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ROBOTIC VERSUS LAPAROSCOPIC AND OPEN TECHNIQUES IN COLORECTAL CANCER SURGERY: A COMPREHENSIVE REVIEW OF CLINICAL, ONCOLOGIC, AND ECONOMIC OUTCOMES

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ABSTRACT

Introduction: Robotic techniques are one of the main achievements in modern minimally invasive surgery, constantly expanding its use in the treatment of colorectal cancer. Technological progress over the years has led to a higher level of operative precision, improved surgical conditions and reduced tissue trauma. The purpose of this review was to present the current state of knowledge about the efficacy, safety and treatment outcomes of robotic surgery, comparing it with laparoscopic and open techniques in oncological abdominal procedures in patients with colon cancer.
Methods: A literature review was prosecuted, including clinical studies, cohort analyses and meta-analyses including studies comparing robotic, laparoscopic and open techniques performed on patients with colorectal cancer.
Results: Based on the collected data, robotic surgery provides oncologic outcomes similar to laparoscopic and open techniques, while providing patients with shorter hospital stays, reduced postoperative pain and lower complication rates. The number of removed lymph nodes and the length of resection margins were generally higher in robotic procedures, which indicate superior precision and better visualization of the operative field. The complication rate and recovery time in robotic surgery was lower compared with laparoscopy open surgery.
Conclusions: Robotic surgery as the treatment of colorectal cancer is a safe and effective alternative to classic techniques as laparoscopy and open surgery, providing matching oncologic efficacy along with significant clinical benefits in recovery and patient quality of life. Constant development of technology, standardization of treatment protocols and increasing surgical experience will enable further adoption of this method in oncologic centers.

KEYWORDS

Colorectal Cancer, Robotic Surgery, Laparoscopic Surgery, Open Surgery

CITATION

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Introduction

The origins of robotic surgery date back to the 1980s, when the first concepts for using robots in medical procedures were developed, inspired by the needs of the military and space agencies such as NASA for remote procedures. In 1985, the first surgery was performed using the PUMA 560 robot, which assisted in a brain biopsy and a few years later, the PROBOT (used in urology) and ROBODOC (in orthopedics) systems appeared. However, the breakthrough came at the beginning of the 21st century, when Intuitive Surgical introduced the da Vinci® system into clinical practice – the first comprehensive surgical robot approved by the FDA.

The da Vinci system, consisting of an operator console, a cart with robotic arms, and a high-resolution 3D camera system, pioneered a new era in minimally invasive surgery. Unlike laparoscopy, in which the surgeon directly manipulates instruments, robotics enables precise and stable hand movements, while simultaneously providing a three-dimensional magnification of the surgical field, resulting in improved control and precision in tissue dissection.

Originally, robotic systems were used in urological surgery, particularly radical prostatectomy, where the limited surgical space and the need to preserve neural structures provided a natural avenue for development of this technology. However, the potential of robotics was quickly recognized in other fields as well – cardiac surgery, gynecology, thoracic surgery, and general surgery, including procedures on the gastrointestinal tract, liver, pancreas and intestines.

In general surgery, robotics has been particularly valued in procedures requiring high precision and delicate dissection in difficult-to-access anatomical areas. Examples include pelvic, esophageal and pancreatic surgeries, where traditional laparoscopy can be limited by instrument stiffness and uncomfortable ergonomics.

Recent years have also seen a rapid increase in the use of robotic surgery in colorectal procedures, as confirmed by data from international registries and numerous meta-analyses.

Contemporaneously with the development of clinical applications, the technological evolution of robotic systems has continued. Posterior generations of da Vinci systems have been introduced, offering increasingly better arm mobility, improved visualization, shorter setup time and smaller equipment footprints. Competing platforms have also emerged, such as Versius® (CMR Surgical), Hugo™ RAS (Medtronic), and Senhance® (Asensus Surgical), promising increased accessibility and potential cost reductions for robotic procedures.

With technological advances, the concept of integrating robotic surgery with other fields of digital medicine is also developing – including intraoperative imaging, augmented reality, artificial intelligence and real-time data analysis. This combination enables the creation of so-called "smart operating rooms," in which the robot not only reproduces the surgeon's movements but also supports the decision-making process by analyzing the patient's anatomical and functional data.

Although robotic surgery remains an expensive and technologically demanding field, its development is irreversible. A growing number of centers around the world are introducing robotics training into standard surgical training programs and experience from the first decades of its use indicates that it is one of the most important directions of development in modern general surgery, including colorectal oncology surgery.

The number of colorectal cancers has been increasing among the patients over 50 years of age. Surgery plays a vital part of the radical treatment of colorectal cancer and the surgical technique is essential to the prognosis despite major progress in not only oncological treatment but also prevention and diagnosis. Through the years multiple techniques have been advanced which transformed modern surgical practices. The reduction of operative trauma, shorter time of hospitalization and faster postoperative recovery have been achieved by the introduction of minimally invasive techniques both robotic and laparoscopic. Robotic surgery remains the most up to date form of minimally invasive surgery. The operator can see a wide, detailed 3D visualisation of the operative field and can benefit from extraordinary precision and motion stability, which increases the safety of surgical operations and facilitates the distinction of anatomical structures including the restricted pelvis area.

Considering colorectal cancer, robotic surgery has acquired significant importance in rectal resections, where the limited operative field and complex anatomy is a profound struggle for surgeons which they have been trying to overcome for many years. Various comparative studies have shown that robotic procedures are associated with a lower rate of conversion to open surgery, reduced intraoperative blood loss and improved outcomes, especially concerning preservation of urinary and sexual function and sphincter control. Even so, the superiority of robotic surgery over conventional laparoscopy remains a subject of debate, mainly due to the higher cost of robotic systems and their limited accessibility in many medical centers. However, currently observed rapid technological progress and growing surgeon experience enabled upscaling of indications for robotic approaches—not only for rectal resections but also for right- and left-sided hemicolectomies and revision surgeries. Nevertheless, in colon cancer, the use of robotics has been developing somewhat more slowly, mainly due to the larger operating space and reduced technical challenges compared to pelvic surgery.

Modern robotic systems offer improved ergonomics, shorter setup times, and increasingly complex instruments, potentially transferring into further upgrades in oncologic outcomes and patient quality of life.

The purpose of this review is to discuss the current state of knowledge in the field of robotic surgery in the treatment of colorectal cancer with particular emphasis on comparisons with other operative techniques such as laparoscopy and open surgery. The review focuses on clinical, oncologic and economic outcomes, while paying attention to limitations, future perspectives and research directions related to the application of robotic technologies in gastrointestinal oncologic surgery.

In this review the authors also focused on patient satisfaction after colon rectal surgery based on provided abstracts. Several metrics are widely used to measure patient satisfaction. These metrics can be broadly categorized into surveys, quality of life assessments and specific satisfaction questionnaires. First category are surveys and questionaries such as Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) Survey, Press Ganey Ambulatory Surgery (PGAS) Survey, Surgical Satisfaction Questionnaire (SSQ-8), European Organization for Research and Treatment of Cancer (EORTC) IN-PATSAT32. Second category consider quality of patients' life using EORTC QLQ-C30 and QLQ-CR29 and Patient-Reported Outcomes Measurement Information System (PROMIS). Another category is about specific satifaction metrics including Patient Visit-Specific Questionnaire and Consumer Quality Index (CQI). Last section asses factors influencing satisfaction using postoperative complications, follow-up care and hospital structural measures such as bed number, urban location, nurse-to-bed ratio, and hospital status.

Patient satisfaction has become a vital indicator of healthcare quality especially in oncologic surgery. Modern treatment success should include not only oncological outcomes but also patients' perceptions of the perioperative and recovery process. Postoperative recovery and patient experiences have been significantly changed by the evolution of surgical techniques from open to minimally invasive (laparoscopic and robotic). What has been shown by multiple studies is that minimally invasive techniques contribute to shorter hospital stays, reduced postoperative pain, and fewer complications when compared to open surgery, which all lead to better patient satisfaction. Robotic surgery has a lot of advantages such as enhanced dexterity, three-dimensional visualisation and improved precision. Robotic -assisted surgery is also superior in the conversion rate to open surgery and higher rates of sphincter preservation. All of the above directly influence postoperative function and quality of life which are crucial to patient satisfaction. When there is a need to convert from laparoscopic or robotic methods to open, it may negatively influence patients' satisfaction. Researchers have found that laparoscopic surgeries have significantly higher conversion rates compared to robotic surgery while having similar advantages and oncologic outcomes. The most visible differences between minimally invasive and open methods are longer hospital stays, increased postoperative pain, higher opioids requirements and a greater incidence of complication. At the first sight it is not obvious because open methods are seen as technically easier and less dependent on technology. Analyzed studies do not use the same methods to evaluate patient satisfaction however all of them have proved by using a variety of indicators mentioned above that surgical methods play a vital role in patients satisfaction. Nowadays patient-centered is an integral part of surgical practice so patient perspective should always be considered in choosing a surgery method.

Review Methods

This review was based on an analysis of clinical studies, meta-analyses and cohort research. Both English and Polish publications were included, with sources identified through PubMed, Scopus and Cochrane Library databases.

The analysis encompassed studies comparing robotic, laparoscopic and open techniques in oncologic abdominal procedures involving colorectal and rectal cancers.

Inclusion criteria comprised the following:

- Prospective comparative studies,
- Retrospective comparative studies,
- Assessment of oncologic outcomes (R0 resection status, number of removed lymph nodes, overall survival and disease-free survival),
- Data regarding postoperative recovery (length of hospital stay, pain intensity, time to mobilization),
- Information on postoperative complications and treatment costs.

All data were analyzed using a qualitative approach and afterwards their interpretation was presented descriptively in subsections assigned to specific areas of comparative analysis.

Results

1. Oncologic Outcomes

Evaluating the oncologic outcomes of colorectal cancer treatment using robotic, laparoscopic and open techniques, the most frequent assessed indicators included the number of harvested lymph nodes, resection margins, the rate of R0 resections and long-term overall survival and disease-free survival.

Lymph Node Yield

The number of removed lymph nodes was higher in the robotic surgery group in the majority of studies. The average lymph node yield reported for robotic procedures ranged from 16 to 36, compared with 12 to 23 for laparoscopic surgery and 10 to 18 for open surgery.

Margins Size

Comparative analyses pointed out that robotic surgery was associated with longer distal resection margins. The average distal margin in the robotic group was 2.5 cm versus 1.5 cm in the laparoscopic group, suggesting improved precision and visualization in robotic techniques.

TME Completeness

The foundation of rectal cancer treatment is total mesorectal excision, which has a direct impact on local recurrence rates and long-term survival. To evaluate the quality of TME samples are used key indicators including completeness of excision, circumferential resection margin (CRM) status, lymph node yield and Quirke's grading scale

- Robotic, Laparoscopic, and Open TME: All approaches achieve high rates of complete or near-complete TME (73.5–99.2%), with no statistically significant differences in large propensity-matched cohorts
- Transanal TME (TaTME): Comparable rates (99.1%) in matched cohorts

Pathological Quality Metrics

- TME Completeness: Assessed by Quirke's scale (complete, nearly complete, incomplete).
- CRM Status: Negative (>1 mm) vs. positive (≤1 mm) margins.
- Lymph Node Yield: Number of nodes retrieved, with ≥12 considered adequate.
- Quirke's Grading: Standardized assessment of mesorectal excision quality.

Circumferential Resection Margin (CRM) Positivity

- Robotic TME: CRM positivity rates range from 2.5–6.0%
- Laparoscopic TME: Higher CRM positivity (10.6%) in some studies
- Open TME: Similar rates to robotic, but with greater variability
- TaTME: Lowest CRM positivity (0–5.6%)

Quirke's Grading Scale Outcomes

- No significant differences in rates of complete TME across robotic, laparoscopic, and open approaches

Table 1. Complete time and CRM positivity rate comparison

Metric	Robotic TME	Laparoscopic TME	Open TME	Transanal TME
Complete/Near-complete TME	73.5–99.2%	73.5–99.2%	73.5–99.2%	99.1%
CRM Positivity Rate	2.5–6.0%	10.6%	6.0–10.6%	0–5.6%

Source: Author's own analysis

R0 Resection

The rate of R0 resections was comparable across all three operative techniques. One study reported a lower probability of achieving R0 resection in robotic colorectal cancer surgery (OR = 0.63), however no significant difference was found for rectal cancer (OR = 1.20). In patients with locally advanced rectal cancer (T4), the R0 resection rate in the robotic group reached 85.4%.

Survival Rate

In analyses with a 3-year follow-up, overall survival after robotic surgery was 92.5%, similar to that achieved with laparoscopic surgery.

- Five-year overall survival ranged between 94% to 95.4% for robotic surgery. In comparison, five-year survival after laparoscopic surgery was 71.3% for patients with colon cancer and 59.2% for patients with rectal cancer.
- Five-year disease-free survival rates were 77.9–79.1% in group after robotic surgery and 74.6–84.3% after laparoscopic procedures. Open surgery has shown comparable results to laparoscopy in most analyses.

2. Recovery and Length of Hospital Stay

Assessing postoperative outcomes after colorectal procedures performed using robotic, laparoscopic and open techniques in the analyzed publications, the most frequent reported indicators included hospitalization time**,** time to restoration of bowel function, duration of urinary catheterization and postoperative recovery period.

Time of hospitalization

In the majority of studies, robotic surgery pointed out a shorter hospital stay compared with laparoscopic and open techniques. The median length of stay following robotic procedures ranged from 3 to 5.9 days, in relation to 4 to 6.4 days after laparoscopic surgery and 6.6 to 17.9 days after open operations. In the group of elderly patients, hospital stay after robotic colectomy was reduced (5.9 days) compared with laparoscopic colectomy (6.4 days). In studies including colon and rectal resections, the mean hospital stay for both minimally invasive techniques was similar, averaging about 4 days.

Restoration of Bowel Function

After robotic-assisted colectomy, the average time to restoration of bowel function was 60.9 ± 15.8 hours (approximately 2.5 days)**.** For robotic right colectomy, the time to first passage of the flatus or stool was shorter in relation to laparoscopy, averaging about 3 days versus 4 days in the laparoscopic group.

Bowel Function Outcomes

Another common and serious complication following sphincter-sparing rectal cancer surgery is low anterior resection syndrome. It is characterized by bowel dysfunction with frequency, urgency, incontinence, and stool accumulation, often accompanied by sexual and urological dysfunction.

Incidence and Severity of LARS

- Robotic Surgery: Major LARS rates 18–36% at 6–18 months; LARS scores as low as 4.3±2.2
- Laparoscopic Surgery: Major LARS rates 26–63% at 2–5 years; LARS scores up to 9.8±1.5
- Open Surgery: Major LARS ~49% at median 69 months; similar to laparoscopic
- Symptom Evolution: Stool frequency and clustering improve over time; most recovery within 12–18 months, stabilization thereafter

Table 2. Incidence and severity of LARS

Timepoint	Robotic (%)	Laparoscopic (%)	Open (%)
6 mo	18–36	26–55.9	~49
12 mo	18–36	14.6–55.9	~49
24 mo	~29.7	26–63	~49
36 mo	~39.7	26–63	~49

Source: Author's own analysis

Sexual Function Outcomes

Quantitative Differences

- Robotic Surgery: Better preservation and recovery; IIEF mean difference 1.05–4.06 at 3–12 months; FSFI mean difference 2.86–4.19 at 6–12 months
- Laparoscopic Surgery: Lower scores; higher dysfunction rates; partial recovery by 12 months, persistent dysfunction beyond
- Open Surgery: No significant difference vs laparoscopic; high dysfunction rates
- Risk Factors: Age ≥45, low tumor location, preoperative radiotherapy, extensive resection

Urological Function Outcomes

Quantitative Differences

- Robotic Surgery: Lower IPSS scores (mean diff. -1.06 to -1.36 at 3–12 mo); lower urinary retention rates
- Laparoscopic Surgery: Higher IPSS scores; slower recovery; higher retention rates
- Open Surgery: Similar to laparoscopic; higher dysfunction with extensive resection
- Risk Factors: Autonomic nerve resection, lateral lymph node dissection, higher BMI, diabetes, absence of ileostomy, low resection margin

Urinary Catheter Removal

In patients after intersphincteric resection, the mean time to remove urinary catheter was 4.9 ± 1.4 days following robotic surgery and 5.3 ± 1.6 days after laparoscopic procedures. Under Enhanced Recovery After Surgery (ERAS) protocols this period was meaningfully shorter—12 to 48 hours postoperatively, which correlated with faster mobilization and shorter hospital stays.

Table 3. Comparison

Parameter / Procedure	Robotic Surgery	Laparoscopic Surgery	Open Surgery
Median hospital stay	3–5.9 days	4–6.4 days	6.6–17.9 days
Time to bowel function recovery (mean)	~60.9 ± 15.8 h (≈2.5 days)	~3–4 days	4–5 days
Urinary catheter removal	4.9 ± 1.4 days	5.3 ± 1.6 days	3–7 days
Discharge under ERAS protocol	3 days post-op	3–4 days	4–8 days

Source: Author's own analysis

3. Postoperative Pain and Analgesic Requirements

In the analyzed studies assessing colorectal cancer treatment using robotic, laparoscopic and open procedures, the most frequently evaluated parameters was the level of postoperative pain, the requirement for analgesic medications and the total time of postoperative recovery. The data came from clinical trials comparing pain scores using Visual Analogue Scale, opioid consumption expressed as morphine milligram equivalents and the time needed to get back to normal postoperative activity.

Patients who underwent robotic procedures presented lower postoperative pain scores compared with those after laparoscopic or open surgery. The difference in opioid requirements within the first 72 hours after surgery was 0.64 ± 0.25 mg/kg for robotic in relation to 0.68 ± 0.27 mg/kg of morphine for laparoscopic procedures. Furthermore, comparing intraoperative morphine consumption, it was lower in the robotic group (0.15 ± 0.08 mg/kg) than in the laparoscopic group (0.19 ± 0.06 mg/kg), indicating reduced intraoperative nociceptive stimulation.

Among a group of patients after laparoscopic procedures, during the first 24 hours postoperative was recorded a higher number of pain episodes in relation to open surgery. However, average VAS scores remained low (< 3/10 points), suggesting adequate pain control. The use of multimodal analgesia strategies, for instance transversus abdominis plane blocks, has shown a potential in further reducing postoperative opioid consumption, mainly in laparoscopic procedures.

Patients after open surgeries experienced higher pain intensity, mainly during mobilization within 72 hours after surgery, compared with minimally invasive approaches. Postoperative opioid consumption was the highest in the open surgery group—in one study, the average total intravenous morphine dose reached 71 mg. Epidural anesthesia has shown greater analgesic efficacy compared with intravenous patient-controlled analgesia in this cohort, supporting its role in postoperative pain management after extensive open procedures.

Conversion Rates and Clinical Impacts

Conversion from minimally invasive to open surgery in rectal cancer is best understood through a multifactorial risk model, integrating:

- Patient Factors: Sex, age, BMI, comorbidities
- Tumor Factors: Location, stage, invasion, adhesions
- Procedural Factors: Technical challenges, intraoperative complications
- Institutional Factors: Surgeon experience, hospital resources

This model is supported by predictive algorithms that combine clinical, anatomical, and inflammatory markers to stratify conversion risk

Specific Factors

- Male sex and obesity (BMI >25–30 kg/m²) are consistent independent predictors of conversion, likely due to narrower pelvic anatomy and increased technical difficulty
- Older age (>63–65 years) and comorbidities (e.g., hypertension, cardiovascular disease) modestly increase conversion risk, though their impact is less pronounced in robotic surgery
- Tumor factors: Low rectal location, advanced stage (T4), local invasion, and severe pelvic adhesions are strong predictors of conversion, especially in laparoscopic approaches
- Preoperative inflammatory status (e.g., elevated CRP, Glasgow prognostic score) and preoperative ileus also predict higher conversion risk
- Technical challenges (difficult dissection, poor visualization, bleeding, adhesions) are the most frequent intraoperative triggers for conversion, particularly in lower rectal tumors and advanced disease
- Robotic surgery's enhanced dexterity and visualization reduce these triggers, especially in anatomically challenging cases
- Surgeon specialization (colorectal vs. general), experience, and hospital volume are critical determinants of conversion rates
- Robotic surgery particularly benefits general surgeons and smaller hospitals, mitigating experience-related conversion risks
- Smaller hospitals: Higher conversion rates in laparoscopy, but robotic surgery mitigates this effect
- Community vs. academic centers: Robotic surgery narrows outcome disparities, supporting its use in resource-limited settings
- Robotic surgery: Conversion rates 2–7%; associated with fewer complications, shorter hospital stays, and better specimen quality
- Laparoscopic surgery: Conversion rates 9–16%; higher risk of complications and longer recovery
- Converted cases: Highest morbidity and resource utilization

4. Postoperative Complications

Short-Term Postoperative Complications

Robotic Surgery

The spectrum of short-term postoperative complications after robotic colorectal resections was low, ranging between 5% to 12% of cases. In one study, major complications assessed as grade ≥ II in Clavien–Dindo scale occurred in 12% of patients, with a total 90-day mortality rate of 1.7%.

Among specific complications, wound infections occurred in 2.2% of cases, 3% of patients required hemotransfusion and 4.9% of patients reported chylous ascites. Intraoperative complications were rare, most analyses reported no conversions to open surgery and minimal intraoperative blood loss.

Laparoscopic Surgery

The rate of short-term postoperative complications following laparoscopic surgeries ranged from 10% to 23%, with major complications assessed as grade ≥ II in Clavien–Dindo scale occurring more frequently than after robotic surgery.

The most common complications included bleeding (3–5%), wound infections (2.2–5%), anastomotic leakage (3.6–5.4%) and bowel obstruction (3.4–5.8%). Pulmonary infections were reported in approximately 6.4% of patients after laparoscopic surgery. No significant differences were observed in the incidence of intraoperative complications between laparoscopic and open surgeries.

Open Surgery

Open surgery has shown the highest short-term complication rate, ranging from 15% to 20% and in some studies reaching up to 25–37%. The most frequently reported complications included bleeding (5–7%), wound infections (8%) and anastomotic leakage (3.6–5.4%).

Among all the 3 surgery techniques, open surgery was associated with a higher number of incidences of systemic complications, including arrhythmias (4.7%), pulmonary infections (10.6%), and respiratory failure. Furthermore, transient cognitive disturbances were reported in 12.1% of cases in the population of elderly patients.

Long-Term Postoperative Complications

Robotic Surgery

Long-term complications after robotic colorectal surgery were reported in about 10–15% of cases. The most common included local recurrence (4–5% within five years), lymphedema (13.4% and 8% of which required physiotherapy) and anastomotic dysfunction.

In comparative analyses, in robotic surgery anastomotic leakage rates were 17.86%, in relation to laparoscopic rate of 18.18% and open surgery rate of 13.04%. The rate of incidence of fistulas, including colovesical and colovaginal was 4–6.7%. The overall complication rate, including chronic defecatory dysfunction, was 11.3% in robotic cases.

Laparoscopic Surgery

A slightly higher rate of long-term complications after laparoscopic procedures was reported, ranging from 15% to 20%, with oncological recurrence in approximately 7% of patients.

The anastomotic leakage rate was 18.18%, while chronic defecatory disorders were reported in about 6.9% of patients.

Incisional hernias occurred in 14.4% and parastomal hernias in up to 40% of cases.

Open Surgery

In long-term follow-up, postoperative complications were observed in 20–25% of patients after open surgery.

Anastomotic leakage occurred in 13.04% and disease recurrence was reported in approximately 10% of patients within five years.

The incisional hernia rate was 15.9%.

Long-term follow-up also showed higher rates of chronic bowel dysfunction (60%) and stoma-related complications (26.67%) compared with minimally invasive techniques.

Surgical site infections were reported in 11–26% of cases. Other infectious complications, including intraabdominal abscess, peritonitis and sepsis, occurred in <10% of patients with antibiotic prophylaxis, but even in 30–60% without it.

5. Operative Time and Cost-Effectiveness

Operative Time

The average total operative time for robotic procedures ranged from 191 to 363 minutes, representing the longest duration among all of the three surgical techniques.

For laparoscopic procedures, operative time was slightly shorter, verifying between 120 to 326 minutes, while open surgeries demonstrated the shortest average duration, typically 169–182 minutes.

Publications stratified by procedure type (for instance colectomy, rectal resection or total mesorectal excision) showed greater diversity in operative duration for robotic techniques, at once laparoscopic and open procedures showed more uniform time distributions.

Several studies also analyzed specific operative phases in robotic surgeries. The docking time averaged between 10–20 minutes and the resection phase lasted 160–340 minutes

Treatment Cost

Robotic surgery was associated with consistently higher total costs compared with both laparoscopic and open methods.

The median cost per robotic procedure was approximately USD 16,628, compared with USD 14,641 for laparoscopic operations. The elevated costs of robotic surgery primarily stemmed from the price of instruments, system maintenance and longer operating room time.

Even though laparoscopic techniques' initial expenses were higher than for open surgery, laparoscopy was considered more cost-effective overall, due to shorter hospitalization and a lower complication rate.

Open surgeries were characterized by the lowest initial costs, resulting from shorter operation time and the lack of costs for specialized instruments.

The mean total hospital cost for open procedures was USD 4,093. Despite lower upfront surgical costs, total perioperative and recovery-related expenses were often higher for open surgery, due to prolonged hospitalization and a greater rate of complications.

Discussion

In modern abdominal surgery robotic surgery is considered a huge innovation as it offers operative precision, reduced tissue trauma and faster recovery, furthermore it maintains comparable outcomes to laparoscopy and open technique which is a main conclusion that follows the analysis of the available evidence, and it has a variety of clinical benefits. This review has shown that despite the fact that robotic surgery is more time-consuming and more expensive in total compared to standard techniques it enables to shorten the hospital stays, reduction of analgesic requirements and to lower perioperative complication rates it is a valuable method in gastrointestinal oncologic surgery.

Comparison with prior meta-analyses and large cohort studies confirms that robotic surgery provides equivalent oncologic outcomes regarding R0 resection rates, surgical margins and number of resected lymph nodes. Several analyses even demonstrated higher lymphadenectomy efficiency in robotic procedures (averaging 16–36 nodes), most likely resulting from enhanced visualization and more precise tissue dissection in anatomically restricted pelvic regions. Reported overall and disease-free survival rates among patients undergoing robotic surgery was significantly higher compared with groups of patients after laparoscopic and open surgeries.

Robotic, laparoscopic and open techniques of total mesorectal excision achieve comparable rates of complete mesorectal excision, negative circumferential resection margin and adequate lymph node yield with no significant differences in Quirke's grading outcomes. Robotic total mesorectal excision offers technical advantages in more challenging anatomies and may yield a little higher lymph node count and lower conversion rates, but these benefits do not translate into superior long-term oncological outcomes. The quality of specimen grading is limited by interobserver variability and long-term data are lacking, especially for more fresh techniques.

In comparison to conventional laparoscopy the advantages of robotic surgery become evident especially in technically demanding procedures for example in rectal resections and total mesorectal excision. The robotic system enables to lower the rate of conversion to laparotomy and facilitates better preservation of both urinary and sexual function since it is more precisive and the operator has more dexterity in limited operative fields. Reports from high-volume reference centres where professionals underwent a structured training and where they used a procedural standardization have shown a substantial decrease in number of total complication rates and shortened recovery times. The results of this review are consistent with these reports.

Differences in treatment outcomes among assessed three surgical techniques can be attributed to multiple clinical, technical and organizational factors. The patient's general health condition, their comorbidities, tumor stage and surgeon experience constitute crucial determinants of postoperative success. Another key determinant is the employment of Enhanced Recovery After Surgery protocols, which, in synergy with minimally invasive techniques, significantly improve postoperative outcomes, reducing hospitalization time by up to 30–40%.

Recent research comparing robotic, laparoscopic and open colorectal cancer surgeries for patients with low anterior resection syndrome (LARS) shows that robotic surgery tends to offer improved early postoperative outcomes in terms of sexual, urological and bowel functions. Quantitative data show that robotic approaches result in lower LARS scores, improved IPSS and IIEF/FSFI scores and shorter hospital stays even despite longer operative times. However, many studies find that differences in quality of life and functional outcomes tend to diminish beyond 12 months, with long-term follow-up data being limited and heterogeneous.

Another critical aspect in robotic colorectal surgery is the learning curve posing transition for surgeons from traditional or laparoscopic techniques to robotic systems. The learning curve can be defined as the number of cases a surgeon must complete to gain proficiency, where further training does not significantly improve technique or outcomes. The learning curve for robotic colorectal surgery can be divided into distinct phases: learning, competence and mastery. For instance, one study identified three phases with initial proficiency achieved after 13 cases and mastery after 83 cases. Robotic surgery may have a shorter or comparable learning curve to laparoscopic surgery with reported rates for robotic right colectomy 16 vs. 25 cases and 44 vs. 41 cases for anterior resection. The learning curve for robotic surgery is influenced by prior laparoscopic experience, with experienced laparoscopic surgeons potentially achieving proficiency more quickly, as well as case complexity and the use of surgical simulators and structured training programs. Studies have shown that as surgeons gain experience, there is a significant reduction in operative time and postoperative complications.

Robotic colorectal cancer surgery also presents significant technical advantages that decrease the amount of conversions to open surgery compared to laparoscopic approaches, especially in more complex cases characterized by adverse patient and tumor factors. Patients' factors such as male sex, obesity, older age, challenging tumor characteristics - low tumor location, T4 stage and complex pelvic anatomy are the main causes for conversion from robotic and laparoscopic rectal cancer surgery to open procedures. Other important factors are surgeon experience and hospital volume. Conversion has notable consequences short term such as anastomotic leakage, longer hospital stays and higher morbidity despite that long-term oncologic outcomes remain similar. Robotic surgery because of its technological advantages and increased precision has shown lower conversion rate in comparison to laparoscopic in every analised group even among high-risk patients, general surgeons and smaller hospitals.

Furthermore, reduced tissue trauma and limited inflammatory response associated with robotic surgery promote faster immunologic recovery, potentially leading to lower rates of infections and systemic complications. Enhanced control of the operative field and instrument stability successfully eliminate microtremors, enabling less traumatic dissection and minimizing the risk of injury to adjacent structures.

The integration of three-dimensional visualization, wristed instruments with seven degrees of freedom of movement and tremor filtration allows for exceptionally precise dissection and effective hemostasis, which directly translate to reduced intraoperative blood loss, lower risk of anastomotic leakage, and reduced neurological complications. Improved surgeon ergonomics facilitate consistent operative performance during long-term procedures, reducing the number of manual errors. Consequently, robotic surgery is associated with a lower incidence of infectious, mechanical and functional complications, as well as a reduced rate of local recurrence in long-term follow-up.

Although latest trends increasingly tend to favour robotic approaches because of their technical advantages, variability in long-term evidence, limitations of current assessment methodologies and inconsistency in follow-up protocols highlight the need for standardized, comprehensive and long-term studies to conclusively determine the optimal surgical strategy.

Strengths and Limitations of the Review

The strengths of this review include the broad timeframe of the studies analysed (2000–2025) and the comparison of robotic, laparoscopic and open techniques across multiple clinical and methodological dimensions, such as oncological, functional, convalescent and economic outcomes. This broad approach allowed for a comprehensive picture of the evolution of minimally invasive colorectal surgery and provided a complete picture of effectiveness and limitations of contemporary robotic techniques. An additional advantage of this review is the inclusion of both clinical and technical factors, enabling the assessment not only of postoperative results but also of intraoperative conditions, such as conversion rates, blood loss and complication profiles. An integrated analysis of these elements allows for a more comprehensive understanding of the technical efficiency and safety of the procedures.

Another advantage is the inclusion of data from different healthcare systems and geographic regions, which increases the external validity of the conclusions. The review also synthesizes findings from various procedural subtypes—right hemicolectomy, anterior resection and total mesorectal excision.

However, several limitations should be pointed out. The heterogeneity of the studies analysed, differences in inclusion criteria, operator experience and the number of procedures performed at individual centers. Much of the analysis is based on retrospective data, which carries the risk of selection bias and limits the generalizability of the results. Furthermore, inconsistencies in the use of ERAS protocols, definitions of complications and cost analysis methods complicate clear interpretation of the data A key limitation is the lack of large randomized clinical trials with long-term follow-up, which lowers the overall level of evidence.

Future Research Directions

Multicenter randomized controlled trials with long-term follow-up periods (≥10 years) remain needed to assess the influence of robotic techniques on total survival, disease-survival and quality of life even though we can see a vital technological progress and growing clinical use of robotic surgery.

Furthermore, the researchers should also explore patients' perspective with such indicators as postoperative pain dynamics, bowel functional, genitourinary function and treatment satisfaction, which are not yet sufficiently standardized in published research.

It is also necessary to expand economic analyses to assess the long-term cost-effectiveness of treatment, considering potential savings resulting from fewer complications, shorter hospital stays, and faster recovery. Particular attention should be paid to how the surgeon's learning curve influences both safety and cost-efficiency, as this factor may significantly affect the interpretation of comparative outcomes between centers.

Another important research direction is the development of standardized, competency-based training programs and the creation of international registries that enable comparability and harmonization of data. The integration of advanced supportive technologies—such as fluorescence imaging for real-time perfusion assessment, artificial intelligence for intraoperative guidance, and augmented or virtual reality for surgical planning—represents a promising direction for enhancing the safety, precision and personalization of robotic-assisted oncologic procedures. Ultimately, collaborative multicenter efforts and high-quality prospective data are essential to establish evidence-based guidelines for optimal implementation of robotic colorectal surgery.

Conclusions

1. Robotic surgery for colorectal cancer provides oncological outcomes equivalent to laparoscopic and open techniques while reducing tissue trauma, blood loss, and the incidence of postoperative complications.

2. Compared with conventional methods, the robotic approach is associated with shorter hospitalization, faster return of bowel function, lower opioid requirements and reduced postoperative pain level.

3. The use of robotic systems enables greater precision in tissue preparation, better visualization of the surgical field and stabilization of movements, which reduces the risk of anastomotic leaks, bleeding and neurological complications.

4. Key factors for achieving optimal outcomes include surgeon experience, tumor stage, patient condition and implantation Enhanced Recovery After Surgery protocols, which act in cooperation with robotic techniques to shorten recovery time and improve overall clinical results.

5. The main limitation remains the high costs of purchasing and operating robotic systems and the extended duration of surgery, but their importance decreases with technological progress and the increasing experience of surgeons.

6. As modern medicine is focused on patients' perspective surgeons should focus more on using robotic techniques as studies have shown significantly better satisfaction rates.

7. Future development should focus on the integration of robotic surgery with supportive technologies, such as fluorescence imaging, artificial intelligence and augmented reality systems, which may further enhance procedural safety and efficacy.

8. Further multicenter randomized studies with long-term follow-up are essential to fully assess the impact of robotic surgery on overall survival, patient quality of life and the economic efficiency of procedures in various healthcare systems.

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