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ORIGINAL ARTICLE

Comparison of three-dimensional versus two-dimensional laparoscopic surgery for rectal cancer: a meta-analysis

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Abstract

Purpose Three-dimensional (3D) vision technology has recently been validated for the improvement of surgical skills in a simulated setting. This study assessed the current evidence regarding the efficiency and potential advantages of 3D compared with two-dimensional (2D) laparoscopic rectal surgery for rectal cancer.

Methods We comprehensively searched PubMed, EMBASE and the Cochrane Library and performed a systematic review and cumulative meta-analysis of all randomized controlled trials (RCTs) and non-randomized controlled trials (nRCTs) assessing the two approaches.

Results Four trials including a total 331 cases were identified. The positive circumferential resection margins (CRMs) were significantly lower for the 3D group ($P = 0.02$). The operative time was significantly shorter in the 3D group than in the 2D group ($P < 0.00001$). There was less estimated blood loss (EBL) in the 3D group than in the 2D group ($P = 0.02$). Perioperative complication rates, conversion rate, harvested lymph nodes, first flatus, length of stay, pneumonia, wound infection, ileus, anastomotic fistula and urinary retention did not differ significantly between the two groups ($P > 0.05$).

Conclusions In summary, 3D laparoscopic rectal surgery appears to have advantages over 2D laparoscopic rectal surgery in terms of positive CRM and operation time; however, it is not better than 2D laparoscopic rectal surgery in terms of the conversion rate and postoperative complications.

Keywords Three-dimensional · Two-dimensional · Laparoscopic surgery · Rectal cancer · Meta-analysis

Introduction

Rectal cancer is one of the major causes of cancer-related mortality in both men and women worldwide [1, 2]. Since the introduction of minimally invasive techniques for gastrointestinal surgery, laparoscopic approaches have experienced a gradual rise in use for low anterior resection in rectal cancer. The laparoscopic approach has shown better short-term outcomes than the open approach [3, 4], with no differences in oncologic outcomes [5] and no long-term disadvantages [6]. However, surgeons work in a three-dimensional (3D) space but are guided in two-dimensional (2D) images provided by laparoscopy cameras; losing true depth perception and lacking spatial orientation may increase the risk of errors and the operative time [7, 8]. The high-definition resolution of the 3D imaging system can clearly image the microtissue structure, which is more conducive to fine operation and conforms to the concept of minimally invasive treatment [9]. However, the potential advantages of 3D imaging systems on the performance or outcomes following advanced laparoscopic procedures have not been proven. We therefore systemically searched and analysed the available literature to evaluate the efficiency and potential advantages of 3D laparoscopic surgery.

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Methods

Literature search strategy

We searched PubMed, EMBASE and the Cochrane Library for relevant articles (up to February 1, 2019). The following MeSH terms and their combinations were searched in [Title/Abstract]: 2D/3D/Two-dimensional/Three-dimensional, Laparoscopic, Rectal/Colorectal/Total mesorectal excision (TME). The search strategy also used several text terms to identify relevant information. Reference lists from relevant primary studies and review articles were examined to find other additional publications.

Study inclusion and exclusion criteria

All available randomized controlled trials (RCTs) or non-randomized trials (nRCTs) that compared 3D with 2D laparoscopic rectal surgery for rectal cancer and that had at least one of the quantitative outcomes mentioned in the next section were included. Repeat publications and duplication of data from the same unit or hospital, absence of the outcomes of interest, other aspects of rectal cancer (synchronous colorectal cancer, acute intestinal obstruction, recurrent rectal cancer, rectosigmoid cancer and colorectal metastases), rectal benign diseases, case reports, non-English articles, and review/opinion articles guidelines, and conferences were excluded.

Data extraction and quality assessment

Two investigators independently extracted and evaluated all eligible studies. Any disagreement was resolved by the third author. The primary outcomes were perioperative complication rates, conversion rates, harvested lymph nodes, positive circumferential resection margins (CRM), complete TME and distal margins. The secondary outcomes were operative time, estimated blood loss (EBL), first flatus, length of stay, pneumonia, wound infection, ileus, anastomotic fistula and urinary retention. For each study, the patient characteristics were extracted if available. Efforts were made to obtain the exact numerical data from the authors via e-mail if not available in the articles. The quality of randomized trials was assessed through the Jadad score (score assigned ranged from 0 to 5 for each study) [10]; conversely, the quality of the observational comparative studies was assessed by the Newcastle-Ottawa scale (NOS), in which a score of 0 to 9 was assigned to each study [11]. Scores ≥ 3 points and ≥ 6 points were considered high quality using the Jadad scale and NOS, respectively.

Statistical analysis

Continuous variables were pooled using the weighted mean difference (WMD) with 95% confidence interval (CI), while the odds ratio (OR) with 95% CI was applied to perform the statistical analysis for the dichotomous variables. Furthermore, the primary outcomes between the 3D and 2D groups were assessed in subgroups based on RCTs and non-RCTs. Statistical heterogeneity was evaluated using the chi-square test with significance set at $P < 0.10$, and heterogeneity was quantified using the I^2 statistic. The random-effects model was used for data analysis if there was heterogeneity between the studies; otherwise, the fixed-effects model was used [12]. Funnel plots were used to assess the publication bias. If the data on continuous outcomes were reported as medians and ranges, we estimated the mean and standard deviation according to Hozo's methods [13]. The meta-analysis was conducted with Review Manager Version 5.3 (the Cochrane Collaboration, Oxford, London, UK). $P < 0.05$ was considered significant.

Results

Our initial search identified 967 potentially relevant studies, of which 179 studies were removed because of duplication. After screening the titles and abstracts, 765 were excluded due to lack of relevance. The remaining 23 papers were considered potentially eligible for full text review. Of these, 4 studies were included in the meta-analysis [14–17] (Fig. 1). Two RCTs [15, 17] and two nRCTs [14, 16] were included, with a total of 331 patients ($n = 171$ in the 3D group and $n = 160$ in the 2D group). Examination of the references listed for these studies and for the review articles did not yield any further studies for evaluation. The characteristics of the included studies are summarized in Table 1.

Primary outcomes

The overall complication rate data were supplied for 2 of the 4 trials with 134 patients involved [15, 17]. Among 68 patients in the 3D group, 36 patients (52.9%) had complications, while among 66 patients in the 2D group, 36 patients (54.5%) had complications; Fig. 2 shows that there was no significant difference between the 3D and 2D groups (OR, 0.93; 95% CI, 0.46–1.85; $P = 0.83$). The data for the overall conversion rate were supplied for 2 of the included 4 trials with 134 patients involved [15, 17]. Among the 68 patients in the 3D group, 5 patients (7.3%) needed to be converted to laparotomy, while among the 66 patients in the 2D group, 7 patients (10.1%) needed to be converted to laparotomy; Fig. 3 shows that there was no significant difference between the 3D and 2D groups (OR, 0.67; 95% CI, 0.20–2.28; $P = 0.52$). Harvested lymph

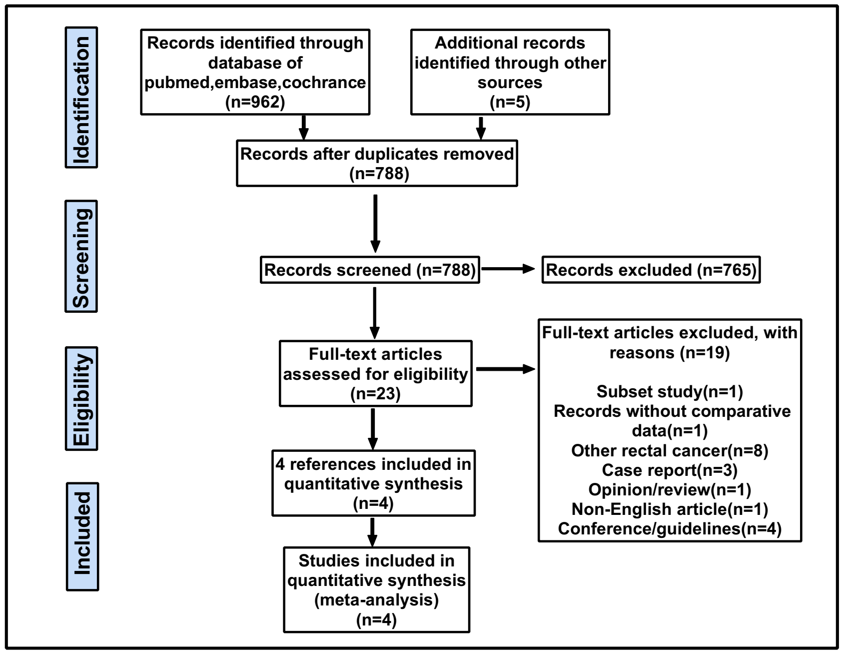

Fig. 1 Study selection diagram for meta-analysis of 3D and 2D procedures

nodes were reported in 4 studies including 331 patients [14–17]; there were no significant differences between the 3D and 2D groups, regardless of the overall effect (WMD, 0.34; 95% CI, − 0.18–0.87; $P = 0.20$; Fig. 4a) or subgroup analyses: RCT (WMD, 0.03; 95% CI, − 1.13–1.19; $P = 0.96$; Fig. 4a) and nRCT (WMD, 0.43; 95% CI, − 0.17–1.02; $P = 0.16$; Fig. 4a). The data regarding positive CRM were supplied for 3 of the included 4 trials with 286 patients involved [14, 15, 17]. Among 144 patients in the 3D group, 5 patients (3.5%) were found to have positive CRM, and 16 patients (11.3%) were found to have positive CRM in the 2D groups. The percentage of patients with positive CRM was significantly lower in the 3D group than in the 2D group in the overall effect (3.5% and 11.3%; OR, 0.28; 95% CI, 0.10–0.79; $P = 0.02$; Fig. 4b). However, there were no significant differences between the 3D and 2D groups in the subgroup analyses: nRCT (OR, 0.41; 95% CI, 0.12–1.36; $P = 0.14$; Fig. 4b) and nRCT (OR, 0.13; 95% CI, 0.02–1.10; $P = 0.06$; Fig. 4b). The complete TME and distal margins were reported by only one study [17], and these could not be pooled in a meta-analysis.

Secondary outcomes

The operative time data were supplied for all of the included trials with 331 patients involved [14–17]. The operative time was significantly shorter in the 3D group than in the 2D group (WMD, 11.33; 95% CI, − 14.53 to − 8.13; $P < 0.00001$) (Table 2). EBL was reported in 3 studies including 243 patients [14–16]; there was less blood loss in the 3D group than in the 2D group (WMD, − 7.09; 95% CI, − 12.85 to − 1.33; $P = 0.02$) (Table 2). The length of stay was reported in 2 studies including 198 patients, and there were no significant differences between the 3D group and 2D group (WMD, − 0.38; 95% CI, − 0.85–0.10; $P = 0.12$) (Table 2). The first flatus was reported in only one study [15], and there was no difference between the 3D and 2D groups ($P = 0.235$). For this reason,

Table 1 Characteristics of the studies included in the meta-analysis

Author/year	Study type	NOS stars/ Jadad score	3D vs 2D							Follow-up (months)
			No. of patients	Mean age (year)	%male	BMI (kg/m^2)	T2	T3	T4a	
Curtis NJ, 2019	RCT	−/3	45 vs 43	69 ± 10 vs 69 ± 11	64 vs 51	27 ± 4 vs 29 ± 5	NA	NA	NA	1
Zhang Q, 2017	Pro	7★/−	76 vs 76	55.3 ± 2.3 vs 56.2 ± 2.5	50 vs 51	23.3 ± 2.2 vs 22.9 ± 2.1		40 vs 38	36 vs 38	12–24
Zeng Q, 2017	RCT	−/3	23 vs 23	NA	61 vs 71	NA	4 vs 4	19 vs 19	NA	5–17
Ji F, 2017	Re	6★/−	27 vs 18	66 ± 12 vs 69 ± 7	70 vs 61	NA		NA	NA	NA

★ number of stars for Nottingham Ottawa scale for each included trial, *NOS* = Nottingham-Ottawa scale, *3D* = three-dimensional, *2D* = two-dimensional, *BMI* = body mass index, *Pro* = prospective, *Re* = retrospective, *RCTs* = randomized controlled trial, *NA* = not available

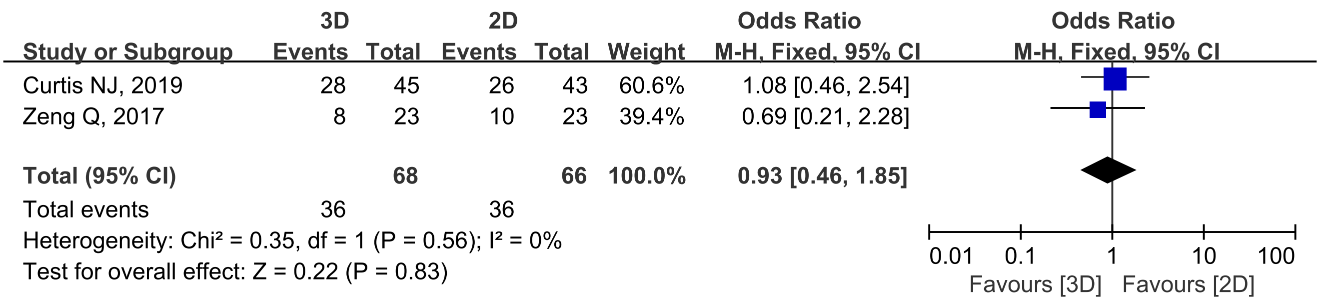

Fig. 2 Forest plot of comparison between 3D and 2D groups in terms of perioperative complications. ORs are shown with 95% CIs

the outcome could not be pooled in the meta-analysis. The data for pneumonia, wound infection, ileus, anastomotic fistula and urinary retention were supplied for 2 of the included 4 trials with 131 patients involved [15, 17], and there were no significant differences between the 3D and 2D groups ($P > 0.05$) (Table 2).

Publication bias and sensitivity analysis

Since only 4 studies were included in the meta-analysis of 3D versus 2D laparoscopic surgery for rectal cancer, no sensitivity analysis was performed. We did not attempt to assess the publication bias because there were fewer than the minimum of 10 relevant studies required for meaningful evaluation [18].

Discussion

This meta-analysis demonstrated that 3D laparoscopic rectal surgery appears to have advantages over 2D laparoscopic rectal surgery in terms of positive CRM and operation time; however, it is not better than 2D laparoscopic rectal surgery in terms of postoperative complications and the conversion rate.

This meta-analysis demonstrated that 3D laparoscopic rectal surgery has the advantage of significantly reducing the operation time compared with 2D laparoscopic rectal surgery. Since the 2D laparoscopic system produces more errors during the operation, the operation time is longer than 3D laparoscopic rectal surgery, which also indicates that 3D can help the operator perform the surgery better and more safely, especially with complex surgery, such as deep lymph node dissection and intestinal anastomosis [19]. A 3D laparoscopic system has the subjective impression of better spatial and depth perception. For beginners, the use of a 3D laparoscopic system can shorten the learning curve of laparoscopic surgery [19–21]. High and low anterior resections are different in terms of the operative time and complications. Of the 4 articles in the meta-analysis, 3 articles included high anterior resection. Unfortunately, the operative time and complications were not expressed in terms of the subgroup of high and low anterior resection. After excluding one article that only included low resection, we again conducted a meta-analysis and found that the results for the operative times were still significantly different. In several studies, we could not find any difference in the performance time between the 2D vision system and the 3D vision system [15, 22]. The different results may be explained by the diversity of 3D vision systems used in different studies, and the surgeries being performed by different surgeons who were not at the same point on the learning curve. A study by Cicione et al. found a better performance score under 3D conditions compared to 2D conditions, but no reduction in operative time for pyeloplasty and partial nephrectomy that were performed by surgeons without previous laparoscopic experience [23]. Nolan et al. found that training with 3D systems that were comparable to the shoebox shortened the training time in comparison to 2D systems for both continuous and intracorporeal suturing [24]. Unfortunately, there was a difference between the initial and later operations of each trial. We did not obtain the original data from the

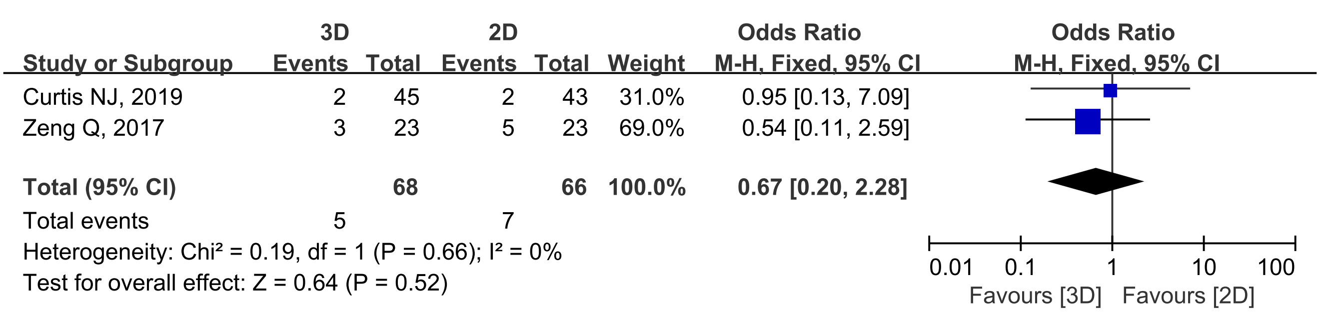

Fig. 3 Forest plot of comparison between 3D and 2D groups in terms of conversion rate. ORs are shown with 95% CIs

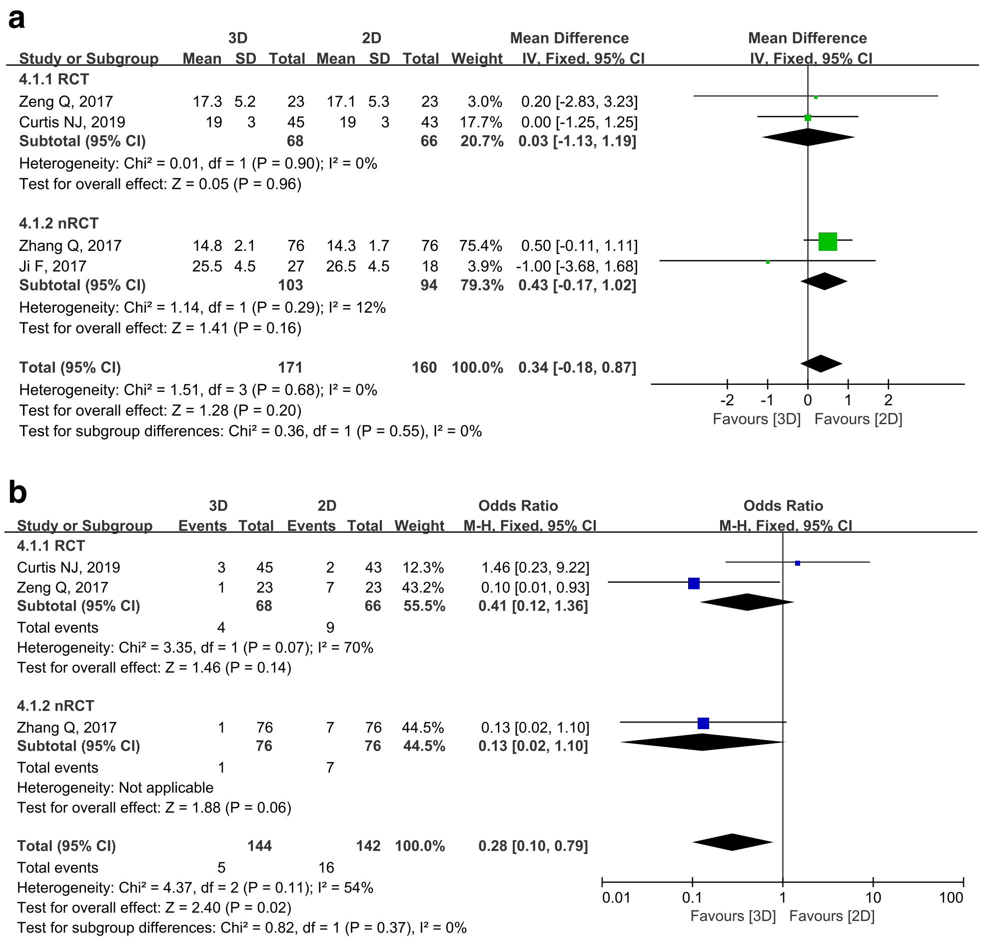

Fig. 4 Forest plot of comparison between 3D and 2D groups in terms of the pathological outcomes. **a** Harvested lymph nodes. **b** Positive CRM. ORs and WMD are shown with 95% CIs

authors. There are obvious advantages of 3D laparoscopic rectal surgery in terms of precision operations. In the meta-analysis, the difference in EBL between the two groups was less than 10 ml. Moreover, the statistically significant differences between the two groups had no actual clinical significance.

The 3D vision model offers superior quality images and stereoscopic vision for surgeons, which can overcome the shortcomings of 2D laparoscopic surgery [25]. Another major advantage of 3D laparoscopic rectal surgery found in our meta-analysis was a significant reduction in positive CRM. In this meta-analysis, the pooled positive CRM for 3D

Table 2 Secondary outcomes of comparison between 3D and 2D groups

Outcomes of interest	No. of studies	No. of patients		WMD/OR, (95% CI)	*p* value*	Study heterogeneity			
		3D	2D			x^2	df	I^2, %	*p* value*
Operative time, min	4	171	160	− 11.33 [− 14.53, − 8.13]	*< 0.00001*	2.25	3	0	0.52
EBL, ml	3	126	117	− 7.09 [− 12.85, − 1.33]	*0.02*	0.46	2	0	0.79
Length of stay, day	2	99	99	− 0.38 [− 0.85, 0.10]	0.12	0.22	1	0	0.64
Pneumonia	2	66	65	0.99† [0.19, 5.19]	0.99	0.00	1	0	0.99
Wound infection	2	66	65	0.48† [0.12, 1.96]	0.30	2.17	1	54	0.14
Ileus	2	66	65	0.76† [0.29, 2.02]	0.59	0.17	1	0	0.68
Anastomotic fistula	2	66	65	2.26† [0.49, 10.46]	0.30	0.50	1	0	0.48
Urinary retention	2	66	65	1.20† [0.35, 4.13]	0.78	0.75	1	0	0.39

† Odds ratio;*statistically significant results are shown in italics; *WMD/OR* = weighted mean difference/odds ratio; *df* = degrees of freedom; *CI* = confidence interval; *3D* = three-dimensional; *2D* = two-dimensional; *EBL* = estimated blood loss

laparoscopic rectal surgery was 3.5% compared to 11.3% for 2D laparoscopic rectal surgery. The positive CRM rate of this meta-analysis seemed quite high in the 2D group. In particular, Zeng et al. reported that the positive CRM rate was 30.4% in the 2D group and seemed unusually high. In fact, David Jayne et al. confirmed that the overall positive CRM rate was 5.7% [26]. Several mechanisms contribute to poor outcomes in surgical trials, such as biased data analysis by non-blinded investigators and the biased assessment of subjective parameters from non-blinded patients [27]. The 3D vision model seems to enhance the microdissection accuracy, leading to more comfortable mesorectal dissection with a lower risk of positive CRM, which correlates with increased local recurrence rates and decreased survival [28, 29]. This finding indicates that 3D laparoscopic rectal surgery provides better management of complex procedures, allowing the number of patients who may benefit from a minimally invasive approach to be increased. Similar reports focusing on rectal surgery are rare. One meta-analysis focusing on colorectal surgery highlights a significant reduction in operative time but no significant difference in complications or lymph node yield [30].

The 3D system offers clearer anatomic structural views of the pelvic floor so that it increases nerve protection and reduces the risk of damaging the male seminal vesicle and female posterior vaginal wall in rectal surgery [31]. Although 3D laparoscopic rectal surgery has many advantages for rectal cancer treatment, it does not provide short-term benefits to patients in terms of postoperative complications in the present meta-analysis. Previous studies have also shown that the postoperative recovery time from 3D laparoscopic surgery is not shorter than that of 2D laparoscopic surgery [32]. Future high-powered and well-designed RCTs are needed to draw definitive conclusions on postoperative complications.

The present meta-analysis has the following limitations that must be considered when the results are evaluated. First, although a meta-analysis of RCTs would be ideal, the limited number of RCTs prevented us from reaching any definitive conclusions. In addition, the follow-up period was generally short, and long-term outcomes remain to be proven. Nevertheless, this meta-analysis was conducted at an appropriate time, and we have provided the most up-to-date information in this area.

This meta-analysis has demonstrated that 3D laparoscopic rectal surgery appears to have advantages over 2D laparoscopic rectal surgery in terms of the operation time and positive CRM; however, it is not better than 2D laparoscopic rectal surgery in terms of the conversion rate and postoperative complications. Future, large-volume, well-designed RCTs with extensive follow-up are needed to confirm and update the findings of this analysis.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent Informed consent does not apply to the study.

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