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Original Article

Comparison of robotic and manual scope holders in laparoscopic colorectal cancer surgery

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Abstract: Objective: To compare the performance of a robotic (da Vinci Xi-based) scope holder with manual holding during laparoscopic colorectal cancer (CRC) surgery. Methods: A total of 170 CRC cases were retrospectively assigned to two equal groups: an investigation group (da Vinci Xi-assisted procedures) and a reference group (human camera assistant). Surgical and recovery outcomes were analyzed, including pain intensity, stress levels, and gastrointestinal and humoral immune functions. Additionally, the safety of the procedures and surgeons' subjective experiences were evaluated. Results: The investigation group showed significant improvements, including reduced blood loss, shorter surgical duration, earlier drain removal and discharge, lower costs, and less post-operative pain (24, 48, and 72 hours post-surgery). This group also exhibited lower stress levels, fewer complications, and better recovery in terms of gastrointestinal and humoral immunity (all $P<0.05$). Surgeons in the investigation group reported higher scores for procedural vigor, operational efficiency, and comfort ($P<0.05$). Conclusion: The robotic system offers clinical advantages in laparoscopic CRC procedures.

Keywords: Colorectal cancer, safety, laparoscopic surgery, rehabilitation indicators, robotic scope holder

Introduction

Colorectal cancer (CRC) is a highly fatal condition with increasing prevalence among gastrointestinal malignancies, ranking only behind gastric and liver cancers globally [1]. Documented risk factors include heritable genetic predisposition, obesity, and consumption of processed foods, sugar-sweetened beverages, alcohol, and tobacco [2]. In 2020, approximately 1.93 million new CRC cases were diagnosed worldwide, with 940,000 fatalities, and a five-year survival rate of 60% was reported [3]. Radical surgery is recommended for early-stage CRC [4]. Traditionally, open surgery, which is invasive and traumatic, is used. However, with advances in medicine, minimally invasive laparoscopic surgery has become more widely adopted. Laparoscopy offers enhanced clarity, allowing surgeons to better identify lesions and understand the relationships between the colon, rectum, and nearby structures, thereby improving resection precision [5].

Surgical outcomes, however, are influenced by the stability of the laparoscopic scope holder. Poor performance of the holder can cause an unstable surgical field, compromising colorectal resection precision [6]. Traditionally, a human assistant holds the laparoscope, allowing for adaptable positioning. However, this method heavily relies on the assistant's expertise [7]. The da Vinci system-based robotic scope holder automates camera manipulation, reducing surgical complexity and human error. Its limitations include the need for specialized maintenance and higher operational costs [8, 9]. Despite this, limited research exists on optimal strategies for selecting endoscopic assistance. This study aims to explore the role of robot-assisted endoscopy in CRC.

This study presents several innovations. It compares the performance of the robotic scope holder (da Vinci Xi-based) to manual camera holding in laparoscopic CRC surgeries, potentially improving laparoscopy efficiency and proposing a superior alternative. Additionally, the

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study comprehensively analyzes patient recovery, pain, stress, gastrointestinal/humoral immune functions, and safety to highlight the robotic system's strengths, paving the way for its broader application. Finally, the evaluation of the operator's subjective experience provides insights into the real-world applicability of the system.

Materials and methods

General data

This retrospective study included 170 CRC patients managed laparoscopically. Clinical data were retrieved from the hospital's electronic health records for patients treated at the Second Affiliated Hospital Naval Medical University between February 2022 and February 2025. Group assignment was based on the type of surgical assistance: 85 patients were assigned to a reference group (robotic-assisted) and 85 to an investigation group (manual assistance). This study was approved by the ethics committee of the Second Affiliated Hospital Naval Medical University.

Inclusion criteria: ① Diagnosis of CRC [10]; ② No surgical contraindications; ③ Complete clinical data.

Exclusion criteria: ① Extracolonic infiltration or metastasis; ② Organ failure; ③ Familial polyposis; ④ Other colorectal diseases; ⑤ A history of anticancer treatment.

Methods

Investigation group: This cohort underwent laparoscopic resection using the Da Vinci system. The robot was secured to the rail on the affected side of the operating table, with the lead surgeon operating from the healthy side. After preparation, the robot was covered with a sterile drape. Pneumoperitoneum was created through the umbilicus before Trocar (10 mm) placement. The laparoscope, mounted on the robotic arm, was calibrated to ensure horizontal alignment with the Trocar. Final system positioning was adjusted using the console. After inserting the laparoscope into the abdominal cavity, the surgeon controlled the device using the attached handle, adjusting based on the endoscopic image to achieve an optimal operative field. Special care was taken to preserve the mesentery. Lesion removal and lymphadenectomy followed. The inferior mesenteric artery was divided in cases involving the rectum or lower sigmoid colon, while right colon cancers required extended dissection to clear areas medial to the ileocolic vein and anterior to the artery. The da Vinci Xi robotic system provided scope stabilization with sub-millimeter targeting accuracy (post-calibration fiducial localization error: ≤1 mm, 1080p 3D-HD imaging, 220 mm working radius).

Reference group: A certified assistant manually stabilized the laparoscopic scope. Lesion resection followed the same protocol as described above.

Post-surgical patients received patient-controlled analgesia (PCA; lockout interval: 15 minutes). The analgesic solution consisted of tropisetron (10 mg; Shandong Qidu Pharma, H20163117, 5 ml:5 mg per vial) and fentanyl (3 μg/kg; Jiangsu Nhwa Pharma, H20113509, 10 ml:0.5 mg), mixed with sterile sodium chloride solution (0.9%, 150 mL).

Camera management protocols: Camera assistants were certified by the Chinese Medical Doctor Association, with experience in ≥50 colorectal procedures and an FLS module score ≥80, ensuring <5% view loss.

Robotic systems were calibrated for <1 mm error using the Camera Calibration Wizard, with recalibration after repositioning.

Lead surgeon-driven real-time verbal feedback was implemented for manual navigation, with assistant replacement upon a score <7.

All procedures were video-documented, and cohort similarity was verified by a blinded third party.

Outcome measures

(1) Surgical metrics [11]: ① Intraoperative bleeding: Total blood loss = change in gauze weight (pre- and post-use) + fluid volume in the suction apparatus. ② Operative duration. ③ Intraoperative infusion amount. ④ Urine output.

(2) Rehabilitation metrics [12]: Time to: ① Drain removal; ② First flatus; ③ First oral feeding; ④ Discharge; ⑤ Inpatient expenses.

Table 1. Comparison of baseline data

Indicators	Investigation group (n=85)	Reference group (n=85)	χ^2/t	P
Age (years)	58.23±2.09	58.61±2.14	1.171	0.243
Sex			0.024	0.876
Male	49 (57.65)	50 (58.82)		
Female	36 (42.35)	35 (41.18)		
Cancer staging			1.554	0.213
I	54 (63.53)	46 (54.12)		
II	31 (36.47)	39 (45.88)		
Cancer type			0.379	0.538
Colon cancer	44 (51.76)	48 (56.47)		
Rectal cancer	41 (48.24)	37 (43.53)		
Illness duration (months)	9.23±1.17	8.91±1.02	1.901	0.059

(3) Pain [13]: Postoperative pain at 12, 24, 48, and 72 hours was assessed using the Visual Analog Scale (VAS; range: 0-10) [11]. Severity was classified as mild pain (≤4), moderate pain (4-6), or severe pain (≥6).

(4) Stress response markers [14]: Epinephrine (E), norepinephrine (NE), and cortisol (Cor) were measured using enzyme-linked immunosorbent assay (ELISA, Jiangxi Jianglan Pure Biological Reagents Co., Ltd.; JLC20590, JLC20655, JLC20509). Preoperative and 24-hour postoperative blood samples (3 mL) were collected, and assay limits of detection (LOD) were 50 pg/mL for E, 100 pg/mL for NE, and 1.4 nmol/L for Cor.

(5) Gastrointestinal function indices [15]: Motilin (MTL), gastrin (GAS), and somatostatin (SS) were quantified pre- and 24 hours post-surgery using human ELISA kits. LOD for MTL was 6.8 pg/mL, for GAS 3.2 pg/mL, and for SS 4.5 pg/mL.

(6) Humoral immune indexes [16]: Immunoglobulin A (IgA), IgM, and IgG were detected via ELISA preoperatively and 24 hours post-surgery. The LOD values were 0.10 IU/mL for IgA, 0.12 IU/mL for IgM, and 0.08 IU/mL for IgG.

(7) Safety [17]: Safety was assessed by monitoring complications such as anastomotic leakage, postoperative infection, and bowel obstruction.

(8) Surgeons' subjective experiences [18]: Surgeons' subjective assessments were evaluated through an internally designed survey measuring intraoperative procedural vigor, teamwork, operational efficiency, and surgeon comfort. Higher scores (max 100) reflect more positive subjective appraisals.

Statistical analyses

Statistical analysis was performed using SPSS software (v28.0). Continuous variables are presented as mean ± standard deviation, while categorical data are reported as counts and proportions (n/%). Inter-group differences for continuous data were assessed using independent samples t-tests, and paired t-tests were applied for pre- vs. post-treatment comparisons within the same cohort. For categorical variables, inter-group differences were analyzed using the Chi-square (χ^2) test. A *P*-value <0.05 was considered statistically significant. Figures were generated using GraphPad Prism (v7.0).

Results

Comparison of baseline data

As shown in **Table 1**, the reference and investigation groups had similar baseline characteristics with respect to age, sex, tumor stage, cancer type, and illness duration (all P>0.05), supporting baseline comparability.

Comparison of surgical metrics

Surgical outcomes differed statistically between the groups in terms of intraoperative blood loss and operative duration, with the investigation group demonstrating superior results (both P<0.05). However, intraoperative fluid infusion volume and urine output showed no significant difference (P>0.05). See **Table 2**.

Table 2. Comparison of surgical metrics [n ($\bar{x}$±s)]

Groups	n	Intraoperative blood loss (mL)	Operative duration (min)	Intraoperative infusion volume (mL)	Urine output (mL)
Investigation group	85	98.62±21.35	225.78±24.73	1553.34±258.31	518.34±40.89
Reference group	85	139.54±40.02	264.31±32.94	1629.84±301.26	510.94±45.73
t		8.317	8.624	1.777	1.112
P		<0.001	<0.001	0.077	0.268

Table 3. Comparison of rehabilitation indicators [n ($\bar{x}$±s)]

Groups	n	Time to drain removal (d)	Time to first flatus (d)	Time to first oral feeding (d)	Time to discharge (d)	Inpatient expenses (ten thousand yuan)
Investigation group	85	3.19±0.45	2.14±0.39	2.37±0.48	9.24±1.08	3.58±0.32
Reference group	85	3.70±0.30	2.09±0.36	2.44±0.51	11.31±1.56	3.96±0.37
t		8.694	0.869	0.921	10.058	7.162
P		<0.001	0.386	0.358	<0.001	<0.001

Table 4. Comparison of pain [($\bar{x}$±s), points]

Groups	n	12 h post-operation	24 h post-operation	48 h post-operation	72 h post-operation
Investigation group	85	2.24±0.36	4.02±0.35	3.36±0.29	2.05±0.18
Reference group	85	2.19±0.37	4.87±0.34	4.11±0.42	2.64±0.23
t		0.893	16.060	13.548	18.625
P		0.373	<0.001	<0.001	<0.001

Comparison of rehabilitation metrics

In addition to lower inpatient expenses, the investigation group had drains removed faster and were discharged earlier than the reference group (P<0.05). No significant differences between groups were found in the times to first exhaust and first oral feeding (both P>0.05). See **Table 3**.

Comparison of pain status

Postoperative pain at 12 hours was comparable between the groups (P>0.05). However, significant differences emerged at 24, 48, and 72 hours, with the investigation group reporting consistently lower pain scores than the reference group (P<0.05). See **Table 4**.

Comparison of stress response markers

At baseline, no significant differences in stress markers were observed between the groups (all P>0.05). While both groups exhibited an increase in E, NE, and Cor in both cohorts at 24 hours post-surgery, the investigation group showed notably lower values than the reference group (all P<0.05). See **Figure 1**.

Comparison of gastrointestinal function parameters

Gastrointestinal markers showed similar baseline values between the investigation and reference groups (all P>0.05). At 24 hours post-surgery, significant reductions in MTL, GAS, and SS were observed in both groups, with values remaining higher in the investigation group compared to the reference group (all P<0.05). See **Figure 2**.

Comparison of humoral immune indexes

Both groups showed similar humoral immunity profiles at baseline (P>0.05). At 24 hours post-surgery, levels of IgA, IgM, and IgG decreased in both groups, with the investigation group maintaining higher levels than the reference group (all P<0.05). See **Figure 3**.

Comparison of safety

A significant intergroup difference in complication rates was observed, with the robot-assisted group demonstrating a notably lower incidence of complications compared to the manual technique group (3.53% vs. 12.94%; P<0.05). See **Table 5**.

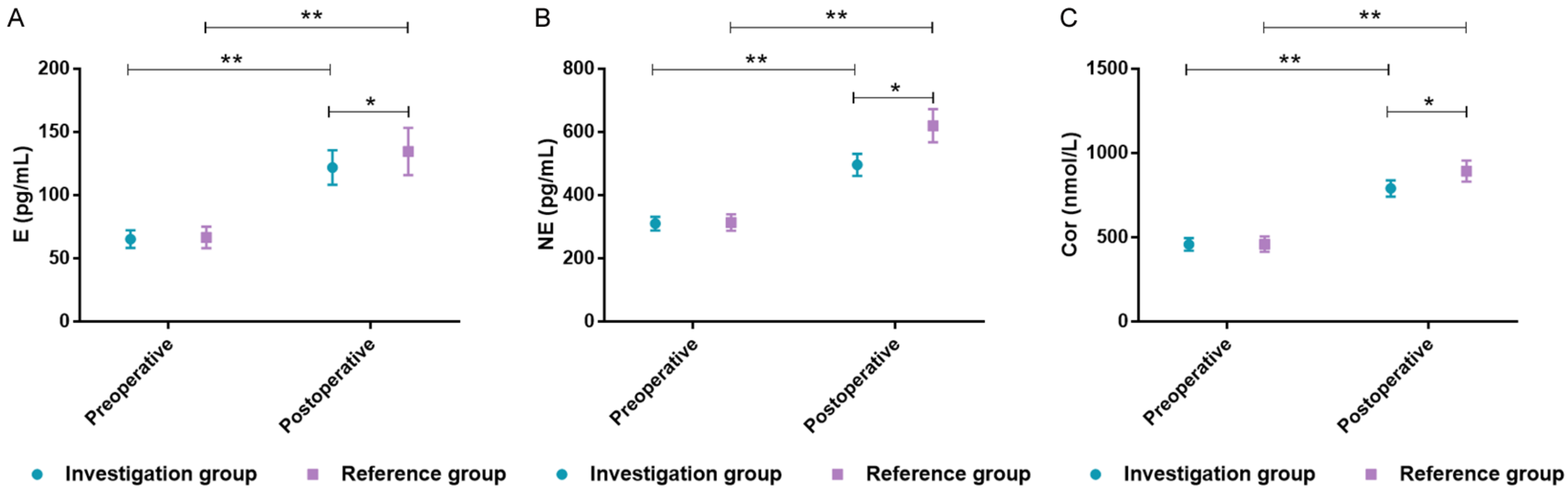

Figure 1. Comparison of stress response markers. A. Epinephrine (E) concentrations pre- and post-operation in the two cohorts. B. Pre- and post-operative measurements of norepinephrine (NE). C. Serum cortisol (Cor) concentrations prior to and following the surgical intervention. Note: **P<0.01, *P<0.05.

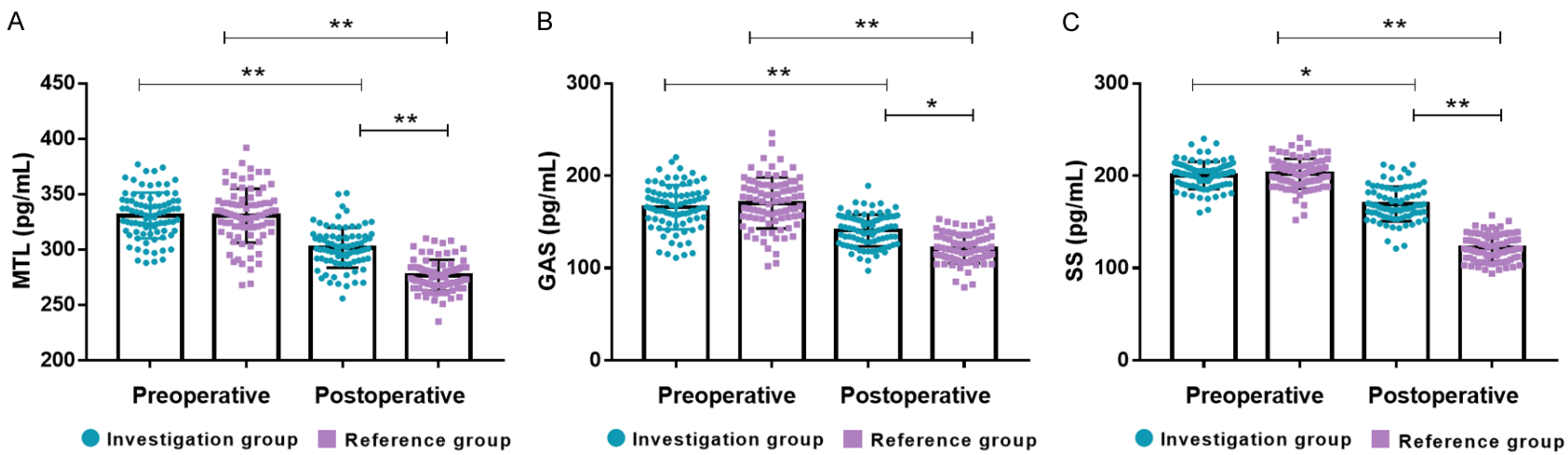

Figure 2. Comparison of gastrointestinal function parameters. A. Motilin (MTL) concentrations measured pre- and post-operation in both the experimental and control cohorts. B. Gastrin (GAS) levels prior to and following the surgical procedure. C. Pre- and postoperative somatostatin (SS) levels. Note: **P<0.01, *P<0.05.

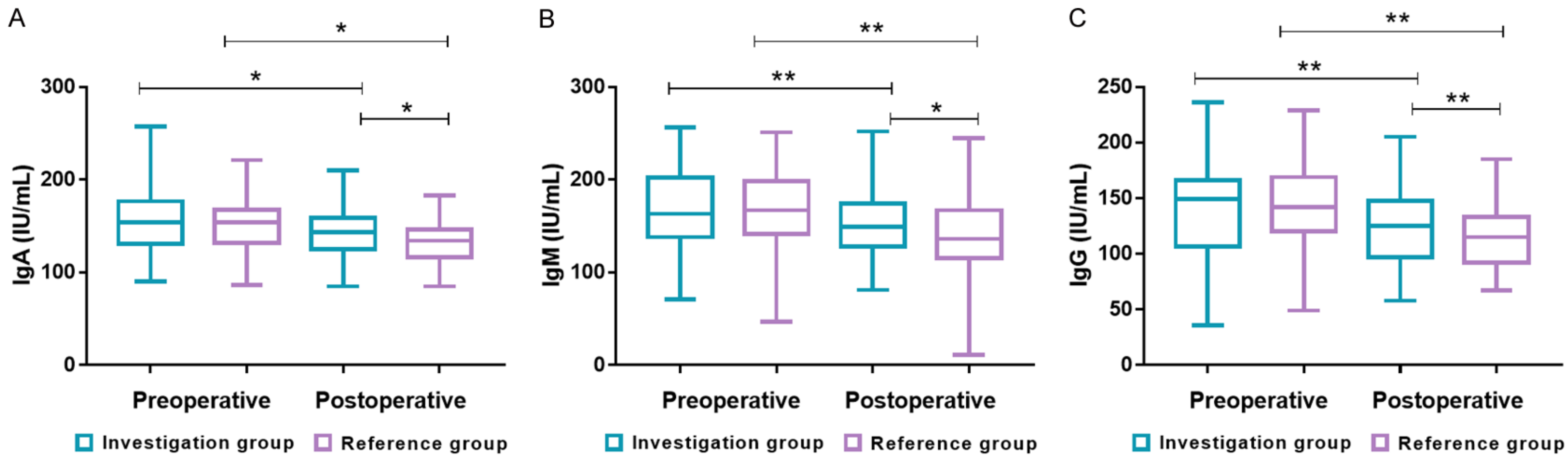

Figure 3. Comparison of humoral immunity indexes. A. Immunoglobulin (Ig)A measurements before and after surgery across the two cohorts (Investigation vs. Reference). B. Pre-surgical and post-surgical IgM values. C. IgG levels pre- and post-operation. Note: **P<0.01, *P<0.05.

Table 5. Comparison of comparison of safety [n (%)]

Groups	n	Anastomotic leakage	Infection	Bowel obstruction	Total
Investigation group	85	2 (2.35)	0 (0.00)	1 (1.18)	3 (3.53)
Reference group	85	6 (7.06)	2 (2.35)	3 (3.53)	11 (12.94)
χ^2		-	-	-	4.982
P		-	-	-	0.026

Table 6. Comparison of surgeons' subjective experiences [($\bar{x}\pm s$), points]

Groups	n	Procedural vigor	Teamwork	Operational efficiency	Surgeon comfort
Investigation group	85	89.64±2.12	86.39±3.78	87.78±2.54	88.54±3.02
Reference group	85	84.55±4.07	86.12±3.95	82.09±3.16	83.31±3.39
t		10.226	0.455	12.939	10.621
P		<0.001	0.650	<0.001	<0.001

Comparison of surgeons' subjective experiences

Subjective evaluations related to teamwork showed no significant differences between the groups (P>0.05). However, measures including procedural vigor, operational efficiency, and surgeon comfort were statistically better in the investigation group (all P<0.05). See **Table 6**.

Discussion

Laparoscopic procedures are valued for being minimally invasive and safe. In the management of CRC, small trocar sites are created in the abdomen, through which a laparoscope is directed toward the affected area. The connected monitor projects a high-definition view of the anatomical structures, providing excellent visual guidance [19]. Effective laparoscopic lesion observation requires frequent scope adjustments, making secure scope-to-imaging connection essential. A compromised linkage can lead to transmission delays or reduced image quality [20]. Manual scope holding stability varies depending on the operator's expertise and may be compromised by fatigue during lengthy procedures [21]. In contrast, robotic stabilization ensures steady, precise, and sustained support without the risk of fatigue. However, the precise role of robotic assistance in surgical safety and outcomes remains to be further explored.

In our study, the investigation group demonstrated superior performance in terms of intraoperative bleeding, operative duration, drain removal/discharge time, and inpatient expenses. Manual manipulation of the laparoscope relies heavily on the surgeon's instructions, as anticipating precise movements can be difficult. These adjustments are often time-consuming and may cause distractions, potentially diminishing surgical accuracy and increasing the risk of iatrogenic peritumoral tissue damage [22, 23]. The da Vinci robotic system offers superior scope stabilization and can predict surgical maneuvers, enhancing stability during adjustments and minimizing camera-induced disruptions. This allows the surgeon to focus more on lesion resection, thus reducing operative time [24]. With superior positioning accuracy and precision, this system helps reduce tissue trauma, shortening postoperative drainage time and accelerating patient recovery [25]. Wan et al. [26] examined the use of robotic camera holders in endoscopic procedures and found fewer lens cleaning instances and reduced inappropriate movements compared to manual holding, supporting our findings. In endoscopic extraperitoneal radical prostatectomy, the system similarly improved control over horizontal and zoom movements, with fewer cleaning episodes and camera errors [27].

We also observed better postoperative pain relief and lower complication rates in the robotic group. Prolonged excision during laparoscopic CRC radical resection, due to the widespread nature of the disease, often requires extended manual scope holding. The resulting muscular fatigue may lead to intraoperative hand tremors, compromising surgical quality and contributing to higher postoperative complication rates and increased pain [28, 29]. The da Vinci robotic system addresses these issues by eliminating fatigue, preventing human tremors during extended operations, and ensuring stable visual fields. This enhances lesion resection precision, minimizes surgical trauma and complications, and reduces pain [30, 31]. Additionally, the robotic system helped reduce surgery-induced stress in our cohort, promoting earlier restoration of gastrointestinal motility and humoral immunity. This improvement may result from the robotic approach's ability to shorten procedures, increase precision, and reduce invasiveness. FreeHand robotic camera holders in laparoscopic appendectomy have been shown to improve safety and efficiency, reducing operator discomfort and eliminating reliance on a camera-holding assistant [32].

The groups also differed significantly regarding procedural vigor, efficiency, and surgeon comfort. Conventional laparoscopy relies heavily on human camera assistants. Prolonged and static scope holding leads to cumulative fatigue, which reduces the surgeon's comfort and concentration, potentially lowering procedural efficiency [33]. The use of the da Vinci robotic system eliminates such fatigue by providing stable and efficient camera manipulation based on CRC anatomy and anticipating the surgeon's actions for automatic view adjustment. Improved ergonomics and comfort for the surgeon directly translate to enhanced resection precision [34, 35]. A study indicates reduced setup time and stable imaging in laparoscopic procedures using self-contained robotic camera holders [36], aligning with our conclusions regarding enhanced team coordination and improved surgeon ergonomics.

Several limitations should be noted. First, long-term outcomes (≥3 months) are not included in this study. Prolonged follow-up and tumor-related endpoints (e.g., disease-free survival, local recurrence) are necessary to better understand the anticancer effects of the robotic system. Additionally, the lasting benefits of the system should be validated by assessing long-term patient well-being (e.g., via the European Organization for Research and Treatment of Cancer Quality of Life Questionnaire-Core 30) and functional recovery durability (e.g., 3-month post-operative defecation/incontinence). To increase representativeness, multi-region recruitment should be considered, as the current study relies on a single-region sample.

In summary, da Vinci Xi-assisted laparoscopic CRC procedures yield superior results. Patients benefit from improved pain control, reduced complications, mitigated stress, faster extubation and discharge, and earlier recovery of gastrointestinal and humoral immune function. Additionally, the surgical team reports a more favorable subjective experience.

Disclosure of conflict of interest

None.

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