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Progress, challenges, and future perspectives of robot-assisted natural orifice specimen extraction surgery for colorectal cancer: a review

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Abstract
With the continuous advancements in precision medicine and the relentless pursuit of minimally invasive techniques, Natural Orifice Specimen Extraction Surgery (NOSES) has emerged. Compared to traditional surgical methods, NOSES better embodies the principles of minimally invasive surgery, making scar-free operations possible. In recent years, with the progress of science and technology, Robot-Assisted Laparoscopic Surgery has been widely applied in the treatment of colorectal cancer. Robotic surgical systems, with their clear surgical view and high operational precision, have shown significant advantages in the treatment process. To further improve the therapeutic outcomes for colorectal cancer patients, some scholars have attempted to combine robotic technology with NOSES. However, like traditional open surgery or laparoscopic surgery, the use of the robotic platform presents both advantages and limitations. Therefore, this study reviews the current research status, progress, and controversies regarding Robot-Assisted Laparoscopic Natural Orifice Specimen Extraction Surgery for colorectal cancer, aiming to provide clinicians with more options in the diagnosis and treatment of colorectal cancer.

Keywords Robotic surgery, Laparoscopic surgery, Natural orifice specimen extraction surgery, Colorectal cancer, Minimally invasive surgery

Introduction

Colorectal cancer (CRC) is a common malignant tumor. According to Global Cancer Statistics, CRC accounts for 10.2% of the incidence and 9.2% of the mortality of all malignant tumors worldwide, with 1.8 million new cases and 860,000 deaths annually [1]. In recent years, CRC treatment has diversified, but surgery remains the only curative approach [2]. Depending on the tumor stage, a variety of surgical options are available, including but not limited to endoscopic submucosal dissection, right hemicolectomy, left hemicolectomy, abdominoperineal resection, anterior resection, total mesorectal excision, and transanal local excision [3]. Traditional surgeries, whether open or laparoscopic, require an abdominal

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incision to remove the tumor specimen. However, with the continuous advancements in precision medicine and the relentless pursuit of minimally invasive concepts, Natural Orifice Specimen Extraction Surgery (NOSES) has emerged. Compared to traditional surgical methods, NOSES better embodies the principles of minimally invasive surgery by removing the specimen through natural orifices, thereby making scar-free surgery possible [4, 5]. In recent years, robotic surgical systems have been widely applied in clinical practice due to their advantages, such as effective tremor filtration, more than tenfold magnification of the surgical field, clear three-dimensional high-definition imaging of the patient's internal structures, and seven highly sensitive mechanical arms [6, 7]. To further improve the treatment outcomes for CRC patients, clinicians have attempted to combine robotic surgical systems with NOSES. However, there are still relatively few reports on the use of robotic NOSES in the treatment of CRC, and its efficacy remains somewhat controversial. Therefore, this study reviews the current research status, progress, and controversies regarding robot-assisted laparoscopic NOSES for CRC, aiming to provide clinicians with more options in the diagnosis and treatment of CRC.

Robotic surgical systems

Introduction

The advent of robotic surgical systems began in 1985 with the first application of a robot for precise localization in neurosurgery [8]. Thirty years after the clinical application of robotic surgical systems, Tan A and colleagues conducted a systematic review and meta-analysis, revealing that compared to open surgery, robotic surgery reduced intraoperative blood loss, transfusion rates, hospital stay, and overall complication rates, albeit at the expense of increased operative time [9]. In 2000, the U.S. Food and Drug Administration (FDA) officially approved the da Vinci robotic surgical system, which has since been widely used in urology, gynecology, cardiothoracic surgery, gastrointestinal surgery, and hepatobiliary surgery [10].

The da Vinci robotic surgical system has evolved to its fourth generation, consisting mainly of three components: the patient-side cart with robotic arms, a vision cart with imaging systems, and the surgeon console. Traditional laparoscopic surgery often faced technical limitations such as restricted two-dimensional imaging, limited imaging angles, physiological tremors from handheld instruments, and limited instrument mobility [11]. The da Vinci robot, based on the classic master-slave operation principle, comprises four robotic arms and two consoles. Three arms carry surgical instruments, while one arm is equipped with a high-definition three-dimensional imaging system. The system features high degrees of freedom and includes Endo Wrist technology, which overcomes the limitations of laparoscopic operations and eliminates physiological tremors [12].

The surgeon console provides a magnified three-dimensional view of the surgical field. It includes adjustable finger rings, adjustable interpupillary distance, a cushioned headrest, and ergonomic armrests. These technological features enable precise operations in narrow spaces such as the pelvis. The ergonomic design and advanced capabilities of the da Vinci system allow for delicate and complex procedures to be performed with enhanced precision and control [13].

Application of robotic surgical systems in colorectal surgery

Kotsiliti E conducted a multicenter randomized controlled trial involving 1,171 patients with mid to low rectal cancer. The patients were randomly divided into two groups: 586 in the robotic group and 585 in the laparoscopic group. The results showed that the complete resection rate for rectal cancer was 95.4% in the robotic group compared to 91.8% in the laparoscopic group. Additionally, the robotic group experienced less surgical trauma and better postoperative gastrointestinal function recovery than the laparoscopic group [14].

Feng Q and colleagues conducted a real-world multicenter randomized controlled study comparing robotic and laparoscopic surgery for mid to low rectal cancer. The study included 1,240 patients from 11 hospitals across eight provinces in China. Short-term results indicated that the robotic group had a lower positive circumferential resection margin rate, fewer complications within 30 days post-surgery, the rate of complete one-time resection of the tumor is higher, shorter postoperative gastrointestinal recovery time and hospital stay, fewer abdominoperineal resection and conversion to open surgery cases, less intraoperative blood loss, and fewer intraoperative complications compared to the laparoscopic group [15].

Liu Y and colleagues pointed out that robotic surgery offers clearer anatomical views, which aids in identifying and preserving pelvic autonomic nerves, facilitating early recovery of urogenital function post-surgery. A 2023 meta-analysis demonstrated that robot-assisted rectal cancer surgery resulted in better postoperative recovery of urogenital function compared to laparoscopic rectal cancer surgery [16].

In summary, the application of robotic surgical systems in colorectal surgery has become increasingly mature, and patients undergoing robotic surgery tend to benefit more compared to those undergoing traditional laparoscopic surgery.

Natural orifice specimen extraction surgery

Introduction

NOSES is a surgical approach that uses laparoscopic, robotic, transanal endoscopic microsurgery (TEM), or flexible endoscopic platforms to perform conventional abdominal and pelvic surgeries (resection and reconstruction). The specimen is extracted through natural orifices (rectum, vagina, or mouth) without any auxiliary incision in the abdominal wall. Postoperatively, patients have no abdominal incision for specimen extraction, only a few small trocar scars, demonstrating excellent minimally invasive results. Currently, NOSES is applied to various organs and tissues within the abdominal and pelvic cavity, including the colorectal, gastric, small intestine, hepatobiliary, pancreatic, urogenital systems, and gynecology [17, 18].

According to the extraction route, NOSES can be classified into three types: transanal NOSES, transvaginal NOSES, and transoral NOSES Colorectal NOSES primarily includes transanal and transvaginal specimen extraction routes. The anus is the most commonly used extraction route for colorectal NOSES, suitable for patients with smaller and easily removable specimens. Due to the good elasticity of the vagina, it is mainly suitable for female patients with larger specimens that cannot be extracted through the anus [17, 18].

Based on the specimen extraction method, NOSES can be divided into three types: Eversion Method: The upper margin of the specimen is first severed, and the specimen is everted and extracted through the anus. The lower margin is then severed under direct vision outside the body to complete the resection. Pull-Out Method: The lower margin of the specimen is severed, and the specimen is pulled out through the natural orifice (rectum or vagina). The upper margin is then severed under direct vision outside the body to complete the resection. Resection and Drag-Out Method: Both the upper and lower margins of the specimen are completely severed inside the abdominal cavity. The specimen is then dragged out through the natural orifice (rectum or vagina) to complete the resection and extraction [17, 18].

The eversion method is primarily suitable for low rectal resections, the pull-out method for mid-rectal resections, and the resection and drag-out method can be used for high rectal, sigmoid colon, left hemicolectomy, right hemicolectomy, and total colectomy. Additionally, the resection and drag-out method is the main extraction method for other abdominal and pelvic organ NOSES surgeries [17–19].

Currently, there are ten main colorectal NOSES procedures, covering all parts of the colorectum. Among them, rectal NOSES includes five types of surgeries targeting high, mid, and low rectal regions, while colonic NOSES includes five types of surgeries mainly for left hemicolectomy, right hemicolectomy, and total colectomy [17–19]. For specific details, refer to Table 1.

Table 1 CRC NOSES procedure

Abbreviation	Surgical procedure	Specimen retrieval approach	Tumor location
CRC-NOSES I	Laparoscopic low anterior resection with tumor retrieval through the anus without auxiliary incisions in the abdomen	rectum	Low rectum
CRC-NOSES II	Laparoscopic mid-rectal anterior resection with specimen retrieval through the rectum without auxiliary incisions in the abdomen	rectum	Middle rectum
CRC-NOSES III	Laparoscopic mid-rectal anterior resection with specimen retrieval through the vagina without auxiliary incisions in the abdomen	vagina	Middle rectum
CRC-NOSES IV	Laparoscopic high-rectal anterior resection with specimen extraction through the rectum without auxiliary incisions in the abdomen	rectum	High rectum / Distal sigmoid colon
CRC-NOSES V	Laparoscopic high-rectal anterior resection with specimen extraction through the vagina without auxiliary incisions in the abdomen	vagina	High rectum / Distal sigmoid colon
CRC-NOSES VI	Laparoscopic left hemicolectomy with specimen extraction through the anus without auxiliary incisions in the abdomen	rectum	Left colon / Proximal sigmoid colon
CRC-NOSES VII	Laparoscopic left hemicolectomy with specimen extraction through the vagina without auxiliary incisions in the abdomen	vagina	Left colon / Proximal sigmoid colon
CRC-NOSES VIII	Laparoscopic right hemicolectomy with specimen extraction through a natural orifice without auxiliary incisions in the abdomen	vagina/rectum	Right colon
CRC-NOSES IX	Laparoscopic total colectomy with specimen extraction through the anus without auxiliary incisions in the abdomen	vagina	Total colon
CRC-NOSES X	Laparoscopic total colectomy with specimen extraction through the vagina without auxiliary incisions in the abdomen	rectum	Total colon

Indications and contraindications

Compared to conventional laparoscopic surgery, the main differences in NOSES lie in the specimen extraction route and the method of digestive tract reconstruction. Other surgical steps, including bowel resection, lymph node dissection, and mesenteric mobilization, are consistent with conventional laparoscopic surgery. Therefore, the indications for NOSES must first meet the requirements of conventional laparoscopic surgery [19]. Additionally, NOSES has its specific indications, which mainly include: (1)Tumor infiltration depth should ideally be T2 to T3. (2)For transrectal NOSES, the specimen circumferential diameter should be less than 3 cm. (3)For transvaginal NOSES, the specimen circumferential diameter should be between 3 and 5 cm [20]. However, in clinical practice, it is necessary to consider the patient's actual condition and adapt the indication criteria based on factors such as mesenteric thickness and the anatomical structure of the natural orifices. NOSES can also be performed on patients with benign tumors, Tis (carcinoma in situ), or T1 stage tumors that are too large for transanal removal or have failed local excision. Relative contraindications for NOSES include advanced local tumor stages, large lesions, and obesity (BMI ≥ 30 kg/m²). Additionally, since there is currently no evidence to confirm whether a vaginal incision might affect female fertility, it is not recommended to perform NOSES on unmarried women, women without children, or married women planning to have more children [17–20].

Clinical application of NOSES

Research on Benign Colorectal Diseases: Chen MZ et al. conducted a study involving 159 patients who underwent NOSES procedures. Among them, 10 patients experienced retroperitoneal small bowel herniation, with 7 requiring further surgical treatment. Complications included anastomotic leakage in 5 cases, postoperative intestinal obstruction in 7 cases, anastomotic bleeding in 3 cases, and superficial wound infection in 1 case. Results post-surgery were comparable to traditional laparoscopic colon resection surgeries [21].

Research on CRC Treatment: Guan X et al. analyzed data from the Chinese national database, involving 5,055 CRC patients treated with NOSES. Short-term follow-up and tumor-related outcomes analysis revealed a median lymph node dissection count of 14.0, median surgery duration of 180.0 min, median intraoperative blood loss of 50.0 mL, median postoperative flatus time of 48.0 h, and median postoperative hospital stay of 9.0 days. The overall complication rate post-surgery was 14.1%. Notably, patients undergoing transvaginal specimen extraction (TVSE) had a significantly higher incidence of rectovaginal fistula compared to those undergoing transanal specimen extraction. Survival analysis of 701 patients showed a median follow-up time of 25.3 months, with 32 patients succumbing to tumor-related causes, 93 patients experiencing distant metastasis, and 20 patients encountering local recurrence. The 3-year survival rate, 3-year disease-free survival rate, and 3-year local recurrence rate were 93.2%, 82.2%, and 3.6%, respectively [22].

Systematic Review and Meta-analysis: A systematic review and meta-analysis encompassing 21 studies and 2,378 patients (1,079 NOSES cases, 1,299 traditional laparoscopic surgery cases) revealed no statistically significant differences in terms of lymph node dissection count, local and distant recurrence rates, 3-year and 5-year disease-free survival rates, and overall survival period when compared to traditional laparoscopic surgery [23].

These clinical findings demonstrate that NOSES can be performed for both benign and malignant colorectal diseases. While ensuring disease eradication, it eliminates the need for abdominal incisions, thereby alleviating patient anxiety associated with large postoperative wounds.

Robot-assisted NOSES application in CRC

Safety and feasibility

Delaney CP et al. [24] first applied the da Vinci robotic system to colorectal surgery. Although it offers three-dimensional imaging technology and flexible robotic arms, it also increases surgical operation time and economic costs. Aslaner A et al. [25] were the first to use the fourth-generation da Vinci robot for NOSES. Their study included 57 patients undergoing robot-assisted NOSES and 93 patients undergoing robotic rectal cancer resection. All patients underwent total mesorectal excision, transanal or transvaginal specimen extraction, anastomosis, and protective loop ileostomy. The results demonstrated that robot-assisted NOSES is a safe and feasible minimally invasive surgery that can be successfully performed in selected patients, yielding satisfactory short-term outcomes. Moreover, the long-term survival outcomes of both groups were similar. Zhou et al. [26] reviewed 162 cases of robot-assisted NOSES, reporting a mean operation time of (188.7 ± 79.8) min, intraoperative blood loss of (47.1 ± 33.2) mL, anastomotic leakage rate of 4.9%, reoperation rate of 2.5%, and no mortality cases. The results were comparable to laparoscopic NOSES. In terms of benign colorectal diseases, Driouch J et al. [27] included 31 patients who successfully underwent robot-assisted NOSES without conversion to open surgery. Postoperative Wexner urinary incontinence score, Wexner constipation score, and Altomare ODS score all showed improvement compared to preoperative scores, indicating that robot-assisted NOSES can be safely performed for benign diseases with reasonable operation time, short hospital stay, and manageable complication rates. These studies collectively suggest that robot-assisted NOSES is safe and feasible for both benign and malignant colorectal diseases, and its precise and flexible operation can effectively protect vital organs and neurovascular bundles within the abdominal and pelvic cavities.

Clinical efficacy

Gao G et al. [28] conducted a single-center retrospective analysis including 45 patients undergoing robot-assisted transvaginal specimen extraction (TVSE) surgery and 45 patients undergoing robot-assisted small incision specimen extraction. The results showed that, in terms of short-term efficacy, the TVSE group had longer operation times compared to the small incision group, with lower postoperative pain intensity and lower rates of additional analgesic medication use. The TVSE group also required slightly less time for initial gas passage, and there were no statistically significant differences in overall complications, gastrointestinal function recovery time, postoperative hospital stay, estimated blood loss, or pathological results between the two groups. In terms of long-term efficacy, the 3-year overall survival rate (94.9% vs. 91.7%, $P=0.702$) and 3-year disease-free survival rate (88.4% vs. 86.2%, $P=0.758$) were comparable between the two groups. In selected patients with tumor diameters < 5 cm with sigmoid or high rectal cancer, the efficacy of robot-assisted TVSE was equivalent to that of robot-assisted small incision specimen extraction surgery. Li L et al. [29] reported that compared to the conventional robotic resection (CRR) group, the robot-assisted NOSES group had less intraoperative blood loss ($P=0.001$), lower demand for additional analgesia ($P=0.020$), shorter time to first passage of gas postoperatively ($P=0.010$), and shorter time to initiation of liquid diet postoperatively ($P=0.003$). The 3-year overall survival rate (92.3% vs. 89.7%, $P=1.000$) and 3-year disease-free survival rate (82.1% vs. 84.6%, $P=0.761$) were comparable between the two groups. Zhao et al. [30] conducted a retrospective analysis of 31 patients with colorectal tumors, among whom 17 patients underwent robot-assisted NOSES and 14 underwent conventional surgical specimen extraction. The results showed that the NOSES group had a lower rate of lymph node metastasis, less intraoperative blood loss, earlier time to first postoperative ambulation, and no surgery-related complications during the perioperative period. During a follow-up period of 3 to 6 months postoperatively, none of the patients experienced tumor recurrence, progression, or mortality. In summary, in terms of short-term and long-term efficacy, postoperative pathology results, robot-assisted NOSES shows no significant difference compared to traditional surgery, demonstrating consistency with traditional surgery in terms of clinical efficacy.

Advantages over traditional laparoscopic surgery

The advantages of robot-assisted NOSES over laparoscopic surgery are evident in several aspects, including reduced intraoperative blood loss, preservation of organs and neurovascular structures, and postoperative gastrointestinal function recovery. In a study by Yao H et al. [31], which included 180 patients undergoing robot-assisted NOSES, the mean distance from the tumor margin to the anus was (8.64±3.64) cm, and the maximum diameter of the tumor specimen was (3.5±1.6) cm. In terms of safety, the mean operation time, intraoperative blood loss, and postoperative hospital stay were (187.5±78.3) min, (47.4±34.0) mL, and (11.3±7.5) days, respectively. In terms of feasibility, the mean number of lymph nodes removed was (14.8±5.0), with no observed positive margins, demonstrating advantages over laparoscopic NOSES. Several studies have confirmed these conclusions [32–34].

During the phase of gastrointestinal reconstruction after specimen removal, if excessive tension at the anastomosis site, suboptimal anastomotic effects, or positive insufflation test are detected, the robotic surgical system can quickly reinforce the anastomosis within the abdominal cavity to prevent postoperative anastomotic leakage. When operating in narrow spaces such as lateral gaps or the posterior rectal space, the robotic surgical system provides a more stable and clearer field of view. Moreover, in larger-sized patients, laparoscopy is limited by the length of surgical instruments and the constraints on the surgeon's movements, significantly affecting surgical progress, whereas the robotic surgical system can address this issue.

Challenges and controversies of robot-assisted NOSES in treating CRC

Challenges and controversies of Robot-assisted surgery

Difficulty in robot-assisted surgery operations

One major limitation of robot-assisted surgery is the increased difficulty in operations. Unlike conventional surgeries where operators directly hold the instruments, in robot-assisted surgery, operators lack direct sensory feedback on the force applied during pulling, cutting, and tissue separation. This lack of tactile feedback can lead to challenges in judging the force exerted during operations, particularly when the anatomical structures are not well-defined, increasing the learning curve for transitioning from laparoscopic to robot-assisted surgery. A study by Yao H et al. [35] on the learning curve (LC) of robot-assisted NOSES included 99 and 66 patients, respectively, with procedures performed by two professors. The LC peaked at the 42nd and 15th procedures, after which the operation time began to decrease. There was no statistically significant difference in the quality of surgery between the two groups, indicating the initial LC of robot-assisted NOSES is safe and feasible. It's worth noting that another reason for the longer operation time in robot-assisted surgery is the complexity of setting up the robot, which consumes considerable time. With advancements in robot surgery systems, the application of augmented reality and force feedback systems in clinical practice can address these issues. Moreover, proficiency in laparoscopy is crucial for shortening the learning curve of robot-assisted NOSES.

High cost of robot-assisted surgery

Another significant limitation is the high cost associated with robot-assisted surgery systems. These systems have not yet been widely adopted, and their installation is directly proportional to the level of economic development. Research by Jayne D et al. [36] showed that robot-assisted rectal cancer surgery increased the average medical costs by approximately £979 compared to laparoscopic surgery. Another study by Yuan Enquan et al. [37] demonstrated that robot-assisted NOSES increased hospitalization costs by ¥7,296.24 compared to laparoscopic surgery. The increased medical costs limit the implementation of robot-assisted surgery in economically underdeveloped regions. Against the backdrop of reforms such as Diagnosis Related Groups (DRG) and Diagnosis-Intervention Packet (DIP) payment models, how to categorize diseases for robot-assisted NOSES, balance the introduction of new technologies with medical insurance expenditure, and provide higher quality medical services to patients warrants further consideration.

Challenges and controversies of NOSES

Tumor-free principle

Based on the method of specimen extraction, NOSES can be classified into three types: Eversion Method, Pull-Out Method, Resection and Drag-Out Method. Below, we will explore how each of these three approaches can better adhere to the tumor-free principle.

Outward Flip Resection: In this method, the upper edge of the specimen is severed inside the abdominal cavity, and then the specimen is flipped outward through a natural cavity. The lower edge of the specimen is then cut off under direct vision outside the body. This approach is prone to tumor dissemination and metastasis for two reasons. First, during the flipping process, tumor cells may detach and adhere to the mucosal surface due to compression, potentially leading to seeding metastasis when the tumor is severed. Second, since the specimen is not completely detached, compression during the process may cause tumor cells to enter the bloodstream, resulting in hematogenous dissemination. Therefore, after flipping the specimen out, thorough irrigation of the intestinal mucosal surface with iodine solution is necessary. Additionally, strict adherence to tumor size is required, typically requiring the tumor diameter not to exceed one-third of the circumference of the bowel. Furthermore, the anal canal should be adequately dilated, up to four fingers, to reduce tumor compression during the pulling-out process, and lubricant should be applied to the specimen bag to facilitate smoother extraction [38].

Pull-Out Resection: In this method, the lower edge of the tumor is severed inside the abdominal cavity, and then the tumor is pulled out through a natural cavity, with the upper edge of the tumor being severed under direct vision outside the body. Similar to outward flip resection, because the blood supply above the tumor is not completely severed, the tumor is susceptible to compression and hematogenous dissemination during the pulling-out process through the anus. Additionally, some tumor cells may detach and disseminate to the mucosal surface due to compression. Compared to outward flip resection, this approach poses greater challenges for irrigation of the mucosal surface since it remains unflipped. Therefore, this method requires higher tumor tissue size and natural cavity conditions to adhere to the tumor-free principle effectively.

Cut-Out Pull-Out Resection: In this method, both the upper and lower edges of the tumor are severed inside the abdominal cavity, and then the tumor is pulled out through a natural cavity. Because the diseased intestinal segment is completely severed within the abdominal cavity, there is no risk of tumor dissemination due to compression during specimen extraction [39]. Additionally, using a specimen protection sheath to create a sterile and tumor-free passage can effectively reduce the risk of tumor dissemination. Compared to the previous two methods, cut-out pull-out resection can better achieve the tumor-free principle. Moreover, because this approach is suitable for tumors in the upper rectum and various parts of the colon, its application in clinical practice is more extensive [40].

Sterile principle

Patients undergoing NOSES should undergo thorough intestinal and natural cavity preparation before surgery [41]. Firstly, intestinal preparation includes mechanical bowel preparation and antibiotic preparation. Unlike in rapid recovery protocols for colorectal cancer patients, mechanical bowel preparation is particularly crucial in NOSES due to the opening of the intestinal tract during surgery to prevent contamination of the abdominal cavity caused by intestinal fluid leakage. Patients are required to pass clear, yellowish, and residue-free liquid after mechanical bowel preparation. Additionally, the timing of intestinal preparation for NOSES is earlier compared to conventional colorectal cancer surgeries to ensure complete drainage of the intestinal cavity during surgery. In recent years, antibiotics have been largely abandoned in preoperative bowel preparation for colorectal cancer due to the difficulty in completely preventing intestinal fluid from entering the abdominal cavity during NOSES. However, the use of oral antibiotics for intestinal preparation is still necessary to significantly reduce the bacterial count in the intestinal cavity, thereby minimizing the risk of intraoperative abdominal infection. Secondly, natural cavity preparation involves vaginal irrigation during specimen extraction through the vagina [42].

Intraoperative sterile operating points include: (1) Prophylactic use of antibiotics to minimize the exposure time of the open bowel. (2) Pre-insertion of dried iodine gauze strips into the abdomen before opening the bowel. (3) After opening the bowel, gauze strips inside the abdominal cavity are taken out through the natural cavity instead of through the Trocar [43]. (4) Timely suctioning of leaked intestinal contents by the assistant suction device during surgery. (5) Irrigation with iodine solution through the anus. (6) Thorough soaking and rinsing of the surgical field with iodine-distilled water [40]. (7) Irrigation of trocar ports to reduce postoperative incision infections and the risk of seeding tumor cells.

For patients at risk of abdominal or incisional contamination, prophylactic use of antibiotics can be employed postoperatively. Multiple studies [44–47] have shown that the positive bacterial culture rate in the intraoperative abdominal washings of NOSES ranges from 0 to 34.4%, while in conventional laparoscopic surgeries, it ranges from 2.9 to 32.6%, with no statistically significant difference between the two groups. Similarly, the positive tumor cell rate in the intraoperative abdominal washings of NOSES ranges from 0 to 7.3%, compared to 0–9.0% in conventional laparoscopic surgeries, with no statistically significant difference between the two groups. Furthermore, as long as the surgical indications are strictly followed, preoperative preparations are well-performed, and intraoperative meticulous procedures strictly adhere to the sterile and tumor-free principles, NOSES can fully meet the requirements of sterility and tumor-free conditions.

Digestive tract reconstruction

Performing complete digestive tract reconstruction entirely under laparoscopy is a major challenge in NOSES. Compared to traditional laparoscopic surgery, it involves greater technical difficulty, a longer learning curve, and places higher demands on surgeons. Anastomotic complications significantly impact postoperative recovery and further treatment of tumors, making them the most concerning complications for gastrointestinal surgeons. Anastomotic complications mainly include anastomotic leakage, stenosis, and bleeding [48]. There are three main methods for digestive tract reconstruction in NOSES: complete laparoscopic side-to-side anastomosis, anastomosis using a natural orifice, and manual suture anastomosis [49]. Surgeons should flexibly choose the appropriate anastomotic device and reconstruction method based on tumor size, depth of infiltration, thickness of specimen tissue, and patient physique. Before anastomosis, attention should be paid to intestinal wall blood supply, anastomotic tension, the presence of stenosis, contamination in the surrounding area, and mesentery torsion. Care should be taken not to forcefully pull or stretch the mesentery when freeing the intestinal tract to prevent damage to mesenteric vessels and subsequent ischemic necrosis of the anastomosed intestinal tract.

When trimming the mesentery, it should be cut perpendicular to the intestinal tract to ensure maximum blood supply. Before anastomosis, pre-assess the tension of the anastomosis by pulling the proximal and distal ends of the intended anastomosed intestine together to determine tension, and mark the point of disconnection with titanium clips to avoid excessive tension after anastomosis. After anastomosis, confirm again that there is no leakage or bleeding at the anastomotic site. Inspection methods include inflation water testing and intraoperative colonoscopy. Finally, place a drainage tube next to the anastomosis to maintain drainage patency. Due to the "dangerous triangle" that occurs in the overlap area of two stapled lines in traditional rectal end-to-end anastomosis, there is an increased risk of anastomotic leakage. Researchers at the First Affiliated Hospital of Zhengzhou University, led by Ji-yuan Mi, have proposed a new anastomotic method called "bag-like pouch-type end-to-side anastomosis," which eliminates the "dangerous triangle" and reduces tension in the posterior wall of the anastomosis, thereby reducing the occurrence of anastomotic leakage [50]. Additionally, some scholars have demonstrated through practice that leaving an anal tube postoperatively can also reduce the occurrence of anastomotic leakage [51].

Extraction of surgical specimens

Extracting specimens through a natural orifice is a distinctive feature of NOSES and also a point of contention and difficulty. Specimen extraction should strictly adhere to the principles of sterility, tumor functionality, and the risk-benefit ratio. First, patients suitable for NOSES should be selected based on indications and contraindications. Secondly, adequate mobilization of the intestinal tract containing the tumor should be performed intraoperatively to ensure it is sufficiently long and relaxed. Furthermore, appropriate tools should be used to dilate the natural orifice. Lubricants may be used if necessary to facilitate specimen extraction [49].

There are three main methods for specimen extraction: through the rectal stump, through a rectal incision, or through a vaginal incision. Extracting specimens through the rectal stump does not require additional incisions, reducing the risk of postoperative fistulas, and is the preferred method of specimen extraction. Regarding whether extracting specimens through the anus damages anal function, Wolthuis et al. [52] conducted a prospective randomized controlled study comparing postoperative fecal incontinence scores and maximum anal pressures in patients with colorectal cancer undergoing NOSES and conventional laparoscopic surgery. The results showed no statistically significant differences between the two groups. When encountering resistance during specimen extraction, muscle relaxants can be used to reduce the tension of the anal sphincter. Additionally, the dilation of the anus during specimen extraction is transient and has minimal impact on anal function. Using a large amount of iodine to flush the intestines and anus during the operation can also meet the requirements of sterility and tumor-free principles. Extracting specimens through the vagina is controversial due to the "special" path, but in fact, the vagina has good elasticity, and the posterior cul-de-sac of the vagina is closely adjacent to the rectouterine pouch anatomically. Incising the posterior cul-de-sac of the vagina can directly communicate the abdominal cavity with the outside world, making it very suitable for specimen extraction. Moreover, the vaginal blood supply is rich, which is beneficial for wound healing, and repairing the incision will not affect normal vaginal function [53].

Discussion

Robot-assisted NOSES has the advantage of minimizing trauma, avoiding postoperative incisional hernias, improving the aesthetic appearance of the abdomen, alleviating postoperative anxiety and depression caused by surgical scars, and accelerating patient recovery. Robots can perform precise operations in narrow spaces such as the pelvis, compensating for the limitations of laparoscopic surgery and reducing the need for conversion to open surgery and intraoperative complications. Additionally, robot-assisted surgery systems can be remotely controlled, providing assistance to patients in remote areas. In summary, robot-assisted NOSES balances disease treatment and reduced trauma, aligning with the concept of accelerating recovery in surgery. While minimally invasive surgery is flourishing, robot-assisted surgery systems are also rapidly evolving. Robot-assisted NOSES has shown comparable or superior short-term and long-term efficacy evaluations compared to traditional laparoscopic surgery. With the high-quality development of medical research, robot-assisted NOSES is expected to become an inevitable trend in the future development of colorectal surgery. Currently, robot-assisted NOSES lacks a standardized training system, and its high surgical complexity and learning costs hinder its development to some extent. For low rectal cancer with sphincter preservation issues, although robot-assisted NOSES provides new insights, it still faces the contradiction between sphincter preservation, functional preservation, and tumor radical cure. Moreover, the mastery of the principles of sterility and tumor-free significantly affects patient prognosis. Therefore, efforts should be made in the future to establish a standardized training system and training centers for robot-assisted NOSES, reduce learning costs, balance the relationship between sphincter preservation, functional preservation, and tumor radical cure, develop specimen extraction tools and natural orifice dilators to completely isolate tumor specimens from normal tissues, ensure sterility and tumor-free conditions, and expand the indications for robot-assisted NOSES.

Author contributions

Huiming Wu and Dingwen Xue (Co-first Author) Conceptualization, Methodology, Data base and literature search, Writing—Original draft preparation, Writing—Reviewing and Editing, Final approval of manuscript. Min Deng: Literature search, Data curation, Writing—Reviewing and Editing, Final approval of manuscript. Renkai Guo: Literature search, Data curation, Writing—Reviewing and Editing, Final approval of manuscript. Huiyu Li: Writing—Reviewing and Editing, Supervision, Funding, Final approval of manuscript. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Human Ethics and Consent to participate declarations

Not applicable.

Consent for publication

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Competing interests

The authors declare no competing interests.

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