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Review

Three-dimensional *Versus* Two-dimensional Laparoscopic Surgery for Colorectal Cancer: Systematic Review and Meta-analysis

GEORGE PANTALOS[1,2,3], DIMITRIOS PATSOURAS[2,3], ELEFTHERIOS SPARTALIS[2,3], DIMITRIOS DIMITROULIS[3,4], GERASIMOS TSOUROUFLIS[2,3,4] and NIKOLAOS NIKITEAS[2,3,4]

[1]Second Department of Pediatric Surgery, P. & A. Kyriakou Hospital, Athens, Greece;
[2]Laboratory of Experimental Surgery and Surgical Research, University of Athens Medical School, Athens, Greece;
[3]Hellenic Minimally Invasive and Robotic Surgery (MIRS) Study Group, Athens, Greece;
[4]Second Department of Propaedeutic Surgery, Laiko General Hospital, University of Athens Medical School, Athens, Greece

Abstract. *Background/Aim: Three-dimensional (3D) laparoscopy is being steadily adopted instead of two-dimensional (2D) for various procedures. Our aim was to compare the outcomes between 2D and 3D laparoscopic procedures for colorectal cancer in order to ascertain the safety, efficacy and potential advantages of 3D imaging systems. Materials and Methods: A systematic database search was conducted in March 2019. Comparative studies reporting clinical outcomes between patients undergoing elective colorectal procedures using either 2D or 3D laparoscopic equipment were eligible. Results: Six studies were selected, including 614 patients in total. Minor reduction in operative time, similar blood loss and increased number of harvested lymph nodes was noted for the 3D group. There was no difference for conversion to open surgery, time to flatus, postoperative hospital stay or postoperative complications. Conclusion: 3D Laparoscopic surgery for colorectal cancer may result in reduction of operative time and higher lymph node yields, leading to improved survival.*

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Correspondence to: George Pantalos, MD, Second Department of Pediatric Surgery, P. & A. Kyriakou Hospital, Levadeias 1 Street, Athens 115 27, Greece. Mobile: +30 6948947461, e-mail: gpantalos@gmail.com

Key Words: Three-dimensional, two-dimensional, 3D laparoscopy, laparoscopic surgery, colon cancer, rectal cancer, colorectal cancer, review.

For the past several decades laparoscopic surgery has been effectively performed in a multitude of surgical fields for various and complex procedures. The potential benefits compared to open surgery include a smaller incision, reduction of pain, faster recovery, and earlier discharge from hospital and return to normal activity. However, drawbacks for the surgeon include loss of depth perception and spatial orientation. In recent years, various technological improvements have been introduced in order to ameliorate drawbacks of laparoscopy, such as three-dimensional (3D) laparoscopic imaging systems (1, 2). 3D visualization eliminates the disadvantage of lack of depth perception in standard two-dimensional (2D) equipment. Furthermore, 3D laparoscopy brings one of the often touted advantages of robotic systems to standard laparoscopy, namely 3D vision and stereopsis (3). Several articles, including randomized control trials (RCTs), have been published recently comparing the outcomes of procedures using either 2D or 3D laparoscopic imaging equipment (4-9). This confirms the interest in this debated topic (10) and the need for high quality research in order to provide evidence-based recommendations.

Colorectal cancer is one of the most common types of cancer worldwide requiring surgical treatment in the majority of cases, with intent to cure nonetheless. A significant percentage of patients undergo laparoscopic surgery for colorectal cancer, especially in developed countries (11). Therefore, a review was conducted to assess the hypothesis that 3D imaging systems is able to improve both intraoperative performance and post-operative outcomes for colorectal cancer procedures.

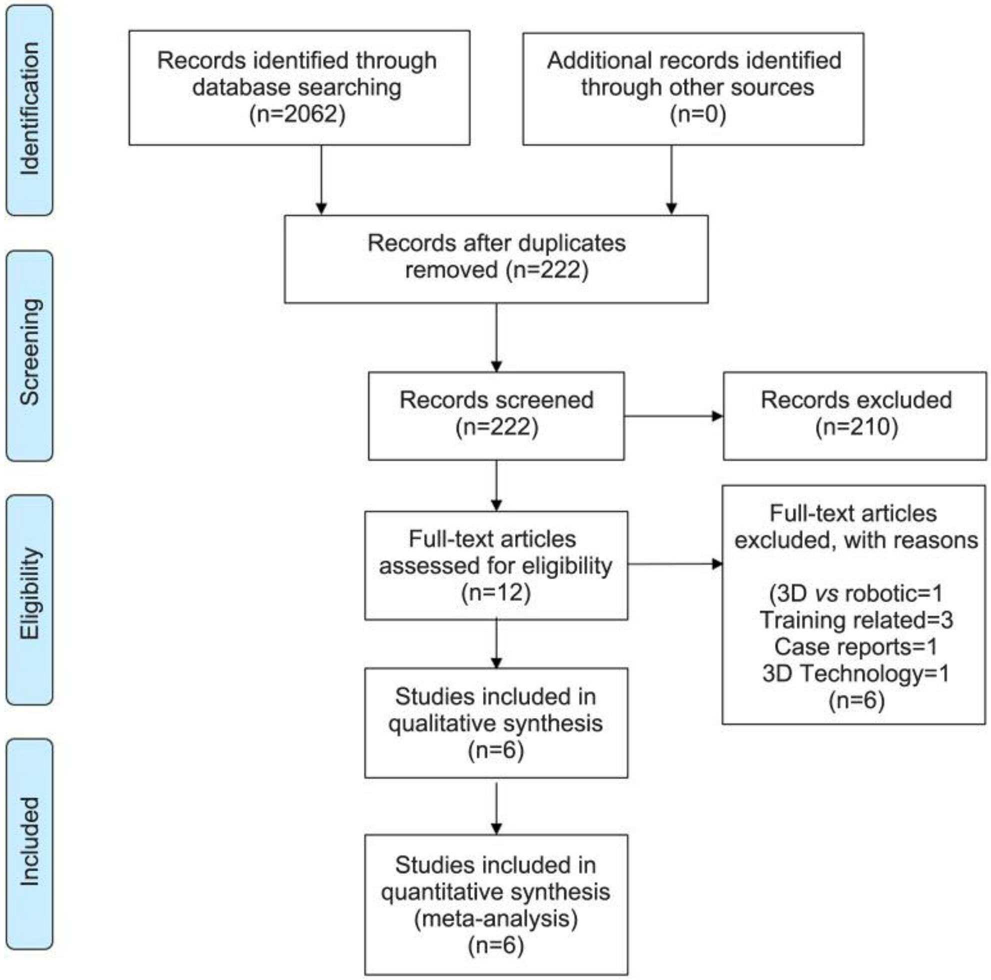

Figure 1. *PRISMA search flow diagram.*

Materials and Methods

Search strategy. The review was conducted according to the PRISMA statement guidelines (12) in order to analyze the safety, efficacy and potential benefits of 3D laparoscopic colorectal procedures in relation to the equivalent 2D laparoscopic procedures. A systematic search of the PubMed/MEDLINE and Scopus databases was conducted in March 2019, using the following search terms:

MEDLINE: ("imaging, three-dimensional"[Mesh] OR 3D OR 3-D OR three-dimension* OR 3-dimension*) AND ("imaging, three-dimensionally"[Mesh] OR "laparoscopes"[Mesh] OR laparosc* OR laparoendosc* OR celioscop* OR "imaging, three-dimensional" [Mesh:NoExp] OR minimally-invasive-surg*) AND ("colon"[Mesh] OR "imaging, three-dimensional"[Mesh] OR "imaging, three-dimensional"[Mesh] OR "imaging, three-dimensional"[Mesh] OR "colorectal surgery"[Mesh] OR ""colorectal surger"[Mesh] OR ""colorectal surgery"[Mesh] OR "ileostomy"[Mesh] OR "colostomy"[Mesh] OR colon OR colonic* OR colectom* OR ileostom* OR colostom* OR polypect* OR rectum* OR rectal* OR colorect* OR colorect* OR polyposis-coli OR sigmoid* OR anus OR anal).

Scopus: ((Two OR three) AND (dimension OR dimensional)) OR 2D OR 3D) AND laparoscop* AND (colectomy OR hemicolectomy OR colon OR rectal OR rectum OR TME OR mesorectal excision).

Original prospective or retrospective comparative studies and RCTs, published in English, reporting patient outcomes for 2D *vs*. 3D laparoscopic procedures for colorectal cancer were considered to be eligible, while case reports or studies comparing robotic to laparoscopic procedures were excluded (Figure 1). Eligible studies had to report at least one of several outcomes (operative time, blood loss, conversion to open surgery, intraoperative mortality, post-operative complications, post-operative hospital stay, lymph nodes resected).

The described operative techniques differed between studies. In order to maximize the potentially included data and to have a more general appreciation of the effect of 3D visualization on performance of colorectal surgery, no attempt was made to constrain the eligibility criteria (*e.g.* intracorporeal or extracorporeal anastomosis). The study by Su *et al*. (9) even describes the use of a novel anastomotic technique called overlapped delta-shaped anastomosis (13). This variability in the operative techniques, that were used, inevitably leads to heterogeneity among studies.

Table I. *Characteristics of included studies on 2D vs. 3D lap.*

Study		Su *et al*. (9)	Currò *et al*. (19)	Tao *et al*. (20)	Yoon *et al*. (21)	Zeng *et al*. (22)	Curtis *et al*. (23)‡
Study type		Retrospective cohort study	Retrospective cohort study	Retrospective cohort study	Retrospective cohort study	Retrospective case-matched study	Multicenter randomized control trial
Country/city		China	Italy	China	Seoul, Korea	China	United Kingdom
Intervention/ procedure		Right or left colectomy, anterior resection	Right colectomy	Right colectomy	Right or left colectomy, anterior resection	Anterior resection or abdomino-perineal resection	Right or left colectomy, anterior resection
Patients, n	Total	97	50	58	278	46	85
	2D	54	25	31	167	23	42
	3D	43	25	27	111	23	43
Operative time, min*	2D	131.9±42.3	110±7.5	152.2±28.9	150±37.4	192.6±22.3	278±38.39
	3D	127.1±36.6	105±6.25	130.5±27.6	155±31.92	172.2±27.5	270±38.39
Blood loss, ml*	2D	48±45.5	NR	84.7±22.3	82.4±37.9	282.6±195.6	60
	3D	54.7±48.4	NR	80.8±29	62.5±52.5	247±173.6	90
Conversion to open surgery, n, %	2D	0	0	0	0	18/23 (78%)	2/42 (4.9%)
	3D	0	0	0	0	20/23 (87%)	2/43 (4.8%)
Intra-operative mortality, %	2D	0	0	0	0	0	0
Post-operative complications, n	3D	6	0	3	13	10	56
	2D	6	1	4	9	9	54
Lymph nodes resected, n*	3D	22.3±9.4	NR	19.3±5.6	41.5±14.5	17.1±5.3	19.7±9.2
		21.1±7.7	NR	20.4±5.7	48.2±16.9	17.3±5.2	20.4±9.2
Time to flatus, days*	2D	3.3±0.9	NR	3±0.75	3±1.49	3.1±1	NR
	3D	3.1±0.7	NR	3±0.75	3.35±0.75	2.8±0.8	NR
	2D	6.6±0.9	NR	9±3.75	6.7±1.49	11.3±3.65	11.1±9.2
Post-operative hospital stay, days*	3D	6.9±1.1	NR	8±2	6.35±0.75	11.5±4.7	9.1±7.6

NR: Not reported. *Data are the mean±standard deviation.

Quality assessment. The quality of included studies was assessed by completing the National Heart, Lung, and Blood Institute (NHLBI) Study Quality Assessment Tools for each individual eligible study (14). Scores 1-3 indicate poor quality, while scores 4-6 indicated fair quality and 7-9 good quality.

Data extraction. All eligible studies were evaluated and the following data were extracted if available: First author, study type, location, type of intervention/procedure, number of patients, intraoperative data (operative time, blood loss, conversion to open surgery, intraoperative mortality), post-operative complications, post-operative hospital stay and lymph nodes resected. The data are summarized in Table I. Patient demographics, somatometric and TNM staging data were also recorded when available and are presented in Table II.

Statistical analysis. A meta-analysis was performed where applicable using Review Manager (RevMan) Software v.5.3 by Cochrane Collaboration (15). All reported outcomes were analyzed as continuous variables using the mean difference (MD) with a 95% confidence interval (CI), except for the post-operative complications rate which was analyzed using the odds ratio (OR) with a 95% CI. Continuous variables reported using medians, means, range or interquartile ranges (IQR) were converted using formulas and performing calculations described by Hozo *et al*. (16) and Luo *et al*. (17), to derive mean and standard deviation (SD). Operative time for the study by Curtis *et al*. (23) was calculated from the provided data using the Cochrane Handbook (18) and RevMan Calculator. Evaluation of heterogeneity was performed using I^2, and due to it being mostly high (>50%), sensitivity analysis was also performed by serially analyzing results after excluding studies causing high heterogeneity. The random-effects model was used for all outcomes.

Results

Description of included studies. Using the described search strategy, a total of 2,062 records were identified. After removing duplicates, 222 records remained. The titles and abstracts of these relevant studies were screened to identify potentially eligible articles. The screening process lead to full-text evaluation of 12 studies. Finally, five retrospective comparative studies and one RCT met the predefined criteria and were included in the review (9, 19-23). Three studies were conducted in China, one in Korea, one in Italy and one in the UK. The quality of the retrospective studies included was fair. The quality of the included RCT was good. The total number of patients in the six included studies was 614: 342 in the 2D group and 272 in the 3D group. Methodological quality was fair. The institutions where the retrospective studies were

Table II. *Patient demographic, somatometric and staging data.*

Study		Su *et al*. (9)	Currò *et al*. (19)	Tao *et al*. (20)	Yoon *et al*. (21)	Zeng *et al*. (22)	Curtis *et al*. (23)‡
Age (years)*	2D	56±10.9	68 (43-75)	55 (37-71)	65,5 (57-72)	NR	69±11
	3D	58.3±10.6	69 (40-78)	57 (35-74)	65 (55-72)	NR	69±10
Gender:	2D	30/24	14/11	16/11	88/79	16/7	22/21
Male/female, n	3D	29/14	12/13	20/11	53/58	14/9	29/16
BMI, kg/m^2*	2D	23.8±2.9	30 (24-35)	23.9 (20.2-27.5)	23.9 (21.8-26.5)	NR	29±5
	3D	24.4±3.0	31 (23-34)	22.7 (18.7-26.9)	24.7 (22.0-26.7)	NR	27±4
Previous abdominal	2D	15 (27.8%)	0	NR	30 (18%)	NR	14 (32.6%)
surgery, n (%)	3D	11 (25%)	0	NR	20 (18%)	NR	12 (26.7%)
ASA score, n	2D	I=38, II=12, III=4	NR	I=10, II=19, III=2	I/II=157 III=10	NR	I=4, II=24, III=11, IV=3, Unknown=1
	3D	I=32, II=9, III=2	NR	I=11, II=15, III=1	I/II=157 III=10	NR	I=2 II=28, III=14, IV=0, Unknown=1
TNM stage, n	2D	I=5, II=20, III=29	NR	I=5, II=15, III=11	PCR=3, I=46, II=52, III=66	NR	PCR=0, I=15, II=13, III=13, IV=1
	3D	I=5, II=18, III=20	NR	I=4, II=14, III=9	0=0, I=37, II=34, III=40	NR	PCR=2, I=13, II=15, III=12, IV=1
T-Stage, n	2D	NR	T1+T2=12, T3+T4=13	NR	T1+T2=62, T3+T4=105	T2=4, T3=19	T1=4, T2=18, T3=18, T4=2
	3D	NR	T1+T2=10, T3+T4=15	NR	T1+T2=47, T3+T4=64	T2=4, T3=19	T1=6, T2=9, T3=22, T4=4
Tumor size, cm*	2D	3.5 (1.1)	NR	5.7 (2.3-8,1)	4 (2,4-5,5)	NR	NR
	3D	3.9 (1.9)	NR	5.2 (2.5-7.9)	3.6 (2.1-5.5)	NR	NR

ASA: American Society of Anesthesiology; BMI: body mass index; NR: not reported; PCR: pathological complete response to neoadjuvant chemotherapy. *Mean (range) or mean±standard deviation. ‡Patient demographics reported for all of the 88 initially randomized patients.

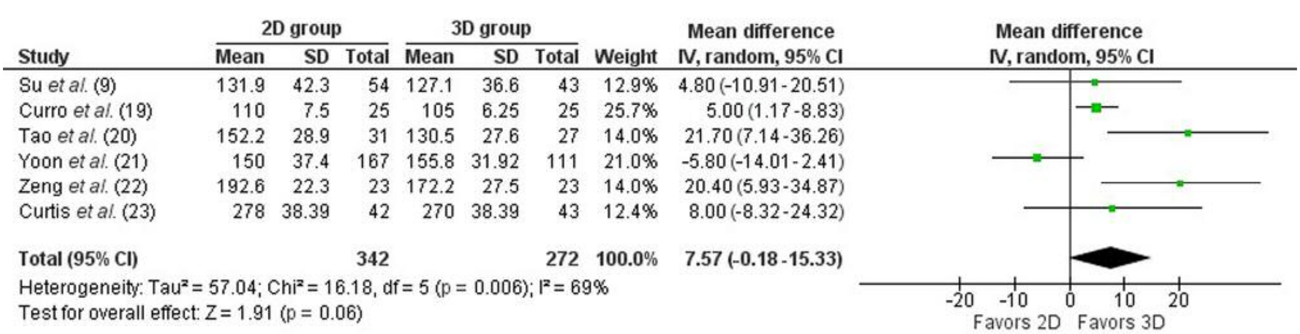

Figure 2. *Forest plot of difference in operative time (minutes) in studies from literature. SD: Standard deviation; IV: inverse variance; CI: confidence interval.*

conducted had a single experienced laparoscopic surgeon perform the operation either in 2D or 3D. The RCT was a multicenter trial so multiple surgeons performed the described operations. Procedures included right-colectomy, left-colectomy, anterior resection and abdominoperineal resection. No patients had metastatic disease (M0), except for two patients included in the study by Curtis *et al*. (23) who underwent surgery but had distant metastases (M1). All procedures were elective.

Operative time. Data for duration of the operative procedure were provided in all the included studies. Meta-analysis of operative time indicated a small difference in favor of the 3D laparoscopic group (MD=7.5; 95%CI=–0.18-15.33; p=0.06). Due to the moderately high heterogeneity of studies (I^2=67%), a random-effects model was used and sensitivity analysis was performed to further analyze and discuss the results (Figure 2).

Study	2D group Mean	SD	Total	3D group Mean	SD	Total	Weight	Mean difference IV, random, 95% CI
Tao *et al.* (20)	84.7	22.3	31	80.8	29	27	34.0%	3.90 (-9.56-17.36)
Yoon *et al.* (21)	82.44	37.9	167	60.55	52.57	111	36.8%	21.89 (10.55-33.23)
Zeng *et al.* (22)	282.6	195.6	23	247	173.6	23	2.0%	35.60 (-71.28-142.48)
Curtis *et al.* (23)	60	0	42	90	0	43		Not estimable
Su *et al.* (9)	48	45.5	54	54.7	48.4	43	27.2%	-6.70 (-25.58-12.18)
Total (95% CI)			**317**			**247**	**100.0%**	**8.27 (-7.12-23.66)**

Heterogeneity: Tau² = 133.94; Chi² = 8.19, df = 3 (p = 0.04); I² = 63%
Test for overall effect: Z = 1.05 (p = 0.29)

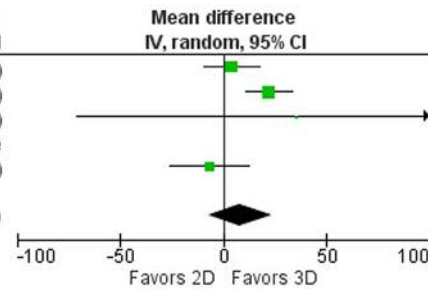

Figure 3. *Forest plot of difference in operative time (minutes) in studies from literature. SD: Standard deviation; IV: inverse variance; CI: confidence interval.*

Study	2D group Mean	SD	Total	3D group Mean	SD	Total	Weight	Mean difference IV, random, 95% CI
Su *et al.* (9)	22.3	9.4	54	21.1	7.7	43	20.0%	1.20 (-2.20-4.60)
Tao *et al.* (20)	19.3	5.6	31	20.4	5.7	27	22.4%	-1.10 (-4.02-1.82)
Yoon *et al.* (21)	41.52	14.58	167	48.23	16.9	111	18.1%	-6.71 (-10.55--2.87)
Zeng *et al.* (22)	17.1	5.3	23	17.3	5.2	23	21.8%	-0.20 (-3.23-2.83)
Curtis *et al.* (23)	19.7	9.2	42	20.4	9.2	43	17.8%	-0.70 (-4.61-3.21)
Total (95% CI)			**317**			**247**	**100.0%**	**-1.39 (-3.82-1.04)**

Heterogeneity: Tau² = 4.66; Chi² = 10.29, df = 4 (p = 0.04); I² = 61%
Test for overall effect: Z = 1.12 (p = 0.26)

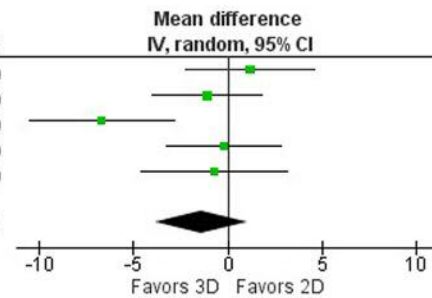

Figure 4. *Forest plot of difference in number of harvested lymph nodes in studies from the literature. SD: Standard deviation; IV: inverse variance; CI: confidence interval.*

Blood loss. Estimated blood loss was reported in all but one of the studies [Currò *et al*. (19)]. The estimated volume of lost blood was similar for the two groups (MD=8.27 ml, 95%CI=−7.12-23.66; p=0.29). Moderately high heterogeneity was observed (I^2=63%); therefore, a random effects model was used (Figure 3).

Lymph nodes harvested. The number of harvested lymph nodes was not reported in one study [Currò *et al*. (19)]. Meta-analysis showed a difference of 1.39 more lymph nodes harvested in the 3D group (MD=−1.39, 95%CI=−3.82-1.04; p=0.26). Heterogeneity among studies was moderately high (I^2=61%) and the random-effects model was applied (Figure 4).

Conversion to open surgery. No conversions to open surgery were reported (0%) in four out of the six studies. Thus, meta-analysis of the results was not undertaken. In the study by Curtis *et al*. (23), conversion rates were similar [2 (4.9%) *vs*. 2 (4.8%)]. Conversion rates were high in the study by Zeng *et al*. (22) but also similar between groups [18 (78%) *vs*. 20 (87%)].
Time to return of bowel function. The number of days to passage of *flatus* was not documented in two studies [Currò *et al*. (19), Curtis *et al*. (23)]. There was no difference between groups (MD=0.00, 95%CI=−0.31-0.32; p=0.98). A random-effects model was used with moderately high heterogeneity (I^2=67%) (Figure 5).

Post-operative hospital stay. The length of hospital stay was similar between the two groups (MD=0.17, 95%CI=−0.35-0.69; p=0.53). Once more, all but one study reported this variable [Currò *et al*. (19)]. There was moderate heterogeneity (I^2=56%) (Figure 6).

Post-operative complications. All data on post-operative complications reported in the studies has been compiled and presented in Table III. The post-operative complication rate was analyzed using the OR. The rate of complications was similar for the two groups (OR=0.88, 95%CI=0.50-1.54; p=0.66). There was no heterogeneity (I^2=0%) (Figure 7).

Discussion

Conventional 2D laparoscopic surgery has provided a lot of advantages and is already the modality of choice for various diseases in current practice. Considering the fact that many landmark studies have only demonstrated medium-term non-inferiority of laparoscopic compared with open colorectal cancer surgery, further refinement of laparoscopic techniques is needed to bolster their eventual superiority (11, 24-35). This topic is still debated for rectal cancer laparoscopic surgery (36, 37). There has been steady improvement of 3D imaging systems (1) in order to enhance viewing quality and minimize surgeon discomfort. As a result, 3D laparoscopy is

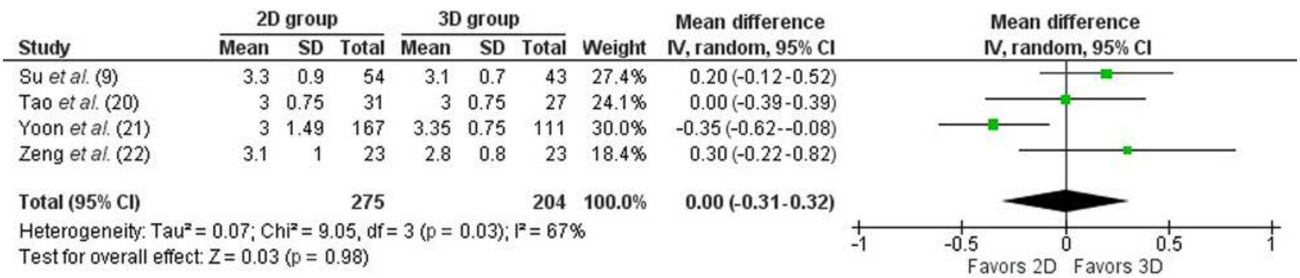

Figure 5. *Forest plot of difference in time to flatus (days) in studies from the literature. SD: Standard deviation; IV: inverse variance; CI: confidence interval.*

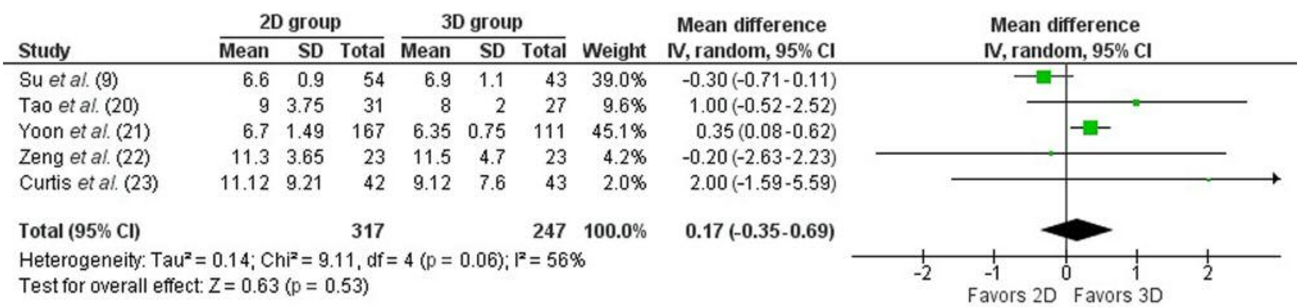

Figure 6. *Forest plot of difference in post-operative hospital stay (days) in studies from the literature. SD: Standard deviation; IV: inverse variance; CI: confidence interval.*

increasingly being used to perform a variety of procedures, while researching potential benefits that justify the added cost. In contrast to surgery for benign diseases, surgery for colorectal cancer is more demanding due to the need for meticulous dissection in adherence to oncological principles. This necessitates the application of advanced laparoscopic skills such as suturing. 3D imaging systems should facilitate technically demanding procedures (10).

Technological progress of 3D imaging systems has enabled its continued use after overcoming some known problems causing visual fatigue (38). Most 3D imaging systems nowadays use lightweight polarizing glasses with no moving parts (referred to as 'passive'), alleviating surgeon discomfort (39). Additionally, increased resolution, such as high-definition and ultra high-definition, have undeniably proven useful. Of course, further research on optimal operating theatre setup to achieve minimal strain for the team is warranted (40- 42).

Cognitive workload of the surgeon has been studied with RCTs published on this topic (38, 43, 44). In general, the perceived cognitive workload was not higher and 3D laparoscopy can even lead to its reduction, assuming that the viewing setup is optimal (41, 45).

The European Association of Endoscopic Surgery held a conference in May 2018 to address these issues and develop consensus about the usage of 3D laparoscopy (10). An expert panel based on available evidence and their meta-analysis produced statements and recommendations for various subjects, including 3D laparoscopy for colorectal surgery. The resulting statement for colorectal surgery with moderate levels of evidence is that the operative time for right colectomy is shortened by using 3D imaging. Conclusions drawn are generally about 3D laparoscopy potentially reducing operative times and perioperative complication rates, particularly in procedures involving laparoscopic suturing.

The majority of included studies in this review were retrospective cohort studies (9, 19-22). Only one of six eligible studies was an RCT (23). Selection bias might have existed due to the fact that most studies were not RCTs and because the operative procedures and their characteristics were not equivalent between studies. Moderately high heterogeneity was found in various studied outcomes and may have affected the meta-analysis, although several factors might have a marked effect on these outcomes regardless of the imaging technology used. However, after taking into account the limitations that arise, some conclusions can be drawn based on the results.

The time required for completing the procedure favored the 3D group, with a difference of about 7.5 minutes. However, due to the high heterogeneity, a sensitivity analysis was

Table III. *Reported postoperative complications*.

Study		Su *et al*. (9)	Currò *et al*. (19)	Tao *et al*. (20)	Yoon *et al*. (21)	Zeng *et al*. (22)	Curtis *et al*. (23)
Patients, n		97	50	58	278	46	85
	2D	43	25	31	167	23	42
	3D	54	25	27	111	23	43
Complications, n		12	1	7	21	19	110
	2D	6	0	3	12	10	56
	3D	6	1	4	9	9	54
Anastomotic leak	2D	0	0	1	1	0	2
	3D	0	1	0	0	0	3
Anastomotic bleeding	2D	0	0	0	0	0	0
	3D	0	0	1	1	0	0
Anastomotic fistula	2D	0	0	0	0	0	0
	3D	0	0	0	0	2	0
Bowel obstruction	2D	0	0	0	4	2	1
	3D	0	0	1	1	1	0
Wound infection	2D	5	0	2	3	1	5
	3D	4	0	1	6	2	1
Sepsis	2D	0	0	0	0	0	4
	3D	0	0	0	0	0	3
Acute kidney injury	2D	0	0	0	0	0	5
	3D	0	0	0	0	0	6
Atrial fibrillation, flutter or supraventricular tachycardia	2D	0	0	0	0	0	3
	3D	0	0	0	0	0	2
Abdominal infection or collection of fluid	2D	0	0	0	0	0	4
	3D	0	0	0	0	0	3
Pancreatitis	2D	0	0	0	0	0	1
	3D	0	0	0	0	0	0
Respiratory infection	2D	0	0	0	2	2	1
	3D	2	0	1	0	2	1
Urinary tract infection	2D	0	0	0	2	0	4
	3D	0	0	0	1	0	2
Urinary retention	2D	0	0	0	1	3	3
	3D	0	0	0	0	1	5
Sexual dysfunction	2D	0	0	0	0	2	1
	3D	0	0	0	0	1	0
Other	2D	0	0	0	0	0	22

performed. In the studies by Currò *et al*. (19), Su *et al*. (9), Curtis *et al*. (23) and Yoon *et al*. (21), there was no significant difference in operative time between groups. It should be noted that all studies except that by Yoon *et al*. (21) favored 3D. Meanwhile, for Tao *et al*. (20) and Zeng *et al*. (22) the operative time was significantly lower for the 3D group. These findings might be attributed to the difference in experience among surgeons, but the overall results approached statistically significant levels (p=0.06). In summary, a compelling case might be made for shortened operative times by using 3D laparoscopy.

After performing the meta-analysis for blood loss, sensitivity analysis was deemed necessary. The studies by Tao *et al*. (20) and Su *et al*. (9) significantly contributed to the high heterogeneity because they reported a low level of blood loss and incredibly similar results for both groups. After compensating for this, lower blood loss was observed for the 3D group (reduced by approximately 50 ml).

Harvested lymph nodes are a means of determining adequate resection, accurate staging and therefore better overall outcomes for patients (46-48). The study by Yoon *et al*. (21) hypothesized that improved hand-eye coordination while using 3D laparoscopy would improve lymph node yields when performing colectomy with D3 lymphadenectomy. Indeed, this study clearly favored the 3D group (on average six more lymph nodes) and was the cause of high heterogeneity. By removing the study by Yoon *et al*. (21) from the analysis, the number of harvested lymph nodes was higher (by 0.25 lymph nodes) for the 3D group, but not significantly.

Complications described were similar for groups, both in severity as well as overall incidence. The risk of publication bias and under-reported complications exists due to the

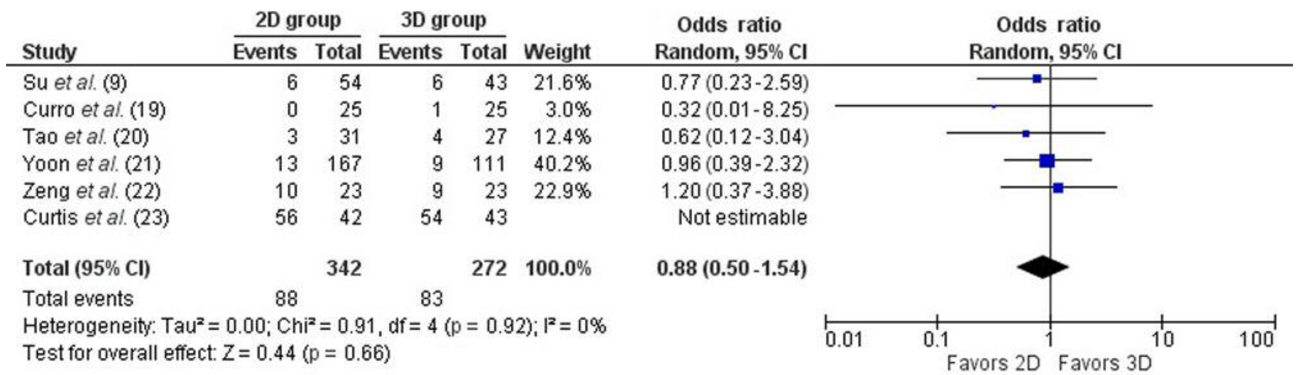

Figure 7. *Forest plot of difference in number of post-operative complications in studies from the literature. CI: Confidence interval.*

retrospective nature of the included studies. The data on complications reported in the RCT by Curtis *et al.* (23) and expanded upon by categorizing them according to the Clavien–Dindo classification (49), is evidently of higher quality. Because the number of complications was similar (54 *vs.* 56) its effect on the meta-analysis was low.

Quality of specimen retrieved for rectal cancer, meaning complete total mesorectal excision (TME) with clear circumferential margins and dissection at the mesorectal fascial plane, is a parameter directly correlated with the oncological outcome (50-54). The study by Curtis *et al.* (23) detailed a clinically significant improvement in specimen quality compared to 2D laparoscopy. Unfortunately, no study included data pertaining to the oncological follow-up and outcomes, since trials for 3D laparoscopy have only recently gained interest. Future trials of 3D laparoscopy in rectal cancer should monitor all these crucial parameters.

There are inherent limitations to the present meta-analysis that are caused by the methodology of the studies (five retrospective cohort studies and only one RCT), the observed heterogeneity and the fact that in each of the included retrospective cohort studies, only a single experienced surgeon with a high-volume case load performed the procedures. This is in stark contrast with the RCT study in the UK in which nine surgeons participated. As a consequence, these results cannot be broadly generalized without taking into account the risk of bias. However, the reported shorter operative time, lower blood loss and higher number of harvested lymph nodes might hint that 3D laparoscopy systems improve surgeons' spatial orientation, navigation and dexterity that should, in principle, improve patient outcomes. In our opinion, future RCTs should be directed to confirm this. If confirmed, 3D laparoscopy may be the evolutionary step that provides the current best solution and standard for colorectal surgical procedures where the added flexibility offered by robotic articulated instruments is unneeded or counter-balanced by the skill of surgeons (32, 39). In the future, consideration should also be given to the parallel evolution of laparoscopic instruments that has begun in recent years (55-57). By combining 3D vision and these handheld instruments with a high degree of freedom movement, we can ultimately envision a future with advantages from robotic systems downscaled and brought to laparoscopic surgery.

Conclusion

Laparoscopic colorectal surgery using 3D imaging systems is safe and effective. In light of viewing these systems as an addon to regular 2D equipment, especially in contrast to the cost of purchase and servicing of robotic equipment, 3D camera systems may prove to be a cost-effective solution to solving one of the major drawbacks of laparoscopy, namely the lack of 3D perception. The benefit of laparoscopic 3D vision may be more profound for moderately experienced laparoscopic surgeons at low-volume centers or in developing countries, but there are no data supporting this. Another potential area of future research is the effect of 3D vision systems on surgical training and the potential minimization of learning curves or faster acquisition of advanced laparoscopic skills (43, 44, 58). Careful planning of future research and more high quality RCTs are needed to demonstrate the potential superiority of 3D laparoscopic vision for colorectal surgery in regards to improved patient outcomes. Short- and long-term follow-up to assess the oncological outcomes is absolutely essential. Finally, even if 3D laparoscopy provides marginal gains compared to established 2D laparoscopy, these must be evaluated. If 3D imaging systems prove cost-effective, gradual replacement of aging 2D equipment might be more readily considered by surgeons and the institutions where their services are provided.

Conflicts of Interest

The Authors declare that there is no conflict of interest in regard to this study.

Authors' Contributions

GP, DP and ES contributed to study design, data extraction, data analysis, and manuscript writing. They also reviewed and revised the paper and approved and submitted the final manuscript. DD, GT and NN reviewed and revised and approved the paper. All Authors approved the final manuscript and its submission.

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