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The characteristics of the optimal beneficiary population for robotic-assisted radical resection of colorectal cancer

LI Hang, GU Haitao, LI Dongxue, XIAO Minfeng*
**Department of Operating Room, Second Affiliated Hospital of Chongqing Medical University, Chongqing 400010, China*
Corresponding author: LI Dongxue, E-mail: 300925@hospital.cqmu.edu.cn

Abstract: Objective To compare the impact of robotic-assisted versus laparoscopic-assisted radical resection for colorectal cancer on perioperative outcomes using propensity score matching (PSM), and to explore the optimal patient population for robotic surgery during its initial and intermediate stages of implementation. **Methods** A retrospective analysis was conducted on patients who underwent radical resection for colorectal cancer at the Second Affiliated Hospital of Chongqing Medical University from January 2022 to December 2023. PSM was performed based on patient's sex, age, body mass index (BMI), and surgical site. The primary outcomes were short-term postoperative results (reoperation rate, time to first flatus, time to first liquid intake, postoperative hospital stay, and total hospital stay) in the matched cohort. Secondary outcomes included intraoperative conditions (operation duration, estimated blood loss, intraoperative transfusion rate, conversion to open surgery, and number of lymph nodes harvested) and postoperative infectious complication rates. **Results** A total of 1,031 patients were included. After 1∶1 PSM between the robotic group (*n*=147) and the laparoscopic group (*n*=884), 142 matched pairs were retained. In the matched cohort, the laparoscopic group had a shorter operation time than the robotic group [179.48 (69.88) min *vs* 237.98 (82.27) min, *U*=6.849, *P*<0.01]. Significant differences were observed between the robotic and laparoscopic groups in estimated blood loss [50 (30) *vs* 50 (20) ,U=2.746, *P* < 0.01], time to first liquid intake [(3.86±1.87) d *vs* (4.27±1.70) d, *t*=2.194, *P*=0.028], time to first flatus [2 (1) d *vs* 3 (1) d, *U*=2.022, *P*=0.043], postoperative hospital stay [9.5 (2) d *vs* 10.0 (4) d, *U*=2.790, *P*=0.005], total hospital stay [14 (4) d *vs* 15 (6) d, *U*=2.574, *P*=0.010], and infectious complication rates (11.3% *vs* 23.2%, *P*=0.008). No significant differences were found in intraoperative transfusion rates, conversion to open surgery, number of lymph nodes harvested, or reoperation rates (*P*>0.05). Subgroup analysis indicated that patients aged <65 years, female, with a BMI of 18.5 to 23.9 kg/m², and those undergoing radical rectal resection were the optimal beneficiaries of robotic surgery. **Conclusion** Robotic surgery demonstrates advantages over laparoscopic surgery in postoperative recovery and infectious complication rates. Surgeons in the early and intermediate stages of robotic surgery adoption may prioritize patients aged <65 years, female, and with a BMI of 18.5 to 23.9 kg/m² for robotic-assisted procedures.
Keywords: Colorectal cancer; Radical resection; Robotic-assisted; Laparoscopic-assisted; Propensity score matching

Colorectal cancer is a disease with high genetic variability, characterized by high incidence and mortality rates [1]. The global number of new colorectal cancer cases is predicted to 2 million to 5 million by 2035[2]. In China, there were 590,000 new cases and 300,000 deaths in 2022 [3]. Currently, among various treatment modalities for colorectal cancer, surgical resection has become the preferred medical option for radical cure [4]. As of 2018, minimally invasive surgery represented by laparoscopic surgery accounted for 43% of radical colorectal cancer surgeries [5]. Alongside the thriving development of laparoscopic surgery, the proportion of robotic surgery has also increased annually, reaching 24.9% in 2020 [6]. Robotic surgery for colorectal cancer has become increasingly sophisticated, with some studies suggesting that compared to traditional open surgery and laparoscopic surgery, robotic surgery is more suitable for performing radical colorectal cancer resection [7].

In previous studies on robotic colorectal cancer surgery, the surgical sites included in the case data were diverse. However, different surgical sites may affect the difficulty of the procedure. For example, the right colon is adjacent to the pancreas with complex vascular structures, making it prone to pancreatic injury and damage to tributaries of the superior mesenteric vein during surgery [8]. The difficulty of surgery in this area is higher than that in other sites. Such intergroup heterogeneity caused by surgical sites may compromise the accuracy of study results. Existing literature reports [7] have not emphasized the inaccuracies in research outcomes due to variations in surgical sites. Therefore, this study used propensity score matching to balance baseline data and surgical sites between the two patient groups, compared the perioperative outcomes and incidence of nosocomial infections between robotic and laparoscopic-assisted radical colorectal cancer surgeries, and conducted subgroup analyses for different populations to explore the characteristics of the optimal population benefiting from robotic surgery during its early and intermediate stages of implementation.

1 Data and methods

1.1 Study participants

Retrospective collection of case information was conducted in patients who underwent radical resection of colorectal cancer at the Second Affiliated Hospital of Chongqing Medical University from January 2022 to December 2023. Data were sourced from the electronic medical record system and the Xinglin Infection Management System. Data were independently double-entered using EpiData 3.1, with a third practitioner randomly checking for consistency between the two entries to ensure accuracy. Disputed or missing data were re-verified, and participants with incomplete data were excluded. A total of 1,031 patients were finally included, divided into a laparoscopic group (n=884) and a robotic group (n=147) based on surgical approach.

Inclusion criteria: (1) pathologically diagnosed primary colorectal cancer; (2) laparoscopic or robotic surgery.

Exclusion criteria: (1) incomplete medical records; (2) immediate transfer to another hospital after surgery; (3) preoperative infection.

Surgical procedures for both groups followed the Chinese Expert Consensus on Robotic Colorectal Cancer Surgery (2020 Edition) [9] and the Operative Guidelines for Laparoscopic Radical Resection of Colorectal Cancer (2008 Edition) [10]. This study was approved by the Ethics Committee of the Second Affiliated Hospital of Chongqing Medical University [2024 Kelun Review No. (56)].

1.2 Included indicators

General patient's data included gender, age, body mass index (BMI), and surgical site. Primary outcomes included short-term postoperative outcomes in the matched cohort (reoperation rate, time to first flatus, time to first liquid diet, postoperative hospital stay, total hospital stay). Secondary outcomes included intraoperative parameters (operative duration, estimated blood loss, intraoperative blood transfusion rate, conversion to open surgery, number of lymph nodes dissected) and incidence of infectious complications.

BMI classification referred to the Guidelines for the Prevention and Control of Overweight and Obesity in Chinese Adults (Excerpt) [11]: underweight (BMI < 18.5 kg/m²), normal weight (18.5–23.9 kg/m²), overweight (24.0–27.9 kg/m²), and obese (BMI ≥ 28 kg/m²). Operative duration was defined as the time from skin incision and pneumoperitoneum establishment to closure of the last port (minutes), including robot docking and undocking time. Estimated blood loss was calculated using the gravimetric method [12]. Intraoperative blood transfusion rate was defined as the number of patients receiving intraoperative blood transfusion divided by the total number of patients. Postoperative hospital stay was defined as the number of days from the first postoperative day to discharge, with periods less than 24 hours counted as 0.5 days. Total hospital stay was defined as the number of days from admission to discharge, with periods less than 24 hours counted as 0.5 days. Hospital infection cases were diagnosed according to the Diagnostic Criteria for Hospital Infections issued by the National Health Commission [13].

1.3 Statistical methods

Statistical analysis was performed using R statistical software version 4.2.3 and SPSS version 26.0. All figures were adjusted using Adobe Illustrator 2022. Participants were divided into robotic and laparoscopic groups. Propensity score matching (1:1) was performed using the "MatchIt" package in R, with a random seed set to 1234 and nearest neighbor matching. Balance was assessed using density plots and standardized mean difference (SMD), where SMD < 0.1 indicated good balance (negligible intergroup differences). For continuous variables, t-tests or Mann-Whitney U tests were used; for categorical variables, chi-square tests or Fisher's exact tests were used. In the matched cohort, McNemar tests or McNemar-Bowker tests were used for categorical variables, and Wilcoxon signed-rank tests were used for continuous variables. To explore the optimal beneficiary characteristics of robotic surgery in the early and mid-stages, subgroup analysis was performed on time to first flatus, postoperative hospital stay, and incidence of infectious complications using the "jstable" package. Forest plots for subgroup analysis were generated using the "forestploter" package. Normally distributed continuous variables are expressed as $\bar{x} \pm s$, non-normally distributed variables as [M (IQR)], and categorical variables as frequencies. P < 0.05 was considered statistically significant.

2 Results

2.1 General characteristics of the study population

A total of 1,031 patients were included, with 884 in the laparoscopic group and 147 in the robotic group. The distribution of baseline characteristics and matching results are shown in **Table 1**. Before matching, there was a statistically significant difference in surgical site between the two groups (SMD = 0.511, P < 0.01). After matching, the maximum SMD of all included covariates was 0.053, indicating adequate balance in the matched cohort with negligible intergroup differences. Density distribution plots of the dataset [**Figure 1**] showed partial overlap between the two groups before matching, with increased overlap and only minor non-overlapping regions after matching, confirming good balance of covariates. From the general data of the unmatched cohort, laparoscopic surgery was more frequently performed in older patients, males, and those undergoing radical resection of rectal cancer.

2.2 Comparison of perioperative outcomes in the matched cohort

Regarding intraoperative parameters in the matched cohort, the median operative duration in the laparoscopic group was significantly shorter than that in the robotic group (179.58 min *vs* 237.98 min, P < 0.01). The estimated blood loss in the robotic group was less than that in the laparoscopic group (45.21 mL *vs* 70.85 mL, P = 0.010). No statistically significant differences were observed between the robotic and laparoscopic groups in intraoperative blood transfusion rate (0.7% *vs* 2.1%, P = 0.625), conversion to open surgery rate (1.4% *vs* 2.8%, P = 0.625), or number of lymph nodes dissected (12 *vs* 13, P = 0.173). **[Table 2]**

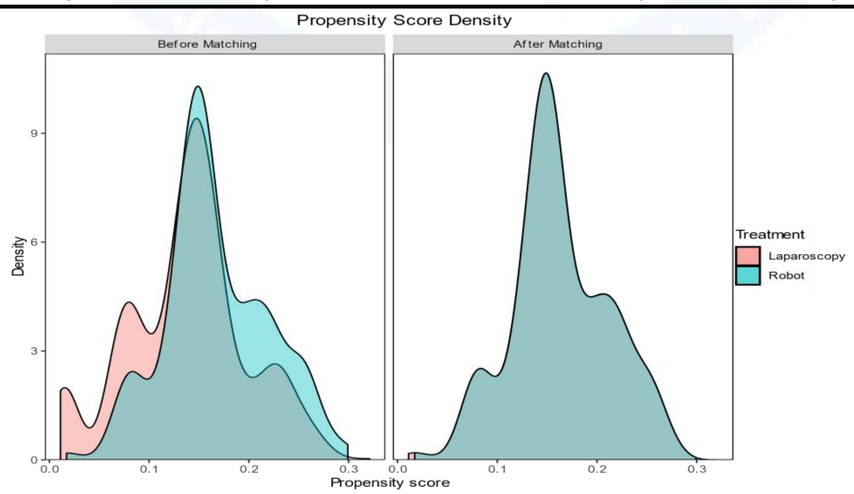
For short-term postoperative outcomes in the matched cohort, the robotic group showed significantly earlier time to first liquid diet and first flatus, shorter postoperative hospital stay and total hospital stay, and a lower incidence of infectious complications (P <0.05). No statistically significant difference was observed in reoperation rate between the two groups (P >0.05). **[Table 3]**

2.3 Subgroup analysis of postoperative recovery indicators in the matched cohort

To explore the optimal target population for robotic surgery in the early and mid-stages, subgroup analysis was performed. When using postoperative infectious complication rate as the outcome indicator **[Figure 2A]**, the optimal target population were patients aged <65 years, female, with BMI 18.5–23.9 kg/m², and undergoing rectal surgery. When using postoperative hospital stay as the outcome indicator **[Figure 2B]**, the optimal target population were patients aged <65 years, male, with BMI 18.5–23.9 kg/m², and undergoing rectal surgery. When using time to first flatus as the outcome indicator **[Figure 2C]**, the optimal target population were patients aged <65 years, female, and with BMI 18.5–23.9 kg/m².

Tab.1 Comparison of general information of the two groups of patients before and after PSM

Variable	Before matching		$U/\chi^2/t$ value	P value	After matching		$U/\chi^2/t$ value	P value
	Laparoscopic group（n=884）	Robotic group（n=147）			Laparoscopic group（n=142）	Robotic group（n=142）		
Age [years,*M*(*IQR*)]	66(17)	64(14)	0.133	0.192	66(14.25)	64.5(15)	0.053	0.469
Gender(case)								
Male	500	88	0.067	0.454	87	84	0.043	0.784
Female	384	59			55	58		
BMI[kg/m²,*M*(*IQR*)]	23.05(4.37)	23.05(4.10)	0.014	0.959	23.23±3.44	23.23±3.29	<0.001	0.965
Surgical site(*n*)								
Rectum	490	86			87	86		
Sigmoid colon	148	44	26.770	<0.001	39	39	0.038	0.998
Left colon	64	1			1	1		
Right colon	182	16			15	16		



Note: A, before matching; B, after matching.

Fig. 1 Density distribution of propensity scores before and after matching

Tab.2 Comparison of intraoperative conditions in matched cohorts (*n*=142)

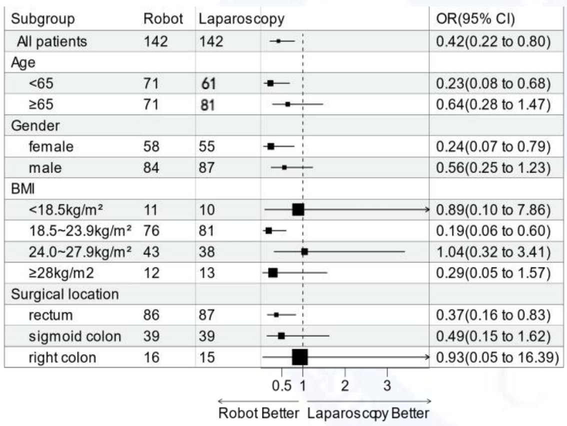
Items	Laparoscopic group	Robotic group	*U*/*t* value	*P* value
Operative duration (min)[a]	179.48(69.88)	237.98(82.27)	6.849	＜0.001
Estimated blood loss (mL)[a]	50（30）	50（20）	2.746	0.006
Intraoperative blood transfusion (n)	3	1		0.625[c]
Conversion to open surgery (n)	4	2		0.625[c]
Number of lymph nodes dissected (n)[a]	12(5)	13(4)	1.364	0.173

Note: [a] M (IQR); [b] Fisher's exact test was used for comparison.

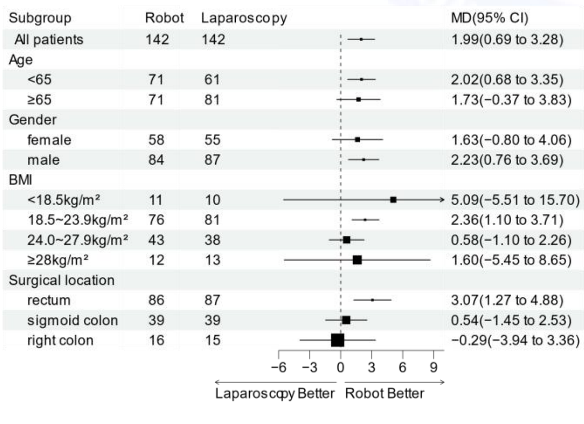
Tab.3 Comparison of postoperative short-term outcomes in matched cohorts (*n*=142)

Items	Laparoscopic group	Robotic group	*U*/*t* value	*P* value
Reoperation（*n*）	4	2		0.500[c]
Time to first flatus（d）[a]	3(1)	2(1)	2.022	0.043
Time to first liquid diet（d）[b]	4.27±1.70	3.86±1.87	2.194	0.028
Postoperative length of stay（d）[a]	10.0(4)	9.5(2)	2.790	0.005
Total length of stay（d）[a]	15(6)	14(4)	2.574	0.010
Infectious complications（*n*）	33	16		0.008[c]

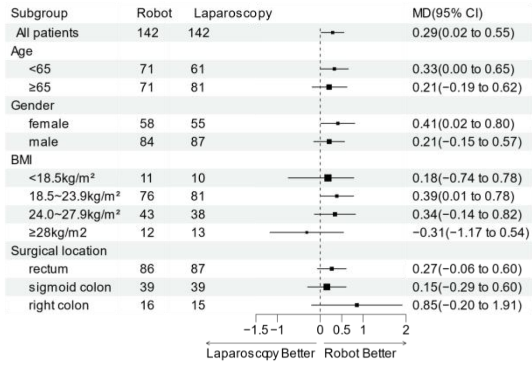
Note: [a] M (IQR); [b] $\bar{x}\pm s$; [c]Fisher's exact test was used for comparison.



A



B



C

Note: A, incidence rate of postoperative infectious complications; B, postoperative length of stay; C, time to first flatus.

Fig.2 Forest map for subgroup analysis

3 Discussion

With the popularization of robotic surgery, an increasing number of studies have focused on analyzing the safety and efficacy of robotic surgery [7]. Previous studies have suggested that the high-definition three-dimensional imaging system of robots helps surgeons visualize anatomical structures, and the 7-degree-of-freedom simulated wrist aids in precise clamping of small blood vessels, making robotic surgery more advantageous in reducing estimated blood loss, lowering the conversion-to-open rate, and shortening postoperative hospital stay [7, 16]. However, some studies, after balancing the clinicopathological characteristics of patients in both groups, found no statistically significant differences between the two groups in these aspects [17], which partially aligns with the results of this study. Sheng *et al.* [7] conducted a meta-analysis of perioperative outcomes of open, laparoscopic, and robotic surgery for colorectal cancer, suggesting that compared with laparoscopic surgery, robotic surgery had the least blood loss, complications, mortality, and intraoperative blood loss, as well as the shortest hospital stay. However, the cases included in this meta-analysis involved surgical sites such as the left colon, right colon, sigmoid colon, and rectum. Therefore, the authors believe that although the meta-analysis results are consistent with some findings of this study, the data analyzed in this study after propensity score matching for surgical sites are more accurate. Differences in surgical sites can lead to variations in preoperative preparation and surgical difficulty, making it impossible to accurately determine the advantages of robotic surgery in radical resection of colorectal cancer. For example, Farah *et al.* [18] used the ACS-NSQIP database in in a retrospective cohort study to perform the stratified and propensity score matching analysis on surgical sites of colorectal cancer, and the results again confirmed that robotic and laparoscopic surgery have different perioperative outcomes in radical resection of colorectal cancer at different sites.

In this study, there were no statistically significant differences between the two groups in intraoperative blood transfusion rate, conversion-to-open rate, number of lymph nodes dissected, and reoperation rate. This may be because this study matched the surgical sites of patients in both groups, adjusting the surgical difficulty coefficient to be consistent, thereby reducing the selective bias potentially caused by surgical difficulty. Additionally, a portion of the robotic group cases included in this study were from the learning and exploration phase of the surgeon's learning curve, which diminished the advantages of the robotic surgical system. The operative duration in the robotic group was longer than that in the laparoscopic group, consistent with previous research results [18]. The longer operative time required in the robotic group may be related to the learning curve; after the surgeon completes the exploration phase of the learning curve, the operative time may shorten rapidly. For example, after performing 41 robotic radical resections for rectal cancer, the operative time of robotic surgery becomes shorter than that of laparoscopic surgery [19]; in right hemicolectomy, surgeons only need 21 robotic procedures to achieve an operative duration similar to that of laparoscopic surgery [20].

Consistent with the conclusions of previous retrospective studies and meta-analyses [7, 21], this study also found that robotic surgery has less estimated blood loss, shorter time to first liquid diet, shorter time to first flatus, shorter postoperative hospital stay, and shorter total hospital stay. Additionally, this study revealed that robotic surgery is more advantageous in reducing infectious complications. The authors believe that compared with laparoscopic surgery, robotic surgery reduces intraoperative intestinal manipulation, minimizes intraoperative intestinal injury, and alleviates intestinal stress responses, thereby accelerating gastrointestinal functional recovery and enabling patients to achieve flatus in a shorter time. After flatus, adhering to the enhanced recovery after surgery (ERAS) concept, patients transition from parenteral nutrition to enteral nutrition, achieving a shorter time to first liquid diet. Enteral nutrition, which aligns with human physiological structure, is more conducive to postoperative recovery, thus contributing to a shorter postoperative hospital stay. The shortened postoperative hospital stay directly reduces the total hospital stay.

This study performed subgroup analysis based on population characteristics to explore the optimal beneficiary population for robotic surgery by comparing the incidence of infectious complications, time to first flatus, and postoperative hospital stay between the two groups. The results showed that patients aged <65 years, female patients, those with low BMI, and those undergoing radical resection of rectal cancer are characteristics of the optimal beneficiary population for robotic surgery, with lower postoperative infectious complication rates and shorter postoperative recovery times. Since the robotic group cases included in this study were from the early to mid-stages of the surgeon's robotic surgery practice, the authors recommend that during the early to mid-stages of implementing robotic surgery, the optimal beneficiary population for robotic surgery should be characterized by age <65 years, female, BMI of 18.5–23.9 kg/m², and undergoing radical resection of rectal cancer.

In conclusion, robotic surgery is superior to laparoscopic surgery in terms of estimated blood loss, time to first liquid diet, time to first flatus, postoperative hospital stay, total hospital stay, and incidence of infectious complications. During the early to mid-stages of implementing robotic surgery, to achieve the best postoperative outcomes, surgeons should select patients with the following characteristics as the optimal beneficiaries: age <65 years, female sex, BMI of 18.5–23.9 kg/m², and undergoing radical resection of rectal cancer. This study also has limitations. First, as a single-center study with a small sample size, it was unable to perform subgroup analysis for the left colon. Second, as a retrospective study, it could not analyze long-term prognosis and survival outcomes of patients, nor avoid potential selection bias in surgeons' choice of surgical approach.

Conflict of interest None

Reference

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·论　著·

机器人辅助下行结直肠癌根治术最佳获益人群特征

李航[1]，　顾海涛[2]，　李冬雪[1]，　肖敏凤[3]

1. 重庆医科大学附属第二医院手术室，重庆 400010；2. 重庆医科大学附属第二医院胃肠外科，重庆 400010；3. 西安医学院护理学院，陕西 西安 710021

摘要：目的　基于倾向性评分匹配(PSM)，比较机器人与腹腔镜辅助下行结直肠癌根治术对患者围手术期各项结局指标的影响，探索机器人手术开展前、中期的最佳手术获益人群特点。**方法**　回顾性分析2022年1月至2023年12月重庆医科大学附属第二医院行结直肠癌根治术的患者资料，基于患者性别、年龄、身体质量指数(BMI)及手术部位进行PSM，主要结局是匹配后队列的术后短期结局(二次手术率、首次排气时间、首次进食流食时间、术后住院时间、总住院时间)，次要结局是匹配后队列的术中情况(手术时间、估计失血量、术中输血率、中转开腹率、淋巴结清扫数目)和术后感染性并发症发生率。**结果**　本研究共纳入1 031例患者资料，将机器人组(n=147)与腹腔镜组(n=884)患者进行1∶1 PSM后，共保留142对研究对象。匹配后的队列中，腹腔镜组的手术时间短于机器人组[179.48(69.88)min *vs* 237.98(82.27)min，U=6.849，$P<0.01$]，机器人组与腹腔镜组在估计失血量[50(20) mL *vs* 50(30) mL，U=2.746，P=0.006]、首次进食流食时间[(3.86±1.87)d *vs* (4.27±1.70)d，t=2.194，P=0.028]、首次排气时间[2.0(1.0) d *vs* 3.0(1.0) d，U=2.022，P=0.043]、术后住院时间[9.5(2.0)d *vs* 10.0(4.0)d，U=2.790，P=0.005]、总住院时间[14.0(4.0)d *vs* 15.0(6.0)d，U=2.574，P=0.010]和感染性并发症发生率(11.3% *vs* 23.2%，P=0.008)方面差异有统计学意义。两组的术中输血发生率、中转开腹率、淋巴结清扫数目、二次手术发生率差异无统计学意义($P>0.05$)。亚组分析显示，年龄<65岁、女性、BMI为18.5~23.9 kg/m²、接受直肠癌根治术的患者是机器人手术的最佳获益人群。**结论**　机器人手术在术后恢复方面和感染性并发症发生率方面优于腹腔镜手术，建议术者在开展机器人手术的前、中期，对年龄<65岁、女性、BMI为18.5~23.9 kg/m²患者可优先考虑行机器人手术。

关键词：结直肠癌；根治术；机器人辅助；腹腔镜辅助；倾向性评分匹配

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The characteristics of the optimal beneficiary population for robotic-assisted radical resection of colorectal cancer

LI Hang[*]，GU Haitao，LI Dongxue，XIAO Minfeng

[*]*Department of Operating Room，Second Affiliated Hospital of Chongqing Medical University，Chongqing 400010，China*

Corresponding author：LI Dongxue，E-mail：300925@hospital.cqmu.edu.cn

Abstract：Objective　To compare the impact of robotic-assisted versus laparoscopic-assisted radical resection for colorectal cancer on perioperative outcomes using propensity score matching (PSM), and to explore the optimal patient population for robotic surgery during its initial and intermediate stages of implementation. **Methods**　A retrospective analysis was conducted on patients who underwent radical resection for colorectal cancer at the Second Affiliated Hospital of Chongqing Medical University from January 2022 to December 2023. PSM was performed based on patients' sex, age, body mass index (BMI), and surgical site. The primary outcomes were short-term postoperative results (reoperation rate, time to first flatus, time to first liquid intake, postoperative hospital stay, and total hospital stay) in the matched cohort. Secondary outcomes included intraoperative conditions (operation duration, estimated blood loss,

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通信作者：李冬雪，E-mail:300925@hospital.cqmu.edu.cn
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intraoperative transfusion rate, conversion to open surgery, and number of lymph nodes dissected) and postoperative infectious complication rates. **Results** A total of 1 031 patients were included. After 1∶1 PSM between the robotic group (n=147) and the laparoscopic group (n=884), 142 matched pairs were retained. In the matched cohort, the laparoscopic group had a shorter operation time than the robotic group [179.48 (69.88) min *vs* 237.98 (82.27) min, U=6.849, P<0.01]. Significant differences were observed between the robotic and laparoscopic groups in estimated blood loss [50(20) mL *vs* 50(30) mL, U=2.746, P=0.006], time to first liquid intake [(3.86±1.87) d *vs* (4.27±1.70) d, t=2.194, P=0.028], time to first flatus [2.0(1.0) d *vs* 3.0(1.0) d, U=2.022, P=0.043], postoperative hospital stay [9.5(2.0) d *vs* 10.0(4.0) d, U=2.790, P=0.005], total hospital stay [14.0(4.0) d *vs* 15.0(6.0) d, U=2.574, P=0.010], and infectious complication rates (11.3% *vs* 23.2%, P=0.008). No significant differences were found in intraoperative transfusion rates, conversion to open surgery, number of lymph nodes harvested, or reoperation rates (P>0.05). Subgroup analysis indicated that patients aged <65 years, female, with a BMI of 18.5 to 23.9 kg/m^2, and those undergoing radical rectal resection were the optimal beneficiaries of robotic surgery. **Conclusion** Robotic surgery demonstrates advantages over laparoscopic surgery in postoperative recovery and infectious complication rates. Surgeons in the early and intermediate stages of robotic surgery adoption may prioritize patients aged <65 years, female, and with a BMI of 18.5 to 23.9 kg/m^2 for robotic-assisted procedures.
Keywords: Colorectal cancer; Radical resection; Robotic-assisted; Laparoscopic-assisted; Propensity score matching

结直肠癌是一种高遗传变异性的疾病，具有高发病率和高死亡率的特点[1]，预计到2035年，全球结直肠癌新发病例可高达200万~500万例[2]。中国2022年新增病例为59万例，死亡病例为30万例[3]。目前，手术治疗已经成为根治结直肠癌的首选医疗方案[4]。截至2018年，以腹腔镜手术为代表的微创手术在结直肠癌根治术中的占比已达到43%[5]。同时，机器人手术的占比也在逐年增加，2020年机器人手术的占比已经达到24.9%[6]。机器人手术治疗结直肠癌越来越成熟，有研究认为，相较于传统开腹手术和腹腔镜手术，机器人手术更适合开展结直肠癌根治术[7]。

在既往结直肠癌机器人手术研究中，不同的手术部位可能会影响手术困难程度，如右半结肠邻近胰腺并且血管结构复杂，术中易引起胰腺损伤和肠系膜上静脉支流受损[8]，手术难度高于其他部位，这种由手术部位造成的组间异质性可能会影响研究结果的准确性。在现有文献报道中，并没有重视由于手术部位不同所造成的研究结果不准确性的问题[7]。因此，本研究通过倾向性评分匹配（propensity score matching，PSM）两组患者的基线资料和手术部位，比较机器人与腹腔镜辅助在结直肠癌根治术中的围手术期结局和医院感染发生情况，并针对不同人群进行亚组分析，探索机器人手术开展前、中期的最佳手术获益人群特点。

1　资料与方法

1.1　研究对象　回顾性收集2022年1月至2023年12月在重庆医科大学附属第二医院接受结直肠癌根治术的患者病例信息，数据来源于电子病历系统及杏林感染管理系统，使用EpiData 3.1版双人独立录入资料，由第三人随时抽查数据资料并对两份资料进行一致性校验以确保数据录入准确性，再次核实有争议及缺失的数据，并删除具有缺失资料的研究对象。最终纳入1 031例患者，根据手术方式的不同，分为腹腔镜组（n=884）和机器人组（n=147）。

纳入标准：(1) 经病理活检明确诊断的原发性结直肠癌；(2) 行腔镜手术或机器人手术。排除标准：(1) 病历资料不完整；(2) 术后立即转他院进行治疗；(3) 术前处于感染状态。两组患者的手术操作流程参照《机器人结直肠癌手术中国专家共识(2020版)》[9]和《腹腔镜结直肠癌根治手术操作指南(2008版)》[10]。本研究获得重庆医科大学附属第二医院伦理委员会批准[2024年科伦审第(56)号]。

1.2　纳入指标　患者的一般资料包括性别、年龄、身体质量指数(body mass index，BMI)、手术部位。主要结局指标是PSM后队列的术后短期结局(二次手术率、首次排气时间、首次进食流食时间、术后住院时间、总住院时间)，次要结局指标包括PSM后队列的术中情况(手术时间、估计失血量、术中输血率、中转开腹率、淋巴结清扫数目)和感染性并发症发生率。

BMI分级参考《中国成人超重和肥胖症预防与控制指南(节录)》[11]，以BMI < 18.5 kg/m^{2}为体重过低，18.5~23.9 kg/m^{2}为体重正常，24.0~27.9 kg/m^{2}为超重，≥28 kg/m^{2}为肥胖。手术时长：从切开皮肤开始建立气腹孔至最后一个气腹孔缝合结束的时间(min)，包括机器人对接和撤机时间。采用重量法[12]计算估计失血量。术中输血率=术中输血人数/总人数×100%。术后住院时间：结直肠癌根治术术后第1日至出院的

在院天数,不足24 h按0.5 d计算。总住院时间:患者办理入院至出院的在院天数,不足24 h按0.5 d计算。医院感染病例诊断符合卫健委颁发的《医院感染诊断标准》[13]。

1.3 统计学方法 使用R 4.2.3和SPSS 26.0软件进行统计分析,文中所有图片均使用Adobe Illustrator 2022进行调整。将纳入研究对象分为机器人组和腹腔镜组,使用R软件的"MatchIt"包进行1∶1 PSM[14],随机种子数设为1 234,采用匹配方法为最邻近匹配法。本研究采用密度分布图和标准均值差(standardized mean difference, *SMD*)进行平衡性检验[15],*SMD*<0.1表示均衡性较好,两组之间的差异较小,可以忽略不计。正态分布的连续变量采用$\bar{x}\pm s$描述,而非正态分布的连续变量表示为中位数(四分位距)[*M*(*IQR*)],分类变量以频数进行描述。连续变量的组间比较采用*t*检验或Mann-Whitney *U*检验,分类变量的组间比较采用χ^2检验或Fisher确切概率法;在匹配队列中的分类变量采用McNemar检验或McNemar-Bowker检验,对连续变量采用Wilcoxon符号秩检验。为了探索机器人手术开展前、中期的最佳获益人群特点,本研究使用"jstable"包对机器人组和腹腔镜组的首次排气时间、术后住院时间以及感染性并发症发生率三个方面进行亚组分析。使用"forestploter"包绘制森林图,实现亚组分析可视化。*P*<0.05为差异有统计学意义。

2 结 果

2.1 研究人群的一般资料 本研究共纳入1 031例患者,其中腹腔镜组884例,机器人组147例,两组患者的一般资料以及匹配结果见表1,匹配前的两组患者在手术部位方面差异有统计学意义(*SMD*=0.511, *P*<0.01),匹配后的两组患者所有纳入协变量的最大*SMD*=0.053,表明匹配队列中的数据集充分平衡,两组之间的差异可以忽略不计。从数据集的密度分布图(图1)可以看出,未匹配前两组之间有部分重叠区域,匹配后两组之间的重叠区域增加,仅有少部分未重叠区域,表明两组的协变量平衡良好。从非匹配队列中两组患者的一般资料可以看出,接受腹腔镜手术的患者以直肠癌根治术为主。

2.2 匹配队列的围手术期结局比较 在匹配队列的术中情况方面,腹腔镜组的中位手术时间明显短于机器人组,而机器人组的估计失血量少于腹腔镜组(*P*<0.05)。机器人组与腹腔镜组患者在术中输血率(0.7% *vs* 2.1%, *P*=0.625)、中转开腹率(1.4% *vs* 2.8%, *P*=0.625)和淋巴结清扫数目(12个 *vs* 13个, *P*=0.173)方面差异无统计学意义。见表2。

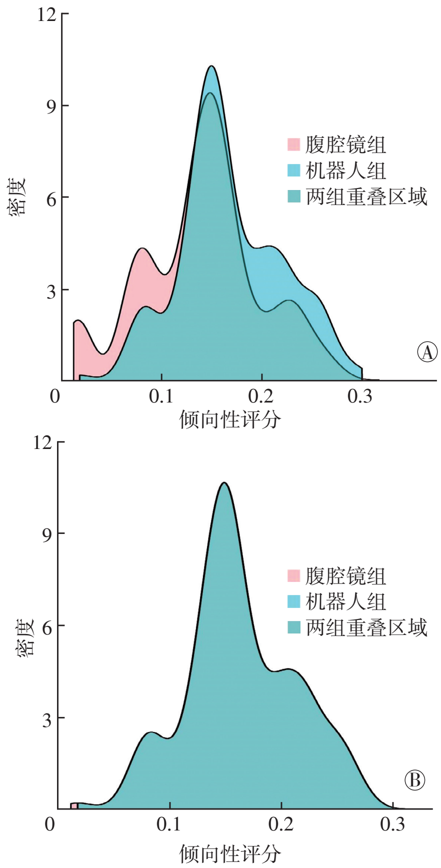
匹配队列的术后短期结局中,机器人组的首次进食流食时间和首次排气时间更早、术后住院时间和总住院时间更短、感染性并发症发生率更低,差异有统计学意义(*P*<0.05)。两组在二次手术发生率方面差异无统计学意义(*P*>0.05)。见表3。

2.3 匹配队列患者术后恢复指标的亚组分析 为探索机器人手术开展的前、中期的最佳手术获益人群,对患者进行亚组分析。以术后感染性并发症发生率为结局指标时,如图2A所示,患者的年龄<65岁、性别为女性、BMI为18.5~23.9 kg/m²、行直肠部位手术时,为最佳手术获益人群;以术后住院时间为结局指标时,如图2B,患者的年龄<65岁、性别为男性、BMI为18.5~23.9 kg/m²、行直肠部位手术时,为最佳手术获益人群;以首次排气时间为结局指标时,如图2C所示,患者的年龄<65岁、性别为女性、BMI为18.5~23.9 kg/m²时,为最佳手术获益人群。

表1 PSM前后两组患者一般资料比较

Tab.1 Comparison of general information between the two groups of patients before and after PSM

变量	匹配前		$U/\chi^2/t$值	*P*值	匹配后		$U/\chi^2/t$值	*P*值
	腹腔镜组(*n*=884)	机器人组(*n*=147)			腹腔镜组(*n*=142)	机器人组(*n*=142)		
年龄[岁, *M*(*IQR*)]	66.0(17.0)	64.0(14.0)	0.133	0.192	66.0(14.3)	64.5(15.0)	0.053	0.469
性别(例)								
男	500	88	0.561	0.454	87	84	0.132	0.716
女	384	59			55	58		
BMI[kg/m², *M*(*IQR*)]	23.05(4.37)	23.05(4.10)	0.014	0.959	23.23±3.44	23.23±3.29	<0.001	0.965
手术部位(例)								
直肠	490	86	26.770	<0.001	87	86	0.038	0.998
乙状结肠	148	44			39	39		
左半	64	1			1	1		
右半	182	16			15	16		



注：A 为匹配前；B 为匹配后。

图 1　PSM 前后倾向得分的密度分布图

Fig.1　Density distribution of propensity scores before and after PSM

表 2　匹配队列的术中情况比较　(n=142)

Tab.2　Comparison of intraoperative conditions in matched cohorts　(n=142)

项目	腹腔镜组	机器人组	U/t 值	P 值
手术时间(min)[a]	179.48(69.88)	237.98(82.27)	6.849	< 0.001
估计失血量(mL)[a]	50(30)	50(20)	2.746	0.006
术中输血(例)	3	1		0.625[b]
中转开腹(例)	4	2		0.625[b]
淋巴结清扫数目(个)[a]	12(5)	13(4)	1.364	0.173

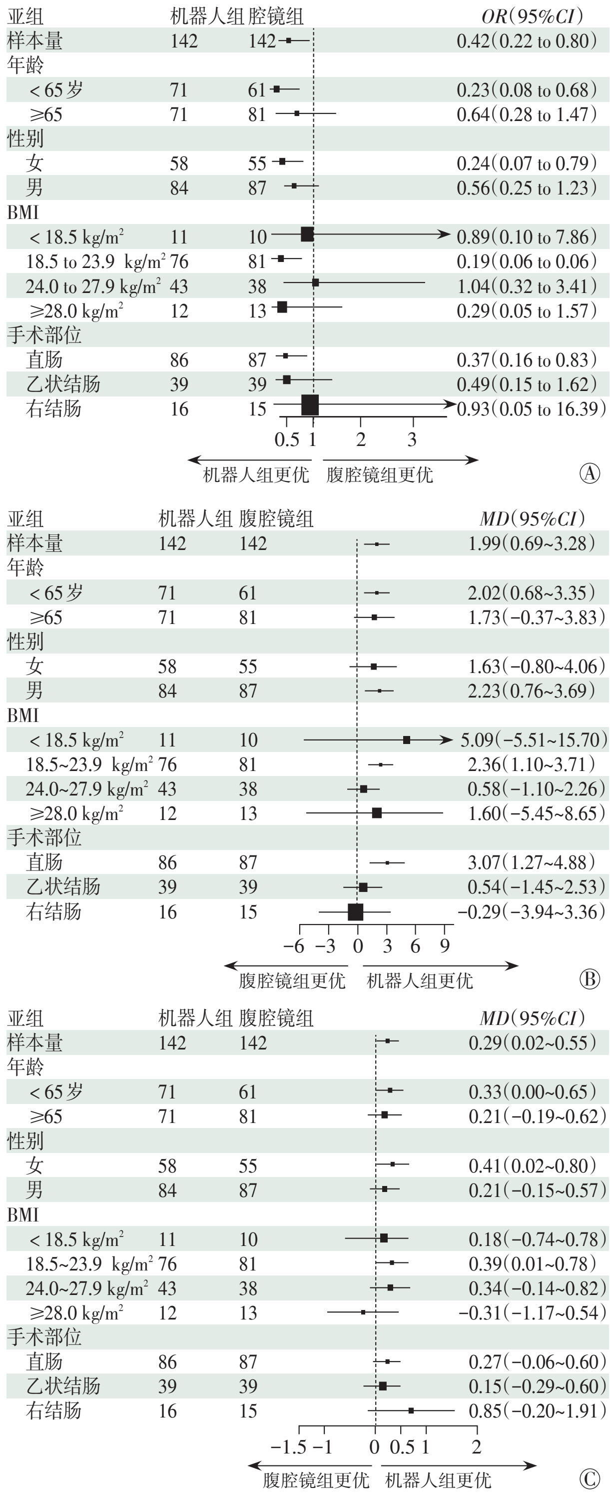
注：[a]为数据以 $M(IQR)$ 表示；[b]为采用 Fisher 确切概率法检验。

表 3　匹配队列的术后短期结局比较　(n=142)

Tab.3　Comparison of postoperative short-term outcomes in matched cohorts　(n=142)

项目	腹腔镜组	机器人组	U/t 值	P 值
二次手术(例)	4	2		0.500[c]
首次排气时间(d)[a]	3.0(1.0)	2.0(1.0)	2.022	0.043
首次进食流食时间(d)[b]	4.27±1.70	3.86±1.87	2.194	0.028
术后住院时间(d)[a]	10.0(4.0)	9.5(2.0)	2.790	0.005
总住院时间(d)[a]	15.0(6.0)	14.0(4.0)	2.574	0.010
感染性并发症[例(%)]	33(23.2)	16(11.3)		0.008[c]

注：[a]为数据以 $M(IQR)$ 表示；[b]为数据以 $\bar{x}\pm s$ 表示；[c]为采用 Fisher 确切概率法检验。



注：A 为术后感染性并发症发生率；B 为术后住院时长；C 为首次排气时间。

图 2　亚组分析森林图

Fig.2　Forest map for subgroup analysis

3　讨　论

随着机器人手术的推广，越来越多的研究集中于分析机器人手术的安全性和有效性[7]。既往研究认为，机器人的高清三维成像系统有助于术者看清

解剖部位，7个自由度的仿真手腕帮助术者精准夹闭细小血管，使得机器人手术在降低失血量、中转开腹率和缩短术后住院时间等方面更具有优势[7,16]。也有研究在平衡了两组患者的临床病理特征后发现，两组患者在以上方面的差异无统计学意义[17]，本研究与其部分结果一致。Sheng等[7]对开腹手术、腹腔镜手术和机器人手术治疗结直肠癌的围手术期结局进行了荟萃分析，结果提示与腹腔镜手术相比，机器人手术的失血量、并发症、死亡率、术中出血量最少，并且住院时间最短，但该荟萃分析纳入病例的手术部位包含了左半结肠、右半结肠、乙状结肠以及直肠。因此，笔者认为，虽然本研究的一些研究结果与该荟萃分析结果相同，但本研究对手术部位进行PSM后进行分析的数据更具有准确性。手术部位不同，会导致术前准备的差异和手术难度的改变，不能准确得出机器人手术在结直肠癌根治术中的优势。例如，Farah等[18]在利用ACS-NSQIP数据库进行的回顾性队列研究中，对结直肠癌的手术部位进行分层和PSM分析，结果再次证明，机器人手术与腹腔镜手术在不同手术部位的结直肠癌根治术中的围手术期结局具有差异性。

在本研究中，两组患者在术中输血率、中转开腹率、淋巴结清扫数目、二次手术率等方面差异无统计学意义，原因可能是本研究匹配了两组患者的手术部位，将两组患者的手术难度系数调整一致，因此降低了可能由于手术难度带来的选择性偏移；同时，本研究所纳入的一部分机器人组病例属于术者处于学习曲线的学习探索阶段的病例，降低了机器人手术系统的优势。机器人组的手术时长大于腹腔镜组，与既往研究结果一致[18]。机器人组所需的较长手术时间，可能与学习曲线有关，术者渡过探索阶段的学习曲线后，手术时间可能会迅速缩短。例如，术者在经历了41例机器人直肠癌根治术后，机器人手术的手术时间将短于腹腔镜手术[19]，而在右半结肠切除术中，术者只需要21例机器人手术便可达到与腹腔镜手术相似的手术时长[20]。

与既往回顾性研究和荟萃分析结论一致[7,21]，本研究同样认为，机器人手术具有更少的估计失血量、更短的首次进食流食时间、首次排气时间、术后住院时间以及总住院时间，同时，本研究还发现，机器人手术在降低感染性并发症方面更具有优势。笔者认为，相较于腹腔镜手术，机器人手术减少了术中肠道的翻动，在减少术中肠道损伤的同时，降低了肠道的应激反应，进而使胃肠道功能恢复更快，患者能够在更短的时间内实现排气。患者排气后，秉承快速康复理念，患者会由肠外营养转为肠内营养，实现更短的首次进食流食时间。而肠内营养的摄入，符合人体生理结构，更有利于患者的术后康复，因此，机器人手术又具有更短的术后住院时间，术后住院时间的缩短，直接减少了患者的总住院时间。

本研究根据人群特点进行了亚组分析，通过比较两组的感染性并发症发生率、首次排气时间和术后住院时间来探讨机器人手术的最佳获益人群。结果显示，年龄＜65岁、女性、低BMI以及接受直肠癌根治术是机器人手术最佳获益人群的特点，这些人群具有更低的术后感染性并发症发生率和更短的术后恢复时间。因本研究所纳入的机器人组病例中包含术者开展机器人手术前、中期的病例，因此，笔者建议在开展机器人手术前、中期的时候，术者应选择的机器人手术最佳获益人群特点是年龄＜65岁、女性、BMI为18.5~23.9 kg/m^{2}和接受直肠癌根治术。

综上所述，机器人手术在估计失血量、首次进食流食时间、首次排气时间、术后住院时间、总住院时间和感染性并发症发生率方面优于腹腔镜手术，在开展机器人手术的前、中期，为了达到最好的术后结局，术者应选择的机器人手术最佳获益人群特点是年龄＜65岁、女性、BMI为18.5~23.9 kg/m^{2}和接受直肠癌根治术。本研究也存在一些不足之处，首先，作为单中心研究，样本量较小，导致无法对左半结肠进行亚组分析；其次，作为回顾性研究，无法对患者的长期预后以及生存结果进行分析，并且无法避免外科医生在手术方式选择上的潜在的选择偏倚。

利益冲突　无

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