective cohort studies with extended follow-up periods.

It is worth noting that when the uncorrected $\alpha=0.05$ was used as the statistical cut-off value in the study results, there was no significant difference in PONV, dizziness and other categorical variables between the Group A (continuous TEAS) and the Group B (twice TEAS), suggesting that the two times of transcutaneous electrical acupoint stimulation during the perioperative period have produced significant antiemetoic and anti-dizziness effects. However, increasing the stimulation did not produce more obvious effect, suggesting that there may be a bottleneck in the selected acupoint in antiemetics and anti-dizziness. At this time, increasing the stimulation frequency or combining with other acupoints with antiemetics and anti-dizziness effects, such as Sanyinjiao (SP 6), Taichong (LR 3), etc., may produce additional effects, but further research is still needed. The incidence of the first exhaust time and the first defecation time in Group A were significantly better than those in Group B, suggesting that continuous TEAS is more beneficial in reducing postoperative delirium and promoting postoperative gastrointestinal function recovery in elderly patients, but this benefit was masked by Bonferroni's strict correction.

This study revealed that one case of skin injury occurred in each of the three groups after the electrode patch was used, which was mild skin redness and swelling, and no skin damage or infection was observed. The technology was safe. A number of studies also support the safety of TEAS in different surgical scenarios.[20,42,43] In addition, TEAS has a low cost and simple operation, which has high economic value and wide promotion feasibility. The addition of continuous TEAS to the comprehensive perioperative management plan for elderly surgical patients may become an effective intervention strategy. Therefore, TEAS is expected to serve as a non-pharmacological, low-cost, and safe adjuvant therapy within the framework of Enhanced Recovery After Surgery (ERAS). In addition, subsequent studies should evaluate the effects of TEAS in different clinical settings, pay attention to the training of medical staff and the rational allocation of resources, and optimize the intervention strategy under real-world conditions, including the formulation of standardized operating procedures and scientific acupoint selection according to the type of surgery and the characteristics of patients, to promote the translation of evidence into clinical practice.

However, we are aware of the limitations of our study. First, this was a single-center randomized controlled trial, which may limit the generalizability of our results to other clinical settings, and a large multicenter study is necessary to demonstrate the effectiveness of TEAS from a broader perspective. Second, adding a research group that received electrical stimulation in non-meridian, non-acupoint areas could better demonstrate the effectiveness of stimulating specific acupoints. Third, this

https://doi.org/10.2147/CIA.S581811

study used delirium incidence as the primary outcome measure and the CAM-ICU scale as the assessment scale, however, it may not be able to assess delirium severity or facilitate further comparisons. Finally, this study lacks follow-up on the patients' cognitive function for more than one month after the operation. The long-term impact of TEAS on the patients' cognitive function remains unknown, and these are undoubtedly closely related to the patients' long-term quality of life and family burden. It is necessary to conduct longer-term follow-up studies in the future.

Conclusion

In summary, this prospective, double-blind, randomized controlled trial demonstrated that perioperative continuous TEAS could significantly reduce the incidence of POD, PONV and postoperative dizziness in elderly patients undergoing laparoscopic gastrointestinal surgery, effectively improve postoperative sleep quality, accelerate the recovery of gastrointestinal function, and did not increase the risk of adverse events such as skin injury. Importantly, as a non-pharmacological, low-cost and easy-to-operate intervention measure, continuous TEAS has broad application prospects in clinical practice and is worthy of being promoted and applied as a routine auxiliary intervention measure in the perioperative management of elderly patients undergoing laparoscopic gastrointestinal surgery.

Abbreviations

POD, Postoperative delirium; TEAS, Transcutaneous electrical acupoint stimulation; ASA, American Society of Anesthesiologists; CMMS, Chinese Mini Mental Status; CAM-ICU, Confusion Assessment Method for the Intensive Care Unit; PSQI, Pittsburgh Sleep Quality Index; PONV, Postoperative nausea and vomiting; VAS, Visual Analog Scale; PCA, Patient-controlled analgesia; BIS, Bispectral Index; BBB, Blood-brain barrier; fMRI, Functional magnetic resonance imaging; DMN, Default mode network; HPA, Hypothalamic-pituitary-adrenal axis; NREM, Non-rapid eye movement sleep; POCD, Postoperative cognitive dysfunction; BMI, Body mass index; ERAS, Enhanced Recovery After Surgery.

Data Sharing Statement

The datasets generated and/or analysis during the current study are not publicly available to ensure higher levels of data safety and protection, but are available from the corresponding author on reasonable request.

Acknowledgments

The author would like to express heartfelt thanks to the staff of the Anesthesia and Pain Medicine Center and Gastrointestinal Surgery Department of the Affiliated Hospital of Jiaxing University for their valuable help and cooperation in this study.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This work was supported by the Traditional Chinese Medicine Science and Technology Program of Zhejiang Province (2024ZL1081), the Clinical Key Specialty Construction Project of Zhejiang Province (Department of Anesthesiology, 2023-ZJZK-001) and the Clinical Key Specialty Construction Project of Zhejiang Province (Department of Critical Care Medicine, 2024-ZJZK-002).

Disclosure

The authors report no conflicts of interest in this work.

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