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Surgical Management of Rectal Cancer: Does Robotic Surgery Emerge as the Best Alternative? A Narrative Review

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Rezumat

Managementul chirurgical al cancerului rectal: chirurgia robotică - cea mai bună alternativă? Review narativ.

Cancerul rectal este una dintre cele mai frecvent diagnosticate afecțiuni maligne, asociată cu morbiditate şi mortalitate ridicată, ceea ce justifică interesul constant pentru perfecționarea metodelor terapeutice disponibile şi dezvoltarea altora noi. Preferința pentru o tehnică chirurgicală față de alta depinde în mare măsură de stadiul, localizarea tumorii, de alți factori legați de pacient şi de experiența echipei chirurgicale. Acest articol îşi propune să ofere o trecere în revistă cuprinzătoare a modalităților chirurgicale utilizate în prezent pentru tratamentul curativ al cancerului rectal, precum şi direcțiile viitoare în acest domeniu, evidențiind cele mai recente progrese şi cele mai recente schimbări de paradigmă în managementul cancerului rectal. Evoluția chirurgiei deschise, laparoscopiei, chirurgiei robotice şi tehnicilor transanale este descrisă în mod cronologic, evidențiind avantajele şi dezavantajele fiecărei proceduri. Deşi chirurgia deschisă rămâne standardul de aur pentru situațiile de urgență, cum ar fi ocluzia sau sângerarea masivă, chirurgia minim invazivă a câştigat teren în ultimul deceniu datorită beneficiilor sale - externare mai rapidă, rate mai mici de infecție, rezultate mai bune pe termen scurt, demonstrând în acelaşi timp rezultate oncologice pe termen lung similare celor din abordarea chirurgicală tradițională. Principalul dezavantaj este strâns legat de procesul de instruire, în special de dobândirea de experiență în cazuri complicate, precum şi de costul total al echipamentului. În timp ce chirurgia robotică a fost implementată cu succes în ultimul timp în cancerul rectal avansat sau/şi recurent, laparoscopia rămâne cea mai utilizată modalitate minim invazivă, care are avantajul incontestabil al timpului de operare mai scurt. În plus, unul dintre cele mai discutate subiecte cuprinde tehnicile transanale nou dezvoltate, care oferă o soluție elegantă pentru tumorile rectale distale, în special la pacienții obezi sau cu pelvis îngust. Optimizarea continuă şi dezvoltarea tehnicilor chirurgicale în cancerul rectal conduc la îndeplinirea obiectivelor medicinei de precizie.

Cuvinte cheie: cancer rectal, tehnici transanale, chirurgie laparascopică, chirurgie robotică

Abstract

Rectal cancer is one of the most frequently diagnosed malignancies, associated with high morbidity and mortality, which justify the constant interest in fine-tuning the available therapeutic methods and developing new ones. The preference for one surgical technique over another is highly dependent on the stage, the location of the tumor, other patient-related factors and the experience of the surgical team. This article aims to offer a comprehensive review of the surgical modalities utilized at the present time for the curative treatment of rectal cancer, as well as the future directions in this field, pointing out the latest progress and the most recent shifts in paradigm in the management of rectal cancer. The evolution of open surgery, laparoscopy, robotic surgery, and transanal techniques is described in chronological fashion, highlighting the advantages and disadvantages of each procedure. Although open surgery remains the gold standard for emergency situations such as occlusion or massive bleeding, minimally invasive surgery has gained ground over the past decade due to its benefits - faster discharge, lower infection rates, better short-term outcomes, while demonstrating similar oncological long term outcomes as in the traditional surgical approach. The main disadvantage is strongly connected with the training process, especially with gaining experience in complicated cases, as well as the total cost of equipment and maintenance. While robotic surgery has been lately successfully implemented in advanced or/and recurrent low and medium rectal cancer, laparoscopy remains the most utilized minimally invasive modality which has the undeniable advantage of shorter operating time. Additionally, one of the most discussed topics comprises the newly developed transanal techniques which offer an elegant solution for distal rectal tumors, especially in obese patients or with narrow pelvises. Continuous optimization and new developments of surgical techniques in rectal cancer lead to accomplishing the goals of precision medicine.

Key words: rectal cancer, transanal techinque, robotic surgery, laparoscopic surgery

Introduction

Background

Colorectal cancer (CRC) is the third most frequently diagnosed malignant neoplasm in the world, accounting for 9.6% of the total cancer cases, and the second leading cancer related cause of death, according to the GLOBOCAN study (1). The prognosis of CRC in 5-year survival rates varies from 10% to 90% depending on the stage and other factors, such as the age and sex of the patient, the pathological staging, the effectiveness of treatment (chemo-radiotherapy, surgery) and molecular markers. Out of this heterogeneous class of neoplasia, rectal cancer, which accounts for one third of the cases, delineates itself as a standalone subtype, with slightly different treatment principles and surgical techniques (2). The American Cancer Society estimates for 2024 about 46,220 new rectal cases (18,890 in women and 27,330 in men) (3). The most used staging systems are the one proposed by the American Joint Committee on Cancer (AJCC) also known as TNM staging and Dukes staging. The survival rate according to the AJCC staging at 5 years is 90% in stage I, 70-80% in stage II, 25-80% in stage III and less than 10% in stage IV (4,5,6).

Nowadays, the treatment for rectal cancer is becoming increasingly more tailored for each individual case, involving an interdisciplinary team. Nonetheless, except for the early stages, surgery remains the cornerstone in the treatment of rectal cancer. This justifies the interest for new techniques and for constantly improving the well-established ones. In the last 30 years, advances in the oncological field have been followed closely by cutting-edge surgical innovations, such as laparoscopic surgery in the 90s, followed by robotic surgery and endoscopic techniques in the 2000s. Nevertheless, to this day, the rectal localization of the malignant tumor implies additional morbidity and treatment related complications compared to the strict colonic localization (6).

Therefore, in rectal surgery, adherence to established principles is critical.

Rationale for the Study

The introduction of robotic techniques in rectal surgery revolutionized some postoperative outcomes in specific situations such as in low rectal cancer where pelvic anatomy is challenging and precision is paramount.

In medium and low rectal cancers, the primary goal is sphincter preservation without compromising oncological principles. While there is a trend towards using minimally invasive techniques, surgeons must have experience for performing protective total mesorectal excision (TME). However, for high-risk cancers or those with threatened circumferential margins, open surgery is typically preferred to ensure optimal outcomes. It was proved that robotic systems alone can facilitate the radical resections needed for T4 tumors and local recurrences, offering the potential for better oncological outcomes (7).

In this context, minimally invasive surgery has been promoted for its capability to access narrow and deep areas, despite having faster operative time, more expensive maintenance, more experienced surgeons, some studies highlighting that laparoscopic surgery may have difficulties in achieving adequate margins. Robotic surgery has demonstrated success in yielding better outcomes by adhering more closely to the principles of rectal surgery.

The data evidence of positive outcomes in robotic surgery continues to grow, however there are some drawbacks in the present, such as cost and hard learning curve.

Objective

In this narrative review, a brief history of open, laparoscopic, and robotic surgery is presented, along with a comparison of the disadvantages and advantages of each technique in rectal cancer. The focus is especially on robotic surgery, highlighting its specific role in rectal cancer. This article is in accordance with the Narrative Review Reporting Checklist (8).

Materials and Methods

Following the PRISMA guidelines, a comprehensive literature research was conducted through the online PubMed database, Web of Science, Google Scholar using the following key words: "rectal" "cancer" and "surgery". Subsequently, the studies that were included focus strictly on providing a comprehensive overview trough years of management of rectal cancer, robotic surgery becoming the central focus of this study. The bibliography of the final selected articles was also consulted.

Evolution of Open, Laparoscopic, Robotic and Transanal Surgery: Historical Perspective

Open Surgery

Since the first documented rectal amputation for inferior rectal cancer in 1826, a novel but mutilating operation performed by Lisfranc, huge advancements have been made in the last two hundred years. Out of the important milestones in the development of rectal cancer surgery, it is firstly worth mentioning the coagulation of the "radical resection", abdomino-perineal resection coined by Miles in 1908 (9). He based his idea on anatomopathological studies that indicated the most frequent sites of recurrence, deducing that cancer spreads in a cylindrical fashion through the lymphatics. Addressing this newfound knowledge, his revolutionary technique included resection of the rectum, the sigmoid colon, the mesorectum, the levator ani muscle and the creation of an abdominal anus (10). Soon after, the abdominoperineal resection (APR) described by Miles became a gold standard for rectal cancer. In 1921, the courageous idea of sphincter preservation was introduced by Hartmann, integrating it in a procedure that proved to be associated with less mortality and morbidity than APR. Years later, a team from Mayo Clinic led by Dixon (1948) showed that the superior rectal localization of the tumor permitted a restorative approach, through abdominal rectal resection and double layer anastomosis with preservation of the natural anus, without an increase in the recurrence rate or mortality (9,10).

Beginning with the 1950s, new anatomopathological studies led gradually to another change: the accepted distal resection margin decreased from 5 cm to 2 cm. The introduction of total mesorectal excision (TME) by Heald in 1982 was a paradigm shift in rectal surgery; contradicting the cylindrical spread theory of Miles, he created a procedure based on embryologically defined dissection planes, knowing that the rectum and the mesorectum have the same primordial origin. TME, consisting of en bloc excision of the tumor and the totality of the mesorectum contained in the visceral fascia with the surrounding vascular and lymphatic vessels, became and remained to this day a reference procedure (7,9,10).

Laparoscopic Surgery

Introduced in the late 20th century, laparoscopic surgery revolutionized many procedures by allowing surgeons to operate through small incisions using a camera and specialized instruments. This technique focused on reducing recovery time, pain, and scarring compared to traditional open surgery (11). Laparoscopy derives from the Greek words "lapara" (λαπάρα), meaning "the soft parts of the body between the rib margins and hips," and "skopein" (σκοπεῖν), meaning "to see, view, or examine" (12). George Kelling, a surgeon from Dresden, Germany, and Dimitri Ott, a gynecologist from St. Petersburg, Russia, are the first to perform true laparoscopic procedures. Kelling performed the first experimental laparoscopy on a dog in 1901 and Ott performed early laparoscopic procedures on humans around the same time (12). In terms of laparoscopic colorectal surgery, the first reports of laparoscopic assistance in colon surgery are those performed by Moises Jacobs in June 1990 (13).

Robotic Surgery

Combining the precision of robotics with the expertise of surgeons has indeed revolutionized medical practice, offering numerous benefits and paving the way for advancements in patient care. Robotic colorectal surgery, also known as robot-assisted colorectal surgery was first performed in the early 2000s. The da Vinci system is the first system approved by the FDA in 2000 (14-17). Despite the dominance of the Da Vinci system, the field of robotic surgery is witnessing the entry of several emerging competitors and alternative systems. Medtronic, Stryker, and Titan Medical have each developed their own robotic platforms to offer new solutions for minimally invasive surgeries (14). Robotics proved feasible even in complex surgeries such as pelvic exenteration, described for the first time in 2014 by Nanayakkara (18).

In Japan, in 2022 an alternative system called Hinotori Surgical Robot used for colorectal cancer was approved. Some of its advantages are the operation arm with eight axes, an adjustable arm base and a flexible three-dimensional viewer. It is expected to be utilized in rectal cancer surgery, as the first case of low anterior resection with Hinotori system was a success (19).

Transanal Techniques

The transanal approach involves using the natural orifices with the help of new technology. The first transanal removal of a rectal tumor (TAE = TransAnal Excision) was performed in 1984, consisting in utilizing open surgery instruments under direct vision. Though a relatively simple technique, with a low incidence of complications, it is only applicable to early first stage tumors situated at a maximum 8 cm of the anal verge and it is associated with a higher rate of recurrence and an even a slightly lower survival rate (20). MITAS (Minimally Invasive TransAnal Surgery), a technique developed in the 90s, partially solves the problem of poor visualization of TAE by using a specially designed anal retractor which allows excision of more proximal tumors (20-22).

Another transanal technique, TEM (Transanal Endoscopic Microsurgery), initially developed for rectal polyp resection, took shape during the 1980s. It involved a rigid rectoscope forming an airtight seal with the anus, laparoscopic instruments and a laparoscopic camera (20); the applicability of TEM quickly expanded to rectal tumors unsuitable for TAE or for endoscopic removal, up to 20 cm from the anal verge. Although the overall surgical outcomes were good, the main disadvantages of TEM were the long learning curve and the costs of the equipment.

One of the newest minimally invasive alternatives is TAMIS, described for the first time in 2009. The particularity of this platform is the use of a unique, multichannel and more pliable port, designed initially for abdominal surgery, from which the main advantages derive: cost efficiency, lower set-up time, easier learning curve, low conversion rate and minimal morbidity. More recently, several teams of surgeons have successfully integrated TAMIS into robotic platforms (20-22).

Principles in the Management of Rectal Surgery

Surgical Principles

Preoperative staging is pivotal in choosing the best possible treatment, requiring a special imaging approach. Thus, endorectal ultrasound is the preferred staging method for early cancer; moreover, the diffusion weighted imaging combined with MRI adds information about mesorectal tissue and rectal tumor (5).

In addition to the principle of TME, in patients selected to undergo open surgery, the localization of the tumor is essential in deciding what type of procedure to perform. Other variables that factor in when deciding the appropriate surgical technique are the histopathological exam, the response to total neoadjuvant therapy, to neo-adjuvant or adjuvant therapy, anatomical constraints (narrow pelvis, obesity) or even cognitive and psychological factors (23).

Upper or mid rectum localization is suitable for (low) anterior resection extended 4 to 5 cm below the distal margin of the tumor. This approach implies reestablishing the intestinal continuity by performing a colorectal anastomosis. If the anastomosis is under the Douglas pouch, in order to prevent anastomotic leakages and its derived infectious complications, it has become common practice to use temporary protective methods, the most utilized being the preventive enterostomy (24-28). Numerous studies have been consistent in proving that the use of diverting stoma decreases the rate of anastomotic leakage and the rate of postoperative reintervention. However, the morbidity associated with this protective technique is undoubtedly high, stoma related complications varying from parastomal hernia, bowel obstruction to electrolyte disorders (24). A feasible and well-studied alternative to ileostomy is the use of transanal drainage tubes (TDT). A recent comprehensive meta-analysis, published by Xu et al. in 2023, which included 4875 patients of which 2381 were cases of TDT, proved that an indwelling time of the TDT for up to 5 days is associated with a significant reduction of anastomotic leakages and of the need of reintervention (29). Moreover, there is an increased interest for intraluminal devices such as Colovac, an internal by-pass sheath that completely shields the anastomotic site from fecal content or Neoveil, a polyglycolic acid (PGA) sheet that wraps around the anastomosis, reinforcing the rectal wall (30,31). Future studies are needed to validate the efficacy of these protective techniques.

Abdominoperineal resection (APR) is defined by completely removing anal sphincter, rectum, and distal colon by using abdominal and perineal approach with definitive stoma. An important aspect for patients who undergo APR is the decreased morbidity compared with very low rectal anastomosis (e.g. anal incontinence, stenosis) (7,23).

Recent Changes in the Oncological Treatment of Rectal Cancer

Multimodal therapy of rectal neoplasm imposes interdisciplinary cooperation between colorectal surgeons, oncologists, radiologists, and radio-therapists. The extent of the disease should be thoroughly assessed using modern imaging methods and special MRI protocols to determine a tailored treatment plan. Furthermore, minimally invasive surgery has brought significant preserva-tion of the inferior hypogastric plexus, leading to the protection of urinary and sexual function, reduced blood loss, and faster discharge. However, these positive outcomes do not replace the necessity of open surgery in selected cases. Rectal surgeons constantly face challenges regarding oncological safety and sphincter preservation when dealing with distal rectal cancer.

Through advances in surgical techniques and the recent introduction of total neoadjuvant therapy led to a marked sphincter conservation, significantly decreasing the need to perform APR (7,23).

The relationship between rectal surgery and chemo-radiotherapy involves the coordinated use of these treatments to manage rectal cancer effectively. The decision to use chemo-radiotherapy in conjunction with rectal surgery is based on multidisciplinary decision-making oncologists, surgeons, pathologists, and radiologists collaborating to design a personalized treatment plan.

The indication and the chronology of surgery in the multimodal treatment of rectal cancer is dependent on the stage of the disease. Patients with T1N0 tumors are divided in non-surgical candidates who perform just endoscopic submucosal dissection and surgical candidates who are suitable for endoscopic submucosal dissection or transanal local excision, if appropriate, followed by adjuvant treatment. Rectal cancer staged as T2N0 is approached either as transabdominal resection or APR depending on the localization. Starting with T3, N0 low-risk, high rectal tumors, only surgical treatment may be sufficient (7).

Total Neoadjuvant Therapy (TNT) is a recent evolving treatment paradigm for rectal cancer, particularly for locally advanced cases (T3, N any; T1–2, N1–2; T4, N any; locally unresectable). TNT involves the administration of both chemo-radiotherapy and systemic chemotherapy before surgical intervention Some of the benefits of TNT include the early prevention or eradication of micro-metastases, higher rates of pathologic complete response, minimizing the length of time patients need an ileostomy, facilitating resection and improving the tolerance and completion rates of chemotherapy (7).

Regarding clinical high-risk rectal cancer tumor in stage cT4a or cT4b with clinical nodal stage cN2 (enlarged lateral lymph nodes considered to be metastatic) and extramural vascular and mesolectal fascia invasion, it was stated in the last updated NCCN guidelines a statistically lower locoregional recurrence rate in chemoRT → surgery → adjuvant chemotherapy (6%) compared with short-course RT → chemotherapy → surgery (10%) (7). If the patient achieves a complete clinical response after chemotherapy a "watch and wait" strategy is adopted.

Implementation of Prehabilitation Programs: Strategies and Outcomes

Prehabilitation is a novel approach, aiming to decrease postoperative morbidity and mortality by priming patients for planned intervention. Further integration of aspects such as doing physical exercise brings a positive overall impact in the patient's health. Hemoglobin level under 13 g/dl, preoperative glycated hemoglobin over 7% are major prognostic markers for complications such us anastomotic leaks and higher rate in wound infection. Nevertheless, studies show the impact of psychological wellbeing, as psychotherapy before surgery decreases the dose of antalgic medication and is associated with faster recovery time. The ideal duration of surgical prehabilitation is between 4 to 8 weeks, providing the most effective preparation for surgery (32).

Robotic vs. Laparoscopic Surgery

The use of robotic surgery in rectal cancer has been increasingly adopted due to its potential benefits over traditional surgery and laparoscopic approaches. Some studies reflect that the robotic surgery is particularly beneficial for low rectal cancer where the pelvic anatomy is challenging and precision is paramount. Some studies demonstrate that the robotic systems can facilitate the radical resections needed for T4 tumors and local recurrences, offering the potential for better oncological outcomes. Obtaining safe margins and improving survival for T4 rectal tumors and local recurrences (LR) of rectal cancer often requires radical resection beyond total mesolectal excision (TME), sometimes through multi-visceral resection. While the use of the laparoscopic approach (LA) for these cases remains controversial and is associated with a high rate of conversion, robotic surgery might offer advantages that can mitigate some of the limitations of LA (see *Table 1*) (33).

ROLLAR (2017) was the first large trial that compared robotic surgery with laparoscopic surgery (34). Done on 471 patients, the aim of this trial was to emphasize the superiority of one of the techniques over another, especially in the short-term outcomes. The results were in favor of robotic surgery: less blood loss, fewer conversion rates to open surgery and slightly faster discharge. The oncological benefits in robotics were similar to laparoscopic surgery. While this study does not demonstrate a

Table 1. Main studies comparing laparoscopy and robotic surgery in rectal cancer

Feroci et al, 2016 (45)	Retrospective study	Middle and low rectal cancer	111	Overall mortality Local recurrences Operative time	10.3% vs 9.4% (p=0.564) 5.2% vs 1.9% (p=0.618) 192 vs 342 min (p<0.001)
Crippa et al, 2021 (38)	Retrospective study	Rectal cancer suitable for mini-invasive approach	600	Operative time Complications rate	214 vs 324 min (p<0.001) 51.2% vs 37.2% (p<0.001)
Xu et al, 2024 (46)	Randomized controlled trial	Middle and low rectal cancer	1171	Loco-regional recurence rate at 3 years Overall all survival	4% vs 1.5% (p=0.025) 93.1% vs 94.8% (p=0.155)
Song et al, 2024 (39)	Retrospective study	Abdominoperineal resection for rectal cancer	133	Postoperative complication rate	64.3% vs 40.5% (p=0.029)
Hopkins et al., 2020 (47)	Retrospective cohort study	Locally advanced rectal cancer with neoadjuvant chemotherapy	7616	Negative margin status Length of stay 90-day mortality	93% vs 96% 5 vs 5 days 1% vs 1%
Feng et al, 2022 (36)	Randomized controlled trial	Middle or low rectal adenocarcinoma	1240	Loco-regional recurence rate at 3 years 30-day postoperative complications	7.2% vs 4% (p=0.023) 23.1% vs 16.2% (p=0.023)
COLRAR, 2023 (37)	Randomized controlled trial	Rectal adenocarcinoma < 10 cm from the anal verge	295	Completeness of TME Postoperative complications	77.1% vs 80.71% (p>0,05) 8.3% vs 12% (p>0.05)

strong short-term benefit, the longer operative time of robotic surgery was highly criticized. The study acknowledged the limitations due to its difficulty in training for robotic surgery, important for both new and experienced surgeons. The learning curve is significantly slower due to fewer virtual reality simulations, especially for colorectal procedures compared to other procedure such as appendectomy. Other limitations were the short-term follow-up and the relatively small number of patients (35). Nevertheless, the number of surgeons well trained in laparoscopy conquers the number of surgeons trained in robotic system (34).

On the other hand, the latest trial, REAL, performed on 1171 patients with middle and low rectal cancer, shows significantly positive outcomes in robotic surgery compared to laparoscopic surgery as follow: higher rate of sphincter-preservation in the robotic group with 83.1% vs. 76.9% laparoscopic group, better macroscopic complete resections (95.4% robotic vs. 91.9% laparoscopic) and better integrity of the mesorectal fascia; Additionally, a lower circumferential resection margin positivity rate was observed (4.0% robotic vs. laparoscopic 7.1%), as well as lower intraoperative complication rate (5.4% vs. 8.7%) and more lymph nodes resection (15% robotic vs. 14% laparoscopic). Another positive outcome was the open conversion rate visible reduced in robotic group (1.7% vs. 3.9%), estimated blood loss (40 ml vs. 50 mL) and postoperative (30 days) complication rate (Clavien-Dindo grade II, 16.1% vs. 22.9%, $p = 0.003$). All these positive outcomes lead to a faster postoperative recovery and shorter hospital stay (median, 7.0 days vs. 8.0 days). The mortality was similar in the two groups (0.2% vs. 0.2%, $p > 0.999$) (36).

However, the COLRAR trial, another study done for rectal adenocarcinoma, localized 10 cm from anal verge, on 295 patients, finds no statistic difference in the 2 groups, in completeness of TME (77.1% robotic and 80.71% laparoscopic), in the postoperative complication rate as well as no difference of retrieved lymph nodes. Nevertheless, a sub-analysis was done on certain group which disclosed a difference in the positive circumferential resection margin lower rate in robotic group (0% vs. 6.1% for L-TME; $P=0.031$), and in the length of opioid use, this being shorter in the robotic group.

The locally advanced rectal cancer with neoadjuvant chemotherapy was well analyzed in a retrospective cohort study on 7616 patients which concluded lesser conversion rate in robotic approach (13% compared to 15%) in laparoscopic approach; differences in margin negative resection rate (96% robotic and laparoscopy 93%), but with no difference in 30-day readmission, 90-day mortality and overall survival rates (37).

Another study published in 2021 done on 600 patients highlighted a lower complication rate (37.2%) for patients who underwent robotic surgery compared to 51.2% in the laparoscopic surgery group. This study demonstrates that robotic surgery has better short terms outcomes compared to the other technique. The main disadvantage was the length of operative time (214 min in laparoscopic surgery vs. 324 min in robotic surgery (38).

Lower postoperative complication rates were observed in another retrospective study done on 133 patients who underwent abdominoperineal resection with 40.5% in the robotic group compared to 64.3% in the laparoscopic group (39).

A Japanese study was done on patients with stage cT4 rectal cancer, proving favorable short- and long-term outcomes of robotic surgery. The operative time was approximately 288 min and the median blood loss was 11 ml. There were no patients who required conversion to open surgery. The incidences of post-operative complications of grade II, III, and IV according to the Clavien–Dindo classification were 17.2%, 3.5%, and 0%. Seventy-three patients (60%) had pathological T4 tumors, and the incidence of positive resection margins was 4.9%. The 3-year overall survival, disease-free survival and local recurrence rates were 87.5%, 70.4%, and 4.0% (40).

In 183 patients with ultra-low rectal cancer (tumor within 5 cm of the anal verge) who underwent minimally invasive surgery, robotic-assisted surgery proved to be superior to laparoscopic surgery for low anterior and intersphincteric resection. However, post-operative anal dysfunction remains a concern (41).

A study with 110 patients who underwent robotic versus laparoscopic surgery had positive outcomes for robotic surgery resulting from smaller tumors margins, minimizing the risk of anal dysfunction by improving post-operative anal function. Superior mesorectal integrity was demonstrated with fewer conversion to open surgery and less intraoperative bleeding. Post-operative complications were similar at 3 and 5 years, while the disadvantage was the length of the operative time (211.7 ± 25.3 min vs. 191.2 ± 23.0 min, $p = 0.001$) (42).

Complications and anastomotic leakage might have no long-term impact on oncological outcomes for mid and low rectal cancer with robotic surgery; however, another study was performed on 3240 patients for advanced rectal cancer who underwent neoadjuvant chemo-radiotherapy followed by radical resection. The results showed that the 5-year survival rate and local recurrence-free survival rate in stage III patients in the robotic group were significantly higher than the laparoscopic group (43, 44)

In some specific situations, robotic and laparoscopic surgery showed comparable perioperative outcomes; however, robotic surgery was associated with a lower conversion rate and greater precision, flexibility, and control. Additionally, robotic surgery demonstrated a reduced risk of complications, such as less blood loss, fewer infections, and better margin resection, compared to laparoscopic surgery. These findings lead to the conclusion that robotic surgery may be a safe and effective technique for treating rectal cancer in selected patients (36-39,45-47).

Robotic vs. Open Surgery

Open surgery remains the first option in emergency situations (occlusion and perforation), while in any other clinical setting, whenever possible, minimally invasive technique is preferred.

Meanwhile conventional laparoscopic surgery for rectal cancer failed to demonstrate non-inferiority in oncological outcomes compared with open surgery in several RCTs (COLOR II, COREAN, ACOSOG Z6051, and ALaCaRT). In the PRODUCT trial conducted at an advanced center in Japan, the CRM positivity rate was 8.6%, which is similar to the results of other RCTs. However, robotic surgery was associated with a significant longer duration of surgery, reduced rate of conversion to open, and earlier return of bowel function (10,23-25).

A meta-analysis, including 11 prospective studies and 6922 patients, showed that robotic surgery has less surgical site infections, lower blood loss, higher negative resection margins and shorter hospital stays, when compared to open resection. Four studies in this meta-analysis reported more harvested lymph nodes in the robotic surgery group than in the open surgery. Also, they found that approximately six times more negative margins were achieved in the robotic surgery group than in the open surgery group. The rate of negative CRM was actually three times higher for those who underwent robotic surgery compared with open surgery (48).

Another study was performed on 171 rectal cancer patients with liver metastases who underwent simultaneous rectal and hepatic resections; there was a difference in the 2 groups (robotic vs. open) in what concerns the complications rate: in the robotic group there were found fewer complications in short-term (30 days) (31.4 vs. 57.6%). There was no mortality seen in either group. Patients who performed robotic surgery had faster bowel function recovery, less blood loss, shorter hospital stay. The robotic group presented a faster recovery of sexual function and bladder function by better preservation of the inferior hypogastric plexus. The 3-year disease-free survival rate and mortality rate were not statistically significant between the two groups (49).

Similar findings resulted from a 2018 Japanese study: Robotic surgery was found to be associated with less blood loss (7 vs. 420 mL), a longer operation time (342 vs. 230 min) and a lower complication rate (13 vs. 28%, $p=0.032$) compared to open surgery (50).

Robotic vs. Transanal Surgery

Transanal total mesorectal excision (TaTME), or the retrograde dissection technique, was developed to overcome the limitations faced by certain patients at increased risk of incomplete mesorectal excision: bulky distal tumors in the rectum and obesity. Whether robotic surgery is “better” than the transanal approach depends on the particular clinical scenario, the patient individual characteristics and surgeon’s expertise. Both techniques have their merits, however, the learning curve induces specific challenges due the educational landscape (51).

A total of 306 patients with low rectal cancer who underwent Robotic-TME compared to taTME proved that the robotic approach has the same beneficial results on short-term outcomes as the TaTME (52). A study from Singapore compared transanal techniques with the minimally invasive methods, both having favorable outcomes (53). Another study conducted on 120 patients concluded that robotic surgery has better outcomes compared to TaTME due to its sphincter protection. Transanal surgery requires long-term dilation, which can damage sphincter anatomy. Meanwhile, TaTME is more suitable for visualizing the hypogastric plexus, thus better preserving urinary function compared to the robotic approach (54).

The next step in the evolution of minimally invasive surgery is the application of robotics to TaTME, adhering to the principles of NOTES. This exciting new trend leads to better outcomes in mesolectal integrity, resection margins, number of intraoperatively harvested lymph nodes and conversion rate (55).

Benefits and Limitations of Robotic Surgery

Main Technical Advantages

There are some well-established advantages in choosing robotic techniques compared to other approaches in some specific situations (see *Table 2*). Meanwhile open surgery has its first choice for patients with massive bleeding, abdominal wall sepsis, poor cardiorespiratory performance. Minimally invasive surgery has its own benefits proving lower morbidity special in geriatric patients, lower rates of genitourinary dysfunction by having higher rate of nerve preservation, with a better view in deep area. Robotic surgery has its special place being more feasible for locally advanced rectal cancer when strict surgeon criteria are used. Its main strong points are faster bowel function and shorter hospital stay, the ability to access the hard-to-reach places by using its ergonomic instruments with zero tremor combined with better visualization 3D, better short- and long-term outcomes by better nerve preservation, possibility of micro-anastomosis, lymphatic, vascular and lower converting rate (11,13).

Multiple studies proved that robotic surgery is associated with a decreased risk of conversion in patients undergoing minimally invasive surgery for rectal cancer. Factors such as male sex, BMI, advanced tumor stage, and previous abdominal surgery were identified as additional risk factors

Table 2. Comparison between the current surgical modalities in rectal cancer (2, 11, 15-18, 21-22, 33-34, 41-51)

	Open surgery	**Laparoscopic surgery**	**Robotic surgery**	**TaTme**
Advantages	Established technique Direct visualization Versatility Touch enhanced Hand-eye coordination Greater accessibility - 7 degrees of freedom The better/only option in certain situations: - uncooperative patient - abdominal wall sepsis - gross coagulopathy - poor cardiorespiratory performance - cervical hernia - cirrhosis - large intra-abdominal mass - multiple abdominal surgeries in the past - big abdominal wall eventration - massive bleeding - obstructive syndromes	Less traumatic technique Higher sterility Shorter recovery time Better view in deep pelvic area Easier mesorectal dissection due to the optical magnification and CO_2 pressure Less blood loss Thorough lymph nodes dissection Higher rates of nerve preservation Lower rates of genitourinary dysfunction Better short- and long-term outcomes for locally advanced low rectal cancer Lower morbidity especially in the geriatric population	Less traumatic technique Higher sterility Shorter recovery time No tremor 3D visualization Micro anastomosis Ergonomic instruments Possibility of telesurgery Ability to access hard-to-reach places-incomparable with the other techniques Micro hemostasis thorough lymph nodes dissection Higher rates of nerve preservation Lower rates of genitourinary dysfunction Better short- and long-term outcomes for locally advanced low rectal cancer Faster bowel function recovery rates (compared with both open surgery and laparoscopy) Shorter hospital stays	Better vision of the mesorectal plane Feasibility of operating in a narrow pelvis Exact definition of distal resection margin
Disadvantages	More traumatic Less sterile Tremor-amplified Difficult approach in deep pelvic area Longer recovery time More pain and discomfort Greater blood loss Greater risk of metastatic peritoneal spread	Longer learning curve 2D-image Lack of haptic feedback Decreased degrees of freedom Amplified tremor Complications related to laparoscopic instruments: - Laparoscopic entry complications (aorta injury, intestinal perforation, CO_2 embolism, subcutaneous emphysema, pneumothorax and hypercarbia) - Postlaparoscopic shoulder pain (phrenic nerve irritation)	Higher cost Lack of haptic feedback Longer learning curve Longer procedure time	Longer learning curve Longer procedure time Higher cost

for conversion in multivariable analysis. Patients with a BMI of 30 kg/m2 or above had an increased risk of conversion, however, robotic surgery was found to considerably decrease the conversion in the obese cohort. Although there was no difference in positive circumferential margins, anastomotic leakage rate or mortality, the conversion rate was lower in the robotic group in a series of 352 patients (168 robotic and 184 laparoscopic) operated on for rectal cancer by two experienced laparoscopic surgeons. A recent retrospective study of 400 patients involving 159 obese patients confirmed a significantly lower robotic conversion rate in these patients. The higher risk of conversion compared to non-obese patients is observed in multiple studies (47 versus 24.4 per cent respectively; P < 0.001) (43). Another meta-analysis done on 3762 patients, conversion to open surgery was reported in (3.01%) patients in the robotic surgery group and in (7.38%) patients in the laparoscopic surgery group. The evaluation of anastomotic leakage performed in fourteen studies reported on 81 of 1318 patients (6.14%) undergoing robotic surgery and in 159 of 1994 patients (7.97%) undergoing laparoscopic surgery (55,56).

Main Technical Limitations

The haptic feedback is currently being more developed and evaluated in engineering labs, the results regarding of the effectiveness of haptic feedback in the literature not being consistent. The newest promising development in the haptic technology requires teamwork between neuroscientists, engineers, and surgeons and may yield an efficient and tactile displays in the future (57).

The learning curve for robotic surgery is important for both new and experienced surgeons, because virtual reality simulation is less used for colorectal procedures compared to simpler procedures such as appendectomy (39). A shift in surgical training is also made feasible by the digital interface of surgical robots, which helps by shortening learning curves and most importantly, lowers mortality and morbidity (40). Eligible studies suggest that surgeon learning curves are complex. For general surgical procedures, an optimal number of patients for learning a new procedure ranges from 0 to 80, where 0 indicates that the surgeon is already experienced. The learning curve for robotic surgery is important for both new and experienced surgeons. Robotic surgery offers significant benefits such as 3D visualization, enhanced precision and better dexterity, but it requires specific training and practice to achieve proficiency (58).

In terms of operative duration, robotic surgery is generally associated with significantly longer operative times. A study involving 139 patients aimed to demonstrate that the robotic procedure has a longer duration compared to laparoscopic surgery, with times of 190 minutes for robotic surgery versus 155 minutes for laparoscopic surgery. Some studies suggest that for patients undergoing colon and rectal resection, robotic surgery performed by experienced surgeons results in operative times and lengths of stay that are similar to those of laparoscopic surgery. This indicates that as surgeons become more proficient with robotic techniques, the efficiency of robotic-assisted procedures may improve, aligning closely with the outcomes typically seen in laparoscopic surgeries. Median operative times were also similar between the two approaches for rectal (197.0 vs. 231.5 min, p = 0.9) resections. Different studies have reported a shorter operative time using a hybrid technique composed of a robotic and laparoscopic procedure (36-39,46,47,59).

Costs

Robotic vs. Laparoscopic

A recently published study aimed to compare hospitalization costs for a period of 8 years (2012-2019) and clinical outcomes between robotic-assisted surgery and laparoscopic approaches for major abdominal operations. Regardless of procedure type, robotic surgeries remained more expensive, thus, the average of hospitalization cost within the robotic reach up to $18,300 ±13,900, while in the laparoscopic cohort it was $16,000 ± 14,800 (p<0.001). Abdominoperineal robotic procedure performed on 28,590 patients was 26.3 ± 19.1dollars, while laparoscopic procedure 45,890 ±22.6 ± 21,928 dollars (p < 0.001) (60).

The following 4 studies Park et al., Rouanet et al., Feng et al., Pan et al., show significant difference in cost between robotic and laparoscopic procedure (($14,567.89 vs. $11,548.33; p= 0.005 and $18,929.71 vs. $15,662.73, $11,733.61 vs. $7,436.97; p<0.0001, $12,544.63 vs. $8,746.01; p<0.001) (61,62,63,64).

The cost of instruments was higher for robotic procedures compared to laparoscopic instruments ($4,717.60 vs. $2,279.58). However, the conversion rate was lower in robotic procedure along with the associated cost ($107.94 vs. $511.71) (65).

Rbotic vs. Open

One study (Ramji et al.) compared robotic and open procedure ($16,316.85 vs. $11,213.94.) along with operative cost ($10,607.72 vs. $3,874.99).

Hospitalization costs in Robotic surgery are scientifically lower compared to open surgery ($506.88 vs. $907.18; p<0.001) (66).

Robotic vs Transanal

Meanwhile the study by Candido et al. reported a higher cost of transanal surgery compared to laparoscopic ($2,809.72 vs. $1,634.37), robotic vs. transanal surgery was proven in multiple studies by having the highest cost among all procedures (67).

Conclusions

The management of rectal cancer is constantly evolving. The multimodal therapy of the rectal neoplasm imposes interdisciplinary cooperation between colorectal surgeons, oncologists, radiologists, and radiotherapists. The extent of the disease should be thoroughly assessed using modern imaging methods and special MRI protocols to determine a tailored treatment plan. Furthermore, minimally invasive surgery, especially robotic procedure has brought significant preservation of the inferior hypogastric plexus, leading to the protection of urinary and sexual function, reduced blood loss, and faster discharge. However, these positive outcomes do not replace the necessity of open surgery in selected cases. The data evidence of positive outcomes in robotic surgery continue to grow, however, there are some drawbacks in the present, such as cost and availability of time by using robotic techniques.

Rectal surgeons constantly face challenges regarding oncological safety and sphincter preservation when dealing with distal rectal cancer and the robotic surgery seems to solve some of the challenges. The recent implementation of Total Neoadjuvant Therapy (TNT) has resulted in higher tumor downstaging in more cases, leading to a higher number of patients eligible for a "watch and wait" strategy and sphincter preservation. Additionally, as new technological innovations continue to develop, it is important to adopt these techniques to improve patient outcomes. It is crucial to acknowledge that new techniques require a learning curve. Surgeons must have a deep understanding of anorectal anatomy and its function to perform precise anatomical dissection. Education programs and an increased number of surgical volume cases are essential for better patient outcomes.

Although the robotic approach has gained ground lately in rectal surgery with great results, the best surgical approach for the patient is actually highly dependent on the surgeon skills of obtaining negative margins, regardless whether it is minimally invasive or a traditional procedure.

Author's Contributions

Conceptualization, M.M.R. and L.M.M.; methodology, R.M.M.; software, L.M.M.; validation, V.M.P., M.N.B. and L.S.; formal analysis, E.B.; investigation, V.M.P, R.M.M.; resources, R.M.M., L.M.M.; data curation, R.M.M.; writing-original draft preparation, R.M.M., L.M.M.; writing-review and editing, R.M.M.; visualization, M.N.B,L.S.; supervision, M.M..; project administration, R.M.M.; funding acquisition, V.M.P. All authors have read and agreed to the published version of the manuscript."

Conflicts of Interest

The authors declare no conflicts of interest.

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