

# Comparison of short-term outcomes between Chinese surgical robot “Micro Hand S” assisted and laparoscopic total mesorectal excision for rectal cancer: a retrospective study

**Yanlei Wang**

Central South University Third Xiangya Hospital

**Guohui Wang**

Central South University Third Xiangya Hospital

**Zheng Li**

Central South University Third Xiangya Hospital

**Ling Hao**

Central South University Third Xiangya Hospital

**Bo Yi**

Central South University Third Xiangya Hospital

**shaihong zhu** (✉ [1459082987@qq.com](mailto:1459082987@qq.com))

Central South University Third Xiangya Hospital

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## Research

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# Abstract

**Background** As the first domestically produced Chinese surgical robot for clinical use, the Micro Hand S robot has been applied to total mesorectal excision (TME) for rectal cancer in our center since 2017. The aim of this study was to evaluate the safety and feasibility of the Micro Hand S robot-assisted TME (R-TME) in comparison with laparoscopic TME (L-TME).

**Methods** Between May 2017 and February 2018, patients who underwent R-TME and L-TME in the Third Xiangya Hospital were included in this study. The data including intraoperative outcomes, postoperative outcomes, pathological outcomes, and functional outcomes were analyzed and compared.

**Results** Totally, 30 patients underwent L-TME and 21 patients underwent R-TME. The patient characteristics of the two groups were similar. Regarding intraoperative and postoperative outcomes, the R-TME group had significantly less blood loss (95.2 vs. 130.0 ml,  $p = 0.022$ ), shorter time to first flatus (2.1 vs. 2.9 d,  $p = 0.017$ ) and first liquid intake (2.8 vs. 3.7 d,  $p = 0.027$ ) than the L-TME group. There was no significant difference in the operative time, conversion, protective ileostomy, length of hospital stay, pain score, complications, and 30-day mortality between the two groups ( $p > 0.05$ ). In addition, the pathological and functional outcomes also did not differ significantly.

**Conclusion** The Micro Hand S robot-assisted total mesorectal excision is safe and feasible with short-term outcomes comparable to laparoscopic surgery. Prospective and large sample size trials are needed to further confirm this conclusion.

## Background

Surgical resection is one of the main treatments for rectal cancer. Total mesorectal excision (TME) for rectal cancer as the standard operation can reduce local recurrence and improve overall survival [1, 2]. As with the technical development, the modalities of TME continue to evolve. Since the introduction of laparoscopic TME (LTME), it has been widely accepted because of its comparable oncological outcomes, less trauma, quicker recovery and less blood loss than open TME (OTME) [3, 4]. However, laparoscopic TME (LTME) also poses a technical challenge to surgeons due to the long rigid instruments, 2D vision, uncontrollable camera platform especially in the narrow deep space of the pelvic cavity. The well-known da Vinci surgical robotic system which overcomes the disadvantages of laparoscope demonstrates a 3D vision, tremor filtering, and wristed instrumentation with seven degrees of freedom (DOFs). The technical advantages of robotic TME (RTME) promise an excellent manipulation, which result in superior clinical outcomes as compared with L-TME [5-7].

To deliver more value to Chinese patients, Central South University in cooperation with Tianjin University developed the first domestically produced Chinese minimally invasive surgical robot system, Micro Hand S, in 2013 (Fig. 1). It is a master-slave robot that consists of a surgeon console, a slave cart, and a stereo image viewer [8]. Similar to the da Vinci surgical robot, the Micro Hand S surgical robot demonstrates 3D visual imaging, motion scaling, tremor filtering, and wristed instrumentation with seven degrees of

freedom. The Micro Hand S was successfully applied in some simple surgeries including acute appendectomy, gastric perforation repair, cholecystectomy [8].

Recently, our center performed more complicated surgery such as total mesorectal excision (TME) with the Micro Hand S surgical robot (R-TME). In order to evaluate the safety and feasibility of R-TME, we taken laparoscopic TME (L-TME) as a reference treatment in the present study. For the first time, we compared the short-term outcomes of R-TME and L-TME for rectal cancer in terms of intraoperative outcomes, postoperative outcomes, pathological outcomes and functional outcomes.

## Patients And Methods

The data of all patients who underwent R-TME and L-TME were reviewed retrospectively between May 2017 and February 2018. A preoperative colonoscopy with biopsy was performed in all patients and rectal cancer was histologically proven. A pelvic MRI examination was preoperatively performed to evaluate the clinical stage. Neoadjuvant chemoradiation therapy (CRT; 50.4 Gy in 25 fractions for 5 weeks and 5-fluorouracil based chemotherapy) was administered if the circumferential resection margin (CRM $\leq$ 1mm) was suspicious, threatened, or positive or if lymph nodes that escaped the TME plane were detected by MRI. After the completion of neoadjuvant CRT, a pelvic MRI examination was performed for restaging and surgery was performed 6-8 weeks later. We excluded the patients who underwent palliative resection, concurrent resection, emergency operation and patients with double or recurrent tumor. Patients with distant metastasis, severe dysfunction of vital organs, history of abdominal and/or pelvic surgery were also excluded from this study. The selection of laparoscopic or robotic surgery was made based on patient's decision after a full explanation of each procedure. All patients were followed at least 6 months.

The data included patient demographics, tumor characteristics (tumor size, distance from anal verge, clinical tumor and nodule stage), intraoperative outcomes (blood loss, operative time, conversion rate, blood transfusion, protective ileostomy), postoperative outcomes (time to first flatus, time to first liquid intake, length of hospital stay, pain score, postoperative complications and 30-day mortality), pathological outcomes (lymph nodes, proximal/distal/circumferential margins, histological differentiation, quality of TME) and functional outcomes (the Wexner Incontinence score, the International Prostate Symptom Score-IPSS, and the 5-item version of the International Index of Erectile Function-IIEF-5).

The distance from anal verge was confirmed by rigid proctoscopy. Conversion to open surgery was defined as transformation from the initial approach (robot or laparoscope) to open surgery except specimen extraction. Pain score was obtained by visual analogue score. A postoperative complication was defined as adverse event within 30 days after the operation. All postoperative complications were recorded and graded using the Clavien-Dindo classification, with grade III or above considered to be a severe complication [9]. Then, the comprehensive complication index (CCI) was calculated based on the Clavien-Dindo classification [10]. All histopathological examinations were performed by an experienced pathologist. An involved distal resection margin (DRM) was identified if malignant cells were found at the

cutting edge by microscopy. Accordingly, an involved circumferential resection margin (CRM) was identified if malignant cells were found within 1 mm or less from the circumferential resection margin by microscopy. The quality of TME was graded according to the protocol proposed by Quirke and classified macroscopically as complete, nearly-complete, or incomplete [11]. Functional outcomes were evaluated at pre- and post-operation through questionnaires. The sphincter and urinary function were evaluated using the Wexner Incontinence and IPSS scores (a higher score indicating worse function on a scale of 0-20 or 0-35, respectively). The sexual function was assessed using IIEF-5 score (a lower score indicating worse function on a scale of 0-25).

All procedures were performed by a single surgeon who had performed more than 100 laparoscopic colorectal resections. Informed consent was obtained from all patients. The study was approved by the Ethical Committee of the Third Xiangya Hospital and was registered on clinicaltrial.gov (NCT02752698).

## Surgical technique

### Robotic procedure

We used a three-armed Micro Hand S surgical robot and a four-port technique. The arrangement of the ports is displayed in **Fig. 2**. A 12-mm trocar was inserted through supraumbilical port for the 3D camera (**Camera port**). Two special 10-mm trocars were inserted through two operating ports, located at 5-8cm lateral to the right side of the umbilicus (**Port A**) and 3-4 cm above the intersection of the umbilicus and the left anterior axillary line (**Port B**), to connect the right/left robotic instrument, respectively. A 10-mm trocar was inserted through assistant port located at 10cm above of the right operating port (**Assistant port**).

After the establishment of the pneumoperitoneum, the patients were placed in lithotomy position with 20-30° Trendelenburg and up to 15-20° right tilt. Then the Micro Hand S surgical robot was docked at the left side of the patient by adjusting the location of the three passive arms of the patient cart. First, we ligatured of the inferior mesenteric vessels and then mobilized colon. The inferior mesenteric artery/vein (IMA/IMV) were respectively divided at its origin or at the inferior margin of the pancreas. The sigmoid and descending mesocolon were dissected from medial to lateral. Medial mobilization started with the sigmoid mesocolon. The left ureter was identified and preserved. When the splenic flexure was completely dissected from posterior tissue, we then turned to lateral mobilization until the completely mobilization of sigmoid and descending colon and splenic flexure. Second, we dissected the pelvic cavity, firstly the posterior dissection, then the lateral, and lastly the anterior dissection. Posterior dissection progressed along the space between the mesorectal fascia and the presacral fascia (Waldeyer's fascia) until to the level of the fourth sacral vertebra. The hypogastric nerves were identified and preserved carefully. Lateral dissection progressed until to the level of the lateral ligaments of the rectum. Anterior dissection started with the incision of the anterior peritoneal brim and continued over the plane of Denonvilliers' fascia. Once the dissection was completed, the robot was undocked and the rectum was transected using an Endo-GIA. The specimen was retracted through an abdominal incision. A circular stapler was inserted through the anal and an intracorporeal end-to-end anastomosis was created under

laparoscope. An ileostomy was created upon a surgeon's decision during the operation if necessary. Pictures of the operation are shown in **Fig. 3**. More details are shown in additional files [see **Additional file 1-3**].

### Laparoscopic procedure

L-TME was performed with five working ports according to general standardized laparoscopic principles. The standard operation method from the robotic procedure was followed, including the ligation of the mesenteric vessels, dissection of sigmoid mesocolon and mesorectum, and creation of an anastomosis.

### Statistical analysis

Data analysis was performed using SPSS 20.0 software. Continuous variables were expressed as the mean  $\pm$  standard deviation ( ) and comparisons of the groups were performed using Student's *t* test. Categorical variables were expressed as frequencies (percentages) and comparisons of the groups were performed using Pearson's chi-square or Fisher's exact test. The differences were considered statistically significant at  $p < 0.05$ .

## Results

### Patient characteristics

A total of 30 patients in the L-TME group and 21 patients in the R-TME group were included. All patients were discharged successfully. There were no significant differences in age, gender, BMI, ASA score and Charlson score in the two groups (all  $p > 0.05$ ). The distance from the anal verge of the L-TME group was lower than the R-TME group, but there was no statistically different (7.1 vs. 8.2 cm,  $p = 0.082$ ). The tumor size was comparable in the two groups (3.4 vs. 3.3 cm,  $p = 0.791$ ). The distribution of clinical tumor stage was similar ( $p = 0.687$ ). The majority of clinical nodule stage was N0 stage in both groups ( $p = 0.764$ ). One patient in the L-TME group and two patients in the R-TME group received neoadjuvant CRT ( $p = 0.073$ ). The patient characteristics of the two groups are displayed below ( $p > 0.05$ ) (**Table 1**).

### Perioperative outcomes

The intra- and postoperative outcomes are listed in **Table 2**. No deaths or readmissions in either group occurred within 30 days after operation. Low anterior resection (LAR) was performed in the majority of the two groups (90.0% vs. 95.2%,  $p = 0.876$ ). The R-TME group was associated with less blood loss (95.2 vs. 130.0 ml,  $p = 0.022$ ), a shorter time to first flatus (2.1 vs. 2.9 d,  $p = 0.017$ ) and a shorter time to first liquid intake (2.8 vs. 3.7 d,  $p = 0.027$ ) than the L-TME group. The average operative time of the R-TME group was longer than that of the L-TME group. However, the difference was not significant (288.3 vs. 265.0 min,  $p = 0.082$ ). The learning curve for RTME showed a descending trend in mean operative time from 316.5 min in the first 10 consecutive cases to 262.7 min in the last 11 cases ( $p = 0.002$ ) (**Fig. 4**). One patient who initially underwent R-TME experienced an intraoperative complication of an ureter injury and was converted to open surgery; the conversion rate was similar between the two groups (0% vs. 4.8%,  $p =$

0.412). Protective ileostomy was created in 18 patients of the L-TME group and 8 patients of the R-TME group ( $p = 0.124$ ). There were no significant differences in terms of length of hospital stay.

The postoperative complications are displayed in **Table 3**. In total, 23 complications in 20 patients were identified: 17 patients (33.3%) had a single complication and 3 patients (5.8%) had more than one complication, but only the high-grade complications were listed. The most common complications were wound complication (9.8%), followed by pulmonary complication, urinary retention, ileus and fluid collection (5.8%). The overall morbidity was 36.7% in the L-TME group and 42.3% in the R-TME group. The frequencies of complications were similar between the two groups (all  $p > 0.05$ ). According to the Clavien-Dindo classification, the details of the postoperative complications were as follows. In the L-TME group, 7 patients (23.3%) experienced grade I complications, 3 patients (10.0%) grade II and 1 patients (3.3%) grade III; 4, 4, 1 patients (19.0%, 19.0%, 4.8%) in the R-TME group ( $p = 0.822$ ). None experienced grade IV or grade V complication. One patient in the L-TME group had a postoperative intra-abdominal abscess and underwent reoperation, which was classified as grade IIIb. One patient in the R-TME group had postoperative intraluminal bleeding and underwent endoscopic hemostasis, which was classified as grade IIIa. The rate of severe complications ( $\geq$  grade III) was 3.3% for the L-TME group and 4.8% for the R-TME group ( $p = 1.000$ ). The average CCI score was  $19.5 \pm 9.9$  and  $19.2 \pm 6.2$  ( $p = 0.740$ ).

### Pathological outcomes

The pathological outcomes are presented in **Table 4**. The numbers of lymph nodes harvested were  $16.5 \pm 6.0$  for the L-TME group and  $15.7 \pm 5.3$  for the R-TME group ( $p = 0.646$ ). One patient with a positive CRM in the L-TME group and two patients in the R-TME group were identified ( $p = 0.749$ ). The lengths of PRM (18.4 vs. 16.2 cm,  $p = 0.113$ ) and DRM (2.3 vs. 2.0 cm,  $p = 0.408$ ) were similar. The type of histology of the tumor was mainly moderate differentiation in both groups and no significant difference was observed in the grade of histological differentiation ( $p = 0.669$ ). The quality of TME specimen (complete/nearly-complete/incomplete) were 26/2/2 patients (86.6/6.7/6.7%) in the L-TME group and 19/1/1 patients (90.4/4.8/4.8%) in the R-TME group ( $p = 1.000$ ).

### Functional outcomes

Sixteen male patients in the L-TME group and 12 male patients in the R-TME group were included for evaluating sphincter, urinary and sexual functions at pre-operation and 3, and 6 months post-operation. The patient characteristics and functional outcomes in male patients are listed in **Table 5**. The Wexner Incontinence scores were higher at 3 months as compared with pre-operation for the L-TME group (10.3 vs. 4.1,  $p < 0.001$ ) and the R-TME group (9.5 vs. 5.1,  $p = 0.012$ ). The scores then decreased, and were comparable, to the preoperative level at 6 months. The scores of both groups at the same time points were not significantly different ( $p > 0.05$ ). The IPSS and IIEF-5 scores showed the similar trend as above. However, the IPSS scores for both groups did not decreased to pre-operation at 6 months ( $p < 0.05$ ). The IIEF score was comparable to pre-operation at 6 months in the R-TME group ( $p = 0.136$ ), but not in the L-TME group ( $p = 0.044$ ).

The follow-up period was 7-12 months. During the follow-up period, no recurrence or metastases was observed in both groups.

## Discussion

Currently, the main therapy for rectal cancer is laparoscopic resection. Rectal cancer is located in a narrow and rigid space of the pelvic cavity that has many important vessels and nerves. This situation poses a great technical challenge to surgeons. Furthermore, TME as a standard operation for rectal cancer, requires complicated laparoscopic manipulations to reach the extremes of the pelvis for the complete resection of the rectum and peripheral lymph nodes [12]. The above situation with the addition of using a straight and rigid laparoscopic instrument makes laparoscopic TME surgery a highly difficult technique. The Micro Hand S robot system, the first domestically produced Chinese minimally invasive surgical robot system, possess the following features: an 3D vision imaging system contributing to a more accurate spatial orientation, motion scaling allowing for a more precise manipulation, and a wristed instrument increasing the dexterity of the instrument. All these characteristics facilitate TME surgery in a small space. Therefore, based on the above consideration, we selected rectal cancer surgery to evaluate the safety and feasibility of the Micro Hand S robot in its initial phase. In the current study, we found that the R-TME group was with a less blood loss, shorter time to first flatus and first liquid intake than the L-TME group, without compromising on other outcomes.

The patient characteristics of the two groups were comparable. Notably, the number of patients who received neoadjuvant CRT was small because selective neoadjuvant CRT was administered in this study. In fact, for tumors and lymph nodes located in the TME plane without suspicious or positive CRM, standard TME surgery can promise a curative resection, and neoadjuvant CRT is not indispensable [13]. Moreover, neoadjuvant CRT may induce tissue edema, which increases the difficulty of pelvic dissection and the risk for intra- and postoperative complications [14]. Therefore, selective neoadjuvant CRT was administrated in this study.

The R-TME group had less intraoperative blood loss (95.2 vs. 130.0 ml) than the L-TME group ( $p < 0.05$ ). To our experience, with a high resolution view, the surgeon can easily identify the potential space with few vessels between anatomic structures and the dissection can be performed more smoothly. The wristed instruments unlike the rigid laparoscopic instruments demonstrated flexible performance during robotic surgery. What's more, the Micro Hand S was equipped with motion scaling strategies [15] and the surgeons can downscale the motion of instruments at the ratio of 1:3, 1:6, 1:10 as needed. In the narrow pelvic cavity, the surgeon adopted a ratio of 1:3 to realize a precise dissection. All these features improved accuracy of the manipulations which were helpful to reduce blood loss. Meanwhile, these technical advantages helped to reduce bowel injury and promised a quicker recovery of the bowel.

In this study, the mean operative time was not significantly different between the L-TME and R-TME groups (265.0, 288.3 min), although the operative time of the R-TME group was 23.3 min longer than that of the L-TME group. However, several studies have shown that the da Vinci surgical robot-assisted TME

had a significant longer operative time than L-TME for rectal cancer [16-18]. The reasons below may contribute to this fact: (i) The patient characteristics may be responsible for this fact, such as the higher tumor location in the robotic group. The distance from anal verge reflected the depth of dissection in the pelvis and surgical difficulty [19]. Therefore, the relative high location of lesions may decrease surgical difficulty, thus reducing the operative time; (ii) In this study the surgeon had rich experience using the da Vinci surgical robotic system for resection. Meanwhile, the Micro Hand S and da Vinci robot operated in a similar manner. This situation dramatically facilitated the learning curve of the Micro Hand S robot for rectal resection. As shown in **Fig. 4**, the operative time of the last 11 consecutive cases decreased significantly when compared with the first 10 cases. The operative time decreased rapidly after a few cases; (iii) The adopted trocar position, as seen in **Fig. 2**, permitted completion of the surgery after the initial docking of the robot and avoided a re-docking, further reducing the operative time. Encouragingly, our data was similar to the result of the ROLLAR trial for robotic surgery (288.3 vs. 298.5 min) [20]. A low conversion rate is an important advantage of robotic surgery for rectal cancer, and the reported conversion rate ranged from 1.31% to 5.68% [21-23]. In our study, one patient was converted because of an ureteral injury due to severe adhesion, and the conversion rate (4.76%) was acceptable.

The comprehensive complication index (CCI) that integrated all postoperative complications has shown to be an effective measure to evaluate the differences in treatment effects. The current study demonstrated that both groups had similar CCI. The rate of overall complications ( $\geq$  grade III) in the R-TME group was 42.8%, similar to the findings of Ramji et al. (42.3%) [19] and Mégevand et al. (37.14%) [24], and the rate of severe complications (4.8%) was lower than their results (11.54%, 17.14%). In the previous studies the most common complication was anastomotic leakage, but it did not occur in our study. The low anastomotic leakage rate was related in part to the low rate of neoadjuvant CRT and the inclusion of major upper-middle cases.

The quality of the TME specimen is an important prognostic factor for resection. The current study had 19 “complete” patients (90.6%) in robotic surgery similar to the results of Kim et al. (32 patients, 97.0%) [25] and Aselmann et al. (43 patients, 97.7%) [26], which was higher than the result of the ROLLAR trial (178 patients, 75.4%) [20]. Previous studies shown that no significant difference in local recurrence has been observed in “nearly-complete” versus “complete” patients, whereas “incomplete” patients were associated with a higher risk of local recurrence [27]. Therefore, nearly-complete and complete mesorectal excisions were acceptable and incomplete mesorectal excision was unacceptable. A meta-analysis reported that the rate of acceptable and unacceptable TME was 92.6% (636/687), 6.0% (41/687) respectively [28], which was similar to our result (95.2%, 4.8%). These results shown that in our study the quality of the R-TME specimen was safe.

As a factor reflecting the quality of surgery, a circumferential surgical margin (CRM) with a distance of  $> 1$ mm is the most acceptable standard. The current study had 2 (9.5%) positive CRMs ( $< 1$  mm), which was higher than that of meta-analyses (2.9% to 6.6%) [21, 29-31]. All the two patients were with tumors of low location and N2 stage, one of which was T4 stage and the other was resected by abdominoperineal procedure. And all the two cases were in initial ten cases. These characteristics were the risk factors for

positive CRM [32, 33], which may contribute to the high CRM rate. With the aid of the 3D view, the robotic system provided the possibility of visualizing the membrane anatomy and dissected along the space between the two layers of the pelvic fascia around the rectum, which was particularly beneficial to achieve curative resection.

Functional outcomes were assessed in three aspects: sphincter, bladder and sexual functions. Because of inadequate data about female patients, the analysis only included male patients. The scores worsened after operation and progressively improved at 3 or 6 months post-operation, with no significantly difference between the two groups. As shown by Luca et al. [34], although the features of surgical robot were helpful in identification and preservation of pelvic autonomic nerves, no evidence shown a superiority in performing nerve-sparing rectal cancer surgery. The scores at 6 months post-operation did not reach the level of pre-operation and need to take longer time to observe the change in the future study.

The limitations of this study were as follows. First, the study was with a small sample size and a study with large sample size is essential to gain a better understanding of robotic surgery. Second, we included the robotic cases in the learning phase, which may bias our results. Third, the Micro Hand S robot as the first generation, is still in the clinical stage. Therefore, we did not include complicated cases in this study, such as ultra-low rectal cancers. This selection bias inevitably impaired the objectivity of the results. By performing complicated cases in the future, the advantages of robotic surgery will be fully demonstrated. In addition, the long-term oncologic outcomes were not included in this study and should be evaluated in future studies.

## Conclusion

The present study indicates that TME assisted by the Micro Hand S robot is safe and feasible for rectal cancer and the Micro Hand S robot may be an alternative for rectal cancer. A randomized controlled trial needs to be conducted in the future to further confirm our results. The long-term oncological parameters of R-TME will also be assessed in future studies.

## Abbreviations

APR: Abdominoperineal resection; ASA: American society anesthesia; AV: Anal verge; BMI: Body mass index; CCI: Comprehensive complication index; CRM: Circumferential resection margin; CRT: Chemoradiation therapy; DRM: Distal resection margin; IIEF: International index of erectile function; IPSS: International prostate symptom score; IMA: Inferior mesenteric artery; IMV: Inferior mesenteric vein; IQR: Interquartile range; LAR: Low anterior resection; LN: Lymph node; L-TME: Laparoscopic TME; POD: Postoperative day; PRM: Proximal resection margin; R-TME: Robot-assisted TME; TME: Total mesorectal excision; VAS: Visual analogue score

## Declarations

**Ethics approval and consent to participate:** The study was approved by the Ethical Committee of the Third Xiangya Hospital.

**Consent for publication:** Written informed consent for publication of clinical images was obtained from the patient. A copy of the consent form is available for review by the Editor of this journal.

**Availability of data and materials:** The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Competing interests:** The authors declare that they have no competing interests

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**Authors' contributions:** Zhu shaihong, Yi bo and Wang guohui performed the experiment conception and design. Zhu shaihong, Yi bo, Wang yanlei and Li zheng performed the research. Wang yanlei, Li zheng and Ling hao retrieved the data and performed the data collection. Wang yanlei and Wang guohui analyzed the data and did the paper writing. All authors read and approved the final manuscript.

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## Tables

**Table 1** Patient characteristics

	L-TME (n=30)	R-TME (n=21)	<i>P</i>
Age, years <sup>a</sup>	60.2±10.5	57.9±10.8	0.442
Sex, n (%)			0.788
Male	16 (53.3)	12 (57.1)	
Female	14 (47.7)	9 (42.9)	
BMI, kg/m <sup>2</sup> <sup>a</sup>	22.7±4.4	22.2±3.1	0.670
ASA score, n (%)			0.138
I	12 (40.0)	10 (47.7)	
II	10 (33.3)	10 (47.7)	
III	8 (26.7)	1 (4.6)	
Charlson score, n (%)			0.579
0	10 (33.3)	7 (33.3)	
1	8 (26.7)	9 (42.9)	
2	10 (33.3)	4 (19.0)	
≥3	2 (6.7)	1 (4.8)	
Distance from AV, cm <sup>a</sup>	7.1±2.0	8.2±2.4	0.082
Tumor size, cm <sup>a</sup>	3.4±1.4	3.3±1.2	0.791
cT stage, n (%) <sup>b</sup>			0.687
T1	5 (16.7)	3 (14.3)	
T2	7 (23.3)	6 (28.6)	
T3	14 (46.7)	7 (33.3)	
T4	4 (13.3)	5 (23.8)	
cN stage, n (%) <sup>b</sup>			0.764
N0	20 (66.6)	12 (57.2)	
N1	5 (16.7)	4 (19.0)	
N2	5 (16.7)	5 (23.8)	
Neoadjuvant CRT, n (%)	1 (3.3)	2 (9.6)	0.073

BMI, body mass index; ASA, American Society Anesthesia; AV, anal verge; cT stage, clinical tumor stage; cN stage, clinical nodule stage; CRT, chemoradiation therapy

<sup>a</sup> Values are the mean (standard deviation)

<sup>b</sup> based on pre-operative MRI

**Table 2** Intra- and postoperative outcomes

	L-TME (n=30)	R-TME (n=21)	<i>P</i>
Operative procedure, n (%)			0.876
LAR	27 (90.0)	20 (95.2)	
APR	3 (10.0)	1 (4.8)	
Blood loss, ml <sup>a</sup>	130.0±63.6	95.2±26.4	0.022
Operative time, min <sup>a, b</sup>	265.0±47.7	288.3±44.0	0.082
Docking time <sup>b</sup>	--	27.5±10.2	--
Conversion, n (%)	0 (0.0)	1 (4.8)	0.412
Blood transfusion, n (%)	1 (3.3)	0 (0.0)	1.000
Protective ileostomy, n (%)	18 (60.0)	8 (38.1)	0.124
Time to first flatus, days <sup>a</sup>	2.9±1.2	2.1±0.9	0.017
Time to first liquid intake, days <sup>a</sup>	3.7±1.5	2.8±1.0	0.027
Length of hospital stay, days <sup>a</sup>	11.3±4.8	9.9±3.7	0.239
Pain score (VAS), POD1 <sup>c</sup>	4.7±1.4	4.4±1.6	0.414
Pain score (VAS), POD3 <sup>c</sup>	3.7±0.9	3.5±1.2	0.526
30-d mortality, n (%)	0 (0.0)	0 (0.0)	1.000

LAR, low anterior resection; APR, abdominoperineal resection; VAS, visual analogue score; POD, postoperative day.

<sup>a</sup> Values are the mean (standard deviation)

<sup>b</sup> operation time is from skin incision to skin closure

<sup>c</sup> pain score is based on visual analogue score

**Table 3** Postoperative complications

	L-TME (n=30)	R-TME (n=21)	<i>P</i>
Postoperative complication, n (%)	11 (36.7)	9 (42.8)	0.656
Wound complication	3 (10.0)	2 (9.5)	1.000
Pulmonary complication	2 (6.7)	1 (4.8)	1.000
Urinary retention	2 (6.7)	1 (4.8)	1.000
Ileus	1 (3.3)	2 (9.5)	0.749
Fluid collection	2 (6.7)	1 (4.8)	1.000
Deep vein thrombosis	0 (0.0)	1 (4.8)	0.412
Intraabdominal abscess	1 (3.3)	0 (0.0)	1.000
Intraluminal bleeding	0 (0.0)	1 (4.8)	0.412
Clavien-Dindo classification, n (%)			0.822
I	7 (23.3)	4 (19.0)	
II	3 (10.0)	4 (19.0)	
III	1 (3.3)	1 (4.8)	
IV or V	0 (0.0)	0 (0.0)	
Severe grade (III-V)	1 (3.3)	1 (4.8)	1.000
CCI <sup>a</sup>	19.5±9.9	19.2±6.2	0.740
30-d mortality, n (%)	0 (0.0)	0 (0.0)	1.000

CCI, comprehensive complication index

<sup>a</sup> Values are the mean (standard deviation)

**Table 4** Pathologic outcomes

	L-TME (n=30)	R-TME (n=21)	<i>P</i>
Retrieved LN <sup>a</sup>	16.5±6.0	15.7±5.3	0.646
PRM, cm <sup>a</sup>	18.4±5.2	16.2±4.0	0.113
DRM, cm <sup>a</sup>	2.3±1.0	2.0±0.7	0.408
DRM involvement, n (%)	0 (0.0)	0 (0.0)	1.000
CRM involvement, n (%)	1 (3.3)	2 (9.5)	0.749
Histological differentiation, n (%)			0.669
Well	4 (13.3)	5 (23.8)	
Moderate	16 (53.3)	10 (47.6)	
Poorly	7 (23.4)	3 (14.3)	
Other	3 (10.0)	3 (14.3)	
TME quality, n (%)			1.000
Complete	26 (86.6)	19 (90.4)	
Nearly-complete	2 (6.7)	1 (4.8)	
Incomplete	2 (6.7)	1 (4.8)	

LN, lymph node; PRM, proximal resection margin; DRM, distal resection margin; CRM, circumferential resection margin

<sup>a</sup> Values are the mean (standard deviation)

**Table 5** Functional outcomes in male patients

	L-TME (n=16)	R-TME (n=12)	<i>P</i>
Age, years <sup>a</sup>	62.4±8.8	58.8±9.8	0.305
Distance from AV, cm <sup>a</sup>	6.7±2.0	7.3±1.7	0.371
CRT, n (%)	1 (6.25)	0 (0)	1.000
Wexner <sup>a</sup>			
Preoperative	4.1±3.5	5.1±3.8	0.492
3 months	10.3±3.8	9.5±4.1	0.622
<i>P</i> (vs. baseline)	< 0.001	0.012	
6 months	6.8±4.4	6.7±3.6	0.958
<i>P</i> (vs. baseline)	0.071	0.300	
IPSS <sup>a</sup>			
Preoperative	4.5±3.1	4.3±2.5	0.821
3 months	8.8±5.0	7.9±4.0	0.617
<i>P</i> (vs. baseline)	0.006	0.014	
6 months	7.1±3.8	6.8±3.0	0.827
<i>P</i> (vs. baseline)	0.039	0.032	
IIEF-5 <sup>a</sup>			
Preoperative	16.8±4.0	17.0±4.8	0.911
3 months	11.2±5.2	12.3±4.7	0.582
<i>P</i> (vs. baseline)	0.002	0.023	
6 months	13.4±5.0	14.3±3.9	0.645
<i>P</i> (vs. baseline)	0.044	0.136	

AV, anal verge; CRT, chemoradiation therapy

<sup>a</sup> Values are the mean (standard deviation)

## Figures



**Figure 1**

The “Micro Hand S” surgical robotic system: surgeon console (right), 3D imaging system (middle) and slave surgical cart (left)

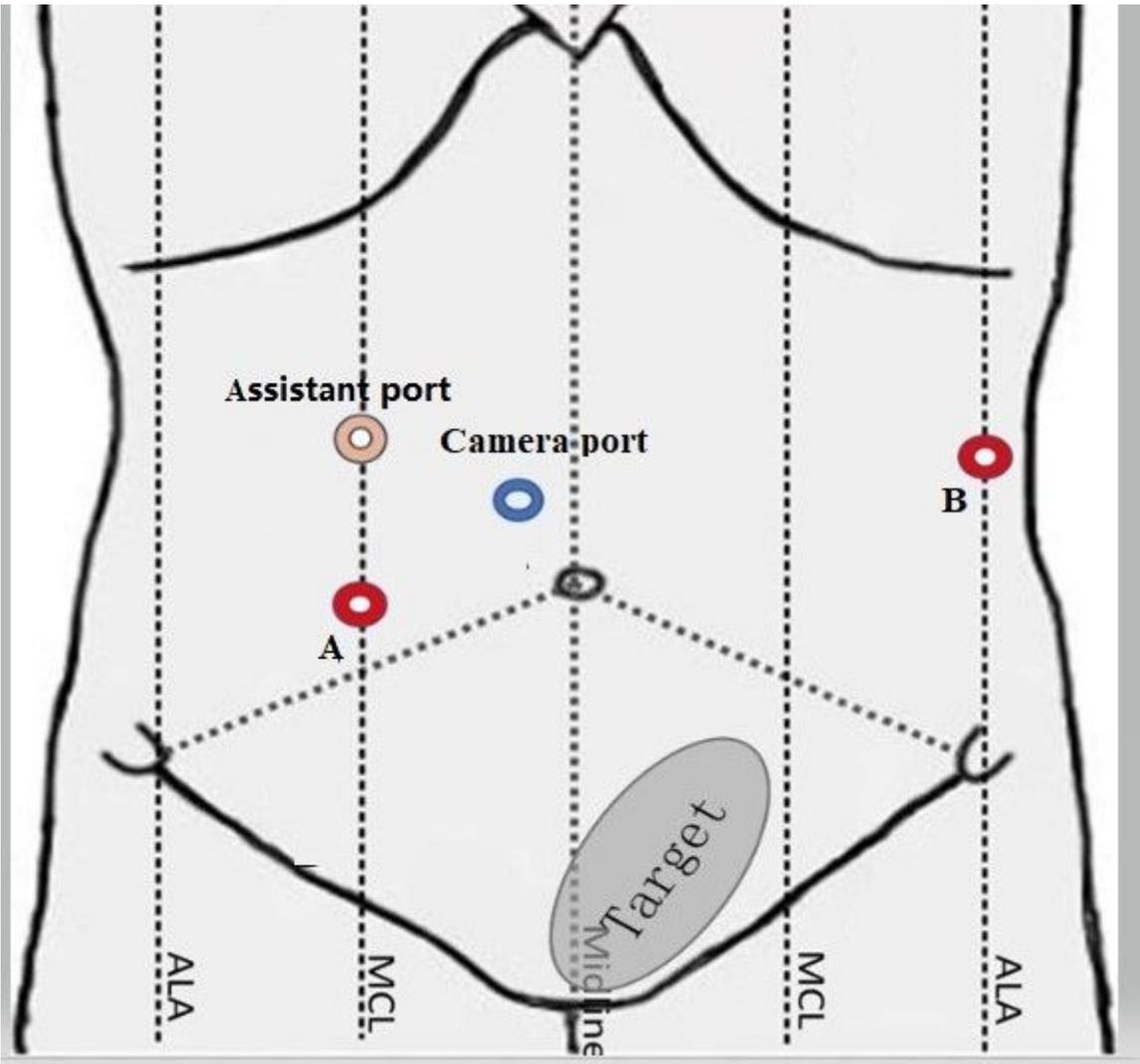
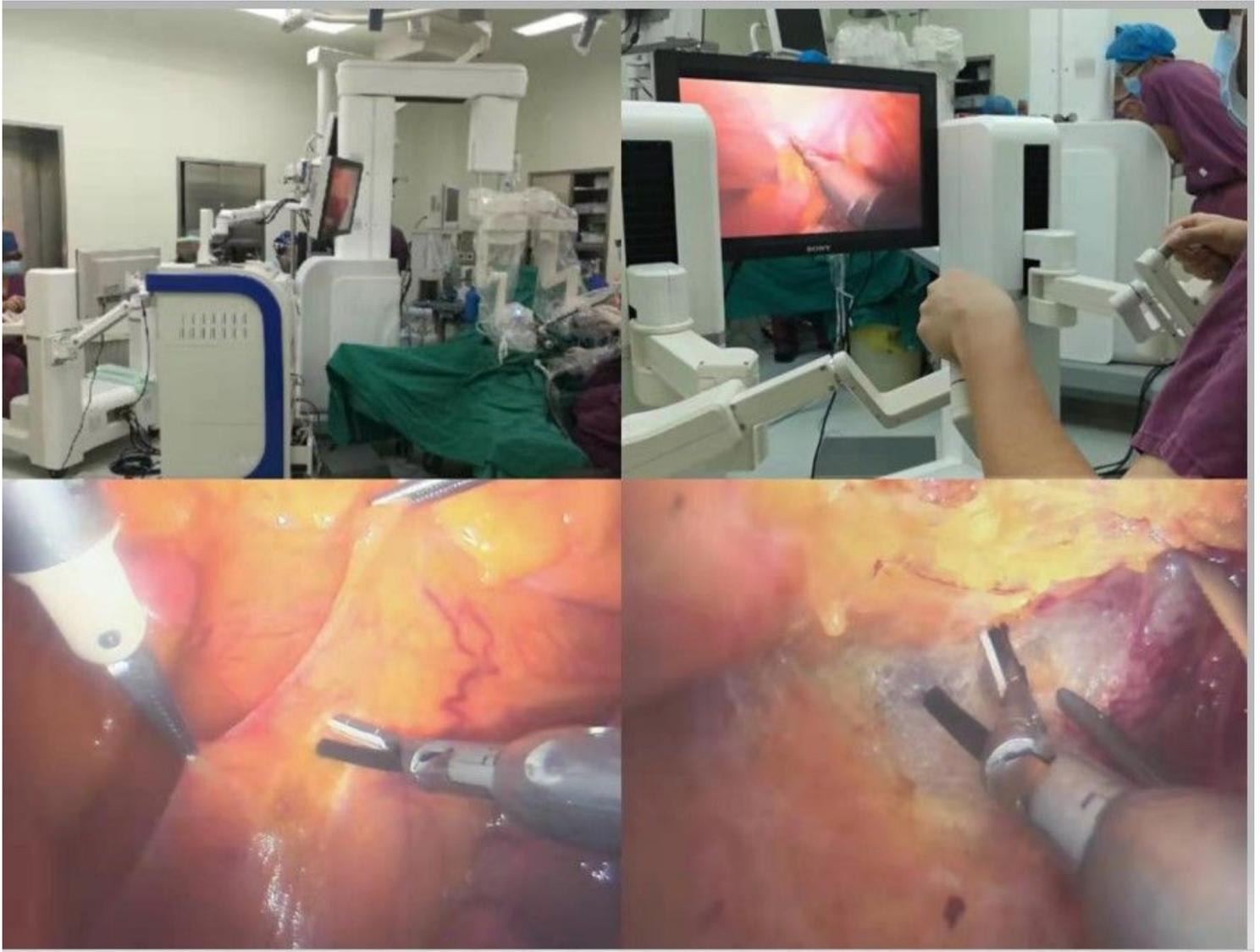


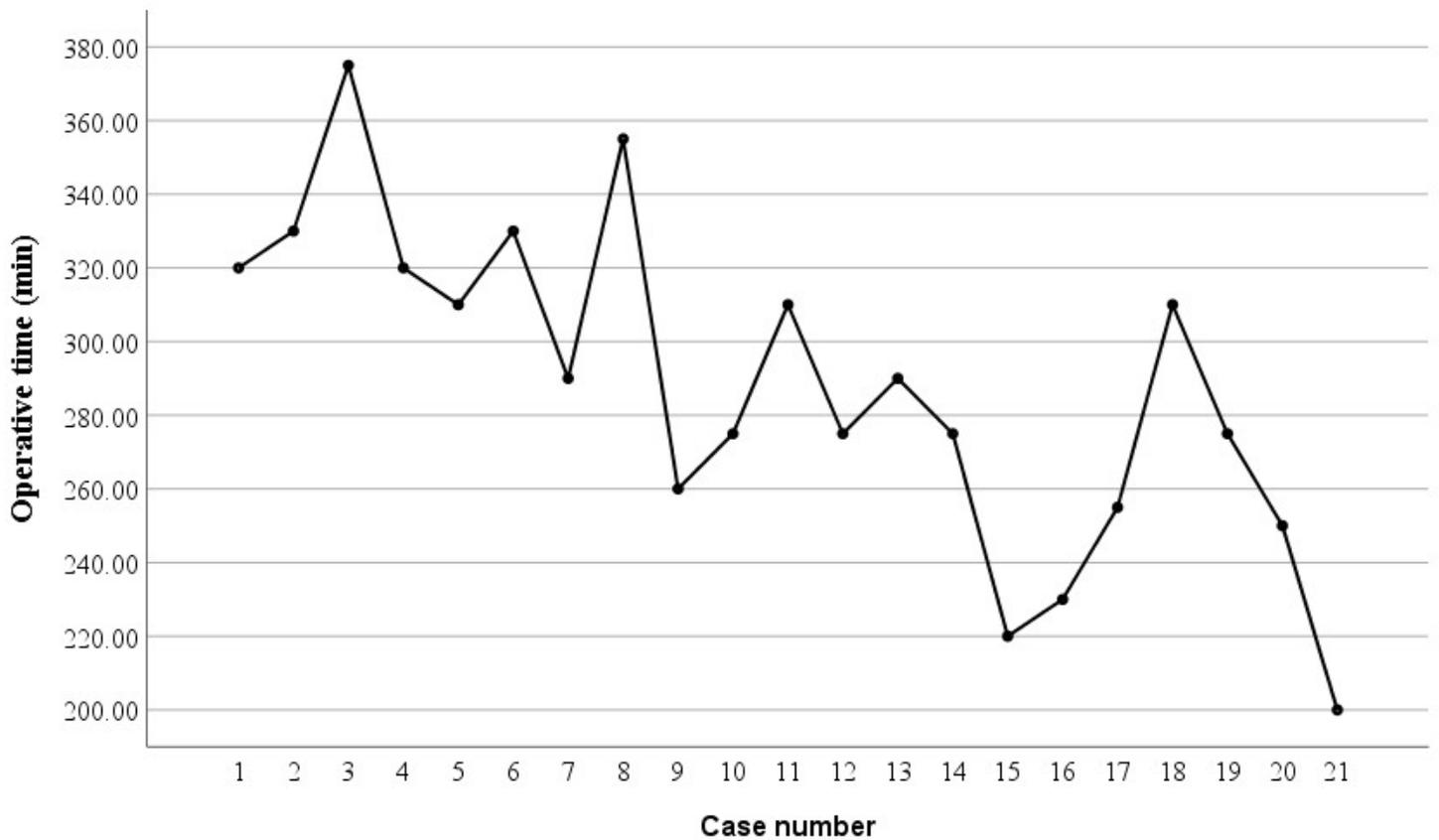
Figure 2

The arrangement of the surgical ports



**Figure 3**

Pictures of the robotic surgery



**Figure 4**

Learning curve for robotic surgery

## Supplementary Files

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