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REVIEW

Learning curve in robotic rectal cancer surgery: current state of affairs

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Abstract

Introduction Robotic-assisted rectal cancer surgery offers multiple advantages for surgeons, and it seems to yield the same clinical outcomes as regards the short-time follow-up of patients compared to conventional laparoscopy. This surgical approach emerges as a technique aiming at overcoming the limitations posed by rectal cancer and other surgical fields of difficult access, in order to obtain better outcomes and a shorter learning curve.

Material and methods A systematic review of the literature of robot-assisted rectal surgery was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The search was conducted in October 2015 in PubMed, MEDLINE and the Cochrane Central Register of Controlled Trials, for articles published in the last 10 years and pertaining the learning curve of robotic surgery for colorectal cancer. It consisted of the following key words: "rectal cancer/learning curve/robotic-assisted laparoscopic surgery".

Results A total of 34 references were identified, but only 9 full texts specifically addressed the analysis of the learning curve in robot-assisted rectal cancer surgery, 7 were case series and 2 were non-randomised case-comparison series. Eight papers used the cumulative sum (CUSUM) method, and only one author divided the series into two groups to compare both. The mean number of cases for phase I of the learning curve was calculated to be 29.7 patients; phase II corresponds to a mean number 37.4 patients. The mean number of cases required for the surgeon to be classed as an expert in robotic surgery was calculated to be 39 patients.

Conclusion Robotic advantages could have an impact on learning curve for rectal cancer and lower the number of cases that are necessary for rectal resections.

Keywords Minimally invasive surgery · Robotic surgery · Rectal surgery · Rectal cancer · Learning curve

Summary Robotic surgery represents a technological revolution in the management of rectal cancer. This approach has several advantages, and one of them could be the reduction in surgical learning curve.

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Introduction

Since minimally invasive surgical techniques were first introduced, many advantages of a laparoscopic approach to colorectal surgery have been reported [1–3]. However, the learning curve for such procedures in this pathology is long and not without complications. Although some studies suggest that laparoscopic surgery for treating cancer is not affected by the learning curve [4], in the CLASICC trial, which was performed by the UK Medical Research Council (MRC), positivity of the circumferential resection margin of the mesorectum (15.5 %) and conversion rate (33.3 %) were higher in the laparoscopic subgroup than in the open surgery subgroup (CLASICC) [2].

In the case of rectal cancer, the rigidity of the instruments; the tight pelvic workspace; the limited degrees of freedom of movement; the use of a camera without a fixed support for reducing shaking and vibration, which needs to be handled by an assistant; and poor ergonomics for the surgeon during the operation make the laparoscopic approach a complex surgery.

Thus, many authors state that minimally invasive surgery for the treatment of rectal cancer should be performed by expert surgeons who have mastered the technique [5] after being subjected to long periods of training [6].

Since Pigazzi et al. first reported the use of the da Vinci surgical robot for radical excision of the mesorectum, in 2006 [7], robot-assisted surgery for colon cancer has gained popularity. It widens the scope of possibilities for conventional laparoscopic surgery, with the provision of a three-dimensional image to enhance vision and articulated clamps with 360° of rotation to improve the range of motion. It also provides adequate ergonomics for the surgeon. This technique was created with the aim of overcoming the limitations posed by using the laparoscopic approach for rectal cancer surgery and for other surgical fields with difficult access.

The short-term clinical results acquired using this technique can be extrapolated to those obtained using laparoscopy [8, 9]. In addition, the estimated number of procedures required to complete the learning period may be lower than for laparoscopic surgery, if we take into account the advantages of robotic surgery.

With the adoption of new techniques, it is important to assess the effects on the surgeon's learning curve. Numerous studies have been published on robot-assisted surgery, but just a few evaluate the learning curve in rectal surgery [10–22]. Some authors suggest that the number of cases needed to overcome the learning phase is 15–35 patients [11–19, 21]. In this regard, the advantages of robotic surgery for rectal cancer may help shorten the learning curve in comparison with the conventional laparoscopic approach. Previous studies analysing the learning curve in laparoscopic rectal surgery estimate that a higher number of cases would be necessary, with approximately 40–90 patients required before a plateau is reached [5, 23–26].

The aim of the present study was to review the current state of affairs as regards the learning curve in robot-assisted colorectal cancer surgery through a systematic review of the literature.

Methods

Search strategy and results

We conducted a systematic review of the literature of robot-assisted rectal surgery, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [27].

The search was conducted in October 2015 in PubMed, MEDLINE and the Cochrane Central Register of Controlled Trials, for articles published in the last 10 years and pertaining the learning curve of robotic surgery for colorectal cancer. It consisted of the following key words: "rectal cancer/learning curve/robotic-assisted laparoscopic surgery".

A total of 34 references were identified. All abstracts were subsequently manually reviewed to identify potentially relevant studies for our purpose.

Initially, 13 items were considered to be potentially relevant; however, only nine [10, 11, 14, 15, 17–21] full texts specifically addressed the analysis of the learning curve in robot-assisted rectal cancer surgery. Additionally, a study involving the analysis of the learning curve for rectal cancer, but which also included rectal benign pathology (prolapses, etc.) [12], was excluded because the analysis was carried out for the benign and malignant pathologies combined (Fig. 1).

Study inclusion and exclusion criteria

In this work, we only included those articles that focused on the study of the learning curve in robot-assisted rectal cancer surgery, were limited to adult patients and were written in English.

We excluded studies that addressed the study of the learning curve for other locations in the colon or colorectal benign pathologies or those that focused on the study of the learning curve of conventional laparoscopy. Studies that duplicated data and non-human studies were excluded.

Data collection and data analysis

Two reviewers (RMJR and MRMD) independently extracted the following parameters from each study: first author, year of publication, study design, demographics (gender, age, BMI and previous surgery), intraoperative data (duration of operation, lymph node harvest, blood loss and intraoperative complications) and outcomes (postoperative complications, return to theatre, delayed complications, disease recurrence for malignant resections and length of hospital stay).

All relevant text, tables and figures were reviewed for data extraction. Discrepancies between reviewers were resolved by discussion and consensus.

Results

Nine robot-assisted rectal cancer articles [10, 11, 14, 15, 17–21] were considered for further analysis. A total of 917 patients were included, with an age range of 58–66 years and a BMI range of 21.9–27.4 kg/m^2.

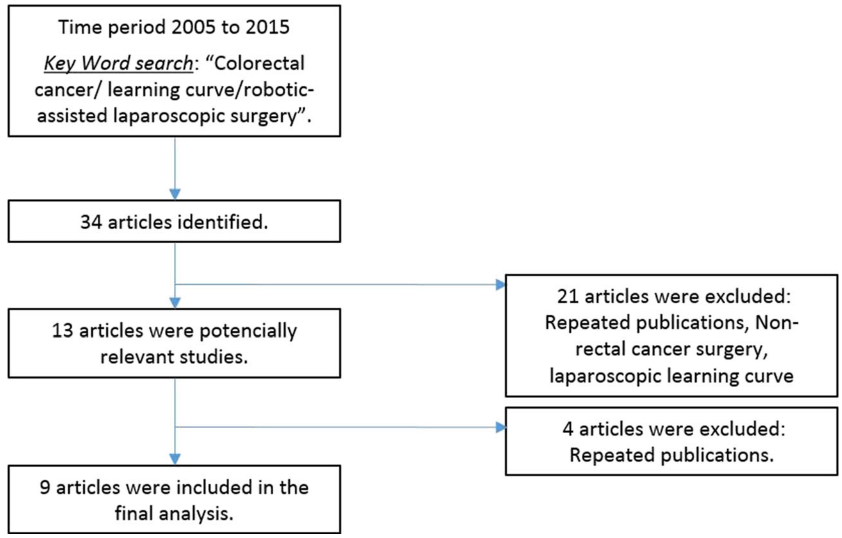

Fig. 1 Flow chart of literature search

Type and quality of the included studies

Among the nine included studies, seven were case series [10, 11, 14, 15, 17, 18, 21] and two were non-randomised case-comparison series [19, 20].

These studies were subject to significant bias, both in terms of selection criteria for trial participants and also in their reporting of data, given that surgeries were performed by enthusiasts of robot-assisted rectal surgery.

During critical appraisal of the literature, it became apparent that there was significant heterogeneity in the data between study populations.

Indication for robot-assisted rectal cancer surgery

The underlying indications for robot-assisted rectal cancer surgery included adenocarcinomas, polyps and carcinoid tumours. As regards the type of resection, we observed anterior resection (AR), low anterior resection (LAR), ultra-low anterior resection (ULAR), intersphinteric resection (ISR), abdominoperineal resection (APR) and Hartmann resection (Table 1).

Intraoperative data

Total duration of surgery ranged from 197.4 to 397.2 min, including robot setup and docking time.

Conversion to standard laparoscopy or laparotomy

Thirteen robotic cases required conversion to either conventional multiport laparoscopy or laparotomy. The complications leading to conversion were unspecified in all cases. Conversion was defined by some authors [17, 19] as an unintended extension of a minilaparotomy to a size greater than 3–4 cm, during the operation, or as an operation that started robotically but converted to an open approach [15]. Other authors did not define when conversion was considered.

Akmal et al. [10] reported a conversion of two patients (2.5 %) in each of the two learning phases. Melich et al. [20] reported one (1.1 %) conversion to open surgery and four (3.8 %) conversions to laparoscopic surgery (non-significant). All conversions (two) reported by Kim et al. [18] took place during learning phase 1. Jimenez-Rodriguez et al. did not find significant differences between the conversion rates during the three learning phases [11].

Postoperative complications

In total, among all included studies, 144 complications were reported (Table 2). There were 65 anastomotic leaks, rendering this the most common postoperative complication following robotic rectal surgery. Authors also reported 47 ileus, 16 bleedings and 3 wound infections.

Learning curve

Eight papers used the cumulative sum (CUSUM) method to analyse the learning curve [11, 14, 15, 17–20]. Among these, Jimenez-Rodriguez et al. and Parks et al. [11, 17] used a combined approach using both CUSUM and risk-adjusted (RA) CUSUM. Only Akmal et al. divided the series into two groups, with group 1 containing the first 40 cases and group 2 containing the subsequent 40 cases [10].

The results of each phase are displayed in Tables 3, 4 and 5, respectively.

Only three papers made reference to the number of cases with non-involved circumferential margin (>1 mm) [17–19].

Table 1. Characteristics of robotic tumoral rectal resection

	Name	Year	Study design	No. of patients	No. of phases	Age (years)	BMI (kg/m^2)	Robotic device	Type of rectal surgery	Operative time (min)	Estimated blood loss (ml)
1	Akmal et al. [10]	2012	Case series	80	2	60	27.2	da Vinci	40 LAR 21 CAA 19 APR	303.5	225
2	Sng et al. [15]	2013	Case series CUSUM	197	3	60[a]	23.5[a]	da Vinci	3 AR 126 LAR 10 ULAR 45 ISR 13 APR	278.7	50[a]
3	Jiménez Rodríguez et al. [11]	2013	Case series CUSUM	43	3	66	27.4	da Vinci	7 APR 36 AR	197.4	1 (2.3 %)[b]
4	Kim et al. [18]	2014	Case series CUSUM	167	3	58	23.7	da Vinci	102 LAR 65 CAA	211.9	48.1
5	Parks et al. [17]	2014	Case series CUSUM	130	3	59	23.1	da Vinci	130 LAR	199.9	53.6
6	Parks et al. [19]	2014	Non-randomised case comparison (robot vs laparoscopic) CUSUM	89 vs 89	2	58 vs 63	23 vs 22	da Vinci	178 LAR	208.6 vs 202.7	55.8 vs 73.2
7	Foo et al. [21]	2015	Case series CUSUM	39	3	62[a]	21.9[a]	da Vinci	34 LAR 4 APR 1 HARTMANN	397.2	100[a]
8	Melich et al. [20]	2015	Non-randomised case comparison (robot vs laparoscopic) CUSUM	92 vs 106	3	60 vs 63	23.1 vs 22.3	da Vinci	198 LAR	285 vs 262	201 vs 231
9	Yamaguchi et al. [14]	2015	Case series CUSUM	80	3	63[a]	22.9[a]	da Vinci	6 APR 6 AR 22 ISR 46 LAR	280[a]	17[a]
	Total			*917* vs *195*		*58–66* vs *63*	*21.9–27.4* vs *22.6*		*49 APR* *45 AR* *67 ISR* *854 LAR* *10 ULAR* *86 CAA* *1 HARTMANN*	*197.4–397.2* vs *202.7–262*	*17–225* vs *73.2–231*

CUSUM cumulative sum, *BMI* body mass index, *AR* anterior resection, *LAR* low anterior resection, *ULAR* ultra-low anterior resection, *ISR* intersphincteric resection, *APR* abdominoperineal resection, *CAA* coloanal anastomosis

[a] Median; all other continuous variables are described as a mean

[b] This author used *transfusion necessity* instead of *estimated blood loss*

Table 2 Published complications during the learning curve of robotic colonic cancer surgery

Name	Year	Conversion (absolute)	Anastomotic leak	Ileus	Bleeding	Wound infection
Akmal et al. [10]	2012	4	6	11	–	–
Sng et al. [15]	2013	0	19	30	7	2
Jiménez-Rodriguez et al. [11]	2013	6	6	1	0	0
Kim et al. [18]	2014	2	18	–	5	1
Parks et al. [17]	2014	0	6	3	2	–
Parks et al. [19]	2014	0 vs 5	1 vs 5	2 vs 3	2 vs 3	–
Foo et al. [21]	2015	0	3	–	–	–
Melich et al. [20]	2015	1 vs 4	6 vs 4	–	–	–
Yamaguchi et al. [14]	2015	0	0	0	0	0
Total		*13* vs *9*	*65* vs *9*	*47*	*16*	*3*

Values represent the number of cases where the complication occurred

Alkmal et al. described the mean circumferential rectal margin (2.1 cm in phase 1 and 1.5 cm in phase 2) but did not reference the number of cases with an affected circumferential rectal margin.

Discussion

Surgery is a fundamental pillar in treatment strategies for rectal cancer. Since Heald [28] demonstrated decreased recurrence rates after a surgical approach was used, total mesorectal excision through the "holy plane" has become the standard technique for rectal resection, with the excision being either subtotal or total depending on the tumour location. However, this technique is difficult, and achieving dissection within the correct planes requires such extensive training of the surgeon that performing it in all centres is not advised. Instead, as is the case for other malignancies, this complex procedure should be centralised in reference hospitals, a practice made possible by the limited volume of cases [29, 30]. In programs such as Vickingo [31], training sessions have been carried out to ensure an adequate level of knowledge of the surgeons who perform this technique.

The latest innovations in energy-based devices have led to an improvement in the approach to these techniques, both in terms of decreased surgery time and extent of bleeding [32]. However, each technological feature has its own learning curve, even if the ultimate goal is to improve results for better local disease control and increased disease-free survival.

Learning curve in laparoscopic rectal cancer surgery

The laparoscopic approach provides well-established advantages in abdominal surgery, such as early recovery, minimal lesions and scarring and other aesthetic advantages; however, it is not without complications [33–36].

The specific movements that the surgeon must make in order to manipulate the instruments inside the cavity (known as the fulcrum effect) are counterintuitive, i.e., if the surgeon wants the tip of the instrument to move up, he must move his hand down, and vice versa.

In addition, the two-dimensional (2-D) vision prevents adequate visualisation of the depth of the abdominal organs and their lesions. This 2-D screen, the "eyes" of the surgeon, is not directly aligned with the body area where the lesion or the instruments are localised. Instead, it requires the professional to move to obtain the best working angle and simultaneously the best view.

Moreover, in the case of rectal cancer specifically, technical problems arising from the location of the tumour are an additional issue: limited pelvic space, tumour size, which decreases working space even further, and others [37–41].

However, several authors have shown that even though there are technical difficulties associated with minimally invasive surgery, laparoscopic mesorectal excision is feasible and safe and can result in superior short-term results in comparison with open surgery [1–3].

Learning curve in robot-assisted rectal cancer surgery

Robot-assisted colorectal surgery was first introduced in 2002, with the first successful reports of this technique published that year [42]. In the short period of time since then, short- and medium-term results have been shown to be comparable to those of the laparoscopic approach [7–9]. It remains to be seen if such outcomes can surpass those of laparoscopy, with some studies indicating better conversion rates and better postoperative functional rates for robotic procedures [8, 35, 43–45].

Table 3 Phase I

Name	No. of cases	Total operative time	Robotic time	Conversion	Anastomotic leak	Circumferential margin Non-involved (>1 mm)	Postoperative hospital stay (days)
Akmal et al. [10]	40	310 (180–540)	60 (25–130)	2	5	–	7.8 (2–33)
Sng et al. [15]	35	265 (190–470)[a]	135 (60–244)[a]	0	2	–	8 (5–20)[a]
Jiménez-Rodriguez et al. [11]	9	246	160 ± 30	1	–	–	13.2
Kim et al. [18]	32	252 ± 42.1	112.3	2	6	29	9.8 ± 7.2
Parks et al. [17]	44	229.8 ± 48.5	75.2 ± 29.4	0	1	40	9 ± 3.3
Parks et al. [19]	44 vs 41	229.8 ± 48 vs 242.3 ± 80	75.2 ± 29	0 vs 4	1 vs 2	44 vs 39	9 ± 3.3 vs 10.2 ± 4.1
Foo et al. [21]	8	243 ± 38[a]	96.4 ± 25[a]	0	1	8	6.3 ± 2.4[a]
Melich et al. [20]	31 vs 31	397 (373–420) vs 308 (291–325)	297 vs 261	1 vs 3	1 vs 2	–	9.5 vs 12
Yamaguchi et al. [14]	25	415 (156–683)[a]	–	0	0	–	8 (7–12)[a]
Total	*268*	*229.8–415*	*60–297*	*6* vs *7*	*17* vs *4*	*30*	*6.3–13.2* vs *11.1*

[a] Median with interquartile range; all other continuous variables are described as the mean with standard deviation

Table 4 Phase II

Name	No. of cases	Total operative time	Robotic time	Conversion	Anastomotic leak	Circumferential margin Non-involved (>1 mm)	Postoperative hospital stay (days)
Akmal et al. [10]	40	297 (150–660)	64 (38–120)	2	1	–	7.3 (2–22)
Sng et al. [15]	93	285 (182–475)[a]	156 (65–367)[a]	0	11	–	9 (5–50)[a]
Jiménez-Rodriguez et al. [11]	12	279.9	201.6 ± 40.6	1	–	–	8.7
Kim et al. [18]	40	213.8 ± 44.5	90 ± 32.8	0	7	39	10.8 ± 7.3
Parks et al. [17]	34	189.4 ± 52.3	56.1 ± 23.2	0	0	32	8 ± 4.2
Parks et al. [19]	45 vs 48	187.9 ± 53 vs 168 ± 52	53.7 ± 23 vs –	0 vs 1	0 vs 3	43 vs 40	7.9 ± 4.2 vs 9.7 ± 7.7
Foo et al. [21]	17	540.9 ± 133.4[a]	136.6 ± 37.5[a]	0	2	17	9.2 ± 7.2[a]
Melich et al. [20]	31 vs 31	253 (238–268) vs 275 (263–288)	205 vs 237	0 vs 0	2 vs 0	–	9.6 vs 9.1
Yamaguchi et al. [14]	25	292 (157–509)[a]	–	0	0	–	7 (6–12)[a]
Total	*337*	*187.9–540* vs *168–275*	*53.7–205* vs *237*	*3* vs *1*	*3* vs *3*	*38*	*7–10.8* vs *9.4*

[a] Median with range; all other continuous variables are described as the mean with standard deviation

Table 5 Phase III

Name	No. of cases	Total operative time	Robotic time	Conversion	Anastomotic leak	Circumferential margin Non-involved (>1 mm)	Postoperative hospital stay (days)
Akmal et al. [10]	–	–	–	–	–	–	–
Sng et al. [15]	69	250 (145–515)[a]	135 (60–244)[a]	0	6	–	10 (5–122)[a]
Jiménez Rodriguez et al. [11]	22	210.4 ± 4	156.4	0	–	–	13.8
Kim et al. [18]	95	197 ± 47.1	68.4 ± 23.7	0	5	91	8.6 ± 5.3
Parks et al. [17]	52	181.6 ± 54	52.8 ± 25.7	0	5	49	8 ± 5.1
Parks et al. [19]	–	–	–	–	–	–	–
Foo et al. [21]	14	310.6 ± 164.5[a]	104.2 ± 35.5[a]	0	0	13	6.4 ± 1.6[a]
Melich et al. [20]	30 vs 44	204 (196–211) vs 220 (212–219)	155 vs 183	0 vs 0	4 vs 2	–	9.9 vs 9.1
Yamaguchi et al. [14]	30	196 (135–529)[a]	–	0	0	–	7 (6–15)[a]
Total	*312*	*196–310.6* vs *220*	*52.8–156.4* vs *183*	*0*	*20* vs *2*	*51*	*6.4–13.8* vs *9.1*

[a] Median with range; all other continuous variables are described as the mean with standard deviation

In spite of these encouraging reports, just as with any new technology, robot-assisted rectal cancer surgery is subject to a learning curve. So far, this appears to be shorter than that required for laparoscopic surgery [10, 11, 14, 15, 17–21]. Certain advantages of the robot could reduce the number of cases required to perform optimal surgery, with satisfactory results in what is a highly complex procedure.

There are a number of studies that have considered the learning curve for robot-assisted rectal cancer surgery, providing a value of 15–35 cases [11, 14, 15, 17, 21], which is significantly lower than the 30–70 surgeries quoted for the laparoscopic approach [5, 6]. However, some authors have noted that this lower number could be the result of bias, given the small number of cases included in these series (less than 50 each) [19]. Other authors who also applied the CUSUM method, but that included more patients in the study, estimated the learning curve to be at least 41–43 cases, a number similar to that estimated for laparoscopic surgery [16, 17, 19].

These values have been obtained by using different methods for analysing the learning curve. The CUSUM system appears to be the preferred strategy, a method that analyses different parameters (operative time, success rate, etc.) according to a discrete mathematical formula [11, 14, 15, 17, 18, 20]. This approach returns three differentiated phases in the learning curve, in which the operative and immediate postoperative parameters are analysed.

In the studies reviewed in the present analysis [10, 11, 14, 15, 17–21], the mean number of cases for phase I of the learning curve was calculated to be 29.7 patients. This is the cut-off point at which the majority of authors observed a decreasing operative time until a plateau was reached. Phase II corresponds to a plateau starting at the end of phase I and ending in a cut-off point where values begin to increase again. The mean number of cases until phase II was reached was found to be 37.4 patients. Finally, phase III shows an increase in all values except the total duration of operation, including robot setup and docking time. The mean number of cases required for the surgeon to be classed as an expert in robotic surgery was calculated to be 39 patients.

The articles reviewed showed a progressive decrease in both total operative time and in robotic time. Operative time ranged from 229 to 415 min in phase I, 168 to 540 min in phase II and 196 to 310 min in phase III. In the same way, the conversion rate seems to have improved with progressive phases, with no conversions reported in phase III by any author.

The studies where cases were divided into groups depending on the date of intervention [10, 19] obtained similar results for intergroup comparisons to those of previous analyses: shorter operative times in the latter cases, with lower hospital costs, albeit with similar conversion rates in all groups. However, despite the similarity of the values reported, the choice of cut-off point for the division of patients could fall on chance, and as happened in the work of Byrn et al. [46], where grouping was performed according to the calendar year.

None of the reviewed studies analysed the surgeons' prior experience with colorectal surgery, which could produce bias when assessing the learning curve [22]. In this sense, surgeons with extensive experience in rectal surgery may learn faster than those who are less familiar with rectal pathology.

Despite recently published studies [21, 22], the experience of laparoscopic surgeons should be considered an influencing factor in the learning of robot-assisted techniques, since tactless surgery and prior optical handling could decrease the time required to reach an adequate level of expertise.

On the other hand, it is important to consider the possibility of introducing surgeons to robot-assisted technology in groups consisting of surgeons with prior experience and those who have had the opportunity to train using the educational consoles available at many centres. Both the orientation of colleagues with prior experience in the first case and the acquisition of skills in the handling of the three robotic arms and the camera could influence the number of cases that determine the learning curve.

In laparoscopic surgery, studies have been published that report that cancer outcomes are no different during the learning period to when a high level of expertise has been achieved [4]. Similar studies are also needed for the robot-assisted approach in order to ensure patient safety during the surgeon's learning phase.

Conclusions

Most published studies suggest a shorter learning curve for robot-assisted rectal cancer surgery versus that carried out laparoscopically. However, these series do not analyse prior colorectal or minimally invasive experience. Furthermore, there are no randomised series comparing the learning curves of a single surgeon. Thus, we believe that further studies are needed to properly determine the number of cases required to master the robot-assisted technique for colorectal cancer surgery.

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