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REVIEW

Short- and long-term outcomes of minimally invasive vs. open pelvic exenteration in rectal tumours: a focused meta-analysis

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Abstract

Purpose Pelvic exenteration (PE) is a complex surgical procedure used to treat patients with recurrent or locally advanced rectal cancer (LARC) as a final recourse. Thus, minimally invasive surgery (MIS) has emerged as an alternative to the traditional open PE as it may reduce surgical trauma and improve recovery. This meta-analysis compared the clinical outcomes between MIS and open PE in patients with LARC.

Methods A systematic review and meta-analysis were conducted following PRISMA and AMSTAR guidelines. Six retrospective studies comprising 368 patients (179 MIS patients; 189 open patients) were included. Data on operative parameters along with short-term and long-term outcomes, including the 3-year overall (OS) and disease-free survival (DFS), were extracted. Risk ratios (RRs) and odds ratios (ORs) were calculated for binary outcomes, while standardised mean differences (SMDs) were calculated for continuous outcomes. All measures were reported with 95% confidence intervals (CIs) using random-effects models.

Results MIS was associated with significantly reduced blood loss (standardised mean difference (SMD), −1.57; 95% CI, −2.27 to −0.88; $p < 0.00001$), shorter hospital stays (SMD, −6.46; 95% CI, −12.21 to −0.71; $p = 0.03$), and quicker diet resumption (SMD: −0.79; 95% CI, −1.36 to −0.21; $p = 0.008$) than open PE. MIS was associated with a borderline reduction in total complications (OR, 0.45; 95% CI, 0.20–1.00; $p = 0.05$) and lower rates of abdominal wound complications (OR, 0.22; 95% CI, 0.11 to 0.45; $p < 0.0001$). No significant differences were observed in R0 resection rates, major complications, or mortality. For long-term outcomes, MIS demonstrated significantly improved 3-year OS (RR, 1.19; 95% CI, 1.01 to 1.41; $p = 0.04$), whereas 3-year DFS showed no significant difference (RR, 1.02; 95% CI, 0.79 to 1.41; $p = 0.87$).

Conclusion MIS offers significant short-term advantages over open PE, including reduced blood loss, faster recovery, and fewer complications while demonstrating improved 3-year OS. These findings support MIS PE as a safe, effective, and viable option for patients with recurrent or LARC.

Keywords Rectal cancer · Pelvic exenteration · Minimally invasive surgery · Outcome

Yih-Jong Chern and Cheng-Chou Lai have equal contributions to the work.

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Introduction

Pelvic exenteration (PE) is an extensive and complex surgical procedure, frequently regarded as a final recourse for patients with recurrent or locally advanced rectal cancer (LARC) that cannot be managed using conventional treatments. This radical surgery, which involves the en bloc removal of multiple pelvic organs, has become a pivotal intervention for achieving clear margins and improving survival outcomes in LARC [1, 2]. Rectal cancer remains a significant global health burden with many cases diagnosed at advanced stages [3]. Therefore, PE offers a potential curative approach for patients with disease invading adjacent organs or recurring after initial treatment. By establishing local control, the long-term survival and improved quality of life of patients become possible. The procedure encompasses various techniques, including anterior, posterior, and total PE, tailored to the tumour's location and extent [4, 5].

Traditionally, PE is performed using open surgical techniques. However, while effective, these techniques are associated with high morbidity and extended recovery periods [6]. Consequently, with advancements in surgical technology, minimally invasive approaches, such as laparoscopic and robotic surgeries, have been introduced. These techniques aim to reduce surgical trauma, shorten recovery times, and maintain oncologic outcomes at a level comparable to that of open surgery [7, 8]. Studies comparing traditional open PE and minimally invasive PE (MIPE) have shown promising results, indicating that MIPE achieved similar oncologic outcomes with lower perioperative morbidity [9–11]. The evolving landscape of these surgical techniques underscores the importance of optimising surgical approaches to enhance patient outcomes while minimising complications [10, 12, 13]. Despite the potential benefits of PE, data on its outcomes remain limited and heterogeneous, necessitating a systematic evaluation. To address this, a meta-analysis (MA) was conducted to synthesise existing evidence and compare the efficacy of traditional open surgery vs. MIPE in achieving pelvic clearance and improving survival outcomes [14, 15]. This comprehensive analysis aimed to comprehensively explore the roles and effectiveness of these surgical approaches, offering valuable insights for clinical decision-making and future research directions. By evaluating factors such as perioperative complications along with short-term and long-terms survival, this study informs best practices and guides the adoption of optimal surgical techniques in the management of advanced and recurrent rectal cancer [16–20].

Materials and methods

Search strategy

A literature search was performed across three databases: PubMed, Embase, and the Cochrane Library, on 25 September 2024. The keywords used for the search were 'rectal neoplasm', 'pelvic exenteration', 'minimally invasive surgery', 'laparoscopic surgery', and 'robotic surgery'. Additionally, MeSH terms were used to ensure comprehensive literature retrieval.

The research starting date was limited to 2000 to corroborate with the introduction of modern surgical techniques and instruments for MIPE. Only English-language articles were included, and case reports, abstracts, posters, review articles, and studies involving non-human samples were excluded.

Eligibility criteria

A full-text review was conducted on articles satisfying the following criteria: (1) studies involving patients with LARC who underwent PE, either through open or MIS and (2) studies that clearly reported postoperative and/or survival outcomes. Conversely, the following studies were excluded: (1) those involving bony destruction, except for sacrectomy, (2) those involving non-colorectal tumours, and (3) those reporting only MIS outcomes.

All authors participated in the article review process (i.e. search, categorisation, and screening), with two authors independently reviewing each article. Any disagreements were resolved through group discussion to reach a consensus.

Protocol and registration

This systematic review was registered in PROSPERO (Registration No.: CRD42024621323) and was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [21] and AMSTAR (Assessing the methodological quality of systematic reviews) [22] Guidelines.

Data collection

The same two authors collected basic information from each study, including the publication year, number of participants, study location, and participant demographics (age, sex, body mass index [BMI], and American Society of Anesthesiologists [ASA] score). Additionally, the type of surgery—such as total, anterior, or posterior PE—was recorded. In addition, associated procedures including sphincter preservation, lateral pelvic lymph node dissection, posterior vagina wall resection, plastic reconstruction, urinary conduit construction, sacrectomy, and internal iliac artery transection were recorded.

Operative parameters were also collected, including operative time, blood loss, blood transfusions, R0 resection rates, and postoperative outcomes such as length of hospital stay, time to diet resumption, and readmission within 30 days. In contrast, postoperative complications included anastomosis leak, pelvic abscess, abdominal wound infection, bowel obstruction, urinary tract infection, urological complications or perineal wound problems, and mortality.

Quality assessment

The risk of bias of each included study was assessed using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool. Two independent authors (ZHY and BKJ) conducted the risk of bias assessment, and disagreements were resolved by consensus or by a third author (YJH).

Outcomes of interest

The primary outcomes of interest were (1) short-term postoperative outcomes, including operative time, intraoperative blood loss, length of hospital stay, total complication rate, and major complications (Clavien–Dindo grade ≥ IIIa); (2) histopathological outcomes such as R0 resection rates; and (3) long-term oncological outcomes, including 3-year disease-free survival (DFS) and 3-year overall survival (OS). Secondary outcomes included the individual complications (e.g. abdominal wound infection, anastomotic insufficiency, pelvic abscess, ileus, urinary tract infection).

Statistical analysis

Statistical analysis was conducted using Cochrane's Review Manager (version 8.10.0). For continuous outcomes, such as operative time and blood loss, we employed the Meta-Analysis Accelerator tool, facilitating the conversion of median and range values into mean and standard deviation values at a 95% confidence level [23]. Subsequently, continuous outcomes were reported as standardised mean differences (SMDs) with 95% confidence intervals. For dichotomous outcomes, we used risk ratios (RRs) or odds ratios (ORs), as appropriate, along with 95% confidence intervals (95% CI) calculated using the Mantel–Haenszel method. All effect sizes were pooled using a random-effects model. Pooled differences were derived to address potential inter-study heterogeneity, which was evaluated using the *I*-squared statistic (I^2), where values > 50% indicated substantial heterogeneity. Sensitivity analyses were performed when appropriate, and a p-value of < 0.05 was considered statistically significant.

Results

Overall, 344 articles were initially identified. After removing duplicates and irrelevant articles, 45 publications were selected for further review. Four studies could not be retrieved. Following full-text screening, 10 studies were excluded for being non-comparative, 18 did not align with the subject matter, one study was unrelated to colorectal origins, and six studies involved overlapping patient cohorts. Ultimately, six publications satisfied the predefined inclusion and exclusion criteria (Fig. 1). All included studies were retrospective and published after 2000. Upon reviewing the extracted data, the same two authors reached 100% consensus.

The general characteristics of these studies and patients are listed in Table 1. The study years ranged from 2016 to 2024 (patients underwent surgery between 2004 and 2023). The overall patient number in these six studies was 368, comprising 179 who underwent MIS and 189 who underwent open methods. The median patient age across the included studies ranged from 45 to 68 and 43 to 68 years in the MIS and open methods groups, respectively. The male:female ratios were 57.0% and 56.6% in the MIS and open PE groups, respectively. The BMI across these studies ranged between 20.3–23.1 and 19.4–23.3 kg/m^2 in the MIS and open methods groups, respectively. The proportion of patients with ASA ≥ III was comparable between the MIS and open surgery groups across studies, with reported rates ranging between 0–20.0% and 0–22.2% in the MIS and open methods groups, respectively.

Table 2 presents the operation type and associated procedures in these studies. In the MIS group, 74 patients underwent total PE, 4 underwent anterior PE, and 64 posterior PE. In the open group, 89 patients underwent total PE, 3 anterior PE, and 73 posterior PE. Two studies recorded lateral pelvic lymph nodes dissections, and 39 patients underwent MIS and 41 underwent an open approach. Reconstruction post-PE was mentioned in four studies, which demonstrated that 46 and 43 patients were included in the MIS and open method groups, respectively. Urinary conduit (ileal neobladder, ileal conduit, or sigmoid conduit) were also recorded in four studies, displaying that 113 cases underwent MIS and 126 underwent an open approach. Ogura et al. described two patients that underwent sacrectomy via MIS and one patient that was treated using an open approach [18]. Additionally, Chan et al. observed two patients underwent an open approach-based sacrectomy. The total number of conversions was 6 (3.4%) [16].

Table 3 presents intra-operative and postoperative short-term outcomes of each study. The short-term outcomes of PE via minimally invasive and open approaches were compared in Fig. 2. No significant differences were found in R0 resection rates (RR, 1.03; 95% CI, 0.97–1.10; $p = 0.32$; $I^2 = 0\%$) or surgical duration (SMD, 1.01; 95% CI, − 0.57 to 2.60; $p = 0.21$; $I^2 = 97\%$) between the two approaches. Compared with open surgery, the MIS was determined to significantly reduce blood loss and hospital

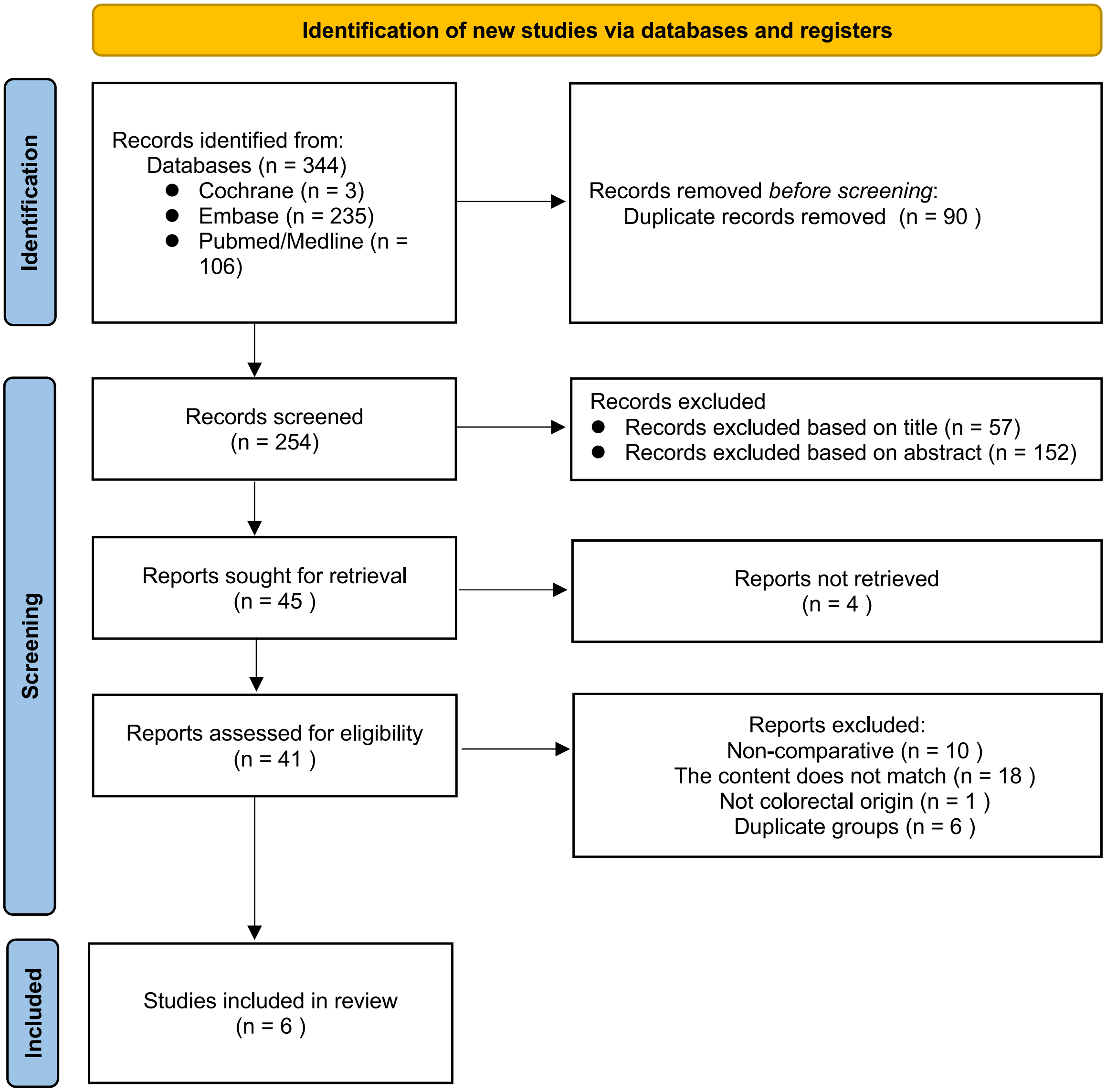


Fig. 1 PRISMA diagram

stay (standard mean difference, − 1.57; 95% CI, − 2.27 to − 0.88, $p < 0.00001$, $I^2 = 84\%$; standard mean difference, − 6.46; 95% CI, − 12.21 to − 0.71, $p = 0.03$, $I^2 = 74\%$, respectively). Time to resuming diet was also shorter in the MIS group than in the open group (standard mean difference, − 0.79; 95% CI, − 1.36 to − 0.21, $p = 0.008$, $I^2 = 0\%$). Additionally, compared with the open group, the MIS group had a borderline total complications and lower rate abdominal wound complications (OR, 0.45; 95% CI, 0.20–1.00; $p = 0.05$; $I^2 = 55\%$; OR, 0.22; 95% CI, 0.11–0.45; $p < 0.0001$; $I^2 = 0\%$). However, no significant difference was noted between the two groups regarding the 30-day readmission rate, mortality, major complications (defined as Clavien–Dindo classification ≥ grade IIIa), anastomotic insufficiency, pelvic abscess, ileus, urinary tract infection, or urological complication rates (Fig. 2).

In the MA of PE outcomes for patients with recurrent or LARC, both the 3-year DFS and OS were compared between the MIS and open surgery groups (Fig. 3). For the 3-year DFS, the pooled RR compared between the MIS with open surgery groups was 1.02 (95% CI, 0.79–1.32; $p = 0.87$), indicating no statistically significant difference between the groups. Study heterogeneity was low ($I^2 = 33\%$), suggesting consistency in results across studies. For the 3-year OS, MIS demonstrated significant advantages over open surgery, with the pooled RR for OS being 1.19 (95% CI, 1.01–1.41; $p = 0.04$), favouring MIS. This analysis's heterogeneity was poor ($I^2 = 12\%$), indicating strong consistency among the

Table 1 Characteristics of included studies

Study ID	Author	Year (enrolment interval)	Location	Patients (MIS/open)	Age of MIS/open	Male of MIS/open	BMI of MIS/open (kg/m^2)	ASA≧III in MIS/open
1	Ogura et al. [18]	2016 (2004/07–2015/04)	Japan	31 (13/18)	56/64	11/15	22.0/21.3	0%/0%
2	Ichihara et al. [17]	2019 (2012/07–2016/04)	Japan	24 (15/9)	69/63	9/5	20.3/22.2	20.0%/22.2%
3	Tashiro et al. [20]	2020 (2012/05–2018/08)	Japan	11 (6/5)	65/63	6/5	21.8/19.4	-/-
4	Kazi et al. [15]	2021 (2013/08–2020/09)	India	158 (61/97)	45/43	37/50	* 22%/27%	0%/0%
5	Tang et al. [19]	2023 (2010/01–2019/12)	China	144 (48/48)	57/58	24/26	23.1/22.9	14.5%/14.5%
6	Chan et al. [16]	2024 (2015/01–2023/03)	Singapore	46 (36/12)	68/68	15/6	22.0/23.3	13.9%/8.3%

*BMI > 25

BMI body mass index, *MIS* minimally invasive surgery, *ASA* American Society of Anesthesiologists

Table 2 Surgical procedures

Study ID	1	2	3	4	5	6
Author	Ogura et al. [18]	Ichihara et al. [17]	Tashiro et al. [20]	Kazi et al. [15]	Tang et al. [19]	Chan et al. [16]
Total (MIS/OPEN)	13/18	15/9	6/5	61/97	48/48	36/12
TPE						
MIS/Open	9/15	10/7	-	41/55	10/7	4/5
Anterior PE						
MIS/Open	4/3			8/17	16/19	4/-
Posterior PE						
MIS/Open	-	5/2	1/1	20/42	22/22	16/6
Sphincter preservation (supralevator)						
MIS/Open	-	-	2/2	13/35	-	26/6
LPLND						
MIS/Open				27/29	12/12	
Plastic reconstruction						
MIS/Open	3/3			30*/19*	13/18	-/3
Urinary conduit						
MIS/Open	10[a] and 3[b]/17[a] and 1[b]		11/5	37[a] and 4[c]/53[a] and 2[c]	48/48	
Sacrectomy						
MIS/Open	2/1	-	-	-	-	-/2
IIA transection						
MIS/Open	bilateral: 3, unilateral: 1, bilateral: 9, unilateral: 2			-	-	-
Conversion	0	1	1	0	0	4

*Perineal reconstruction; [a]ileal conduit; [b]ileal neobladder; [c]Sigmoid conduit

MIS, minimally invasive surgery; *PE*, pelvic exenteration

studies. In summary, MIS displayed significant improvement in its 3-year OS. These findings suggest that MIS may offer a survival advantage in PE, without compromising disease control.

Figure 4 presents the risk of bias assessment for all six studies using the ROBINS-I tool. Most studies demonstrated a low-to-moderate bias risk. Regarding confounding bias, nearly all studies were assessed as having a moderate risk,

Table 3 Short-term outcomes

Author	Ogura et al. [18]	Ichihara et al. [17]	Tashiro et al. [20]	Kazi et al. [15]	Tang et al. [19]	Chan et al. [16]
R0 resection MIS Open	13/13 (100%) 18/18 (100%)	15/15 (100%) 8/9 (88.9%)	6/6 (100%) 4/5 (80%)	N/A	47/48(97.9%) 45/48 (93.8%)	27/36 (75%) 10/12 (83.3%)
OP time, min (median, range) MIS Open	829 (567–1323) 875 (390–1081)	766 (262–1047) 620 (279–1098)	429 (296–600) 373 (178–439)	640 (500–690) 450 (360–540)	344 (150–679) 360 (205–710)	566.5 (275–900) 502.5 (255–751)
Blood loss, mL (median, range) MIS Open	930 (200–2730) 3003 (500–12670)	420 (70–3170) 2160 (110–12000)	340 (230–700) 1153 (606–1358)	900 (600–1700) 1600 (1100–2200)	200 (20–1400) 500 (50–3000)	450 (0–2400) 1200 (200–4000)
Blood transfusion, mL (median, range) MIS Open	0 0–2400 mL	N/A	1/6 (16%) 4/5 (80%)	N/A	N/A	N/A
Length of stay, d (median, range) MIS Open	29 (21–68) 33 (23–76)	32 (10–49) 49 (32–91)	15 (10–180) 16 (11–58)	11 (10–16) 12 (10–20)	12 (6–60) 15 (7–60)	10 (3–42) 30 (6–62)
Time to diet, d (median, range) MIS Open	6 (3–16) 6 (3–24)	N/A	N/A	N/A	3 (1–8) 4 (2–8)	N/A
30-day readmission MIS Open	3/13 (23%) 1/18 (5.6%)	N/A	N/A	90-d 10/61 (16.4%) 8/97 (8.2%)	N/A	8/36 (22.2%) 3/12 (25%)
Post-op mortality MIS Open	0 0	0 0	N/A	0 1/97 (1%)	0 1/48 (2.1%)	0 0
Overall complication MIS Open	8/13 (61.5%) 15/18 (83.3%)	9/15 (60%) 7/9 (77.8%)	2/6 (33.3%) 4/5 (80%)	37/61 (61%) 52/97 (54%)	12/48 (25%) 25/48 (52%)	20/36 (55.6%) 10/12 (83.3%)
Major complication (CD Gr IIIa +) MIS Open	3/13 (23.1%) 8/18 (44.4%)	1/15 (6.7%) 3/9 (33.3%)	1/6 (16.7%) 1/5 (20.0%)	18/61 (29.5%) 19/97 (19.6%)	4/48 (8.3%) 10/48 (20.8%)	5/36 (13.8%) 6/12 (50%)
Anastomosis leak MIS Open	0/13 1/18 (5.6%)	N/A	N/A	N/A	3/48 (6.3%) 5/48 (10.4%)	4/36 (11.1%) 3/12 (25.0%)
Pelvic abscess MIS Open	3/13 (23.1%) 5/18 (27.8%)	1/15 (6.7%) 2/9 (22.2%)	N/A	19/61 (31.1%) 27/97 (27.8%)	4/48 (8.3%) 6/48 (12.5%)	4/36 (11.1%) 6/12 (50%)
Abdominal wound infection MIS Open	0/13 5/18 (27.8%)	1/15 (6.7%) 3/9 (33.3%)	1/6 (16.7%) 3/5 (60%)	5/61 (8.2%) 17/97 (17.5%)	2/48 (4.2%) 9/48 (18.8%)	4/36 (11.1%) 6/12 (50%)
Ileus/bowel obstruction MIS Open	5/13 (38.5%) 5/18 (27.8%)	N/A	N/A	7/61 (11.5%) 13/97 (13.4%)	2/48 (4.2%) 5/48 (10.4%)	11/36 (30.5%) 8/12 (66.7%)
UTI MIS Open	0/13 4/18 (22.2%)	1/15 (6.7%) 3/9 (33.3%)	N/A	N/A	2/48 (4.2%) 3/48 (6.3%)	N/A
Urological complications MIS Open	2/13 (15.4%) 0/18	N/A	N/A	3/61 (4.9%) 5/97 (5.2%)	0/48 1/48 (2.1%)	2/36 (5.6%) 0/12
Perineal wound MIS Open	0/13 4/18 (22.2%)	N/A	N/A	N/A	N/A	N/A

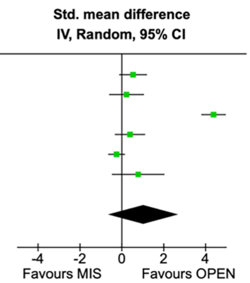
OP, operation; *MIS*, minimally invasive surgery with one study classified as high risk due to the use of an inappropriate analysis method for controlling confounding factors. For other categories, including patient selection, intervention classification, deviations from intended interventions, handling of missing data, outcome measurements, and selection of reported results, all studies were rated as

Fig. 2 Short-term outcomes. **A** intraoperative, **B** postoperative, **C** postoperative complications, and **D** histopathological outcomes

(A) Intraoperative

OP times

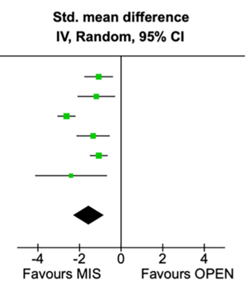
Study or Subgroup	MIS Mean	MIS SD	MIS Total	Open Mean	Open SD	Open Total	Weight	Std. mean difference IV, Random, 95% CI
Chan et al.	577	147.797	36	495.25	160.875	12	16.9%	0.53 [-0.13 , 1.20]
Ichihara et al.	710.25	225.655	15	654.25	274.068	9	16.6%	0.22 [-0.61 , 1.05]
Kazi et al.	617.5	40.97	61	450	36.176	97	17.0%	4.38 [3.79 , 4.96]
Ogura et al.	887	225.95	13	805.25	189.653	18	16.8%	0.39 [-0.33 , 1.11]
Tang et al.	379.25	118.737	48	408.75	113.35	48	17.2%	-0.25 [-0.65 , 0.15]
Tashiro et al.	438.5	118.606	6	340.75	110.616	5	15.7%	0.78 [-0.48 , 2.03]
Total			**179**			**189**	**100.0%**	**1.01 [-0.57 , 2.60]**



Test for overall effect: Z = 1.25 (P = 0.21)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 3.77; Chi² = 173.31, df = 5 (P < 0.00001); I² = 97%

Blood loss

Study or Subgroup	MIS Mean	MIS SD	MIS Total	OPEN Mean	OPEN SD	OPEN Total	Weight	Std. mean difference IV, Random, 95% CI
Chan et al.	825	567.542	36	1650	1162.052	12	17.9%	-1.08 [-1.77 , -0.39]
Ichihara et al.	1020	891.12	15	4107.5	3978.838	9	15.9%	-1.19 [-2.10 , -0.29]
Kazi et al.	1025	237.196	61	1625	221.079	97	20.0%	-2.63 [-3.06 , -2.19]
Ogura et al.	1197.5	756.155	13	4794	3340.198	18	16.9%	-1.35 [-2.14 , -0.55]
Tang et al.	455	309.749	48	1012.5	662.146	48	20.1%	-1.07 [-1.50 , -0.64]
Tashiro et al.	402.5	183.371	6	1067.5	318.709	5	9.3%	-2.41 [-4.13 , -0.68]
Total			**179**			**189**	**100.0%**	**-1.57 [-2.27 , -0.88]**

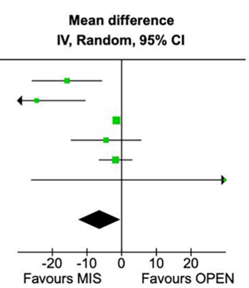


Test for overall effect: Z = 4.43 (P < 0.00001)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.58; Chi² = 31.35, df = 5 (P < 0.00001); I² = 84%

(B) postoperative

Length of Stay

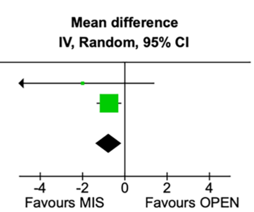
Study or Subgroup	MIS Mean	MIS SD	MIS Total	OPEN Mean	OPEN SD	OPEN Total	Weight	Mean difference IV, Random, 95% CI
Chan et al.	16.25	9.223	36	32	17.125	12	15.8%	-15.75 [-25.90 , -5.60]
Ichihara et al.	30.75	11.211	15	55.25	19.744	9	10.8%	-24.50 [-38.59 , -10.41]
Kazi et al.	12	1.294	61	13.5	2.01	97	31.0%	-1.50 [-2.02 , -0.98]
Ogura et al.	36.75	14.047	13	41.25	14.546	18	15.8%	-4.50 [-14.67 , 5.67]
Tang et al.	22.5	12.121	48	24.25	11.896	48	25.6%	-1.75 [-6.55 , 3.05]
Tashiro et al.	55	66.326	6	25.25	19.919	5	1.0%	29.75 [-26.12 , 85.62]
Total			**179**			**189**	**100.0%**	**-6.46 [-12.21 , -0.71]**



Test for overall effect: Z = 2.20 (P = 0.03)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 27.66; Chi² = 19.28, df = 5 (P = 0.002); I² = 74%

Time to Diet

Study or Subgroup	MIS Mean	MIS SD	MIS Total	OPEN Mean	OPEN SD	OPEN Total	Weight	Mean difference IV, Random, 95% CI
Ogura et al.	7.75	3.885	13	9.75	5.764	18	2.9%	-2.00 [-5.40 , 1.40]
Tang et al.	3.75	1.571	48	4.5	1.347	48	97.1%	-0.75 [-1.34 , -0.16]
Total			**61**			**66**	**100.0%**	**-0.79 [-1.36 , -0.21]**



Test for overall effect: Z = 2.67 (P = 0.008)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 0.50, df = 1 (P = 0.48); I² = 0%

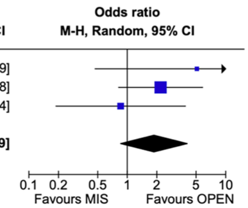
Fig. 2 (continued)

(C) Postoperative complications

30-d readmission

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Chan et al.	3	13	1	18	10.8%	5.10 [0.47 , 55.89]
Kazi et al.	10	61	8	97	62.7%	2.18 [0.81 , 5.88]
Ogura et al.	8	36	3	12	26.5%	0.86 [0.19 , 3.94]
Total		**110**		**127**	**100.0%**	**1.87 [0.85 , 4.09]**
Total events:	21		12			

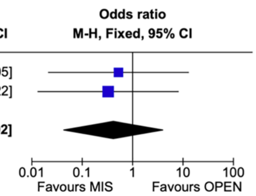
Test for overall effect: Z = 1.56 (P = 0.12)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 1.77, df = 2 (P = 0.41); I² = 0%



Mortality

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Fixed, 95% CI
Kazi et al.	0	61	1	97	43.7%	0.52 [0.02 , 13.05]
Tang et al.	0	48	1	48	56.3%	0.33 [0.01 , 8.22]
Total		**109**		**145**	**100.0%**	**0.41 [0.04 , 4.02]**
Total events:	0		2			

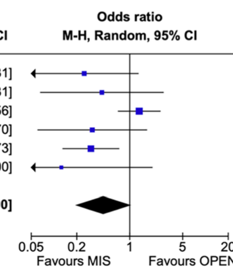
Test for overall effect: Z = 0.76 (P = 0.45)
Test for subgroup differences: Not applicable
Heterogeneity: Chi² = 0.04, df = 1 (P = 0.84); I² = 0%



Overall complication

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Chan et al.	20	36	10	12	14.1%	0.25 [0.05 , 1.31]
Ichihara et al.	9	15	7	9	12.0%	0.43 [0.07 , 2.81]
Kazi et al.	37	61	52	97	28.3%	1.33 [0.70 , 2.56]
Ogura et al.	8	13	15	18	14.0%	0.32 [0.06 , 1.70]
Tang et al.	12	48	25	48	24.8%	0.31 [0.13 , 0.73]
Tashiro et al.	2	6	4	5	6.8%	0.13 [0.01 , 2.00]
Total		**179**		**189**	**100.0%**	**0.45 [0.20 , 1.00]**
Total events:	88		113			

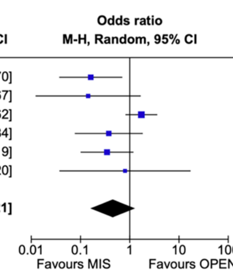
Test for overall effect: Z = 1.97 (P = 0.05)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.49; Chi² = 11.07, df = 5 (P = 0.05); I² = 55%



Major complications (Clavien–Dindo Classification Gr IIIa+)

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Chan et al.	5	36	6	12	18.1%	0.16 [0.04 , 0.70]
Ichihara et al.	1	15	3	9	10.6%	0.14 [0.01 , 1.67]
Kazi et al.	18	61	19	97	25.9%	1.72 [0.82 , 3.62]
Ogura et al.	3	13	8	18	17.0%	0.38 [0.08 , 1.84]
Tang et al.	4	48	10	48	20.6%	0.35 [0.10 , 1.19]
Tashiro et al.	1	6	1	5	7.7%	0.80 [0.04 , 17.20]
Total		**179**		**189**	**100.0%**	**0.45 [0.17 , 1.21]**
Total events:	32		47			

Test for overall effect: Z = 1.58 (P = 0.11)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.84; Chi² = 12.86, df = 5 (P = 0.02); I² = 61%



Anastomosis insufficiency

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Chan et al.	4	36	3	12	39.8%	0.38 [0.07 , 1.99]
Ogura et al.	0	13	1	18	10.3%	0.43 [0.02 , 11.47]
Tang et al.	3	48	5	48	49.9%	0.57 [0.13 , 2.55]
Total		**97**		**78**	**100.0%**	**0.47 [0.16 , 1.35]**
Total events:	7		9			

Test for overall effect: Z = 1.40 (P = 0.16)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 0.14, df = 2 (P = 0.93); I² = 0%

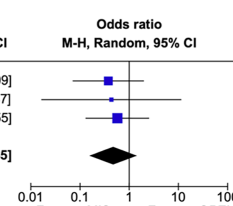
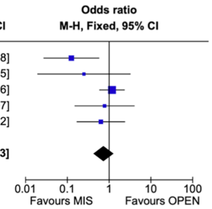


Fig. 2 (continued)

Pelvic abscess

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Fixed, 95% CI
Chan et al.	4	36	6	12	23.9%	0.13 [0.03 , 0.58]
Ichihara et al.	1	15	2	9	7.0%	0.25 [0.02 , 3.25]
Kazi et al.	19	61	27	97	43.0%	1.17 [0.58 , 2.36]
Ogura et al.	3	13	5	18	9.7%	0.78 [0.15 , 4.07]
Tang et al.	4	48	6	48	16.5%	0.64 [0.17 , 2.42]
Total		**173**		**184**	**100.0%**	**0.73 [0.43 , 1.23]**
Total events:	31		46			

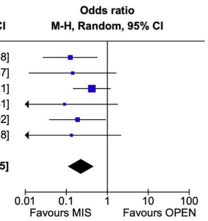
Test for overall effect: Z = 1.18 (P = 0.24)
Test for subgroup differences: Not applicable
Heterogeneity: Chi² = 7.54, df = 4 (P = 0.11); I² = 47%



Abdominal wound infection

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Chan et al.	4	36	6	12	19.9%	0.13 [0.03 , 0.58]
Ichihara et al.	1	15	3	9	7.8%	0.14 [0.01 , 1.67]
Kazi et al.	5	61	17	97	42.4%	0.42 [0.15 , 1.21]
Ogura et al.	0	13	5	18	5.3%	0.09 [0.00 , 1.81]
Tang et al.	2	48	9	48	18.6%	0.19 [0.04 , 0.92]
Tashiro et al.	1	6	3	5	6.0%	0.13 [0.01 , 2.18]
Total		**179**		**189**	**100.0%**	**0.22 [0.11 , 0.45]**
Total events:	13		43			

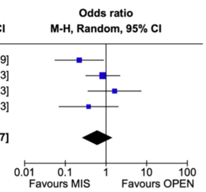
Test for overall effect: Z = 4.26 (P < 0.0001)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 2.58, df = 5 (P = 0.76); I² = 0%



Ileus Bowel obstruction

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Chan et al.	11	36	8	12	23.9%	0.22 [0.05 , 0.89]
Kazi et al.	7	61	13	97	37.0%	0.84 [0.31 , 2.23]
Ogura et al.	5	13	5	18	21.1%	1.63 [0.36 , 7.43]
Tang et al.	2	48	5	48	18.0%	0.37 [0.07 , 2.03]
Total		**158**		**175**	**100.0%**	**0.61 [0.27 , 1.37]**
Total events:	25		31			

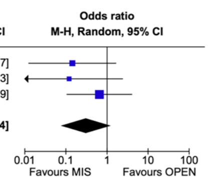
Test for overall effect: Z = 1.21 (P = 0.23)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.22; Chi² = 4.37, df = 3 (P = 0.22); I² = 31%



Urinary tract infection

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Ichihara et al.	1	15	3	9	28.9%	0.14 [0.01 , 1.67]
Ogura et al.	0	13	4	18	19.2%	0.12 [0.01 , 2.43]
Tang et al.	2	48	3	48	51.8%	0.65 [0.10 , 4.09]
Total		**76**		**75**	**100.0%**	**0.30 [0.08 , 1.14]**
Total events:	3		10			

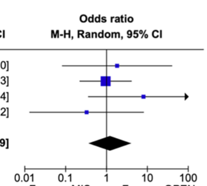
Test for overall effect: Z = 1.77 (P = 0.08)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 1.41, df = 2 (P = 0.49); I² = 0%



Urological complications

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Odds ratio M-H, Random, 95% CI
Chan et al.	2	36	0	12	13.5%	1.81 [0.08 , 40.40]
Kazi et al.	3	61	5	97	60.5%	0.95 [0.22 , 4.13]
Ogura et al.	2	13	0	18	13.4%	8.04 [0.35 , 182.94]
Tang et al.	0	48	1	48	12.5%	0.33 [0.01 , 8.22]
Total		**158**		**175**	**100.0%**	**1.21 [0.39 , 3.79]**
Total events:	7		6			

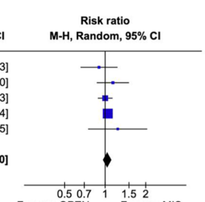
Test for overall effect: Z = 0.32 (P = 0.75)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 2.23, df = 3 (P = 0.53); I² = 0%



(D) histopathological outcomes

Study or Subgroup	MIS Events	MIS Total	OPEN Events	OPEN Total	Weight	Risk ratio M-H, Random, 95% CI
Chan et al.	27	36	10	12	4.3%	0.90 [0.66 , 1.23]
Ichihara et al.	15	15	8	9	5.7%	1.14 [0.87 , 1.50]
Ogura et al.	13	13	18	18	27.4%	1.00 [0.88 , 1.13]
Tang et al.	47	48	45	48	60.9%	1.04 [0.96 , 1.14]
Tashiro et al.	6	6	4	5	1.7%	1.24 [0.75 , 2.05]
Total		**118**		**92**	**100.0%**	**1.03 [0.97 , 1.10]**
Total events:	108		85			

Test for overall effect: Z = 0.99 (P = 0.32)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 2.04, df = 4 (P = 0.73); I² = 0%



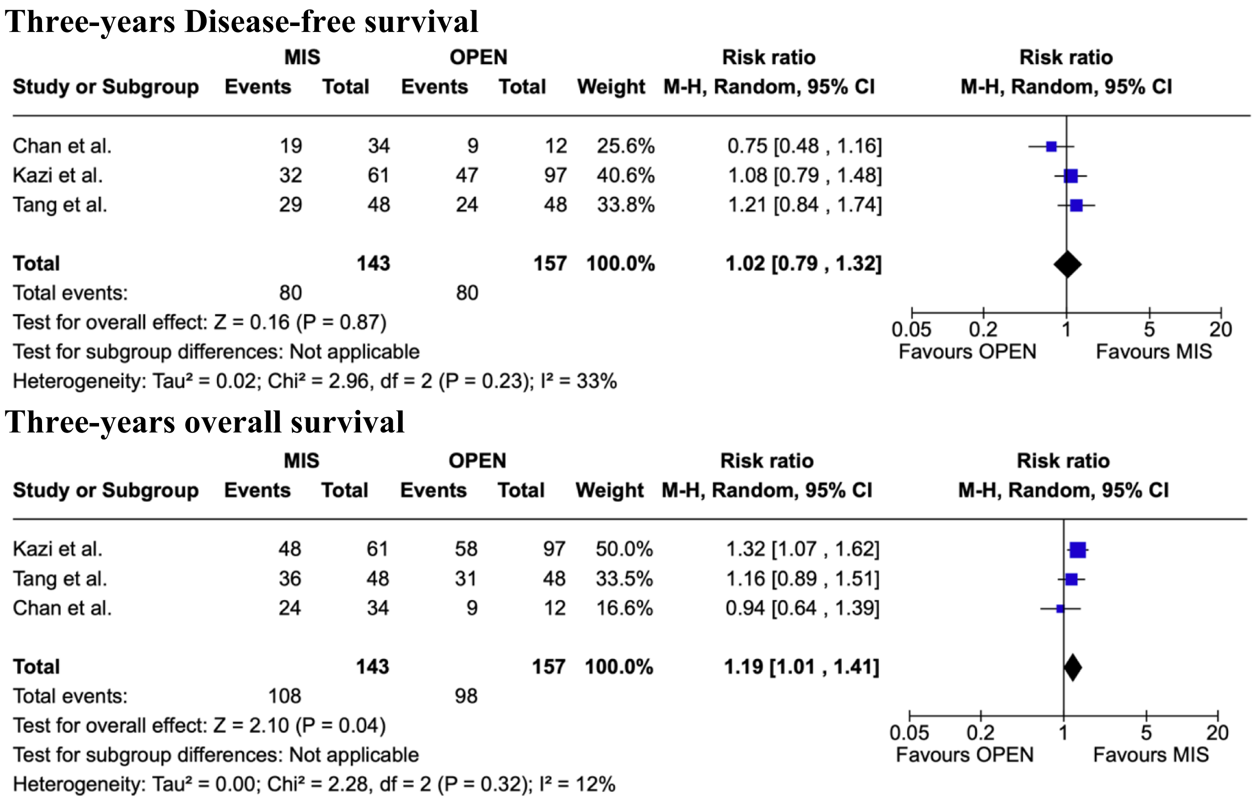


Fig. 3 Long-term outcomes

having a low-to-moderate risk of bias. Overall, all six studies were judged to carry a moderate risk of bias.

Discussion

This review included six studies that discussed patients with rectal cancer who underwent PE and compared short-term outcomes between the minimal invasive and open approach groups. Due to the importance of the R0 resection in recurrent and advanced rectal cancer, this study emphasised the applicability of the minimally invasive approaches. In the MA results, compared with the open group, the MIS group, postoperatively, had significantly reduced blood loss as well as a shorter hospital stay and time to resuming diet. Additionally, compared with the open group, the MIS group had a lower rate of total and abdominal wound complications. Regarding postoperative major complication and mortality rates, no significant difference was detected between these two groups. In this MA, we found that the 3-year OS was significantly improved in the MIS group. However, the 3-year DFS and R0 resection rates displayed no significant differences between these two groups.

This study specifically focused on rectal cancer and did not include other types of cancer. By narrowing the scope, this analysis provided a more precise evaluation of outcomes related to PE in this specific patient population, ensuring that these findings are directly applicable to rectal cancer management and are not confounded by differences in tumour biology, treatment protocols, or prognostic factors associated with other cancer types.

In these six studies, predominantly conducted in Asia (Japan, India, China, and Singapore), the MIS for PE rates ranged from 38.6 to 78.3%, and the patient selection criteria did not distinctly differ by presenting information such as body weight, ASA score, and disease status. The distributions of the two groups used to compare outcomes were appropriate in these studies. The detailed procedure protocols recorded within these studies varied, with only one study recording the numbers of internal iliac vessel transection and two performing pelvic lymph node dissection. These differences may be related to the surgeon's preference or differences in operation record habit. Of the 366 patients in this review, only five underwent sacrectomy as this surgery is difficult to perform using an MIS approach. Thus, it was excluded by the researchers.

Our findings indicate that MIPE is associated with several short-term advantages, including reduced blood loss, shorter hospital stays, and faster bowel function recovery. This is evidenced by a shorter time to diet, without

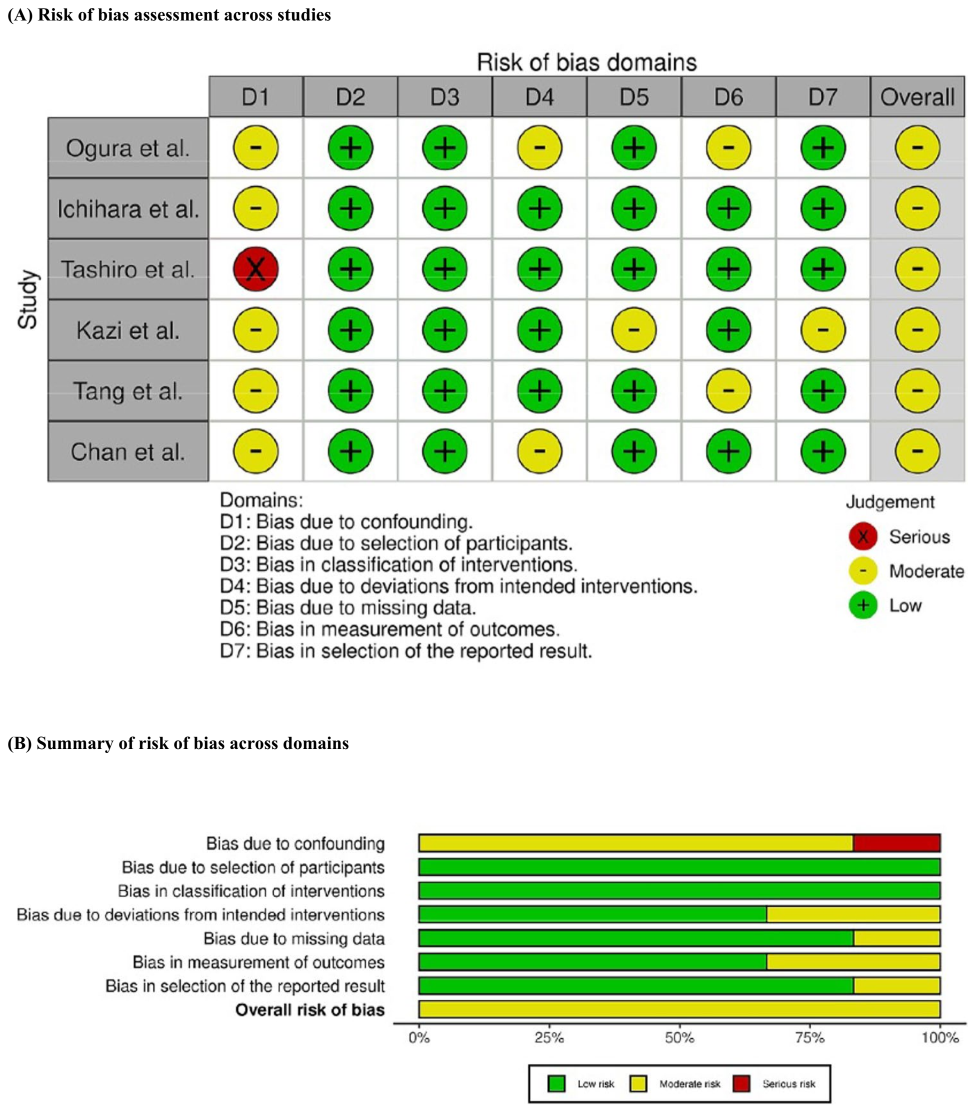


Fig. 4 **A** Risk of bias assessment across studies. **B** Summary of risk of bias across domains

compromising the R0 resection rate. Additionally, the minimally invasive group demonstrated lower rates of total and abdominal wound complications. Similarly, a review by Ryan et al. [14] focused on patients with various cancer types of locally advanced or recurrent pelvic malignancies that underwent PE via MIS or open approaches reported comparable outcomes. Their analysis also identified reduced intraoperative blood loss and shorter postoperative stays in the MIS group and demonstrated a comparable R0 resection rate, which is consistent with our findings. Thus, achieving a safe surgical margin is paramount in PE for rectal cancer as it directly impacts oncologic outcomes and long-term survival. However, unlike Ryan et al. [14], our analysis did not show a longer operative duration in the MIS group than in the open approach group. Furthermore, in this review, the established benefits of MIS were reaffirmed, aligning with the observations in Ryan et al.'s [14] review.

This finding suggests that skilled surgeons can achieve equivalent oncological dissection outcomes while employing the minimally invasive approach in appropriately selected patients. However, among the six articles we reviewed, no classical definition of R0 resection in PE was provided. As PE lacks such a clear margin definition, unlike primary rectal cancer, where achieving microscopically clear margins at the proximal, distal, and circumferential edges—defined as a > 1 mm distance from the tumour—is a widely accepted benchmark for oncological success [24].

For recurrent or LARC, the most challenging aspect of achieving an R0 resection is ensuring a clear circumferential margin, often necessitating contiguous organ sacrifice and PE. Thus, R0 resection is now widely recognised as a critical predictor of oncological outcomes in patients undergoing exenterative surgery, offering improved survival rates, reduced morbidity, and enhanced quality of life [25]. Despite its importance, the definition of a clear margin in exenterative specimens remains variable due to the complex nature of these surgeries. The specimens commonly include multiple organs, neurovascular structures, and bony elements invaded by the tumour, making each case unique and warranting a patient-specific, three-dimensional evaluation rather than a standard approach. According to Brown et al., the most reliable definition of an R0 margin is 'evidence of normal tissue between the cancer and closest inked resection margin' [26]. Establishing standardised definitions and reporting practices is instrumental for the facilitation of meaningful data synthesis and fostering of collaborative research in this field.

The survival benefit observed with MIS may be attributed to its less invasive nature, leading to reduced surgical trauma, faster recovery, and improved tolerance to adjuvant therapies. Studies report that MIS is associated with fewer perioperative complications and indirectly improve long-term outcomes by reducing delays in adjuvant treatment and maintaining the patients' overall condition [27, 28]. Additionally, the enhanced visualisation of MIS, particularly in robotic-assisted techniques, may allow for precise dissection and promote the preservation of critical structures, contributing to improved oncologic outcomes [18].

Achieving an R0 resection is vital in PE, as it significantly reduces recurrence and improves DFS. In cases of extensive local invasion or complex anatomy, the broader access provided by open surgery may offer advantages in ensuring complete tumour removal. Therefore, the choice between MIS and open surgery should be individualised, depending on tumour characteristics, patient factors, and surgical expertise [29].

The comparable DFS between MIS and open surgery indicates that both approaches are effective in achieving disease control. This underscores the oncological safety of MIS-based PE, especially when performed in high-volume centres with experienced surgical teams. However, DFS is influenced by various factors, including tumour biology and adjuvant treatment efficacy, which may mitigate the impact of the surgical approach.

In the MIS group, the OS was significantly improved, highlighting the potential advantages of this approach beyond oncological outcomes. OS encompasses overall health and recovery, reflecting the cumulative impact of reduced perioperative morbidity, faster recovery, and better tolerance to adjuvant therapies. These findings align with prior studies demonstrating that MIS offers superior short-term outcomes, which may contribute to better long-term survival [13].

This review had certain limitations that impact the reliability and generalisability of its findings. Many studies suffer from selection bias, as they often include healthier patients with fewer comorbidities, potentially skewing results. Additionally, data on the use of neoadjuvant and adjuvant therapies, such as chemotherapy or radiotherapy, are frequently incomplete, making assessing the standalone impact of PE or its effectiveness in combination with other treatments challenging. In addition, data presentation often relies on mean values rather than medians, potentially distorting the representation of central tendencies due to the influence of outliers. Owing to the paucity of robust comparative studies, as most existing research comprises single-arm studies, the ability to derive strong conclusions about the relative efficacy and safety of PE compared with that of alternative treatments is limited. Addressing these limitations in future research is essential for advancing PE comprehension in LARC management.

Conclusion

This meta-analysis focused specifically on rectal cancer and demonstrated that MIS significantly improves the short-term outcomes of patients undergoing PE. MIS was associated with reduced blood loss, shorter hospital stays, faster diet resumption, and fewer complications, especially abdominal wound complications. No significant differences were found in major postoperative complications or mortality between the MIS and open surgery approaches, supporting MIS as a safe and effective alternative to open surgery for selected patients. Notably, the MIS demonstrated an improved OS, which may be attributed to its faster recovery rate, potentially enabling patients to initiate and complete adjuvant treatment more effectively, thereby enhancing long-term outcomes.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00384-025-04876-z.

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Author contribution Author Contributions YJH, CCL, YJC, BKJ, and ZHY designed the study; YLY, CKL, CCL and JFY were involved in the collection of samples; YJH, BKJ, and ZHY analyzed the data; YJH, YJC, BKJ, CCL and ZHY drafted the article or revised it critically for important intellectual content; YLY, CKL and JFY supervised the study; YJH, CCL, YJC, BKJ, and ZHY provided final approval of the version to be published. All authors have read and agreed to the published version of the manuscript.

Data availability The data, code, and other materials utilized in this study are publicly accessible online. For researchers requiring additional support or clarification regarding specific analyses, we welcome inquiries and are available to provide assistance upon request via email.

Declarations

Ethics approval and consent to participate Our study does not require approval since it is a meta-analysis.

Conflict of interest The authors declare no competing interests.

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