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TOPIC HIGHLIGHT

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Robotic surgery for rectal cancer: Current immediate clinical and oncological outcomes

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Abstract

Laparoscopic rectal surgery continues to be a challenging operation associated to a steep learning curve. Robotic surgical systems have dramatically changed minimally invasive surgery. Three-dimensional, magnified and stable view, articulated instruments, and reduction of physiologic tremors leading to superior dexterity and ergonomics. Therefore, robotic platforms could potentially address limitations of laparoscopic rectal surgery. It was aimed at reviewing current literature on short-term clinical and oncological (pathological) outcomes after robotic rectal cancer surgery in comparison with laparoscopic surgery. A systematic review was performed for the period 2002 to 2014. A total of 1776 patients with rectal cancer underwent minimally invasive robotic treatment in 32 studies. After robotic and laparoscopic approach to oncologic rectal surgery, respectively, mean operating time varied from 192-385 min, and from 158-297 min; mean estimated blood loss was between 33 and 283 mL, and between 127 and 300 mL; mean length of stay varied from 4-10 d; and from 6-15 d. Conversion after robotic rectal surgery varied from 0% to 9.4%, and from 0 to 22% after laparoscopy. There was no difference between robotic (0%-41.3%) and laparoscopic (5.5%-29.3%) surgery regarding morbidity and anastomotic complications (respectively, 0%-13.5%, and 0%-11.1%). Regarding immediate oncologic outcomes, respectively among robotic and laparoscopic cases, positive circumferential margins varied from 0% to 7.5%, and from 0% to 8.8%; the mean number of retrieved lymph nodes was between 10 and 20, and between 11 and 21; and the mean distal resection margin was from 0.8 to 4.7 cm, and from 1.9 to 4.5 cm. Robotic rectal cancer surgery is being undertaken by experienced surgeons. However, the quality of the assembled evidence does not support definite conclusions about most studies variables. Robotic rectal cancer surgery is associated to increased costs and operating time. It also seems to be associated to reduced conversion rates. Other short-term outcomes are comparable to conventional laparoscopy techniques, if not better. Ultimately, pathological data evaluation suggests that oncologic safety may be preserved after robotic total mesorectal excision. However, further studies are required to evaluate oncologic safety and functional results.

Key words: Surgical procedures; Minimally invasive; Rectal neoplasms; Robotics; Colorectal surgery

Core tip: Laparoscopic oncologic rectal surgery remains a challenging procedure. Robotic systems aim at overcoming the limits of conventional laparoscopic techniques. The evidence on robotic and robotic-assisted rectal cancer surgery is rapidly increasing. Currently, published studies have demonstrated exciting evidence regarding similar or improved short-term outcomes

after robotic rectal surgery when compared to laparoscopic conventional techniques. Moreover, robotic surgery seems to be oncologic safe. Further studies are required to evaluate the long-term oncologic and functional results of robotic over laparoscopic surgery for rectal cancer treatment.

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INTRODUCTION

Laparoscopic colorectal surgery was first described in 1991[1]. In the past two decades, it has progressively expanded. Since it was proven to be as safe and effective as open surgery[2], it was recognized as a reliable alternative to conventional surgery. It has become the standard of care for benign and malignant colonic diseases mainly due to the fact that laparoscopic colectomy is consistently associated to early postoperative outcomes, such as less postoperative pain, reduced postoperative morbidity, shorter length of stay, and earlier return to normal activities[3,4]. Moreover, it was also demonstrated that laparoscopic colectomy has oncological results comparable to open surgery[5-8].

However, the adoption of laparoscopic colectomy remains disappointing in most countries for several reasons, but mainly because it represents a challenging procedure associated to a steep learning curve[9-11]. Moreover, although laparoscopic access has been widely accepted for colonic surgery, there are several limitations associated to the laparoscopic approach to colorectal diseases. The fulcrum effect results in reduced motion range, especially inside the pelvis. A poorly trained camera operator may lead to an unstable bidimensional view leading to a reduction in the dissection accuracy required to properly approach Waldeyer's and Dennonvillier's fascias.

Total mesorectal excision (TME) has long been established as the standard surgical technique[12], laparoscopic TME remains a technically demanding procedure. The reported high conversion rates and involvement of circumferential resection margins[13] are thought to reflect the high level of difficulty associated to laparoscopic TME.

The Da Vinci robotic surgical system (Intuitive Surgical Inc., Sunnyvale, California, United States) has dramatically changed minimally invasive surgery. A robotic-assisted approach could potentially overcome some of the limitations of conventional laparoscopic rectal surgery. Robotic system enables the surgeon to control a three-dimensional, high-definition, 10-fold magnification vision steady camera. It provides wristed motion for endoscopic instruments (7° of freedom, 180° articulation, and 540° rotation). Motion scaling results in reduced physiological tremors, superior dexterity, and far greater ergonomic comfort[14]. Therefore, robotic systems are particularly designed for operations conducted within a small anatomical field in which high precision is demanded, such as cardiac surgery, prostate surgery and rectal surgery. Although robotic-assisted operations have been utilized for years in other surgical specialties, it was not until 2002 that Weber *et al*[15] reported the first two cases of robotic-assisted colectomies.

Case series, comparative, and multicenter studies have demonstrated that robotic rectal surgery is feasible, effective and safe for minimally invasive TME. However, evidence of its clinical superiority regarding short-term outcomes over conventional rectal surgery conducted by expert surgeons is still lacking. Moreover, long-term oncological safety remains to be demonstrated. Ultimately, robotic surgery is expensive, which results in a major impediment to greater spread of its use. Therefore, currently, there are two multicenter randomized controlled trials comparing robotic versus laparoscopic surgery for rectal cancer: the ROLARR and the ACOSOG-Z6051. However, at this moment, both trials are recruiting. Although the abovementioned limitations potentially associated to robotic rectal surgery, two recent systematic reviews followed by meta-analysis have concluded that robotic-assisted surgery decreases conversion rate when compared to a conventional laparoscopic approach for rectal cancer surgery and is also associated to reduced blood loss[16,17].

In the present study, it was aimed at reviewing the rapidly expanding current available literature on short-term clinical and immediate oncological (pathological) outcomes after robotic rectal cancer surgery in comparison with standard laparoscopic rectal surgery or conventional resections, and to provide a perspective on the use of robotics for the curative surgical treatment of rectal cancer.

LITERATURE REVIEW

A systematic review of the electronic literature examining robotics for rectal cancer surgery was performed. Two reviewers (Araujo SEA and Seid VE) conducted a search of electronic databases (PubMed, Google Scholar and Embase) for the period 2002 to 2014. The search strategy included the terms "robot", "robotic", "Da Vinci", "rectum", "rectal surgery", "proctectomy", "anterior resection", and "abdominoperineal excision". No other search restrictions were applied. Then, an additional manual search was conducted in the reference list of all relevant selected publications to prevent article loss by the search strategy. The last search was performed on March 2014.

Case series, comparative studies, and randomized controlled trials were all selected. The definition of oncologic rectal surgery included: anterior resection, low anterior resection, TME, coloanal anastomosis, intersphincteric, and abdominoperineal resections. The exclusion criteria

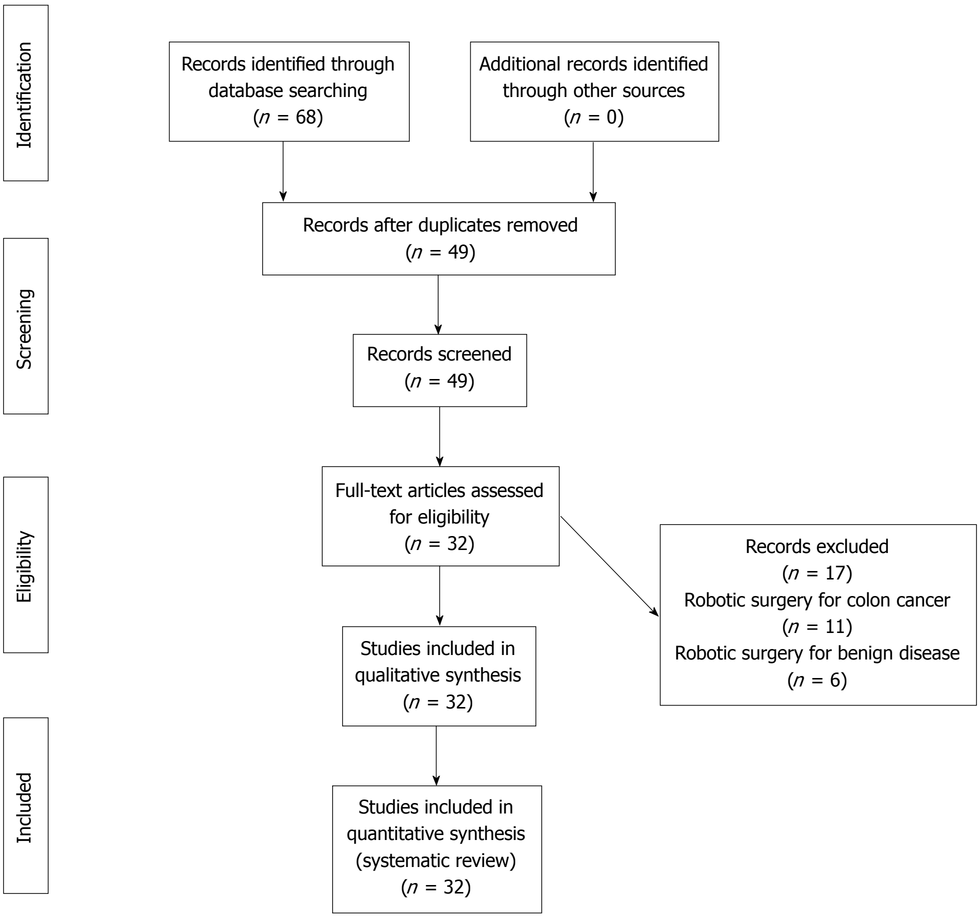

Figure 1 Preferred reporting items for systematic reviews and meta-analyses diagram.

were: review articles or letters, studies on robotic surgery for colon cancer or benign colonic disease, animal experiments, case reports, studies using only robotic camera holders (AESOP 3000; Computer Motion, Santa Barbara, California, United States) or the not commercially available Zeus Surgical System (Computer Motion, Santa Barbara, California, United States), studies with inappropriate data or not written in English language.

The following parameters were extracted to a specific protocol: name of first author, year of publication, country, study design, surgical technique, number of patients, neoadjuvant treatment, type of TME, operating time, estimated blood loss, conversion rate, overall morbidity rate, anastomotic complications, positivity of circumferential resection margins (CRMs), extent of distal resection margins (DRMs), and mean number of lymph nodes harvested.

QUALITY OF THE ASSEMBLED EVIDENCE

Published data on robotic oncologic rectal surgery comprise case series, nonrandomized retrospective and prospective comparative studies, and one randomized trial[18]. In these cases, bias associated to the evidence come from the unknown criteria used to recruit patients, and also from the quality of data collection. Although it is highly expected that experienced colorectal surgeons undertook all procedures, the expertise of the minimally invasive surgical team with laparoscopy and robotic approaches is seldom reported on the evaluated studies.

PATIENTS AND OPERATIONS

The electronic search followed by manual review identified 68 abstracts (Figure 1). After excluding 21 duplicates, 49 papers were reviewed. Seventeen articles were excluded. Eleven papers were on robotic surgery for colon cancer, and six papers comprised patients operated on for benign colonic diseases. Thirty-two studies[18-49] were suitable for inclusion in the systematic review. Seventeen studies[19-21,24,28-40] represented case series, 14[22,23,25-27,41-49] were comparative studies, and there was only one randomized controlled trial[18] (Table 1).

Regarding the distribution of papers according to the publication year (Figure 1), the number of publications on minimally invasive robot-assisted rectal surgery is increasing. In 2006 and 2007, the systematic review returned only one paper per year. Some authors rather not consider these experiences for evaluation, since they represent initial case series. In the years 2010, 2011, 2012, and 2013 it was observed, respectively, eight, seven, five, and three published papers. Although global numbers

Table 1 Use of robotics in rectal cancer surgery (case series, comparative, and randomized studies)

Ref.	Year	Country	Study design	Surgical technique	Number of patients	Neoadjuvant treatment	TME operation		
							Anterior resection	Intersphincteric resection	Abdomino-perineal resection
Hellan *et al*[28]	2007	United States	Case series	Hybrid	39	33	22	11	6
Choi *et al*[29]	2009	Korea	Case series	Hybrid	13	NA	13		
Choi *et al*[19]	2009	Korea	Case series	Totally robotic	50	NA	40	8	2
Ng *et al*[30]	2009	Singapore	Case series	Hybrid	8	NA	8		
deSouza *et al*[31]	2010	United States	Case series	Hybrid	44	31	30	6	8
Pigazzi *et al*[32]	2010	United States, Italy, Korea	Case series	Hybrid	143	93	80	32	31
Baek *et al*[33]	2010	United States	Case series	Hybrid	64	55	34	18	12
Zimmern *et al*[34]	2010	United States	Case series	Hybrid	58	23	47		11
Kang *et al*[20]	2011	Korea	Case series	Totally robotic	269	72	265		4
				Hybrid	120		118		2
Koh *et al*[35]	2011	Singapore	Case series	Hybrid	19	2	18		1
Leong *et al*[21]	2011	Korea	Case series	Totally robotic	29	11		29	
Marecik *et al*[36]	2011	United States	Case series	Hybrid	5	4			5
Alimoglu *et al*[24]	2012	Turkey	Case series	Totally robotic	7	4			7
Kang *et al*[37]	2012	United States	Case series	Hybrid	6	5			6
Karahasanoglu *et al*[38]	2012	Turkey	Case series	Hybrid	30	7	27		3
Park *et al*[39]	2012	United States	Case series	Hybrid	30	20	5	19	6
Du *et al*[40]	2013	China	Case series	Hybrid	22	NA	22		
Pigazzi *et al*[41]	2006	United States	Comparative	Hybrid	6	2	6		
Baik *et al*[18]	2008	Korea	Randomized	Hybrid	18	0	18		
Patriti *et al*[42]	2009	Italy	Comparative	Hybrid	29	7	29		
Baik *et al*[43]	2009	Korea	Comparative	Hybrid	56	5	56		
Bianchi *et al*[22]	2010	Italy	Comparative	Totally robotic	25	13	18		7
Popescu *et al*[44]	2010	Romania	Comparative	Hybrid	38	NA	30	0	8
Kim *et al*[23]	2010	Korea	Comparative	Totally robotic	100	14	100		
Park *et al*[45]	2010	Korea	Comparative	Hybrid	41	14	29	12	
Park *et al*[46]	2011	Korea	Comparative	Hybrid	52	12	52		
Baek *et al*[47]	2011	United States	Comparative	Hybrid	41	33	33	2	6
Kwak *et al*[48]	2011	Korea	Comparative	Hybrid	59	8	54	5	
Kim *et al*[25]	2012	Korea	Comparative	Totally robotic	100	34	55	45	
Park *et al*[49]	2013	Korea	Comparative	Hybrid	40	32		40	
Kang *et al*[26]	2013	Korea	Comparative	Totally robotic	165	39	165		
D'Annibale *et al*[27]	2013	Italy	Comparative	Totally robotic	50	34	50		

TME: Total mesorectal excision; NA: Not available.

seem to be diminishing, an increase in the publication of studies comparing robotic-assisted and conventional laparoscopic approaches for rectal surgery may be observed, starting in 2010.

A total of 1776 patients with rectal cancer underwent minimally invasive robotic or robotic-assisted treatment in 32 studies. Of these, 956 patients were operated on a case series design study. Only 795 patients of eight studies[19-27] were operated on using a totally robotic approach. The mean number of patients operated on with robotic assistance for publication was 55.5 (5-379). Only 125 (7%) patients undergoing robotic TME underwent sphincter ablation operations. Among the 1651 patients who underwent sphincter preserving-operations, 227 (13.7%) were submitted to an intersphincteric dissection prior to coloanal anastomosis.

OPERATING TIME

For the total of 1776 patients with rectal cancer who underwent robotic or robotic-assisted surgical treatment in 32 studies, the mean operating time ranged from 192 to 385 min (Table 2). For the 887 patients operated on using a laparoscopic approach in the selected comparative studies, the mean operating time ranged from 158 to 297 min. In the two studies[25,26] using a cohort of patients undergoing TME through an open approach, the results of this particular group of patients were not considered in the present review.

Although the overall results of operating time in the study of Patriti *et al*[42] have not demonstrated significant differences after robotic and conventional laparoscopy, operative times after robotic surgery with TME with and without sphincter preservation were significantly higher. In the reports of Popescu *et al*[44], Kim *et al*[23], Park *et al*[45], Kwak *et al*[48], Kim *et al*[25], Park *et al*[49], and Kang *et al*[26], operating times were significantly longer after operations with robotic assistance.

ESTIMATED BLOOD LOSS

The estimated blood loss values were not available in 14 publications. For the remaining 17 studies in this systematic review, mean estimated blood loss after oncologic

Table 2 Use of robotics in rectal cancer surgery - clinical outcomes

Ref.	Type of procedure	Number of patients	Mean operating time (min)	Estimated blood loss (mL)	Length of stay (d)	Conversion rate (%)	Overall complication rate	Anastomotic complications
Hellan *et al*[28]	RTME	39	285 (180-540)	200 (25-6000)	4	2.6	12.8%	12.1%
Choi *et al*[29]	RTME	13	260 (210-390)	NA	7	0	23%	7.7%
Choi *et al*[19]	RTME	50	304 (190-405)	NA	9.2 (5-24)	0	18%	8.3%
Ng *et al*[30]	RTME	8	192 (145-2500	NA	5 (4-30)	0	0%	0%
deSouza *et al*[31]	RTME	44	347 (155-510)	250 (50-1000)	5 (3-36)	4.5	4.5%	4.5%
Pigazzi *et al*[32]	RTME	143	297 (90-660)	283 (0-6000)	8.3 (2-33)	4.9	41.3%	10.5%
Baek *et al*[33]	RTME	64	270 (150-540)	200 (20-6000)	5 (2-33)	9.4	35.9%	7.7%
Zimmern *et al*[34]	RTME	58	350	250	6	1.7	24.1%	3.4%
Kang *et al*[20]	RTME	389	305.4 ± 111.5/ 339.3 ± 127.4[1]	NA	8.7 ± 3.0/ 17.6 ± 13.3[1]	0/1[1]	19%	7%
Koh *et al*[35]	RTME	19	316 (232-444)	NA	6.4 (3-21)	0	14.3%	0%
Leong *et al*[21]	RTME	29	325 (235-435)	50 (50-1000)	9 (5-15)	0	10.3%	31%
Marecik *et al*[36]	RTME	5	343 (270-442)	230 (100-400)	5.8 (5-7)	0	20%	0%[2]
Alimoglu *et al*[24]	RTME	7	NA	NA	8.1 (5-10)	0	28.6%	0%[2]
Kang *et al*[37]	RTME	6	335 (267-452)	250 (150-400)	5 (4-7)	0	50%	0%[2]
Karahasanoglu *et al*[38]	RTME	22	270 (175-480)	50 (20-100)	4 (4-20)	0	13.3%	3.3%
	RPME	8						
Park *et al*[39]	RTME	30	369 (306-410)	100 (75-200)	4 (3-6)	0	36.6%	4.2%
Du *et al*[40]	RTME	22	220 (152-286)	33 (10-70)	7.8 (7-13)	0	4.5%	0%
Pigazzi *et al*[41]	RTME	6	264 (192-318)	104	4.5 (3-11)	0	16.6%	0%
	LTME	6	258 (198-312)	150	3.6 (3-6)	0	16.6%	0%
Baik *et al*[18]	RTME	18	203 (149-315)	NA	7 (5-10)[4]	0	22.2%	0%
	LTME	18	196 (114-297)	NA	9 (6-12)[4]	11.1	5.5%	0%
Patriti *et al*[42]	RTME	29	202 ± 12	137 ± 156	11.9 (6-29)	0[4]	30.6%	6.8%
	LTME	37	208 ± 7	127 ± 169	9.6 (5-37)	18.9[4]	18.9%	2.7%
Baik *et al*[43]	RTME	56	178 (120-315)	NA	5 (5-10)[4]	0[4]	5.4%[4]	1.7%
	LTME	57	179 (100-360)	NA	6 (4-16)[4]	10.5[4]	19.3%[4]	7%
Bianchi *et al*[22]	RTME	25	240 (170-420)	NA	6.5 (4-15)	0	16%	4%
	LTME	25	237 (170-545)	NA	6 (4-20)	4	24%	8%
Popescu *et al*[44]	RTME	38	208 (180-300)[4]	100[4]	8.1 ± 4.5	5.2	15.7%	5.2%
	LTME	84	182 (140-220)[4]	150[4]	8.4 ± 3.5	10.5	15.3%	7.1%
Kim *et al*[23]	RTME	100	385.3 ± 102.6[4]	NA	11.7 ± 6.7	2	20%	8.2%
	LTME	100	297.3 ± 83.7[4]	NA	14.4 ± 10	3	27%	11.1%
Park *et al*[45]	RTME	41	231.9 ± 61.4[4]	NA	9.9	0	19.3%	9.7%
	LTME	82	168.6 ± 49.3[4]	NA	9.4	0	29.3%	7.3%
Park *et al*[46]	RTME	52	233 ± 52.4	NA	10 ± 19.2	0	10%	9.6%
	LTME	123	158 ± 49.2	NA	15 ± 12.2	0	15%	5.6%
Baek *et al*[47]	RTME	41	296 (150-520)	200 (20-2000)	6.5 (2-33)	7.3	22%	8.6%
	LTME	41	315 (174-584)	300 (17-1000)	6.6 (3-20)	22	26.8%	2.9%
Kwak *et al*[48]	RTME	59	270 (241-325)[4]	NA	NA	0	32.2%	13.5%
	LTME	59	228 (177-254)[4]	NA	NA	3.4	27.1%	10.1%
Kim *et al*[25]	RTME	100	188 ± 45[4]	NA	7.1 ± 2.1	0	26%	2%
	OTME	100	103 ± 23[4]	NA	6.9 ± 1.5	0[3]	27%	4%
Park *et al*[49]	RTME	40	235.5 ± 57.5[4]	45.7 ± 40	10.6 ± 4.2	0	15%	7.5%
	LTME	40	185.4 ± 72.8[4]	59.2 ± 35.8	11.3 ± 3.6	0	12.5%	5%
Kang *et al*[26]	RTME	165	309.7 ± 115.2[4]	133 ± 192.3[4]	10.8 ± 5.5[4]	0.6	20.6%	7.3%
	LTME	165	277.8 ± 81.9[4]	140.1 ± 216.4[4]	13.5 ± 9.2[4]	1.8	27.9%	10.8%
	OTME	165	252.6 ± 88.1[4]	275.4 ± 368.8[4]	16 ± 8.6[4]	0[3]	24.8%	3.4%
D'Annibale *et al*[27]	RTME	50	270 (240-315)	NA	8 (7-11)	0	10%	10%
	LTME	50	280 (240-350)	NA	10 (8-14)	12	22%	14%

[1]Non-complicated/complicated cases; [2]Abdominoperineal resections only; [3]Conventional (open) approach; [4]The original publication as statistically significant (P < 0.05). RTME: Robotic total mesorectal excision; LTME: Laparoscopic total mesorectal excision; RPME: Robotic partial mesorectal excision; OTME: Open total mesorectal excision; NA: Not available.

robotic rectal surgery varied from 33 to 283 mL. For the comparative studies where data after laparoscopic operations have also been available, mean estimated blood loss was between 127 and 300 mL (Table 2). Only in the reports of Popescu *et al*[44] (100 mL *vs* 150 mL) and Kang *et al*[26] (133 mL *vs* 140 mL), the estimated blood loss was significantly reduced after robotic rectal surgery when compared to the laparoscopic approach.

LENGTH OF STAY

The mean length of stay was not available for only one comparative study[48]. Among rectal cancer patients undergoing robotic surgery, the length of stay for 29 studies ranged from 4 to 10 d (Table 2). For the comparative studies, mean length of hospital stay after laparoscopic rectal surgery ranged from 6 to 15 d (Table 2). In three studies[18,23,46], one of them a small randomized trial[18], which enrolled a total of 84 patients, the mean length of stay was significantly reduced after robotic surgery when compared to laparoscopic access.

CONVERSION

Conversion rates were available for all 32 studies included in this systematic review. Among 1776 patients with rectal cancer undergoing robotic or robotic-assisted surgical treatment in this systematic review, the mean conversion rate varied between 0% and 9.4%. For the laparoscopic cases, mean conversion to open surgery was between 0% and 22% (Table 2).

In three comparative studies[27,42,43] included in this review, robotic surgery for rectal cancer was significantly associated to a lower conversion rate. This three studies included 279 patients. In the publication of Patriti *et al*[42], the majority of patients in the robotic group had previous abdominal surgery and low rectal cancer requiring a TME. In addition, more patients in the robotic group had undergone neoadjuvant chemoradiation when compared to the laparoscopic group. In the second study where conversion was reduced after a robotic approach[43], conversion was null in the robotic group. In the laparoscopic group, the rate was 10.5% (6 cases). The reasons for conversion in the laparoscopic group were hemorrhage from the lateral pelvic wall, failure to progress due to a severe narrow pelvis, and rectal perforation.

POSTOPERATIVE COMPLICATIONS (OVERALL)

For the 32 studies included in this systematic review, the overall morbidity after robotic or robotic-assisted rectal cancer surgery ranged from 0% to 41.3% (Table 2). The overall postoperative complication rate after laparoscopic treatment of rectal cancer on 14 comparative studies and 1 randomized controlled trial varied between 5.5% and 29.3% (Table 2).

In only one comparative study[43], where 56 and 57 patients underwent a robotic and laparoscopic low anterior resection respectively, postoperative morbidity was significantly reduced after robotic surgery (5.4% *vs* 19.3%).

ANASTOMOTIC COMPLICATIONS

Among the 32 studies included in this review, the occurrence of complications of colorectal or coloanal anastomosis was not available on three publications dealing exclusively with sphincter-ablative rectal operations[24,36,37] (Table 2).

After robotic or robotic-assisted sphincter preserving rectal surgery, the mean occurrence of anastomotic complications varied between 0% and 13.5%. After laparoscopic sphincter-preserving surgery, it varied between 0% and 11.1% (Table 2). In one recent study[26], matched robotic, laparoscopic and open rectal cancer cases were compared comprising a total of 674 recruited patients. In this study, robotic surgery was significantly associated to less anastomotic complications (7.3%) when compared to the laparoscopic (10.8%) approach.

IMMEDIATE ONCOLOGICAL OUTCOMES

CRM positivity results after TME or tumor-specific mesorectal excision was available for all studies in this review with the exception of one case series[34], two comparative studies[41,44], and one randomized trial[18]. The mean frequency of CRM positivity after robotic rectal cancer surgery for 1656 operated on rectal cancer patients in the present review was between 0% and 7.5%. After laparoscopic rectal surgery, for 879 patients, it ranged from 0% to 8.8% (Table 3). Only in two recent comparative studies[26,27], the involvement of CRM showed a significant decrease after robotic rectal surgery when compared to the laparoscopic access. In the study of Kang *et al*[26], 495 patients submitted to robotic, laparoscopic, or open rectal surgery were retrospectively selected and matched according to clinical characteristics. No significant differences in baseline characteristics were observed among the matched cohort with 165 pairs of patients. CRM involvement was observed in 4.2%, 6.7%, and 10.3% of patients undergoing robotic, laparoscopic, or open access TME, respectively. In the experience of D'Annibale *et al*[27], 50 patients underwent robotic TME and were retrospectively compared to 50 patients undergoing laparoscopic TME. In spite of CRM involvement could have depended on pathology site and extension, the authors stated that robot-assisted surgery allowed them to achieve a complete and oncologic adequate resection of the specimen due to articulation of the instruments and the 3-D magnified vision.

In the present review, data regarding the extent of lymphadenectomy associated to robotic rectal surgery was available for all 32 selected studies (1776 rectal cancer patients). The mean number of retrieved lymph nodes after robotic rectal surgery was between 10.3 and 20. After laparoscopic surgery, the mean number of retrieved lymph nodes among 987 operated on patients was between 11.1 and 21). In all comparative, and in the randomized study, there was no difference in the extent of lymphadenectomy due to a robotic or laparoscopic approach. In the study of D'Annibale *et al*[27], the mean number of lymph nodes retrieved after robotic TME was 16.5 (range 11-44), and was 13.8 (4-29) after laparoscopic TME. In this paper, there was no difference in the extent of the lymphadenectomy ($P = 0.053$) (Table 2). However, in the discussion session, the authors stated that there was no difference in the extent of lymphadenectomy among the groups ($P = 0.073$).

Regarding the extent of DRM, among the 17 comparative studies, the information was not available for four studies[20,31,34,39] due to not declared reasons, for three studies comprising only patients submitted to robotic abdominoperineal excisions[24,36,37] and for one comparative study[44]. For 1199 patients undergoing robotic rectal

Table 3 Use of robotics in rectal cancer surgery - immediate oncological outcomes

Ref.	Type of procedure	Number of patients	Positivity of circumferential resection margin (%)	Distal resection margins, cm	Mean/median number of lymph nodes harvested
Hellan *et al*[28]	RTME	39	0	2.6 (0.4-7.5)	13 (7-28)
Choi *et al*[29]	RTME	13	0	4.7 ± 1.8	24.6 ± 16.7
Choi *et al*[19]	RTME	50	2	1.9 ± 1.1	20.6 ± 10
Ng *et al*[30]	RTME	8	0	> 2	15 (2-26)
deSouza *et al*[31]	RTME	44	0	NA	14 (5-45)
Pigazzi *et al*[32]	RTME	143	0.7	2.9 ± 1.8	14.1 (1-39)
Baek *et al*[33]	RTME	64	0	3.4 (0.2-10)	14.5 (3-28)
Zimmern *et al*[34]	RTME	58	NA	NA	11.8-15.3
Kang *et al*[20]	RTME	389	3.6	NA	15.7 ± 10
Koh *et al*[35]	RTME	19	5.3	0.8-1	17.8 ± 7.1
Leong *et al*[21]	RTME	29	6.8	0.8 (0-4)	16 (1-44)
Marecik *et al*[36]	RTME	5	0	-[1]	12.4
Alimoglu *et al*[24]	RTME	7	0	-[1]	16 (14-21)
Kang *et al*[37]	RTME	6	0	-[1]	20 (7-58)
Karahasanoglu *et al*[38]	RTME	30	0	4 (2-8)	15 (3-38)
Park *et al*[39]	RTME	30	0	NA	20 (14-25)
Du *et al*[40]	RTME	22	0	2.6 (1-5.5)	14.3 (8-27)
Pigazzi *et al*[41]	RTME	6	NA	3.8 (1.8-9)	14 (9-28)
	LTME	6	NA	3.5 (2.2-5)	17 (9-39)
Baik *et al*[18]	RTME	18	NA	4.0 ± 1.1	18 (6-49)
	LTME	18	NA	3.7 ± 1.1	22 (9-42)
Patriti *et al*[42]	RTME	29	0	2.1 ± 0.9	10.3 ± 4
	LTME	37	0	4.5 ± 7.2	11.2 ± 5
Baik *et al*[43]	RTME	56	7.2	4 (1-7)	17.5 (4-43)
	LTME	57	8.8	3 (1-9)	17 (4-53)
Bianchi *et al*[22]	RTME	25	0	2 (1.5-4.5)	18 (7-34)
	LTME	25	4	2 (1.8-3.5)	17 (8-37)
Popescu *et al*[44]	RTME	38	NA	Negative	11.7 ± 3.8
	LTME	84	NA	Negative	11.1 ± 3.2
Kim *et al*[23]	RTME	100	3	2.7 ± 1.9	14.7 ± 9.7
	LTME	100	2	2.6 ± 1.8	16.6 ± 9.1
Park *et al*[45]	RTME	41	1.2	2.1 ± 1.4	17.3 ± 7.7
	LTME	82	7.3	2.3 ± 1.5	14.2 ± 8.9
Park *et al*[46]	RTME	52	1.9	2.8 ± 1.9	19.4 ± 10.2
	LTME	123	2.4	3.2 ± 2.1	15.9 ± 10.1
Baek *et al*[47]	RTME	41	4.9	3.6 (0.4-10)	13.1 (3-33)
	LTME	41	2.4	3.8 (0.4-11)	16.2 (3-33)
Kwak *et al*[48]	RTME	59	1.7	2.2 (1.5-3)	20 (12-27)
	LTME	59	0	2 (1.2-3.5)	21 (14-28)
Kim *et al*[25]	RTME	100	1	2.7 ± 1.7[2]	20 ± 6.9
	OTME	100	1	1.9 ± 1.3[2]	19.6 ± 8.5
Park *et al*[49]	RTME	40	7.5	1.4 ± 0.9	12.9 ± 7.5
	LTME	40	5	1.3 ± 0.9	13.3 ± 8.6
Kang *et al*[26]	RTME	165	4.2[2]	1.9 ± 1.4	15 ± 9.4
	LTME	165	6.7[2]	2 ± 1.4	15.6 ± 9.1
	OTME	165	10.3[2]	2.2 ± 1.7	17.4 ± 10.9
D'Annibale *et al*[27]	RTME	50	0[2]	3 (2-7)	16.5 (11-44)
	LTME	50	12[2]	3 (1-6)	13.8 (4-29)

[1]Abdominoperineal resections only; [2]The original publication as statistically significant (P < 0.05). RTME: Robotic total mesorectal excision; LTME: Laparoscopic total mesorectal excision; RPME: Robotic partial mesorectal excision; OTME: Open total mesorectal excision; NA: Not available.

cancer, surgery, the mean value of DRM varied between 0.8 and 4.7 cm. For 903 patients undergoing laparoscopic sphincter-preserving rectal cancer surgery, the mean value for DRM ranged from 1.9 to 4.5 cm. In all selected comparative studies, there was no difference for DRM value between robotic and laparoscopic cases. However, in one study[25] comparing 100 matched robotic to open cases, mean DRM was longer (2.7 *vs* 1.9; P = 0.001) after robotic approach.

DISCUSSION

It was demonstrated that laparoscopic colorectal surgery is as safe and effective as open surgery regarding early postoperative outcomes. These data are at this time mature and reflect a modest but significant benefit on short-term outcomes when compared to conventional colectomies[50]. Long-term oncological results also demonstrate that laparoscopic surgery is entirely equivalent to laparotomy regarding oncologic safety[6].

Similarly, laparoscopic rectal resection is fully feasible[51]. However, laparoscopic TME remains a technically demanding procedure associated with a steep learning curve, high conversion and positive CRM rates[11,13]. The 16% rate of CRM involvement reported in the MRC CLASICC trial has been advocated as an indirect evidence of increased technical difficulty associated to laparoscopic TME[13]. Particular features of laparoscopic TME include the limited dexterity of non-articulating instruments attached to a fulcrum effect especially in the narrow male pelvis or when dealing with bulky tumors, and loss of three-dimensional view.

Robotic surgery for the management of rectal cancer remains a highly controversial issue. The current robotic surgical platform provides a stable, three-dimensional, high-definition, 10-fold magnification vision, intuitive articulated instrument manipulation, tremor elimination, superior dexterity, and high precision of the movement of the robotic arms. Therefore, robotic surgical systems may be particularly suited for deep and precise pelvic surgery, obviating some of the limitations of conventional laparoscopic surgery as required during TME operations. The first robotic colectomy was reported in 2002[15]. Since then, the number of publications on robotic colorectal surgery has markedly increased[52]. In 2004, D'Annibale *et al*[53] reported on 52 cases of robotic-assisted colon and rectal surgery. In this report, 10 cases of robotic-assisted anterior resection were included. The first paper on robotic TME included 6 cases of rectal cancer and was published in 2006[41].

The high costs associated with the currently available robotic platform have limited the implementation of this technology. Therefore, before robotic surgery can be accepted as the preferred approach for rectal cancer surgery, it should be confirmed that the technology provides superior short-term outcomes and equal or improved oncologic and functional results in comparison with other approaches. Due to the lack of evidence from controlled randomized trials, a systematic review of the currently available literature might help to critically assess such an argument. The interest on the matter is elevated and the first TME operation was reported in 2004[53]. Nevertheless, since then there is only one very small randomized controlled trial[18] comparing robotic to conventional laparoscopic rectal surgery, published in 2008. On the other hand, we could find at least two non-systematic reviews on robotic surgery for colorectal diseases[54,55], and one systematic review on robotic surgery for rectal cancer[56]. The available published data on robotic colon and rectal surgery comprise case reports, case series, and non-randomized retrospective and prospective comparative studies. All of these studies are, by their very nature, subject to significant bias derived from patient selection, and quality of reported data extraction. However, this concept did not prevent the publication of meta-analyses on robotic colorectal surgery[52], and on robotic rectal surgery[16,17,57]. Because of the lack of available evidence from ongoing prospective randomized trials (ROLLAR[58] and ACOSOG-Z6051[59]), systematic reviews as conducted in the present paper represent the most organized way to evaluate current evidence on robotics for rectal malignancy.

Before the present study design was accomplished, the findings of two recent meta-analyses[16,17] on robotic surgery for rectal cancer demonstrated non-similar results but the same limitations. Both meta-analyses included seven studies. In both, four studies[22,42,43,48] were present. Yang *et al*[17] found that robotic proctectomy is associated with increased operative time, less estimated blood loss, lower conversion rate, and higher hospital costs. Memon *et al*[16] were able to confirm only the findings of lower conversion associated with robotic surgery when compared to conventional laparoscopy. Meta-analyses of robotics for rectal surgery have several limitations. Non-randomized, retrospective or prospective, not case-matched or matched studies are biased. Moreover, the number of studies in the analysis is small, precluding subgroup analysis. In the present study, we calculated the mean number of robotic cancer cases being 55.5 (range, 5-379). Ultimately, uncontrolled variables included in biased studies lead to under- or over-estimation of risk effects[17].

In the present systematic review, it could be observed that robotic TME is associated with a prolonged operating time when compared to laparoscopic TME[23,26,44,45,48,49]. The extended time taken to dock the robot may be an important issue on the longer operating time. In the present review, it was observed that 795 patients of 8 studies[19-27] were operated on using a totally robotic approach. In the hybrid technique, the abdominal part of minimally invasive TME (inferior mesenteric vein and artery division, splenic flexure and left colon mobilization) is accomplished using conventional laparoscopic techniques. And the robot is used for the pelvic TME part of the operation. Most surgeons use the hybrid technique to avoid robot repositioning/re-docking. One time docking could also be done for a fully robotic technique by changing some trocars or arms. In the fully robotic technique reported by several authors[19,60,61], the robotic approach is used for the abdominal and pelvic parts of the operation. To the present moment, no study has compared a hybrid to a fully robotic technique.

There is no current significant evidence that a robotic approach to rectal cancer may reduce estimated blood loss. Only in the small report by Popescu *et al*[44] and Kang *et al*[26], intraoperative blood loss was significantly reduced after robotic rectal surgery. Popescu *et al*[44] have reported on only 38 robotic rectal cancer cases. Moreover, in the study of Kang *et al*[26], the difference between mean estimated blood loss after robotic (133 mL) and laparoscopic (140 mL) cases was very small. Ultimately, it must be remembered that estimating blood loss in a retrospective design may be imprecise.

Regarding hospital stay, in only three studies[18,23,46] involving 239 patients operated with robotic assistance, a shorter hospital stay could be observed. In all other selected comparative studies there was no significant difference. Moreover, Yang *et al*[17] and Memon *et al*[16] independently looked at the same data using meta-analytical techniques and could detect no difference. Variability between comparative retrospective studies may include differences in discharge criteria. Certainly, a shorter duration of hospitalization produced by robotic access to the rectum when compared to laparoscopy remains to be demonstrated.

Robotic surgery may overcome limitations derived from conventional laparoscopic TME. High-definition three-dimensional view and superior dexterity due to motion scale and articulated instruments may contribute to superior visualization and a more precise pelvic dissection. In the present systematic review, conversion to laparotomy after robotic rectal surgery (0%-9.4%) seems to be reduced when compared to laparoscopy (0%-22%). This result was directly observed in three[7,42,43] comparative studies included in this review and may be due to the ability to perform fine dissection in a narrow surgical field. On the other hand, it is important to highlight that none of the studies were randomized neither blinded. Therefore, these results must be interpreted with caution since selection bias may have inadvertently favored robotic cases, since robotics was the technology under evaluation.

There is no current evidence regarding a role for robotic surgery in reducing postoperative or anastomotic complications in all comparative studies selected in this review. In only one small study[43] comprising 56 and 57 patients undergoing a low anterior robotic and laparoscopic rectal resection, respectively, postoperative complications were higher in the laparoscopic group. The authors believe that the higher incidence of anastomotic complications observed in the laparoscopic group may be due to a difficulty in the perpendicular rectal transection leading to an increased number of stapler firings which was reported to be significantly related to anastomotic leakage. However, the number of stapler firings were not accrued in the study[62].

Although most specialists performing minimally invasive TME are highly experienced laparoscopic surgeons, performing precise dissection in the pelvis is especially difficult. On this matter, robotic surgery may provide some advantages. The oncologic outcomes after surgery for rectal cancer rely on the quality of mesorectal excision. Regarding CRM involvement in the present review, available data on robotic cases from case series and comparative studies indicate a (+)CRM from 0% to 7.5%; and from 0% to 8.8% after laparoscopic cases from comparative studies. However, there was no difference regarding (+)CRM rates for 10 comparative studies[22,23,25,42,43,45-49] included in this review. Three meta-analyses support these findings[16,17,23]. Only for the two most recent comparative studies[26,27], (+)CRM was more frequent after a laparoscopic approach.

Regarding the extent of dissected lymph nodes among TME specimens in this systematic review, the results were available for all 32 included studies. There was no significant difference between a robotic and laparoscopic approach in the total number of lymph nodes extracted. Despite the numerous variables determining the number of lymph nodes in the surgical specimen after TME, it is likely that the oncological efficacy and safety of robotic surgical treatment of rectal cancer may be improved after more experienced surgeons foster robotic technique.

Robotics is a minimally invasive technology with advantages over conventional laparoscopic surgery. It has been reported to enhance a surgeon's ability to perform difficult cases such as a low rectal anastomosis in an obese patient. The approach proposed by Prasad *et al*[63] represents a clear example of robotic technology enhanced capabilities. In this approach, after completion of robotic TME, the distal rectum is divided, the specimen is passed through the low rectal (anal) stump, and, with the aid of the robotic movements, a purse-string suture is placed on the distal rectal stump, allowing a single-stapled transanal anastomosis to be performed. However, one of the unique drawbacks of robotic surgery is the loss of tactile sensation (haptic feedback). In the initial experience, it may lead to organ injury and perforation. Only through carefully observing robotic instrumentations effect on the tissue, the surgeon can offset the lack of tactile sensation. External robotic arms collisions remain another important issue in robotic surgery. Patient positioning, port placement, and arms adjustment are crucial for robotic surgery.

Undoubtedly, the most important obstacle to widespread implementation of robotic technology includes the high start-up and maintenance costs (US$1-2.5 million per robot, and approximately US$160000 annually for upkeep)[55]. Baek *et al*[64] reported that robotic surgery is more expensive than laparoscopic surgery for rectal cancer. In their study, total hospital charges were approximately 1.5 times higher in the robotic group compared with the laparoscopic group. Given the high costs involved in surgical treatment using robotics, it is imperative that the cost-effectiveness of robotic rectal cancer surgery be determined based on oncological outcomes and functional results of forthcoming studies.

When evaluating the learning curve of a new technology for oncologic rectal cancer surgery, long-term oncological and functional outcomes (voiding and sexual function) must be addressed. To date, no prospective studies have evaluated long-term functional outcomes of robotic rectal cancer surgery. Kim *et al*[65] have demonstrated that urinary function was recovered over 6 mo after laparoscopic TME compared to over three months after robotic TME. In the same study, patients operated on using a robotic approach also exhibited a shorter recovery time for erectile function (6 mo *vs* 12 mo) when compared to laparoscopic TME. Luca *et al*[66] have assigned that a better preservation of voiding and sexual functions derive from superior movement of articulated robotic instruments, and from a more precise dissection in the narrow pelvis, with accurate identification of the anatomical planes and smaller neural components.

CONCLUSION

In conclusion, it was observed that more frequently, very experienced minimally invasive surgeons are performing robotic rectal cancer surgery. However, the quality of the assembled evidence does not support strong conclusions about most of the parameters of interest. Robotic rectal cancer surgery is still associated to increased cost and operating time. In the setting of the selected patients that characterizes this review, robotic rectal cancer surgery is associated to reduced conversion rates when compared to conventional laparoscopic techniques. Other short-term outcomes are comparable to conventional laparoscopic techniques, if not better. Furthermore, pathological data evaluation suggests that oncologic safety may be preserved after robotic TME. However, further studies are required to evaluate oncologic safety and functional results associated to robotic rectal cancer surgery.

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