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REVIEW

Laparoscopic versus robotic-assisted colectomy and rectal resection: a systematic review and meta-analysis

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Abstract

Purpose Lately, the main technical innovations in the field of colorectal surgery have been the introduction of laparoscopic and robotic techniques; the aim of this study is to investigate the results and the advantages of these two surgical approaches.

Methods Twenty-two studies including 1652 laparoscopic and 1120 robotic-assisted resections were analyzed and categorized into right, left, and pelvic resections of the middle/low rectum, aiming to the following outcomes: operating time, blood loss, bowel function recovery, return to oral intake, morbidity, hospital stay, and costs.

Results The vast majority of the studies were non-randomized investigations (19/22 studies) enrolling small cohorts of patients (median 55.0 laparoscopic and 34.5 robotic-assisted group) with a mean age of 62.2–61.0 years. Funnel plot analysis documented heterogeneity in studies which combined cancers and benign diseases.

Our meta-analysis demonstrated a significant difference in favor of laparoscopic procedures regarding costs and operating time (standardized mean difference (SMD) 0.686 and 0.493) and in favor of robotic surgery concerning morbidity rate (odds ratio (OR) 0.763), although no benefits were documented when analyzing exclusively randomized trials. When we differentiated approaches by side of resections, a significant difference was found in favor of the laparoscopic group when analyzing operating time in left-sided and pelvic procedures (SMD 0.609 and 0.529) and blood loss in pelvic resections (SMD 0.339).

Conclusion Laparoscopic techniques were documented as the shorter procedures, which provided lower blood loss in pelvic resections, while morbidity rate was more favorable in robotic surgery. However, these results could not be confirmed when we focused the analysis on randomized trials only.

Introduction

Colon and colorectal resections are some of the most common surgical procedures. They can be regarded as the standard of care for non-metastatic colon cancers and are often required for treating benign diseases [1–3].

Over the last few years, considerable progress has been made in improving survival and quality of life of patients undergoing colorectal surgery, the main technical innovations being the introduction of laparoscopy in 1991 [4] and the robotic DaVinci system 10 years later [5].

The introduction of laparoscopy was initially the cause for concern regarding the learning curve, and a possible development of port-site metastasis or inadequate oncologic resections [6–9]. All these problems were subsequently resolved, and a number of studies recognized the benefits of minimally invasive surgery. These advantages included lower blood loss, earlier recovery of bowel function, earlier return to oral intake, and shorter hospital stay [10].

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Similarly, some authors recently reported the technical advantages of robotic surgery (e.g., 3D imaging and higher degrees of articulation and rotation) as particularly useful for dissecting intra-pelvic rectal cancers [11].

Nevertheless, there is little scientific literature available regarding studies that compare robotic versus laparoscopic colorectal resections, and they generally include heterogeneous types of research, with considerable variation in their design (randomized/non-randomized), the outcome measures considered (short/long-term results, costs analysis) and the selection criteria of patients (colon and/or rectal cancers/benign diseases). This, naturally, makes difficult to summarize results.

Thus, on the basis of this background and in order to highlight benefits and the short-term advantages of these techniques, we aimed this manuscript to systematic review and a comprehensive meta-analysis of studies which compare laparoscopic and robot-assisted colorectal resections.

Our primary objective was to highlight the designs and selection criteria and patients' clinical and demographical features, along with surgical and functional postoperative results (operating time, blood loss, hospital stay, number of nodes harvested in the specimens), differentiating results whenever possible according to the side of resection. Of note, there have been few studies that have made this type of differentiation, and we feel that it might help readers in understanding the analyses. Moreover, we reviewed and meta-analyzed the costs related to these procedures.

Materials and methods

Data source and study design This investigation was conducted in accordance with the PRISMA Statements for review and meta-analysis (Fig. 1). We conducted a systematic review of literature by searching the PubMed, Ovid (Wolters Kluwer®), and ScienceDirect (Elsevier®) databases for all published series and trials which compared laparoscopic and robotic-assisted colorectal resections. Keywords "laparoscopic vs robotic colectomy" and "laparoscopic vs robotic rectal resection" of "English" language, limited to human, including clinical trials and comparative studies, were searched. We also included references from retrieved publications. Duplicate references were removed by manual search. The authors of this study were blinded to authors' and journals' names while reviewing the series and did not have any contact with the authors of the included papers. We did not consider any journal's scores (e.g., journal's Impact Factors) of published articles as exclusion criteria. Each paper retrieved was assessed for inclusion or exclusion in our study, by revision of titles and abstracts. Published laparoscopic series which lacked a robotic-assisted group or vice versa were excluded (see exclusion list, Fig. 1).

Systematic review Patients from different studies were combined in a pooled analysis for statistical analyses, providing a systematic review of the literature. A first analysis was conducted in order to outline study designs (randomized/non-randomized studies) and the populations included in each group (age at the time of surgery, BMI, American Society of Anaesthesiologists (ASA) score, stage and rate of cancer patients). In order to assess a possible bias, those manuscripts which included a mixed series of cancer and benign diseases were evaluated using a funnel plot analysis.

The subsequent analyses focused on the surgical and functional results of studies that compare laparoscopic and robotic-assisted resections, overall or one single side at the time. In fact, whenever possible, we categorized studies according to the side of resection as follows: (a) right colon resections, (b) left colon resections, and (c) pelvic resections (if included a resection of the middle/low rectum).

Outcome measures We considered as short-term outcome measures (a) operating time (measured in minutes), (b) blood loss (measured in milliliters), (c) bowel function recovery (defined by the passage of the first flatus/stool; measured in days), (d) return to oral intake (usually liquid diet; measured in days), (e) morbidity (defined by the rate of peri-operative complications), and (f) hospital stay (measured in days).

Of note, since complications were often reported using different modalities (e.g., major vs minor complications, and rate of adverse events), we extrapolated the overall morbidity rate in each group (laparoscopic and robotic-assisted surgery).

The oncologic adequateness was assessed as the mean number of lymph nodes harvested in surgical specimens. Cost analysis was conducted by recording the overall hospital costs for both procedures. These costs are expressed in US dollars in order to better compare results.

We did not consider conversion surgery or hospital volume, since they are seldom reported, even though the learning curves and the volume of patients might generate variations in short-term results and costs.

Statistics and meta-analysis Categorical variables were analyzed using frequencies and percentages, and groups were compared using chi-square tests. Continuous variables were provided using means and medians. Moreover, standard deviations (SDs), standard errors (SEs), range, and 95 % confidence intervals (95%CIs) were also recorded.

Age at surgery and BMI were recorded, presented using a weighted mean analysis, and analyzed using a t test according to the formulas provided by Bland and Kerry [12].

Fig. 1 Study design in accordance with the PRISMA guidelines for ▶ systematic reviews and meta-analysis; lists of included and excluded papers are provided; PM: PubMed Search; Ovid (Wolters Kluwer®); SciDir: ScienceDirect (Elsevier®)

PM- Ovid- SciDir Search
Keywords: Laparocopy *vs*
robotic colectomy
Limits: English; Humans

Laparocopy *vs robotic*
rectal resection
Limits: English; Humans

26 manuscripts

Manual search

5 manuscripts

9 manuscript excluded
(see exclusion list)

22 manuscripts for
systematic review

21 manuscripts for meta-analysis

n	Author	Reference	Exclusion
1	Jou YY	Jama Surg 2014	Different outcome measure
2	Jafari MD	Surg Endosc 2013	Absence of laparoscopy group
3	Tyler JA	Dis Colon Rectum 2013	Different outcome measure
4	Collinson FJ	Int J Colorect Dis 2012	Absence of quantitative data
5	Agcaoglu O	Ann Surg Oncol 2012	Absence of colorectal patients
6	Fujii S	Hepatogastroenterology 2011	Different outcome measure
7	Obias V	Int J Med Robot 2011	Absence of laparoscopy group
8	Schlachta CM	Surg Endosc 2010	Absence of robotic-rssisted group
9	Schlachta CM	Surg Endosc 2007	Absence of robotic-rssisted group
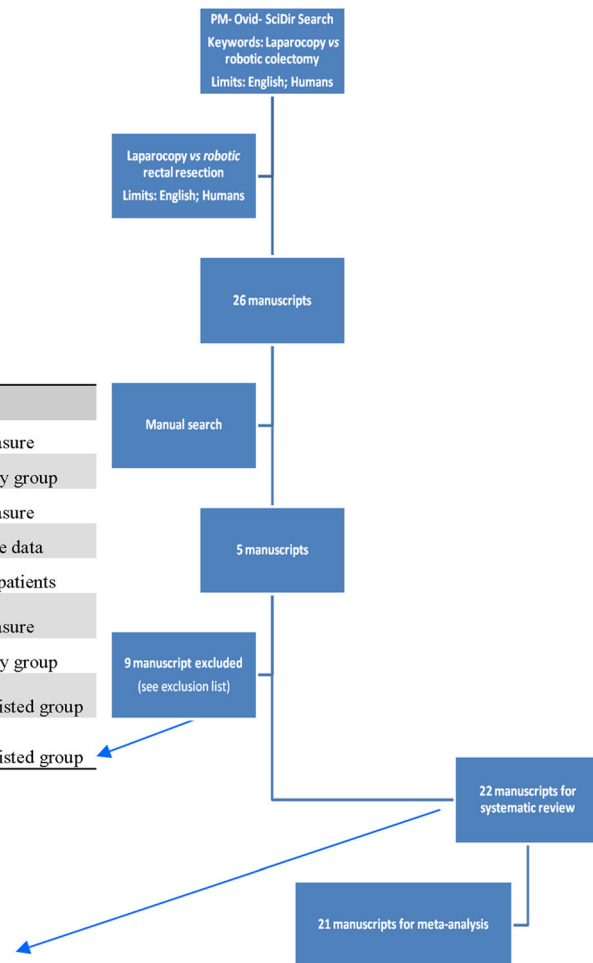
n	Author	Reference	Laparoscopy group	Robotic Assisted group	Design
1	Ielpo B	Int J Med Robotics Comput Assist Surg 2014	87	56	Case-control
2	Erguner I	Surg Laparosc Endosc Percutan Tech 2013	37	27	Case-control
3	Casillas MA Jr	Am J Surg 2013	200	144	Case-control
4	Fernandez R	Am J Surg 2013	59	13	Case-control
5	Lim DR	Surg Endosc 2013	146	34	Case-control
6	Kang J	Ann Surg 2013	165	165	Case-control
7	Deutsch GB	Surg Endosc 2012	92	79	Case-control
8	Miller AT	J Gastrointest Surg 2012	17	17	Case-control
9	Park JS	Br J Surg 2012	35	35	Randomized
10	Baek SJ	World J Surg 2012	150	154	Case-control
11	Bertani E	Int J Colorectal Dis 2011	30	34	Case-control
12	Jimenez Rodriguez RM	Cir Esp 2011	28	28	Randomized
13	deSouza AL	Dis Colon Rectum 2010	135	40	Case-control
14	Park JS	Ann Surg Oncol 2010	82	41	Case-control
15	Bianchi PP	Surg Endosc 2010	25	25	Case-control
16	Baik SH	Ann Surg Oncol 2009	57	56	Randomized
17	Patriti A	JSLS 2009	37	29	Case-control
18	Spinoglio G	Dis Colon Rectum 2008	161	50	Case-control
19	Rawlings AL	Surg Endosc 2007	27	30	Case-control
20	Woeste G	Int J Colorectal Dis 2005	23	4	Case-control
21	D'Annibale A	Dis Colon Rectum 2004	53	53	Case-control
22	Delaney CP	Dis Colon Rectum 2003	6	6	Case-control

A funnel plot was computed using the MetaXL v.2.2 meta-analysis tool (EpiGear, Brisbane, Australia), showing in the horizontal axis the ln odds ratio (OR) and in the vertical line the SE calculated using the inverse variance fixed effects model.

Meta-analyses were conducted when at least three studies provided computable variables. The Mantel–Haenszel method was used to calculate the weighted summary odds ratio. The heterogeneity statistic was then incorporated to calculate the summary odds ratio under the random effects model. The total odds ratio with 95%CI was given both for the fixed effects model and the random effects model, assuming that if the value 1 is not within the 95%CI, the odds ratio is statistically significant at the 5 % level ($p<0.05$). For the meta-analysis of studies with a continuous measure (comparison of means between treated cases and controls), the Hedges g statistic was used for the formulation of the standardized mean difference (SMD). The heterogeneity statistic was then incorporated to calculate the summary standardized mean difference under the random effects model, assuming that if the value 0 is not within the 95%CI, the SMD is statistically significant at the 5 % level ($p<0.05$). Statistical heterogeneity of results was assessed on the basis of a test of heterogeneity. Of note, if the test of heterogeneity is statistically significant ($p<0.05$), more emphasis should be placed on the random effects model.

Statistical analysis was performed using MedCalc for Windows, version 10.2.0.0 (MedCalc Software®, MariaKerke, Belgium). All tests were two-tailed and a $p<0.05$ was considered to be statistically significant.

Results

Study design and patients: systematic review Figure 1 shows the 22 studies analyzed, which included 2772 patients: 1652 laparoscopic and 1120 robotic-assisted colorectal resections [13–34]. The vast majority of literature has been published over the last 3 years, with just seven papers published before 2010. Almost all the literature is based on case–control series except the papers by Park in 2012, Baik in 2009, and Jimenez Rodriguez in 2011 which are randomized trials [20, 26, 33].

The vast majority of papers focused on colorectal pelvic resections [13, 15–17, 19, 21, 24–27, 34], whereas two studies evaluated right colectomies [20, 23], one study exclusively left colectomies [30], and the remaining authors presented a mixed series of colorectal resections [14, 18, 28, 29, 31–33].

Table 1 outlines the features of the study populations. Overall, the mean number of patients enrolled in laparoscopic groups was of 75.1 versus a mean of 50.9 patients in robotic-assisted groups. The median number of patients enrolled was 55 in the laparoscopic resection group and just 34.5 in the robotic-resection group. Because of the great number of

papers evaluating pelvic rectal cancers, pelvic resections were the most frequent procedures in robotic-assisted groups (59.7 % of laparoscopic resections vs 67.8 % of robotic-assisted procedures; chi-square test $p<0.0001$).

Even though the vast majority of the literature referred to studies on cancer patients, the rate of benign diseases was higher in the robotic-assisted group compared to that in laparoscopic patients, although the difference was not statistically significant (respectively 20.5 vs 17.6 %; chi-square 0.06). Moreover, studies that combined cancer and benign patients were analyzed using a funnel plot (Fig. 2) [14, 18, 23, 28, 29, 31, 32], which indicated a mild asymmetry due to heterogeneity in studies conducted by Spinoglio [28] (SE 0.47; ln OR 0.63), Deutsch [18] (SE 0.43; ln OR −1.55), and D'Annibale [31] (SE 0.43; ln OR −1.68), $p=0.0015$.

Both groups presented a high prevalence of patients scoring ASA 1/2 (reaching 82.3 % in the robotic-assisted group; Table 1, chi-square 0.002).

Similarly, the rate of stage I/II patients was high but comparable in both groups (laparoscopy vs robotic-assisted, respectively, 65.7 vs 68.2 %, p not significant (ns)). Weighted mean of ages at surgery has been included in Table 1. According to our analysis, the weighted mean of reported ages was 62.2 years in the laparoscopic group and 61.0 years in the robotic assisted group (t test, p ns).

Similarly, the BMI of patients was found to be comparable between groups (weighted mean laparoscopy vs robotic surgery, respectively, 24.0 vs 23.9; t test, p ns).

Outcome measures: systematic review Table 2 shows the surgical and functional results of the two different procedures according to selected case series. The vast majority of studies reported a longer operating time for the robotic-assisted group, the only exception being Park in 2010 and 2012 [20, 24].

Even though the estimated mean of blood loss varied widely between studies, the vast majority of case series were homogeneous when considering the results between subgroups, with the sole exception of Erguner, who reported lower losses in the group treated with a robotic-assisted procedure [34].

Bowel function recovery was found to be similar between groups, with the sole exception of Miller who reported a shorter recovery time for patients undergoing proctocolectomy via laparoscopic procedures [19] and Lim who reported a shorter recovery for patients treated with robotic-assisted surgery [16].

Moreover, Lim and Baik reported a faster return to oral intake in the robotic-assisted group [16, 26].

Data regarding hospital stay ranged widely between studies. However, Miller alone [19] reported a shorter recovery for patients undergoing proctocolectomy via laparoscopic procedures, while Baik [26] reported a shorter hospitalization in the robotic-assisted group.

Table 1 Clinical and surgical data of studies comparing laparoscopic vs robotic-assisted colectomies

	Laparoscopy	Robotic-assisted	*p* value
Overall enrolled, *n*	1652	1120	n/a
Mean; SD	75.1; 58.3	50.9; 45.6	
Median	55.0	34.5	
Range	6–200	4–165	
Side of surgical procedure, n (%)			
Right colectomy	409.0 (25.2 %)	193.0 (17.8 %)	Chi-square test *p*<0.0001
Left colectomy	245.0 (15.1 %)	157.0 (14.5 %)	
Pelvic resection	967.0 (59.7 %)	736.0 (67.8 %)	
Total	1621.0 (100.0 %)	1086.0 (100.0 %)	
Histology, n (%)			
Cancer	1362.0 (82.4 %)	879.0 (79.5 %)	Chi-square test *p*=0.06
Benign disease	290.0 (17.6 %)	226.0 (20.5 %)	
Total	1652.0 (100.0 %)	1105.0 (100.0 %)	
ASA score, n (%)			
ASA 1/2	777.0 (75.6 %)	483.0 (82.3 %)	Chi-square test *p*=0.002
ASA 3/4	251.0 (24.4 %)	104.0 (17.7 %)	
Total	1028.0 (100.0 %)	587.0 (100.0 %)	
Stage of cancer patients, n (%)			
Stage 1/2	654.0 (65.7 %)	398.0 (68.2 %)	Chi-square test *p*=0.33
Stage 3/4	342.0 (34.3 %)	186.0 (31.8 %)	
Total	996.0 (100.0 %)	584.0 (100.0 %)	
Age (years)[a]			
Weighted mean	62.2	61.0	*t* test *p* ns
BMI[b]			
Weighted mean	24.0	23.9	*t* test *p* ns

n/a not available, *SD* standard deviation, *ASA* American Society of Anaesthesiologists, *BMI* body mass index, *ns* not significant

[a] Wheighted mean calculated on the studies by Delaney CP, D'Annibale A, Spinoglio G, deSouza AL, Bertani E, Miller AT, Park JS, Fernandez R, Lim DR, Baek SJ, Park JS, Baik SH, Ielpo B, Patriti A, Kang J, Bianchi PP, and Jimenez Roriguez RM

[b] Wheighted mean calculated on the studies by Delaney CP, deSouza AL, Bertani E, Miller AT, Park JS, Lim DR, Baek SJ, Baik SH, Ielpo B, Patriti A, Kang J, Deutsch GB, Bianchi PP, and Jimenez Roriguez RM

Even though the vast majority of studies recognized an adequate yield of nodes retrieved in specimens, the studies by Ielpo and Patritri reported a mean number of nodes <12 [13, 27].
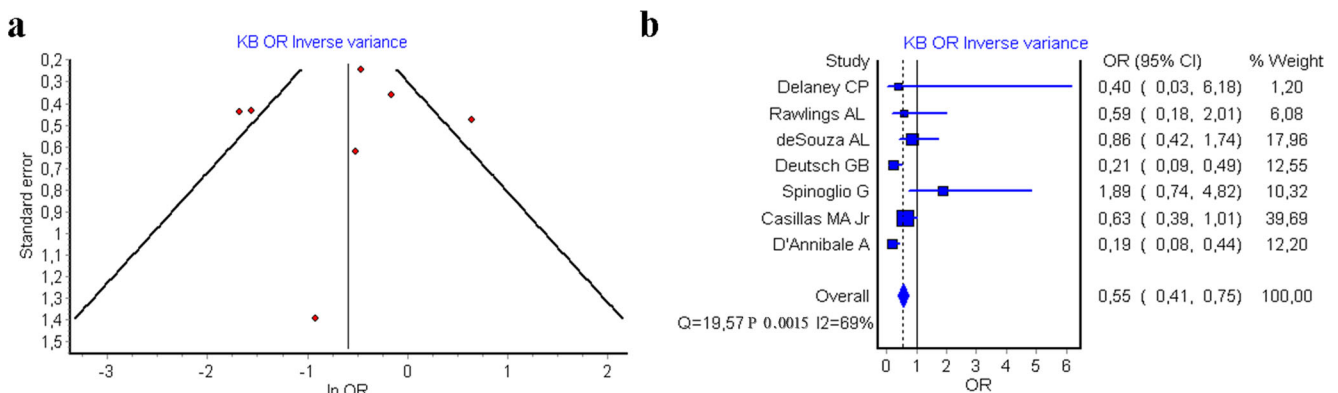

Fig. 2 **a** Funnel plot and **b** dorest plot analyses of studies which compare laparoscopic versus robotic-assisted colectomies presenting mixed series of cancer and benign diseases

Table 2 Outcomes of studies comparing laparoscopic versus robotic-assisted colectomies

Number	Author	OT (min) Lap group	OT (min) RA group	EBL (ml) Lap group	EBL (ml) RA group	BFR (days) Lap group	BFR (days) RA group	T-OI (days) Lap group	T-OI (days) RA group	HS (days) Lap group	HS (days) RA group	LNH, n Lap group	LNH, n RA group	MR (%) Lap group	MR (%) RA group
1	Ielpo B 2014 Lap group n=87 / RA group n=56	252.0 *p 0.020*	309.0	240.0	280.0					10.0	13.0	9.0	10.0		
2	Casillas MA Jr 2013 Lap group n=200 / RA group n=144									4.0[a]	4.0[a]				
3	Erguner I 2013 Lap group n=37 / RA group n=27	190.0[a] *p 0.020*	280.0[a]	125.0[a] *p<0.001*	50.0[a]					5.0[a]	4.0[a]	16.0[a]	16.0[a]	21.6	11.1
4	Fernandez R 2013 Lap group n=59 / RA group n=13	344.0[a] *p<0.001*	528.0[a]	200.0[a]	157.0[a]					8.0[a]	13.0[a]	20.0	16.0		
5	Lim DR 2013 Lap group n=146 / RA group n=34	217.6 *p 0.01*	252.5	78.2	60.3	2.5 *p 0.04*	2.2	5.2 *p 0.009*	4.5	6.2 *p 0.005*	5.5	16.5 *p 0.030*	12.0	10.3	5.9
6	Kang J 2013 Lap group n=165 / RA group n=165	277.8	309.7	140.1	133.0	2.4	2.2	5.2	4.5	13.5	10.8	15.6	15.0	27.9	20.6
7a	Deutsch GB 2012 Right Colectomies Lap group n=47 / RA group n=18	214.4	219.2	123.2	76.4	3.6	3.,0			6.3	4.3	18.7	21.1		
7b	Deutsch GB 2012 Left Colectomies Lap group n=45 / RA group n=61	254.7 *p 0.0006*	289.7	129.6 *p 0.003*	116.4	3.2	3.1			4.2	4.1	30	10		
8a	Miller ATa 2012 Lap group n=7 / RA group n=7	238.0 *p 0.030*	351.0	214.0	486.0	1.7 *p 0.040*	3.0			4.1 *p 0.020*	6.4				
8b	Miller ATb 2012 Lap group n=10 / RA group n=10	316.0	370.0	172.0	245.0	2.6	3.6			6.1	8.5				

Table 2 (continued)

Number	Author	OT (min) Lap group	OT (min) RA group	EBL (ml) Lap group	EBL (ml) RA group	BFR (days) Lap group	BFR (days) RA group	T-OI (days) Lap group	T-OI (days) RA group	HS (days) Lap group	HS (days) RA group	LNH, n Lap group	LNH, n RA group	MR (%) Lap group	MR (%) RA group
9	Park JS 2012														
	Lap group n=35 / RA group n=35	195.0	130.0	35.8	56.8	2.6	2.9	5.1	5.7	7.9	8.3	29.9	30.8	17.1	20.0
		p<0.001													
10	Baek SJ 2012														
	Lap group n=150 / RA group n=154	219.7	285.2	126.2	167.8	2.2	2.1	2.9	3.0	10.8	11.1			33.3	26.6
		p 0.01													
11	Bertani E 2011														
	Lap group n=30 / RA group n=34	210.0	194.0	110.0	170.0	2.0	2.0	3.0	3.0	5.0	5.0	23.5	25.0	13.3	17.6
12	Jimenez Rodriguez RM 2011														
	Lap group n=28 / RA group n=28	135.1	159.4					2.5	2.3	9.2	9.3			14.2	14.2
		p 0.0001													
12	deSouza AL 2010														
	Lap group n=135 / RA group n=40	118.1	158.9	50.0	50.0					5.0	5.0	16.0[a]	17.0[a]		
		p<0.001													
13	Park JS 2010														
	Lap group n=82 / RA group n=41	168.6	131.1			2.7	2.9	6.6	6.7	9.9	9.4	14.2	17.3	23.2	29.3
		p<0.001													
14	Bianchi PP 2010														
	Lap group n=25 / RA group n=25	237.0[a]	240.0[a]			3.0[a]	2.0[a]			6.0[a]	6.5[a]	17.0[a]	18.0[a]	16.0	20.0
15	Baik SH 2009														
	Lap group n=57 / RA group n=56	190.1	191.1			1.9	2.1	5.5	4.7	7.6	5,7	18,,7	18.4	19.3	10.7
								p 0.008		p 0.001					
16	Patriti A 2009														
	Lap group n=37 / RA group n=29	208.0	202.0	127.0	137.0	1.5	1.0	1.1	7.7	9.6	11.9	11.2	10.3	18.9	30.6
17	Spinoglio G 2008														
	Lap group n=161 / RA group n=50	383.8	266.3		1.7					8.3	22.0	22.9	16.8	14.0	
		p<0.001													

Table 2 (continued)

Number	Author	OT (min) Lap group	OT (min) RA group	EBL (ml) Lap group	EBL (ml) RA group	BFR (days) Lap group	BFR (days) RA group	T-OI (days) Lap group	T-OI (days) RA group	HS (days) Lap group	HS (days) RA group	LNH, n Lap group	LNH, n RA group	MR (%) Lap group	MR (%) RA group
18a	Rawlings AL 2007 Right Colectomies														
	Lap group n=15 RA group n=17	169.2	218.9	66.3	40.0					5.5	5.2				
				p 0.002											
18b	Rawlings AL 2007 Left Colectomies														
	Lap group n=27 RA group n=30	199.4	225.2	65.4	90.4					6.6	6.0				
19	Woeste G 2005														
	Lap group n=23 RA group n=4	172.4	236.7	58.9	60.0									21.7	25.0
		p<0.05													
20	D'Annibale A 2004														
	Lap group n=53 RA group n=53	222.0	240.0	37.0	21.0	4.0	4.0	3.0	3.0	10.0	10.0	16.0	17.0		
21	Delaney CP 2003														
	Lap group n=6 RA group n=6	143.5	220.2	95.8	125.0					3.7	3.0				

Miller AT a: proctectomy, Miller AT b: proctectomy with ileal-pouch anal anastomosis

[a] Median values

Lap group laparoscopy group, *RA group* robotoc-assisted group, *OT* operating time, *EBL* estimated blood loss, *BFR* bowel function recovery, *T-OI* time to oral intake, *HS* hospital stay, *LNH* lymph node harvest, *MR* morbidity rate

Morbidity rate was found to range from 10.3 to 33.3 % in the laparoscopic group, and between 5.9 and 30.6 % in the robotic-assisted group. Of note, all the case series reported homogeneous results between the two approaches, but only a few of the reviewed studies used a standard classification in order to stratify adverse events (e.g., Clavien's classification system) [35].

Meta-analysis: overall studies Figure 3 and Table 3 show the results of the meta-analysis conducted on 21 studies [13, 15–34]. We considered operating time, blood loss, bowel function recovery, time to oral intake, lymph node harvest (LNH), hospital stay, costs, and morbidity rate variables. The standard mean difference (SMD) was significantly different between groups in favor of laparoscopic procedures when considering costs and operating time, and in favor of robotic-assisted group when considering morbidity rate (overall rate 19.4 % in robotic-assisted procedures vs 22.2 % in laparoscopic procedures; OR 0.736; 95%CI 0.607–0.959).

Table 3 shows also the results of the meta-analysis conducted focusing on randomized trials [20, 26, 33]: Although just three variables were computable (operating time, hospital stay,

and morbidity rate), we could not document any benefit or advances related to the robotics or laparoscopic procedures.

Meta-analysis: right-sided colectomies and left-sided colectomies Figure 4 shows the results of the meta-analysis of continuous measures conducted on five studies that reported right-sided colectomies [17, 19, 22, 28–31] and six studies concerning left-sided colectomies [16, 18, 29, 30, 32, 33]. The SMD was computable for operating time, blood losses, and hospital stay variables, and it did not indicate any significant differences between groups for all the variables investigated in right-sided colectomies, whereas operating time was found to be statistically in favor of laparoscopic procedures in left-sided resections (Table 3).

Meta-analysis: pelvic resections Figure 5 shows the results of the meta-analysis of continuous measures conducted on seven studies which report pelvic resections [13, 17, 19, 21, 24, 26, 27]. The SMD was computable for operating time, blood loss, LNH, and hospital stay variables, and it indicated a significant difference between groups in favor of laparoscopic procedures which analyzed operating time and blood losses variables (Table 3).
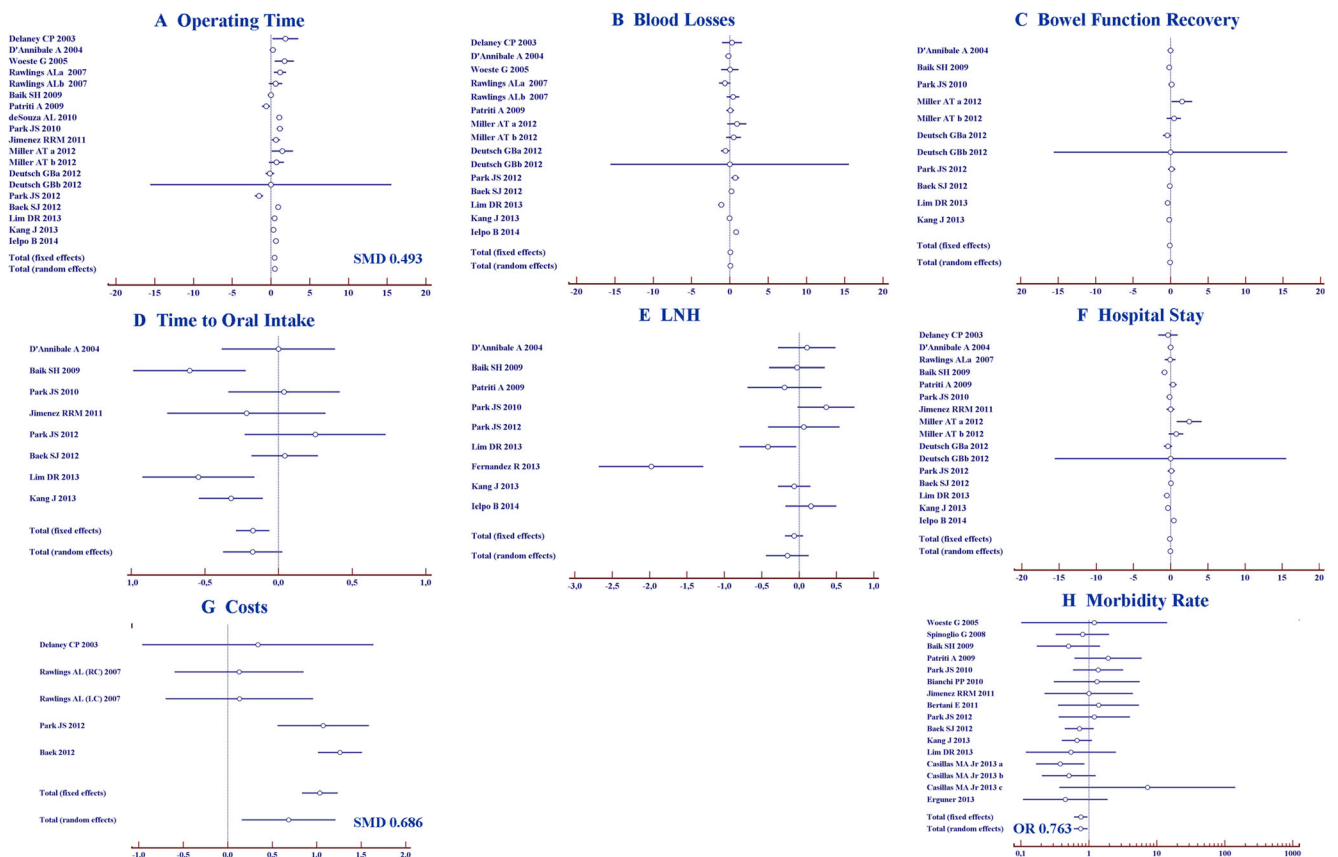

Fig. 3 Meta-analysis of studies which compare laparoscopic and robotic assisted colectomies. Miller AT a: proctectomy; Miller AT b: proctectomy with ileal-pouch anal anastomosis; Rawlings Al a: right colectomy; Rawlings AL b: left colectomy; Deutsch GB a: right colectomy; Deutsch GB b: left colectomy; Casillas MA Jr a: right colectomy; Casillas MA Jr b: left colectomy; Casillas MA Jr c: pelvic resection. *SMD*: standard mean difference; *OR*: odds ratio

Table 3 Meta-analysis of studies comparing laparoscopic *vs* robotic-assisted colorectal resections

	RA group no. of patients	Lap group no. of patients	Total no. of patients	SMD/OR	95%CI	Q test *p* value
Overall studies						
*Operating time	**767**	**1097**	**1864**	**0.493**	**0.189–0.798**	**<0.0001**
Blood losses	602	795	1397	0.0635	−0.240 to 0.367	<0.0001
Bowel function recovery	574	754	1328	−0.0983	−0.211 to 0.014	0.1209
Time to Oral Intake	566	716	1282	−0.175	−0.376 to 0.0262	0.00262
LNH	482	721	1203	−0.156	−0.443 to 0.130	<0.0001
Hospital stay	710	927	1637	−0.0485	−0.266 to 0.169	<0.0001
*Costs	**225**	**218**	**443**	**0.686**	**0.159–1.213**	**0.0026**
**Morbidity rate	**161/826**	**262/1176**	**2002**	**0.763**	**0.607–0.959**	**0.5145**
Randomized studies						
Operating time	119	120	239	−0.297	−1.439 to 0.845	<0.0001
Hospital stay	119	120	239	−0.258	−0.889 to 0.374	0.0034
Morbidity rate	17/119	21/120	239	0.786	0.392–1.576	0.5328
Right-sided colectomies						
Operating time	112	234	346	0.0975	−0.328 to 0.469	0.0674
Blood losses	72	99	171	−0.168	−1.055 to 0.719	0.0012
Hospital stay	72	99	171	−0.0815	−0.399 to 0.236	0.6636
Left-sided colectomies						
*Operating time	**143**	**257**	**400**	**0.609**	**0.381–0.836**	**0.4293**
Blood losses	115	229	344	−0.168	−0.848 to 0.511	0.0004
Hospital stay	139	234	373	−0.222	−0.449 to 0.006	0.4326
Pelvic resections						
*Operating time	**518**	**595**	**1113**	**0.529**	**0.141–0.918**	**<0.0001**
*Blood losses	**421**	**456**	**877**	**0.339**	**0.0124–0.666**	**0.001**
Hospital Stay	518	595	1113	0.111	−0.261 to 0.484	<0.0001
LNH	360	487	847	−0.212	−0.623 to 0.199	<0.0001

RA group robotoc-assisted group, *Lap group* laparoscopy group, *SMD* standardized mean difference, *OR* odds ratio, *Q test* Cohran's Q test for heterogeneity, *LNH* lymph node harvest, *95%CI* 95 % confidence interval

*Bold values: results statistical in favor of laparoscopic group; **bold values**: results statistical in favor of robotic assisted group

Discussion

To date, a number of studies have provided evidence in support of laparoscopic procedures compared to open colorectal resections regarding several short-term outcomes [10], but there have been only a limited number of studies that have investigated the robotic approach, so literature is still at an early stage.

First, it seems important to highlight that we documented some issues concerning study design and power due to the non-randomization (19 out of 22 studies reviewed) and the small number of patients enrolled in each group (median 34.5–55 patients, Table 1). Moreover, funnel plot analysis indicated heterogeneity in studies which combined cancer and benign diseases. According to the recommendations provided by Sterne and co-authors [36], this asymmetry could be related to a possible bias, even though the visual interpretation alone might not be a sufficient criterion. Furthermore, this analysis was conducted on only seven studies. Nevertheless, both these issues (power and histology selection) should be

considered in the design of future studies that aim to compare these approaches.

Finally, we found a prevalence of studies which focused on rectal resections and which enrolled low-risk patients (<65 years old, ASA 1/2, low BMI). This data mirrors the early stage of the literature in this field: Indeed, a certain bias of selection of less co-morbid patients can occur when introducing into practice a new procedure, like robotic resections. In order to validate the selection criteria, we compared the clinical data of a series of unselected patients that had undergone right-sided laparoscopic resections at our department between 2005 and 2012 (49 patients) with those of the right-sided colectomies herein reviewed. Even though a trend of prevalence of ASA 1/2 and stage I/II patients was registered in the robotic-assisted groups, subgroups were found to be homogeneous for these variables, with similar age and BMI (chi-square test and *t* test, *p* ns; data not shown). Therefore, we could consider these demographical features to be consistent with our clinical setting.
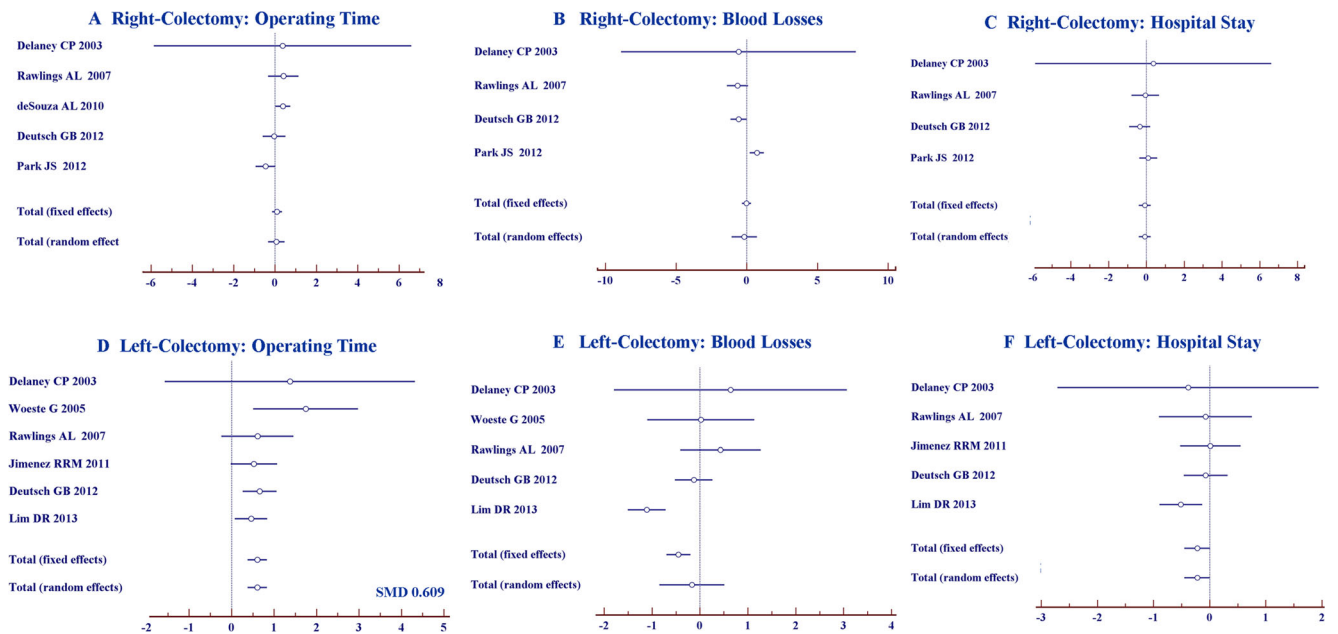
Fig. 4 Meta-analysis of studies which compare laparoscopic and robotic assisted right and left colectomies. *SMD*: standard mean difference

According to our results, a number of authors documented differences of statistical value in relation to some outcome measures, but the main findings regarded operating time, morbidity rate, and costs. Overall, operating time has been reported to be longer in robotic procedures by the vast majority of authors, and this trend was confirmed in our meta-analysis, possibly because of the early stage of learning curves. A possible explanation could be also related to the excursion of the robotic arms and the length of the surgical instruments that

may limit the robotic system. Moreover, there have been reports regarding the difficulties the robotic instruments have in reaching splenic flexure and pelvis and in dissecting different abdominal areas which may require a repositioning of the surgical cast. In order to address these issues, a new generation of daVinci S robot has been recently introduced [37]. Furthermore, as documented by Lim, the progress of the learning curve has a significant impact on operating time, both on the docking and on the consol periods. The results for robotic
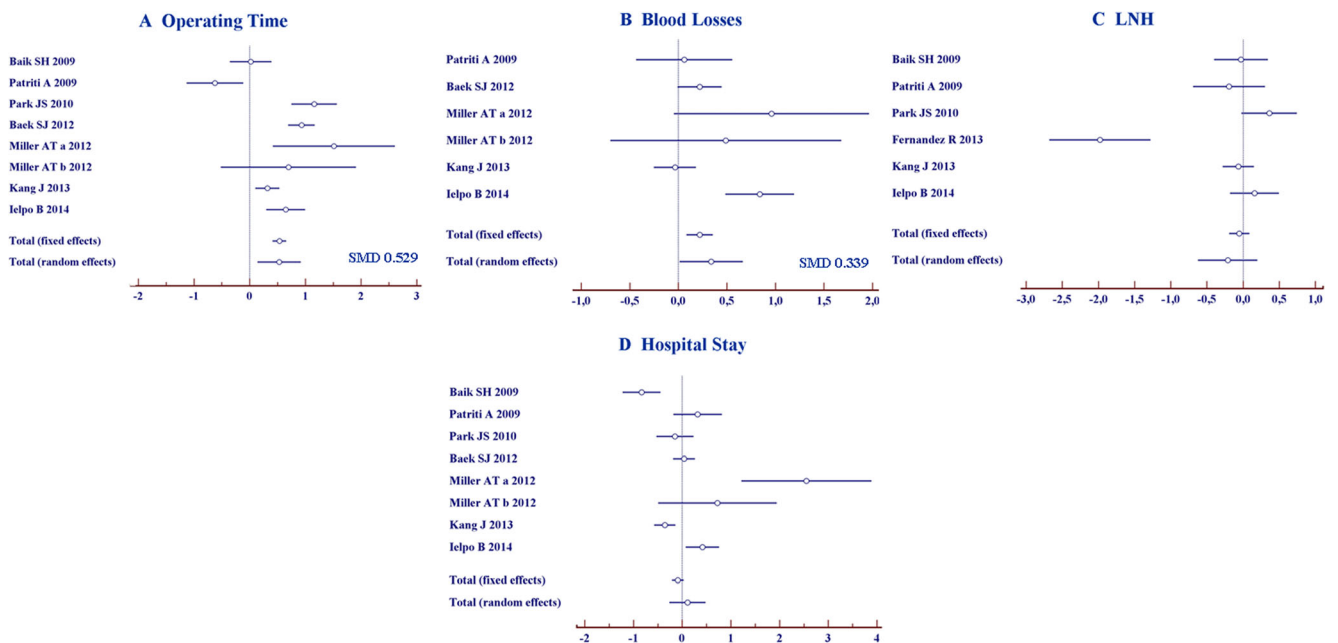

Fig. 5 Meta-analysis of studies which compare laparoscopic and robotic assisted pelvic rectal resections; Miller AT a: proctectomy; Miller AT b: proctectomy with ileal-pouch anal anastomosis. *SMD*: standard mean difference

total mesorectal excision are evidenced after the first 32 cases [38]. On this basis, we would expect a reduction in this difference in the near future, when the use of the robotic instruments becomes a regular practice.

Interestingly, the advantages documented in favor of the laparoscopic group (shorter operating time and minor blood losses) or those highlighted in the robotic patients (lower morbidity rate) could be replicated when we focused the analysis on randomized trials.

A recent meta-analysis which focused on rectal resections documented that conversion rate in the robotic group was significantly lower than in laparoscopic total mesorectal excisions, although no significant differences were reported when analyzing operating time, estimated blood loss, recovery outcome, postoperative morbidity and mortality, length of hospital stay, oncological accuracy of resection, and local recurrences between groups. Moreover, the positive rate of circumferential resection margins and the incidence of erectile dysfunction were found to be lower in robotic group compared to those for laparoscopy [39]. Consistent with these findings, we also found some divergent results, since our meta-analysis highlighted a lower morbidity rate in the robotic-assisted group and lower blood loss in laparoscopic pelvic resections.

Robotic procedures are emerging in gynecology, urology, and abdominal/pelvic surgery [37] and, according to Pigazzi, the most promising frontier regards the total mesorectal excision, since a 3D visualization and greater ability to retract in the deep and narrow pelvis may allow a more precise dissection and may reduce the risk of complications related to pelvic nerve injuries [40].

Costs, however, could remain an issue, since they, as is to be expected, were found to be higher in the robotic-assisted group.

On this basis, we should all wait with great interest for the results of the ROLARR trial, a world-based, prospective, randomized, controlled, un-blinded trial which compares robotic-assisted versus standard laparoscopic surgery for the curative treatment of rectal cancer. This trial commenced in the UK in 2011 and it aims to recruit 400 patients. It will investigate differences in terms of rate of conversion, rate of pathological involvement of circumferential resection margin, 3-year local recurrence, and disease-free and overall survival rates, and also operative morbidity and mortality, quality of life, and cost-effectiveness [41].

Conclusions

It is important to highlight the striking progress that has been made in the last 20 years mostly due to the introduction of these technologies in surgical practice. On the basis of our results, laparoscopic procedures were shorter, providing lower blood losses in pelvic resections. However, morbidity rate was better in robotic surgery. These findings could not be confirmed when we focused the analysis on randomized trials.

Future studies need to focus on (a) the design of powered trials to evaluate benefits, limitations, and cost-effectiveness of these procedures; (b) establishing a clear differentiation of results through histology and side of resection; and (c) a reduction of the training and learning curves which may result in comparable or shorter operating times.

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