Robotic surgery for inguinal and ventral hernia repair: a systematic review and meta-analysis

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Abstract

Background This systematic review and meta-analysis assessed the effectiveness of robotic surgery compared to laparoscopy or open surgery for inguinal (IHR) and ventral (VHR) hernia repair.

Methods PubMed and EMBASE were searched up to July 2022. Meta-analyses were performed for postoperative complications, surgical site infections (SSI), seroma/hematoma, hernia recurrence, operating time (OT), intraoperative blood loss, intraoperative bowel injury, conversion to open surgery, length of stay (LOS), mortality, reoperation rate, readmission rate, use of opioids, time to return to work and time to return to normal activities.

Results Overall, 64 studies were selected and 58 were used for pooled data analyses: 35 studies (227 242 patients) deal with IHR and 32 (158 384 patients) with VHR. Robotic IHR was associated with lower hernia recurrence (OR 0.54; 95%CI 0.29, 0.99; I^2: 0%) compared to laparoscopic IHR, and lower use of opioids compared to open IHR (OR 0.46; 95%CI 0.25, 0.84; I^2: 55.8%). Robotic VHR was associated with lower bowel injuries (OR 0.59; 95%CI 0.42, 0.85; I^2: 0%) and less conversions to open surgery (OR 0.51; 95%CI 0.43, 0.60; I^2: 0%) compared to laparoscopy. Compared to open surgery, robotic VHR was

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associated with lower postoperative complications (OR 0.61; 95%CI 0.39, 0.96; I^2: 68%), less SSI (OR 0.47; 95%CI 0.31, 0.72; I^2: 0%), less intraoperative blood loss (− 95 mL), shorter LOS (− 3.4 day), and less hospital readmissions (OR 0.66; 95%CI 0.44, 0.99; I^2: 24.7%). However, both robotic IHR and VHR were associated with significantly longer OT compared to laparoscopy and open surgery.

Conclusion These results support robotic surgery as a safe, effective, and viable alternative for IHR and VHR as it can brings several intraoperative and postoperative advantages over laparoscopy and open surgery.

Graphical abstract
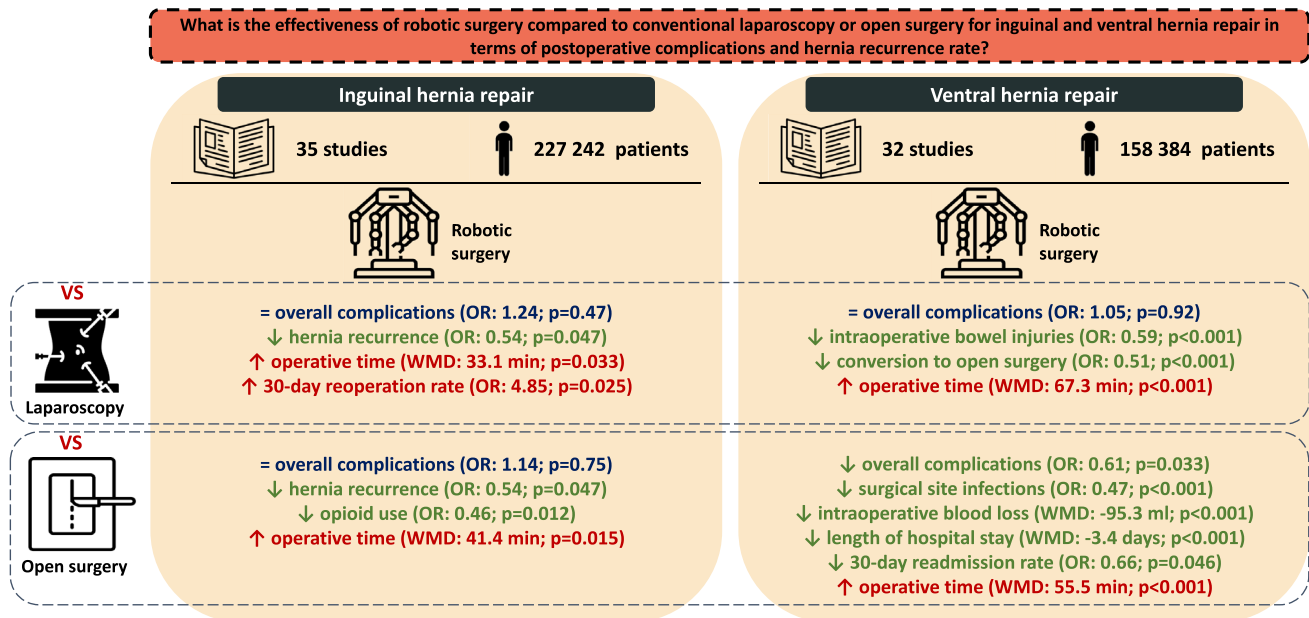
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Keywords Inguinal hernia · Ventral hernia · Robotic surgery · Hernia recurrence · Hernia repair outcomes

Inguinal (IHR) and ventral hernia repair (VHR) are common surgical procedures in adults [1, 2]. Traditionally, they are approached by open surgery, although the use of minimally invasive surgical (MIS) techniques has grown at an exponential rate over the last decades [3, 4]. The advent of robotic surgery further increased the rate of abdominal hernia repairs carried out with MIS [5–8]. In particular, the use of robotic systems brought several technical improvements, such as enhanced magnification and view, dexterity, and maneuverability, which has been seen as clear advantages over laparoscopy [6, 9–13]. Nevertheless, the clinical efficacy of robotic hernia repair over laparoscopic or open surgery is still matter of debate [14–19]. The present systematic review and meta-analysis was designed to provide a critical appraisal of the literature summarizing the outcomes of robotic IHR and VHR in order to answer to the following focus question: what is the effectiveness of robotic surgery compared to conventional laparoscopy or open surgery for

IHR and VHR in terms of postoperative complications and hernia recurrence rate?

Materials and methods

Study design and inclusion criteria

The study protocol was registered in the PROSPERO database (provisional registration number: CRD42023413043) and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statements checklist [20]. The literature search and study selection criteria were defined according to the PICOS framework:

Patients Adult patients with inguinal or ventral hernia candidate for surgical hernia repair.

Intervention Robotic abdominal wall repair. All types of hernia repair procedure were considered.

Comparison Laparoscopic and/or laparotomic abdominal wall repair.

Outcomes

- Primary outcome: postoperative complications (at any time point) expressed as overall complication rate or by type of complication, including hernia recurrence.
- Secondary outcomes: intraoperative variables (e.g., operating time, intraoperative blood loss, intraoperative bowel injury, conversion to open surgery), and postoperative outcomes (e.g., mortality, reoperation rate, readmission rate, postoperative use of opioids, LOS, time until return to work, and time until resume of normal activities).

Study design Any type of analytic studies (i.e., randomized and non-randomized controlled trials, prospective and retrospective studies).

Studies were included irrespective of the surgical technique (e.g., extraperitoneal or intraperitoneal IHR). Narrative and systematic reviews, meta-analysis, non-comparative studies, case reports, notes, commentaries, letters, editorials, and conference abstracts were excluded. The research was limited to human studies written in English.

Literature search strategy

A literature search was performed screening MEDLINE and EMBASE from inception to July 25, 2022. Specific research equations were designed for each database, using the following keywords and/or MeSH terms: *Inguinal, Abdominal, Ventral, Incisional, Abdominal wall, Hernia, Herniorrhaphy, Hernia repair, Abdominoplasty, Wall reconstruction, Robotic surgery/robotic/robotic assisted, Laparoscopy/laparoscopic, Open surgery/laparotomy*. The research equations are reported in Supplementary Table S1. In addition, the reference lists of eligible studies and pertinent review articles were crosschecked to identify potential additional records.

Study selection and risk of bias assessment

The literature search and selection were performed by two independent reviewers (CAS and NdeA). All records from the merged searches and cross-referencing were analyzed for relevance on title and abstract. To enhance sensitivity, only the records excluded by both reviewers were removed. The two reviewers further performed an independent full-text analysis of pre-selected articles. Any disagreement on study inclusion or exclusion was solved by discussion of a tiebreaker (PP). Both reviewers independently assessed the risk of bias using appropriate tools according to the study design. The Newcastle–Ottawa scale was used for

case–control and cohort studies [21] and the Cochrane risk-of-bias tool (ROB-II) for randomized controlled trials [22, 23].

Data extraction and analysis

Both reviewers independently extracted and collected in a predefined excel database the following data: authors, year of publication, journal, study timeframe, design and population, patients' demographics, length of follow-up, surgical procedure details, intraoperative and postoperative (short and long-term) outcomes, impact on patient quality of life and surgery-related costs. Data extracted from the included studies were processed for the qualitative and quantitative analyses. Cohen's Kappa statistic was used to assess the inter-reviewers agreement during the study selection process [24]. The feasibility analysis established that, based on the final data extraction database, it was possible to conduct meta-analyses on the following outcomes: overall postoperative complications, SSI, postoperative seroma or hematoma rate, hernia recurrence, operating time, LOS, intraoperative blood loss, conversion to open surgery, mortality, reoperation rate, readmission rate, intraoperative bowel injury, postoperative use of opioids, time to return to work, and time to return to normal activities. Four different sets of analyses were conducted according to the type of hernia repair and the surgical approach: (1) Robotic vs. Laparoscopic IHR; (2) Robotic vs. Open IHR; (3) Robotic vs. Laparoscopic VHR; (4) Robotic vs. Open VHR.

Individual study results for each outcome were pooled using fixed or random-effects models according to the clinical heterogeneity expected among the selected studies. According to the standard meta-analytical approach, continuous outcomes were analyzed as Weighted Mean Differences (WMD), while dichotomous outcomes were analyzed as Odds Ratios (OR) and Risk Differences (RD). OR is the most commonly used measure in biostatistics, but it cannot include results from studies in which no event is observed, therefore leaving out part of the evidence. For this reason, when OR measure excluded many studies due to the absence of events in dichotomous outcomes, the pooled results were reported as RD. For dichotomous outcomes, if only percentages were available, the corresponding number of patients was calculated based on these percentages and the total sample size in each group. In studies reporting data separately for unilateral and bilateral hernia or reporting LOS separately for inpatients and outpatients, overall results were derived when the numbers of patients in each group were available (if not, the data were excluded). For the 30-day outcomes (mortality, reoperation, readmission), if results were available at a later date and no event was reported in both groups (i.e., no death at all at 90 days), the results at 30-day were imputed based on the 90-day rate (0%). For

the continuous outcomes, the fixed-effects models were run using the inverse variance method and the random-effects ones using the DerSimonian and Laird method, with the estimate of heterogeneity being taken from the inverse variance model. For the dichotomous outcomes, the fixed-effects models were run using the Mantel–Haenszel method and the random-effects ones using the DerSimonian and Laird method, with the estimate of heterogeneity being taken from the Mantel–Haenszel model. Heterogeneity was assessed by the Cochran's Q test and the I^2 statistics. I^2 statistic was used to quantify heterogeneity, with I^2 values of 25%, 50%, and 75% being considered as low, moderate, and high heterogeneity, respectively [22, 25]. The meta-analysis was performed using STATA version 14.2 (StataCorp, College Station, Texas, USA).

Results

Literature search and selection

After the comprehensive stepwise literature research, 468 articles were identified, of which 385 were rejected based on the title and abstract evaluation. The remaining 83 articles underwent the full-text analysis; of these, 24 were excluded because non pertinent to the research question. No additional study was identified through cross-check of the reference lists or manual search. Finally, 64 studies were selected for the qualitative synthesis of the literature, and 58 (90.6%) were used for pooled data analyses (Fig. 1). Data on IHR and VHR were reported by 35 [4, 6, 11–13, 18, 26–55] and 32 studies [7, 8, 10, 16–18, 36, 42, 43, 45, 56–77], respectively (3 studies concerned both IHR and VHR). The inter-reviewer percentage of agreement was 94% with a Cohen's Kappa coefficient of 0.75, demonstrating a substantial agreement.

Study characteristics

The included studies were published between September 2014 and July 2022. The characteristics of the included studies are summarized in Table 1. Overall, 227 242 patients underwent IHR and 158 384 VHR. IHR was performed by robotic, laparoscopic, and open approach in 22 308 (9.8%), 46 139 (20.3%) and 158 795 (69.9%) patients, respectively. VHR was carried out by robotic, laparoscopic, and open technique in 19 225 (12.1%), 90 300 (57%) and 48 859 (30.9%) patients, respectively. Most of the studies (85.9%) have a retrospective design, of which 13 studies (23.6%) used a propensity score matching (PSM) analysis. Only 7 RCTs (10.9%) and 2 (3.1%) prospective studies were found.

The demographic and clinical characteristics of the studied patient populations are reported in Table 2. Focusing on

IHR, 4 (11.4%) studies reported a higher body mass index (BMI) in the robotic group [4, 6, 42, 54] and 1 (2.8%) in the laparoscopic group [40], whereas bilateral procedures were most commonly performed in the robotic group in 3 (8.6%) studies [50, 54, 55] and in the laparoscopic group in 2 (5.7%) studies [52, 53]. Focusing on VHR, a significant between-group difference in terms of BMI, recurrent hernias, and percentage of transversus abdominis release was reported by 4 (12.5%), 2 (6.25%) and 4 (12.5%) studies, respectively. In particular, all 4 (12.5%) studies [10, 18, 36, 69] reported a higher BMI, and 3 (9.4%) studies [58, 64, 75] highlighted a higher percentage of transversus abdominis release in the robotic group.

Inguinal hernia repair

Results from pooled data analyses for the comparisons between robotic vs. laparoscopic hernia repair and between robotic vs. open hernia repair are reported in Table 3 and displayed in Fig. 2 and as Supplementary Material.

Seventeen studies [4, 6, 11, 12, 27, 28, 35–38, 40, 42, 48, 49, 51, 52, 55] were included in the meta-analysis for overall postoperative complication rate, of which 14 (82.3%) compared robotic vs. laparoscopic IHR and 9 (52.9%) robotic vs. open IHR. Eleven (64.7%) studies reported SSI rate comparing robotic vs. laparoscopic IHR [4, 11, 35, 40, 42, 44, 46, 48, 49, 51, 52] and 8 (47%) comparing open vs. open IHR [4, 11, 12, 35, 37, 42, 52, 54]. The incidence of hematoma and/or seroma was analyzed by 11 (78.6%) [6, 26–28, 40, 44, 46, 48, 49, 51, 52] and 4 (28.6%) [12, 37, 45, 52] studies in the corresponding aforementioned groups. Pooled data analyses showed no significant difference in terms of overall postoperative complications, SSI and hematoma/seroma occurrence between robotic and laparoscopic or open surgery for IHR (Table 3).

Twelve studies [6, 11, 18, 26, 34, 38, 39, 44, 46, 48, 52, 54] reported the rate of hernia recurrence after IHR; of these, 11 (91.7%) concerned robotic vs. laparoscopic surgery and 5 (41.7%) robotic vs. open surgery. Pooled data analyses showed statistically significant reduced risk of hernia recurrence in the robotic surgery group compared to the laparoscopic one (OR 0.54), whereas no significant differences were noted when compared to open IHR (Fig. 2).

Operative time was significantly longer for robotic IHR compared to laparoscopy (WMD: 33.1 min) and open surgery (WMD: 41.3 min). Compared to laparoscopy, robotic IHR was associated with a higher 30-day reoperation rate (OR 4.85, Supplementary fig. S12). No statistically significant difference was noted for conversions to open surgery, LOS, 30-day hospital readmission rate, and postoperative use of opioids between robotic vs. laparoscopic IHR.

Fig. 1 PRISMA Diagram. The flowchart shows the literature search and study selection process according to the PRISMA guidelines [20]
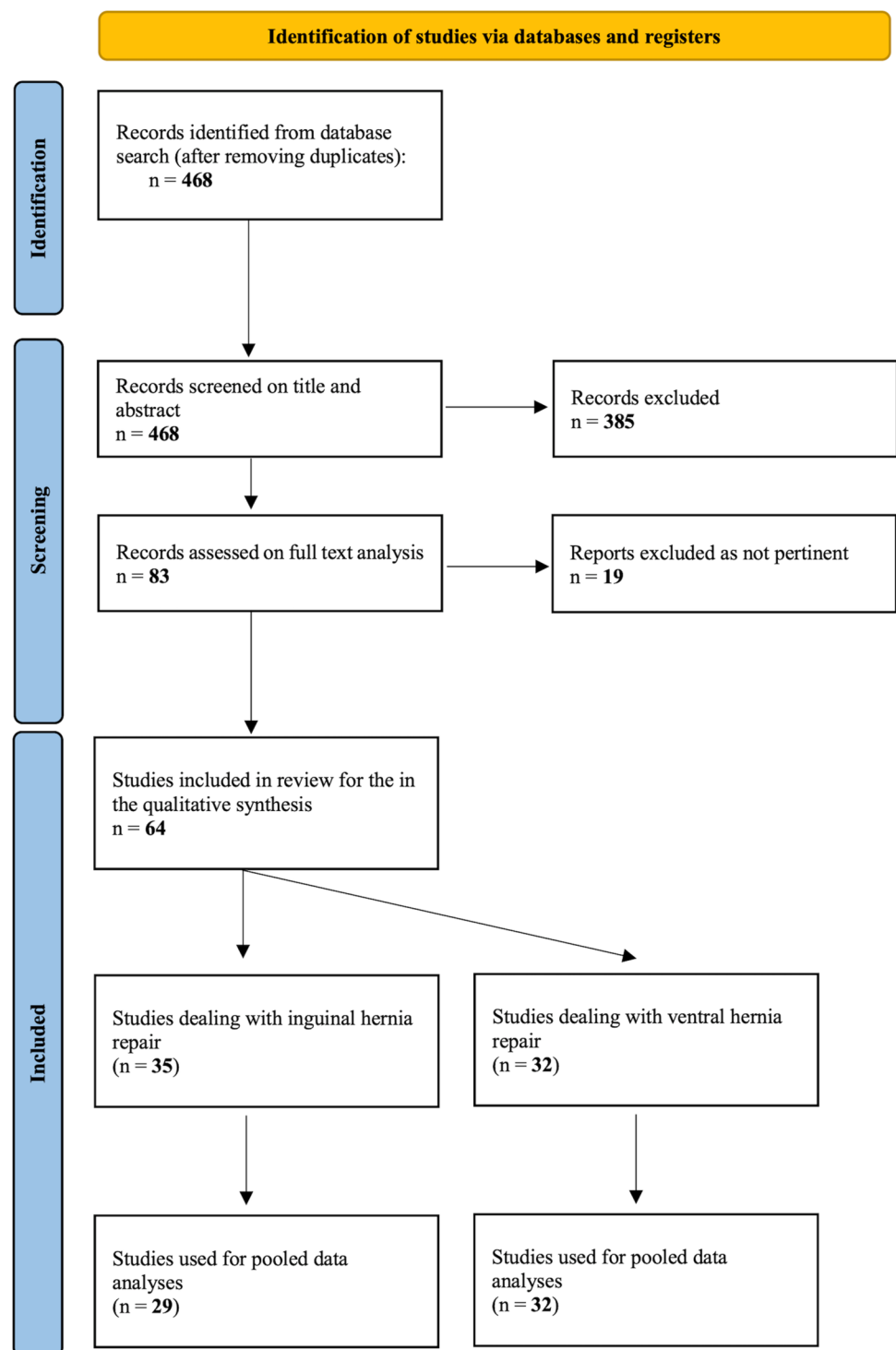
Compared to open surgery, robotic IHR was associated with a significant lower use of postoperative opioids (OR 0.46).

There were insufficient data to perform a meta-analysis on intraoperative blood loss, intraoperative bowel injuries, 30-day mortality, time to return to work, and time to return to normal activities.

Table 1 Summary of the included studies

First Author, Year	Country	Study design	Robotic procedure (ROB)	Laparoscopic procedure (LAP)	Open procedure (OPEN)	Number of patients (ROB/LAP/OPEN)	Risk of bias (NOS)
Inguinal hernia repair (IHR)							
Waite et al. (2016) [41]	USA	R	TAPP	TAPP	–	39/24	5/9
Kolachalam et al. (2017) [12]	USA	R	TAPP	–	Plug-and-patch, Lichtenstein, or Prolene hernia system	95/93	6/9
Kudsi et al. (2017) [6]	USA	R	TAPP	TEP	–	118/157	8/9
Charles et al. (2018) [11]	USA	R	TAPP	TAPP	NS	69/241/191	5/9
Gamagami et al. (2018) [37]	USA	R+PSM	TAPP	–	Lichtenstein, plug-and-patch, Prolene Hernia System	444/444	7/9
Kosturakis et al. (2018) [54]	USA	R	TAPP	–	Modified Lichtenstein technique, Modified Shouldice or Bassini	100/100	6/9
Muysoms et al. (2018) [27]	Belgium	P	TAPP	TAPP	–	49/37	7/9
Abdelmoaty et al. (2019) [33]	USA	R	NS	NS	–	734/1671	6/9
AlMarzooqi et al. (2019) [34]	USA	R	TAPP, TEP	TAPP, TEP	Tissue and mesh repair techniques	847/1841/1925	6/9
Bittner et al. (2019) [13]	USA	R+PSM	NS	NS	NS	83/83 – 85/85	7/9
Huerta et al. (2019) [52]	USA	R	TAPP	TEP	Lichtenstein	71/128/1100	5/9
Pokala et al. (2019) [35]	USA	R	NS	NS	NS	594/540/2413	5/9
Sheldon et al. (2019) [53]	USA	R	TAPP	TEP	NS	49/34/90	5/9
Zayan et al. (2019) [18]	USA	R	TAPP	TEP	–	37/68	6/9
Aghayeva et al. (2020) [26]	Turkey	R	TAPP	TEP	–	43/43	8/9
Gundogdu et al. (2020) [48]	Turkey	R	TAPP	TEP	–	16/33	5/9
Janjua et al. (2020) [31]	USA	R+PSM	NS	NS	NS	1480/2960/2960	7/9
Janjua et al. (2020) [32]	USA	R+PSM	NS	NS	NS	922/1844/1844	7/9
Khoraki et al. (2020) [51]	USA	R	TAPP	TEP	–	45/138	5/9
LeBlanc et al. (2020) [55]	USA	P+PSM	TAPP	TAPP, TEP	–	80/80—112/112	7/9
Prabhu et al. (2020) [40]	USA	RCT	TAPP	TAPP		48/54	[a]
Ephraim et al. (2021) [46]	Israel	R	TAPP	TAPP, TEP	–	80/108	6/9

Table 1 (continued)

First Author, Year	Country	Study design	Robotic procedure (ROB)	Laparoscopic procedure (LAP)	Open procedure (OPEN)	Number of patients (ROB/LAP/OPEN)	Risk of bias (NOS)
Glasgow et al. (2021) [47]	USA	R	TAPP	NS	NS	100/100/100	5/9
Kakiashvili et al. (2021) [50]	Israel	R	TAPP	TAPP, TEP	Bassini	24/16/97	4/9
Muysoms et al. (2021) [49]	Belgium	R	TAPP	TAPP	–	404/272	7/9
Tatarian et al. (2021) [30]	USA	R + PSM	NS	NS	–	346/346	7/9
Tonelli et al. (2021) [38]	USA	R + PSM	NS	NS	NS	342/1026/1026	8/9
Dewulf et al. (2022) [45]	Belgium	R	TAPP	–	Lichtenstein	22/21	4/9
Gerdes et al. (2022) [28]	Switzerland	R	TAPP	TAPP	–	29/29	5/9
Holleran et al. (2022) [4]	USA	R	TAPP	NS	NS	6063/118035/100880	5/9
Quilici et al. (2022) [29]	USA	R	NS	NS	NS	2150/2724/4538	5/9
Shah et al. (2022) [43]	USA	R + PSM	NS	NS	–	3692/3692	7/9
Shenoy et al. (2022) [42]	USA	R	NS	NS	NS	1842/9155/40317	5/9
Kudsi et al. (2023) [44]	USA	R	TAPP	TEP	–	547/606	7/9
Miller et al. (2023) [39]	USA	RCT	TAPP	TAPP	–	48/54	[a]
Ventral hernia repair (VHR)							
Gonzalez et al. (2015) [72]	USA	R	IPOM	IPOM	–	67/67	5/9
Chen et al. (2016) [71]	USA	R	IPOM	IPOM	–	39/33	5/9
Coakley et al. (2017) [63]	USA	R	NS	NS	–	351/32243	5/9
Prabhu et al. (2017) [7]	USA	R + PSM	IPOM	IPOM	–	186/452	8/9
Warren et al. (2017) [64]	USA	R	Preperitoneal, retromuscular, sublay technique ± TAR	IPOM	–	53/103	5/9
Altieri et al. (2018) [17]	USA	R	NS	NS	–	679/20896	5/9
Armijo et al. (2018) [62]	USA	R	NS	NS	NS	465/6829/39505	5/9
Bittner et al. (2018) [8]	USA	R	TAR	–	TAR	26/76	5/9
Carbonell et al. (2018) [65]	USA	R + PSM	Preperitoneal, retromuscular, sublay technique ± TAR	–	Preperitoneal, retromuscular, sublay technique ± TAR	111/222	8/9
Martin-del-Campo et al. (2018) [16]	USA	R + PSM	TAR	–	TAR	38/76	8/9
Walker et al. (2018) [77]	USA	R + PSM	IPOM	IPOM	–	48/48	7/9

Table 1 (continued)

First Author, Year	Country	Study design	Robotic procedure (ROB)	Laparoscopic procedure (LAP)	Open procedure (OPEN)	Number of patients (ROB/LAP/OPEN)	Risk of bias (NOS)
Zayan et al. (2019) [18]	USA	R	NS	NS	–	16/33	6/9
Olavarria et al. (2020) [70]	USA	RCT	IPOM	IPOM	–	65/59	a
Reeves et al. (2020) [56]	Australia	R	TAR	–	TAR	13/13	5/9
Collins et al. (2021) [10]	USA	R + PSM	Retromuscular sublay technique ± TAR	–	Retromuscular sublay technique ± TAR	350/759	8/9
Dauser et al. (2021) [60]	Austria	R	TAR	–	TAR	16/10	5/9
Dhanani et al. (2021) [68]	USA	RCT	IPOM	IPOM	–	65/59	a
Forester et al. (2021) [58]	USA	R	Extra-peritoneal sublay technique ± TAR	IPOM	Preperitoneal or retromuscular sublay technique ± TAR	77/300/418	6/9
Guzman-Pruneda et al. (2021) [61]	USA	R	Retromuscular sublay technique ± TAR	–	Retromuscular sublay technique ± TAR	42/194	6/9
Kudsi et al. (2021) [75]	USA	R	IPOM, extra-peritoneal techniques ± TAR		Onlay, sublay techniques	35/43	5/9
Lapinska et al. (2021) [59]	USA	R + PSM	Repair without myofascial release	Repair without myofascial release	–	615/615	8/9
LeBlanc et al. (2021) [36]	USA	P	Repair without myofascial release	Repair without myofascial release	Repair without myofascial release	159/82/130	6/9
Nguyen et al. (2021) [76]	USA	R	TAR	–	TAR	27/16	5/9
Petro et al. (2021) [69]	USA	RCT	IPOM	IPOM	–	39/36	a
Ayuso et al. (2022) [57]	USA	R	NS	NS	–	5942/19853	5/9
Dewulf et al. (2022) [45]	Belgium, Finland	R	TAR	–	TAR	90/79	7/9
Han et al. (2022) [73]	USA	R	TAR	–	TAR	25/108	6/9
Petro et al. (2022) [66]	USA	RCT	IPOM	IPOM	–	38/33	a
Shah et al. (2022) [43]	USA	R + PSM	NS	NS	–	2703/2703	7/9
Shenoy et al. (2022) [42]	USA	R	NS	NS	NS	283/1721/7210	5/9
Thomas et al. (2022) [74]	USA	R	Onlay, inlay, sublay techniques	Onlay, inlay, sublay technique	–	6544/4116	5/9
Costa et al. (2023) [67]	Brazil	RCT	IPOM	IPOM	–	18/19	a

IPOM intraperitoneal onlay mesh, *LAP* laparoscopic, *NOS* Newcastle Ottawa scale, *NS* not specified, *P* prospective study, *PSM* propensity score matching, *R* retrospective study, *ROB* robotic surgery, *TAPP* transabdominal preperitoneal, *TAR* transverse abdominis release, *TEP* totally extra-peritoneal

[a] The risk of bias for randomized controlled trials is reported in Fig. 4 based on the Cochrane risk-of-bias tool

Table 2 Characteristics of the patient populations analyzed in the included studies

First Author, Year	Design	Number of patients (ROB/LAP/OPEN)	Male patients (n, %) (ROB/LAP/OPEN)	Mean age (years) (ROB/LAP/OPEN)	Mean BMI (kg/m²) (ROB/LAP/OPEN)	Recurrent hernia (n, %) (ROB/LAP/OPEN)	Bilateral hernia (n, %) (ROB/LAP/OPEN)
Inguinal hernia repair (IHR)							
Waite et al. (2016) [41]	ROB vs LAP	39/24	38 (97%)/24 (100%)	58.1/57.5	27.5/27.6	NR/NR	10 (25%)/6 (24%)
Kolachalam et al. (2017) [12]	ROB vs OPEN	95/93	87 (91.6%)/82 (88.2%)	53.5/54	33.5/34.2	NR/NR	12 (12.6%)/13 (14%)
Kudsi (2017) [6]	ROB vs LAP	118/157	**101 (85.6%)/149 (94.9%)**	**58.8/55.1**	**28.44/27.01**	8 (6.8%)/14 (8.9%)	35 (29.7%)/37 (23.6%)
Charles et al. (2018) [11]	ROB vs LAP vs OPEN	69/241/191	59 (85.5%)/214 (88.8%)/175 (91.6%)	**52/57/56**[a]	24.9/25.8/25.1[a]	0/0/0	0/0/0
Gamagami et al. (2018) [37]	ROB vs OPEN	444/444	397 (89.4%)/401 (90.3%)	55.8/56.4	26.8/27	56 (12.6%)/56 (12.6%)	69 (15.5%)/71 (16%)
Kosturakis et al. (2018) [54]	ROB vs OPEN	100/100	100 (100%)/99 (99%)	**57.2/63.5**	**27.8/26.2**	22 (22%)/13 (13%)	**59 (59%)/7 (7%)**
Muysoms et al. (2018) [27]	ROB vs LAP	49/37	48 (97.9%)/35 (94.6%)	Uni: 60.4/59 Bil: 55.3/57.4	Uni: 25/24 Bil: 25/24	2 (4%)/0 (0%)	15 (30.6%)/15 (40.6%)
Abdelmoaty et al. (2019) [33]	ROB vs LAP	734/1671	NR/NR	NR/NR	NR/NR	101 (14%)/200 (12%)	0/0
AlMarzooqi et al. (2019) [34]	ROB vs LAP vs OPEN	847/1841/1925	Results were reported separately for each different technique[c]			0/0/0	0/0/0
Bittner et al. (2019) [13]	ROB vs LAP / ROB vs OPEN	83/83 / 85/85	81 (97.6%)/83 (100%) / 81 (97.6%)/82 (98.8%)	54.4/57.5 / 53.2/56.2	NR/NR / NR/NR	23 (27.7%)/23 (27.7%) / 24 (28.2%)/23 (27.1%)	NR/NR / NR/NR
Huerta et al. (2019) [52]	ROB vs LAP vs OPEN	71/128/1100	71 (100%)/128 (100%)/1097 (99.9%)	59.9/58.3/61.3	27.5/26.3/26.6	**18 (25.4%)/65 (50.1%)/87 (8%)**	**42 (59.2%)/104 (81%)/80 (7.3%)**
Pokala et al. (2019) [35]	ROB vs LAP vs OPEN	594/540/2413	**566 (95.3%)/434 (80.3%)/2029 (84.1%)**	NR/NR/NR	NR/NR/NR	NR/NR/NR	NR/NR/NR
Sheldon et al. (2019) [53]	ROB vs LAP vs OPEN	49/34/90	43 (87.8%)/31 (91.2%)/88 (97.8%)	38.2/40.8/39.7	NR/NR/NR	NR/NR/NR	**19 (38.8%)/14 (41.1%)/1 (1.1%)**
Zayan et al. (2019) [18]	ROB vs LAP	37/68	**37 (100%)/59 (86.8%)**	53.9/52.7	27.36/26.13	7 (18.9%)/6 (8.8%)	NR/NR
Aghayeva et al. (2020) [26]	ROB vs LAP	43/43	40 (93.1%)/40 (93.1%)	52.1/52.3	25.5/25.2	5 (11.6%)/5 (11.6%)	22 (51.2%)/22 (51.2%)
Gundogdu et al. (2020) [48]	ROB vs LAP	16/33	16 (100%)/31 (94%)	49.9/48.3	26.5/27.2	0/0	16 (100%)/33 (100%)
Janjua et al. (2020) [31]	ROB vs LAP vs OPEN	1480/2960/2960	NR/NR/NR	NR/NR/NR	NR/NR/NR	NR/NR/NR	NR/NR
Janjua et al. (2020) [32]	ROB vs LAP vs OPEN	922/1844/1844	NR/NR/NR	NR/NR/NR	NR/NR/NR	97 (10.5%)/204 (11%)/140 (7.6%)	262 (28.4%)/145 (7.9%)/524 (28.4%)

Table 2 (continued)

First Author, Year	Design	Number of patients (ROB/LAP/OPEN)	Male patients (n, %) (ROB/LAP/OPEN)	Mean age (years) (ROB/LAP/OPEN)	Mean BMI (kg/m²) (ROB/LAP/OPEN)	Recurrent hernia (n, %) (ROB/LAP/OPEN)	Bilateral hernia (n, %) (ROB/LAP/OPEN)
Khoraki et al. (2020) [51]	ROB vs LAP	45/138	42 (93.3%)/133 (96.4%)	49.6/50	27.5/26.2	5 (11.1%)/6 (4.3%)	8 (17.8%)/41 (29.7%)
LeBlanc et al. (2020) [55]	ROB vs LAP ROB vs OPEN	80/80 112/112	76 (95%)/74 (92.5%) 107 (95.5%)/108 (96.4%)	58.95/59.7[a] 58.5/63.85[a]	27.1/26.8[a] 26.2/26.3[a]	17 (21.2%)/10 (12.5%) 18 (16.1%)/9 (8%)	38 (47.5%)/34 (42.5%) **55 (49.1%)/4 (3.6%)**
Prabhu et al. (2020) [40]	ROB vs LAP	48/54	44 (91.6%)/48 (88.9%)	56.1/57.2	**24.9/26.9**	5 (10.6%)/3 (5.56%)	0/0
Ephraim et al. (2021) [46]	ROB vs LAP	80/108	73 (91.3%)/96 (88.9%)	51.3/44.6	25.56/25.05	**20 (25%)/7 (6.5%)**	40 (50%)/49 (45.3%)
Glasgow et al. (2021) [47]	ROB vs LAP vs OPEN	100/100/100	NR/NR/NR	NR/NR/NR	NR/NR/NR	NR/NR/NR	NR/NR/NR
Kakiashvili et al. (2021) [50]	ROB vs LAP vs OPEN	24/16/97	23 (95.8%)/16 (100%)/94 (96.9%)	60/48/55[a]	25.6/26/26	2 (8.3%)/0 (0%)/3 (3.1%)	**17 (70.8%)/8 (50%)/12 (12.4%)**
Muysoms et al. (2021) [49]	ROB vs LAP	404/272	**377 (93.3%)/237 (87.1%)**	60/60.3	NR/NR	32 (7.9%)/17 (6.3%)	190 (47%)/127 (46.7%)
Tatarian et al. (2021) [30]	ROB vs LAP	346/346	314 (90.75%)/314 (90.75%)	NR/NR	NR/NR	NR/NR	NR/NR
Tonelli et al. (2021) [38]	ROB vs LAP vs OPEN	342/1026/1026	NR/NR/NR	NR/NR/NR	NR/NR/NR	NR/NR/NR	NR/NR/NR
Dewulf et al. (2022) [45]	ROB vs OPEN	22/21	22 (100%)/21 (100%)	73.8/73.6	[b]	3 (13.6%)/2 (9.5%)	11 (50%)/4 (19%)
Gerdes et al. (2022) [28]	ROB vs LAP	29/29	27 (93%)/24 (83%)	62/53	24/25	0/0	3 (10.4%)/5 (17.3%)
Holleran et al. (2022) [4]	ROB vs LAP vs OPEN	6063/118035/100880	**5619 (96.68%)/17,942 (99.48%)/100,422 (99.55%)**	**60.8/60.3/63.5**	**29.5/26.2/26.2**	0/0/0	NR/NR/NR
Quilici et al. (2022) [29]	ROB vs LAP vs OPEN	2150/27724/4538	NR/NR/NR	58/54/56	26.7/26/25.4	NR/NR/NR	NR/NR/NR
Shah et al. (2022) [43]	ROB vs LAP	3692/3692	3399 (92.06%)/3387 (91.74%)	NR/NR	NR/NR	NR/NR	NR/NR
Shenoy et al. (2022) [42]	ROB vs LAP vs OPEN	1842/9155/40317	**1833 (99.1%)/9094 (99.3%)/40,128 (99.5%)**	**64/64/67[a]**	**26.5/25.8/25.7[a]**	NR/NR/NR	NR/NR/NR
Kudsi et al. (2023) [44]	ROB vs LAP	547/606	500 (91.4%)/568 (93.7%)	59.3/58.4	26.6/26.4	76 (13.9%)/70 (11.6%)	165 (30.2%)/170 (28.1%)
Miller et al. (2023) [39]	ROB vs LAP	48/54	NR/NR	NR/NR	NR/NR	NR/NR	NR/NR

Table 2 (continued)

First Author, Year	Design	Number of Patients (ROB/LAP/OPEN)	Gender (men) (ROB/LAP/OPEN)	Mean age (years) (ROB/LAP/OPEN)	Mean BMI (kg/m²) (ROB/LAP/OPEN)	Recurrent hernia (n) (ROB/LAP/OPEN)	TAR (%) (ROB/LAP/OPEN)
Ventral hernia repair (VHR)							
Gonzalez et al. (2015) [72]	ROB vs LAP	67/67	26 (38.8%)/21 (31.4%)	56.6/55	34.7/33.5	NR/NR	0%/0%
Chen et al. (2016) [71]	ROB vs LAP	39/33	17 (43.6%)/24 (72.7%)	47.2/46.6	33/32	4 (10.2%)/3 (9%)	0%/0%
Coakley et al. (2017) [63]	ROB vs LAP	351/32243	168 (48%)/13,864 (43%)	59.4/57.4	NR/NR	NR/NR	NR/NR
Prabhu et al. (2017) [7]	ROB vs LAP	186/452	110 (59%)/267 (59%)	59/59[a]	32/32[a]	61 (33%)/140 (31%)	0%/0%
Warren et al. (2017) [64]	ROB vs LAP	53/103	22 (41.51%)/27 (26.21%)	**52.9/60.2**	34.7/35.7	4 (7.55%)/2 (1.94%)	**43.4%/0%**
Altieri et al. (2018) [17]	ROB vs LAP	679/20896	365 (53.76%)/9310 (44.55%)	NR/NR	NR/NR	NR/NR	NR/NR
Armijo et al. (2018) [62]	ROB vs LAP vs OPEN	465/6829/39505	187 (40.2%)/2677 (39.2%)/16473 (41.7%)	59/57	NR/NR/NR	NR/NR/NR	NR/NR/NR
Bittner et al. (2018) [8]	ROB vs OPEN	26/76	9 (33.3%)/35 (46%)	52.4/54.6	33.4/32.1	15 (58.3%)/40 (52.6%)	100%/100%
Carbonell et al. (2018) [65]	ROB vs OPEN	111/222	43 (39%)/95 (43%)	55.59/55.08	33.88/33.23	41 (37%)/84 (38%)	85%/83%
Martin-del-Campo et al. (2018) [16]	ROB vs OPEN	38/76	17 (39.5%)/25 (32.9%)	58.9/58.8	33.1/33.51	**11 (28.9%)/49 (64.5%)**	100%/100%
Walker et al. (2018) [77]	ROB vs LAP	48/48	NR/NR	NR/NR	NR/NR	NR/NR	0%/0%
Zayan et al. (2019) [18]	ROB vs LAP	16/33	10 (62.5%)/14 (42.4%)	49/51.5	**48.97/33.71**	2 (12.5%)/4 (12.1%)	NR/NR
Olavarria et al. (2020) [70]	ROB vs LAP	65/59	17 (26%)/22 (37%)	50.1/48	32.4/31.8	8 (12%)/15 (25%)	0%/0%
Reeves et al. (2020) [56]	ROB vs OPEN	13/13	6 (46.1%)/5 (38.5%)	69.9/64.8	NR/NR	NR/NR	100%/100%
Collins et al. (2021) [10]	ROB vs OPEN	350/759	170 (49%)/374 (49%)	70/70[a]	**31/30**[a]	108 (31%)/267 (35%)	55%/55%
Dauser et al. (2021) [60]	ROB vs OPEN	16/10	11 (68.6%)/5 (50%)	71/62[a]	28.4/25.7[a]	NR/NR	100%/100%
Dhanani et al. (2021) [68]	ROB vs LAP	65/59	17 (26%)/22 (37%)	50.1/48	32.4/31.8	8 (12%)/15 (25%)	0%/0%
Forester et al. (2021) [58]	ROB vs LAP vs OPEN	77/300/418	**38 (49.4%)/110 (36.7%)/186 (44.5%)**	63/**69**/64	32.4/32.9/30.7	9 (11.7%)/63 (21%)/87 (20.8%)	**28.6%/0%/6.7%**

Table 2 (continued)

First Author, Year	Design	Number of Patients (ROB/LAP/OPEN)	Gender (men) (ROB/LAP/OPEN)	Mean age (years) (ROB/LAP/OPEN)	Mean BMI (kg/m²) (ROB/LAP/OPEN)	Recurrent hernia (n) (ROB/LAP/OPEN)	TAR (%) (ROB/LAP/OPEN)
Guzman-Pruneda et al. (2021) [61]	ROB vs OPEN	42/194	**15 (36%)**/111 (57%)	59/62[a]	32/31[a]	14 (33%)/60 (31%)	**68%/82%**
Kudsi et al. (2021) [75]	ROB vs OPEN	35/43	13 (37.1%)/17 (39.5%)	62.4/54.9	34.2/34.3	14 (40%)/11 (25.6%)	**Yes (no % reported)/0%**
Lapinska et al. (2021) [59]	ROB vs LAP	615/615	310 (50%)/331 (54%)	55/56	33/33	112 (18%)/106 (17%)	0%/0%
LeBlanc et al. (2021) [36]	ROB vs LAP vs OPEN	159/82/130	64 (40.25%)/40 (48.8%)/61 (46.9%)	**59.75/55.6/59.1**	**33/32.2/30.8**	**62 (39%)/26 (31.7)**/46 (35.4%)	0%/0%/0%
Nguyen et al. (2021) [76]	ROB vs OPEN	27/16	13 (48%)/4 (25%)	58.6/55.4	33.3/32.2	NR/NR	100%/100%
Petro et al. (2021) [69]	ROB vs LAP	39/36	23 (59%)/15 (42%)	56/55[a]	**35/31**[a]	5 (13%)/8 (22%)	0%/0%
Ayuso et al. (2022) [57]	ROB vs LAP	5942/19853	NR/NR	**60.8/59.5**	NR/NR	NR/NR	NR/NR
Dewulf et al. (2022) [45]	ROB vs OPEN	90/79	33 (36.7%)/37 (46.8%)	66/63	31/30	21 (23.3%)/14 (17.7%)	100%/100%
Han et al. (2022) [73]	ROB vs OPEN	25/108	NR/NR	NR/NR	NR/NR	25 (100%)/108 (100%)	100%/100%
Petro et al. (2022) [66]	ROB vs LAP	38/33	NR/NR	NR/NR	NR/NR	NR/NR	0%/0%
Shah et al. (2022) [43]	ROB vs LAP	2703/2703	1179 (43.62%)/1189 (43.99%)	NR/NR	NR/NR	NR/NR	NR/NR
Shenoy et al. (2022) [42]	ROB vs LAP vs OPEN	283/1721/7210	259 (91.5%)/1555 (90.4%)/6450 (89.5%)	64/63/62[a]	30.8/30.4/30.2[a]	NR/NR/NR	NR/NR/NR
Thomas et al. (2022) [74]	ROB vs LAP	6544/4116	**3396 (52%)/1946 (47%)**	57/57[a]	32/32[a]	1432 (22%)/939 (23%)	NR/NR
Costa et al. (2023) [67]	ROB vs LAP	18/19	7 (38.9%)/6 (31.6%)	65.2/59.7	30.5/32.6	NR/NR	0%/0%

Statistically significant results are shown in bold characters

Bil bilateral, *BMI* body mass index, *LAP* laparoscopic, *NR* not reported, *PHS/UHS* prolene hernia system/ultrapro hernia system, *ROB* robotic surgery, *TAPP* trans-abdominal pre-peritoneal, *TAR* transverse abdominis release, *TEP* total extra-peritoneal, *TIPP* trans-inguinal pre-peritoneal, *TREPP* trans-rectus sheath pre-peritoneal, *Uni* unilateral

[a] Data reported as median (not as mean)

[b] Data reported by classes and not as a total

[c] Shouldice, Bassini, McVay, Desarda, Lichtenstein, PHS/UHS, TIPP, TREPP, Plug and Patch, Flat sheet/Onlay, Stoppa, Laparoscopic TAPP, Laparoscopic TEP, Robotic TAPP and Robotic TEP

Table 3 Results of the meta-analyses comparing robotic vs. laparoscopic and robotic vs. open inguinal hernia repair (IHR)

Outcome variables	Robot vs. laparoscopic IHR					Robot vs. open IHR				
	Nb of studies	OR or WMD	95% CI	P value	I^2	Nb of studies	OR or WMD	95% CI	P value	I^2
Overall complications	14	1.24	0.69, 2.22	0.479	87.5%	9	1.14	0.52, 2.49	0.751	94.7%
SSI	11	1.22	0.46, 3.27	0.690	70.9%	8	0.67	0.15, 3.01	0.602	92.7%
Seroma/hematoma	11	1.15	0.87, 1.52	0.333	0%	4	0.90	0.34, 2.37	0.837	27.8%
Hernia recurrence	9	**0.54**	**0.29, 0.99**	**0.047**	0%	4	1.07	0.33, 3.48	0.913	59.9%
Operative time (min)	10	**33.1**	**2.6, 63.6**	**0.033**	99.4%	7	**41.3**	**8.0, 74.7**	**0.015**	99.8%
Intraoperative bowel injuries	3	0.003[a]	− 0.002, 0.009	0.258	0%	3	0[a]	− 0.004, 0.004	1.000	0%
Conversion to open surgery	6	0.49	0.22, 1.08	0.077	68.7%	–	–	–	–	–
LOS (days)	5	0.1	− 1.0, 1.1	0.867	98.9%	6	− 0.3	− 0.9, 0.2	0.248	99.1%
30-day mortality	6	0.001[a]	0, 0.002	0.295	0%	2	1.03	0.51, 2.07	0.931	0%
30-day reoperation rate	2	**4.85**	**1.22, 19.20**	**0.025**	33.3%	3	0.71	0.10, 5.28	0.738	82.2%
30-day readmission rate	6	1.02	0.39, 2.66	0.965	46.5%	6	0.44	0.20, 1.01	0.052	29.9%
Opioid use (yes)	3	0.74	0.33, 1.69	0.479	66.3%	3	**0.46**	**0.25, 0.84**	**0.012**	55.8%

Statistically significant results are shown in bold characters

CI confidence interval, *LOS* length of stay, *OR* odds ratio, *SSI* surgical site infections, *WMD* weighted mean difference

[a]Risk difference (RD)

Ventral hernia repair

Pooled data analyses of the comparisons between robotic vs. laparoscopic VHR and between robotic vs. open VHR are reported in Table 4 and displayed in Fig. 3 and as Supplementary Material.
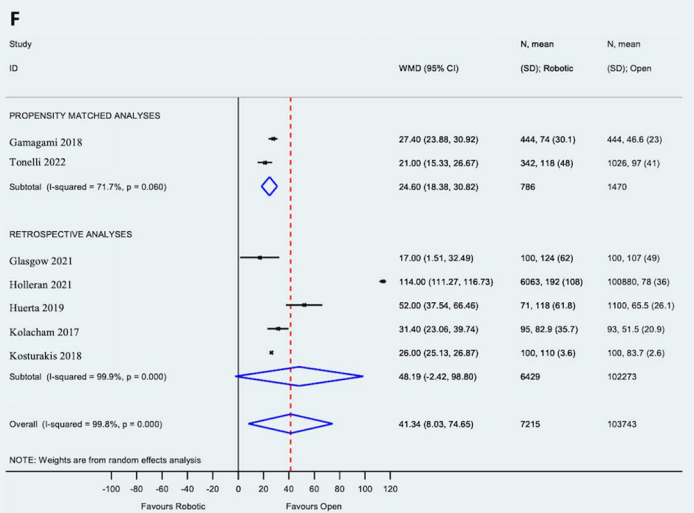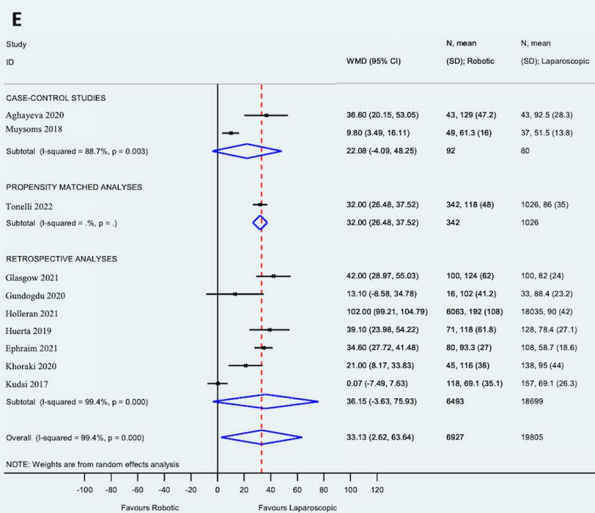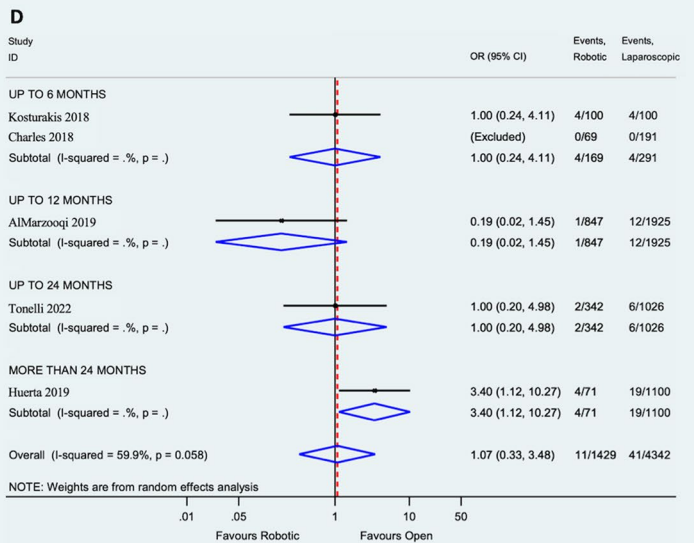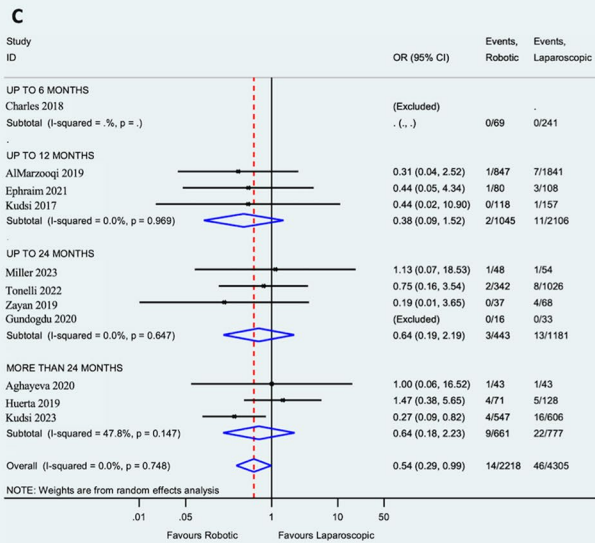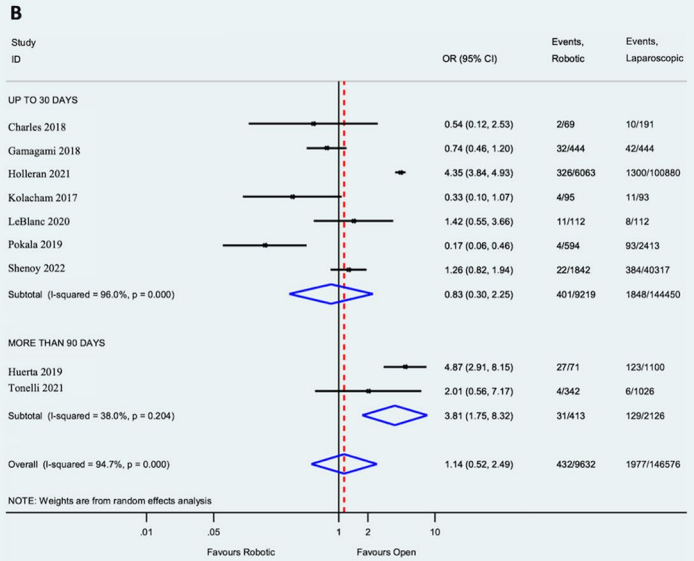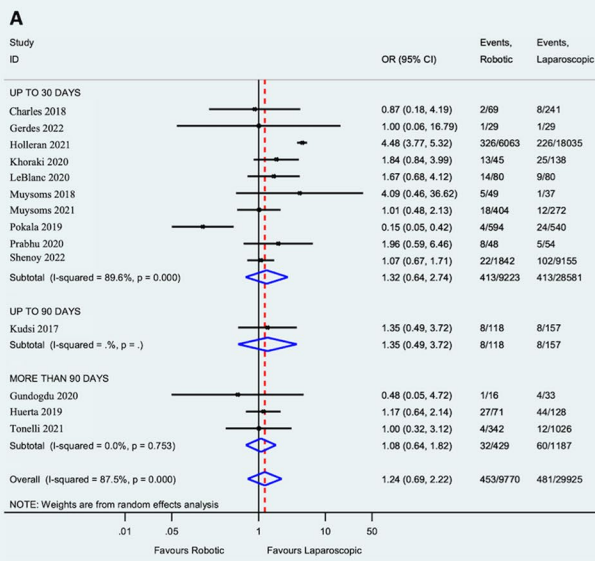
Data on overall complications after VHR were reported by 17 studies [7, 8, 10, 16, 17, 36, 45, 56, 58–60, 62, 67, 69–72], of which 11 (64.7%) compared robotic vs. laparoscopic surgery and 9 (52.9%) robotic vs. open surgery. No significant differences were found for overall complication, SSI, and seroma/hematoma occurrence between robotic and laparoscopic VHR (Table 4). Conversely, when compared to open surgery, robotic VHR was associated with fewer overall complications (OR 0.61) and less SSI (OR 0.47). No significant differences were found between robotic and laparoscopic or open VHR for hernia recurrence. Operative time was significantly longer for robotic VHR, compared to both laparoscopy (WMD: 67.3 min) and open surgery (WMD: 55.5 min).

Compared to laparoscopy, robotic VHR was associated with lower intraoperative bowel injuries (OR 0.59) and less conversions to open surgery (OR 0.51). Furthermore, when compared to open surgery, robotic VHR was associated with significantly reduced intraoperative blood loss (WMD: − 95.3 mL).

No significant difference was noted in terms of LOS, 30-day reoperation rate, 30-day hospital readmission rate, postoperative use of opioids, time to return to normal activities, and time to return to work between robotic and laparoscopic VHR (Table 4). Conversely, LOS (WMD: − 3.4 days) and 30-days readmission rate (OR 0.66) resulted significantly lower in robotic VHR compared to open VHR.

Costs

Fifteen studies [11, 18, 26, 29, 32, 33, 35, 40, 41, 47–49, 51, 60, 62, 64, 69, 70] reported data on costs of robotic surgery compared to laparoscopic or open approaches. A descriptive analysis was conducted to assess the financial burden of robotic surgery for IHR and VHR, considering both total hospital costs and fixed surgery-related costs per patient (Table 5). Almost all studies reported higher fixed and total hospital costs for robotic surgery compared to both laparoscopic and open approaches. Only Zayan et al. [18], who analyzed the costs of robotic surgery without distinguishing between IHR and VHR, showed that robotic abdominal wall repair was associated with lower total hospital costs (7832$ vs. 8605$) but higher fixed costs (5017$ vs. 4638$) than laparoscopy.

A

Study ID	OR (95% CI)	Events, Robotic	Events, Laparoscopic
UP TO 30 DAYS			
Charles 2018	0.87 (0.18, 4.19)	2/69	8/241
Gerdes 2022	1.00 (0.06, 16.79)	1/29	1/29
Holleran 2021	4.48 (3.77, 5.32)	326/6063	226/18035
Khoraki 2020	1.84 (0.84, 3.99)	13/45	25/138
LeBlanc 2020	1.67 (0.68, 4.12)	14/80	9/80
Muysoms 2018	4.09 (0.46, 36.62)	5/49	1/37
Muysoms 2021	1.01 (0.48, 2.13)	18/404	12/272
Pokala 2019	0.15 (0.05, 0.42)	4/594	24/540
Prabhu 2020	1.96 (0.59, 6.46)	8/48	5/54
Shenoy 2022	1.07 (0.67, 1.71)	22/1842	102/9155
Subtotal (I-squared = 89.6%, p = 0.000)	1.32 (0.64, 2.74)	413/9223	413/28581
UP TO 90 DAYS			
Kudsi 2017	1.35 (0.49, 3.72)	8/118	8/157
Subtotal (I-squared = .%, p = .)	1.35 (0.49, 3.72)	8/118	8/157
MORE THAN 90 DAYS			
Gundogdu 2020	0.48 (0.05, 4.72)	1/16	4/33
Huerta 2019	1.17 (0.64, 2.14)	27/71	44/128
Tonelli 2021	1.00 (0.32, 3.12)	4/342	12/1026
Subtotal (I-squared = 0.0%, p = 0.753)	1.08 (0.64, 1.82)	32/429	60/1187
Overall (I-squared = 87.5%, p = 0.000)	1.24 (0.69, 2.22)	453/9770	481/29925

NOTE: Weights are from random effects analysis

Favours Robotic / Favours Laparoscopic

B

Study ID	OR (95% CI)	Events, Robotic	Events, Laparoscopic
UP TO 30 DAYS			
Charles 2018	0.54 (0.12, 2.53)	2/69	10/191
Gamagami 2018	0.74 (0.46, 1.20)	32/444	42/444
Holleran 2021	4.35 (3.84, 4.93)	326/6063	1300/100880
Kolacham 2017	0.33 (0.10, 1.07)	4/95	11/93
LeBlanc 2020	1.42 (0.55, 3.66)	11/112	8/112
Pokala 2019	0.17 (0.06, 0.46)	4/594	93/2413
Shenoy 2022	1.26 (0.82, 1.94)	22/1842	384/40317
Subtotal (I-squared = 96.0%, p = 0.000)	0.83 (0.30, 2.25)	401/9219	1848/144450
MORE THAN 90 DAYS			
Huerta 2019	4.87 (2.91, 8.15)	27/71	123/1100
Tonelli 2021	2.01 (0.56, 7.17)	4/342	6/1026
Subtotal (I-squared = 38.0%, p = 0.204)	3.81 (1.75, 8.32)	31/413	129/2126
Overall (I-squared = 94.7%, p = 0.000)	1.14 (0.52, 2.49)	432/9632	1977/146576

NOTE: Weights are from random effects analysis

Favours Robotic / Favours Open

C

Study ID	OR (95% CI)	Events, Robotic	Events, Laparoscopic
UP TO 6 MONTHS			
Charles 2018	(Excluded)	0/69	0/241
Subtotal (I-squared = .%, p = .)	. (., .)		
UP TO 12 MONTHS			
AlMarzooqi 2019	0.31 (0.04, 2.52)	1/847	7/1841
Ephraim 2021	0.44 (0.05, 4.34)	1/80	3/108
Kudsi 2017	0.44 (0.02, 10.90)	0/118	1/157
Subtotal (I-squared = 0.0%, p = 0.969)	0.38 (0.09, 1.52)	2/1045	11/2106
UP TO 24 MONTHS			
Miller 2023	1.13 (0.07, 18.53)	1/48	1/54
Tonelli 2022	0.75 (0.16, 3.54)	2/342	8/1026
Zayan 2019	0.19 (0.01, 3.65)	1/37	4/68
Gundogdu 2020	(Excluded)	0/16	0/33
Subtotal (I-squared = 0.0%, p = 0.647)	0.64 (0.19, 2.19)	3/443	13/1181
MORE THAN 24 MONTHS			
Aghayeva 2020	1.00 (0.06, 16.52)	1/43	1/43
Huerta 2019	1.47 (0.38, 5.65)	4/71	5/128
Kudsi 2023	0.27 (0.09, 0.82)	4/547	16/606
Subtotal (I-squared = 47.8%, p = 0.147)	0.64 (0.18, 2.23)	9/661	22/777
Overall (I-squared = 0.0%, p = 0.748)	0.54 (0.29, 0.99)	14/2218	46/4305

NOTE: Weights are from random effects analysis

Favours Robotic / Favours Laparoscopic

D

Study ID	OR (95% CI)	Events, Robotic	Events, Laparoscopic
UP TO 6 MONTHS			
Kosturakis 2018	1.00 (0.24, 4.11)	4/100	4/100
Charles 2018	(Excluded)	0/69	0/191
Subtotal (I-squared = .%, p = .)	1.00 (0.24, 4.11)	4/169	4/291
UP TO 12 MONTHS			
AlMarzooqi 2019	0.19 (0.02, 1.45)	1/847	12/1925
Subtotal (I-squared = .%, p = .)	0.19 (0.02, 1.45)	1/847	12/1925
UP TO 24 MONTHS			
Tonelli 2022	1.00 (0.20, 4.98)	2/342	6/1026
Subtotal (I-squared = .%, p = .)	1.00 (0.20, 4.98)	2/342	6/1026
MORE THAN 24 MONTHS			
Huerta 2019	3.40 (1.12, 10.27)	4/71	19/1100
Subtotal (I-squared = .%, p = .)	3.40 (1.12, 10.27)	4/71	19/1100
Overall (I-squared = 59.9%, p = 0.058)	1.07 (0.33, 3.48)	11/1429	41/4342

NOTE: Weights are from random effects analysis

Favours Robotic / Favours Open

E

Study ID	WMD (95% CI)	N, mean (SD); Robotic	N, mean (SD); Laparoscopic
CASE-CONTROL STUDIES			
Aghayeva 2020	36.60 (20.15, 53.05)	43, 129 (47.2)	43, 92.5 (28.3)
Muysoms 2018	9.80 (3.49, 16.11)	49, 61.3 (16)	37, 51.5 (13.8)
Subtotal (I-squared = 88.7%, p = 0.003)	22.08 (-4.09, 48.25)	92	80
PROPENSITY MATCHED ANALYSES			
Tonelli 2022	32.00 (26.48, 37.52)	342, 118 (48)	1026, 86 (35)
Subtotal (I-squared = .%, p = .)	32.00 (26.48, 37.52)	342	1026
RETROSPECTIVE ANALYSES			
Glasgow 2021	42.00 (28.97, 55.03)	100, 124 (62)	100, 82 (24)
Gundogdu 2020	13.10 (-8.58, 34.78)	16, 102 (41.2)	33, 88.4 (23.2)
Holleran 2021	102.00 (99.21, 104.79)	6063, 192 (108)	18035, 90 (42)
Huerta 2019	39.10 (23.98, 54.22)	71, 118 (61.8)	128, 78.4 (27.1)
Ephraim 2021	34.60 (27.72, 41.48)	80, 93.3 (27)	108, 58.7 (18.6)
Khoraki 2020	21.00 (8.17, 33.83)	45, 116 (36)	138, 95 (44)
Kudsi 2017	0.07 (-7.49, 7.63)	118, 69.1 (35.1)	157, 69.1 (26.3)
Subtotal (I-squared = 99.4%, p = 0.000)	36.15 (-3.63, 75.93)	6493	18699
Overall (I-squared = 99.4%, p = 0.000)	33.13 (2.62, 63.64)	6927	19805

NOTE: Weights are from random effects analysis

Favours Robotic / Favours Laparoscopic

F

Study ID	WMD (95% CI)	N, mean (SD); Robotic	N, mean (SD); Open
PROPENSITY MATCHED ANALYSES			
Gamagami 2018	27.40 (23.88, 30.92)	444, 74 (30.1)	444, 46.6 (23)
Tonelli 2022	21.00 (15.33, 26.67)	342, 118 (48)	1026, 97 (41)
Subtotal (I-squared = 71.7%, p = 0.060)	24.60 (18.38, 30.82)	786	1470
RETROSPECTIVE ANALYSES			
Glasgow 2021	17.00 (1.51, 32.49)	100, 124 (62)	100, 107 (49)
Holleran 2021	114.00 (111.27, 116.73)	6063, 192 (108)	100880, 78 (36)
Huerta 2019	52.00 (37.54, 66.46)	71, 118 (61.8)	1100, 65.5 (26.1)
Kolacham 2017	31.40 (23.06, 39.74)	95, 82.9 (35.7)	93, 51.5 (20.9)
Kosturakis 2018	26.00 (25.13, 26.87)	100, 110 (3.6)	100, 83.7 (2.6)
Subtotal (I-squared = 99.9%, p = 0.000)	48.19 (-2.42, 98.80)	6429	102273
Overall (I-squared = 99.8%, p = 0.000)	41.34 (8.03, 74.65)	7215	103743

NOTE: Weights are from random effects analysis

Favours Robotic / Favours Open

◀**Fig. 2** Forest plots for IHR. **A** Overall complications for robotic vs. laparoscopic IHR. **B** Overall complications for robotic vs. open IHR. **C** Hernia recurrence for robotic vs. laparoscopic IHR. **D** Hernia recurrence for robotic vs. open IHR. **E** Operative time for robotic vs. laparoscopic IHR. **F** Operative time for robotic vs. open IHR

Conversely, Petro et al. [69] reported lower ratio of fixed costs (0.97 vs. 1.00) but higher ratio of total hospital costs (1.13 vs. 0.97) for robotic VHR compared to laparoscopy.

Risk of bias assessment

Based on the NOS, only 21 (36.8%) studies were judged at low risk of bias [6, 7, 10, 13, 16, 26, 27, 30–32, 37, 38, 43–45, 49, 55, 59, 65, 77] (Table 1). Concerning the RCTs, 2 were judged at high risk of bias [39, 68], 4 with some concern [40, 66, 67, 69], and 1 at low risk of bias [70] (Fig. 4).

Discussion

The present systematic review identified 64 articles reporting on robotic IHR and VHR and comparing it to laparoscopy of open surgery. Pooled data analyses show lower hernia recurrence rate for robotic IHR over laparoscopic IHR and lower use of opioids for robotic IHR over open IHR. However, robotic IHR was associated with significantly longer OT compared to both laparoscopy and open surgery. Despite longer OT also observed for robotic VHR, the robotic approach was associated with lower bowel injuries and less conversions to open surgery compared to laparoscopy, and lower overall complication rate, less SSI, reduced intraoperative blood loss, shorter LOS, and lower 30-day readmission rate compared to open surgery. Globally, these results support the role of robotic surgery for abdominal wall repair and indicate that it can brings several intraoperative and postoperative advantages over laparoscopy and open surgery.

During the last decades, the use of robotic technology has significantly risen across various surgical disciplines, progressively entering the surgical thinking. Notably, the magnitude of the increase for robotic IHR has peaked 41-fold higher between 2012 and 2018 [3]. This trend was mirrored by a concomitant decrease in the use of open and laparoscopic surgery [3].

Focusing on studies dealing with IHR, no difference was found in terms of overall postoperative complications (including SSI and seroma/hematoma), between robotic and laparoscopic or open approaches. However, robotic IHR was associated with 46% less odds of hernia recurrence compared to laparoscopic IHR. It must be noted that the hernia recurrence rate was evaluated at different time intervals in

the nine studies included for the meta-analysis, spanning from 12 [6, 34, 46] to 24 months [18, 38, 39] and more than 24 months [26, 44, 52]. Despite this, the statistical heterogeneity was nil (0%), and pooled data were derived from a large number of patients in both groups. Consistently, robotic IHR was associated with approximately 33 min and 41 min longer OT than laparoscopy and open surgery, respectively. Conversely, the 30-day reoperation rate was significantly higher for robotic IHR compared to laparoscopy. Analyzing the 30-day reoperation rate, only two studies were included in the meta-analysis. In the study by Khoraki et al. [51], 3 patients (6.7%) required reoperation in the robotic IHR group due to port-site hernia, internal hernia, and hemoperitoneum, while no event occurred in the laparoscopic group. Holleran et al. [4] reported 172 (2.84%), 148 (0.82%) and 1033 (1.02%) unplanned reoperations for robotic, laparoscopic, and open IHR, respectively, without specifying the reasons for the reintervention. The authors reported that the use of robotic platform greatly increased over the study period whereas the unplanned reoperation rate decreased from 12.5% in 2008 to 1.83% in 2019 in the IHR cohort [4]. This could probably reflect an increased surgeon's experience with the robotic platform over the study timeframe and explain the worse outcome during the early stages of the learning curve.

Previous meta-analyses reported contrasting results about the benefits of robotic surgery for IHR. In 2019, Henriksen et al. [78] analyzed 5 retrospective studies and showed less postoperative complications after robot-assisted IHR rather than open IHR, but no differences were found compared to laparoscopic IHR. A Bayesian network meta-analysis comparing open Lichtenstein, laparoscopic trans-abdominal pre-peritoneal (TAPP), laparoscopic totally extra peritoneal (TEP), and robotic TAPP techniques showed comparable short-term outcomes for primary unilateral IHR [79]. Solaini et al. [80] and Zhao et al. [81] reported similar postoperative complications between robotic and laparoscopic surgery, whereas Qabbani et al. [82] showed significantly less complications in robotic IHR than laparoscopic IHR, as well as less hospital readmissions when compared to open IHR. A meta-analysis by Tai et al. [83] reported less hernia recurrences with fascia defect closure than with non-closure in robotic and laparoscopic direct IHR, regardless of the surgical technique. This may be potentially linked to the enhanced anatomical view, increased precision, and improved surgical dexterity of the robotic system, which surely represent important technical advantages in the complex clinical scenario of abdominal wall repair. Overall, the qualitative and quantitative syntheses of the literature demonstrate that robotic IHR is safe, feasible, and effective [84], even in an early phase of learning curve [46], with equivalent clinical effectiveness in terms of postoperative complications compared to laparoscopic and open approaches [78–81].

Table 4 Results of the meta-analyses comparing robotic *vs.* laparoscopic and robotic *vs.* open ventral hernia repair (VHR)

Outcome variables	Robot *vs.* laparoscopic VHR					Robot *vs.* open VHR				
	Nb of studies	OR or WMD	95% CI	P value	I²	Nb of studies	OR or WMD	95% CI	P value	I²
Overall complications	11	1.05	0.41, 2.68	0.925	96.5%	9	**0.61**	**0.39, 0.96**	**0.033**	68%
SSI	11	1.28	0.74, 2.22	0.369	9.1%	14	**0.47**	**0.31, 0.72**	**<0.001**	0%
Seroma/hematoma	9	0.88	0.41, 1.85	0.728	72.8%	10	1.52	0.77, 2.99	0.226	73.6%
Hernia recurrence	7	0.69	0.27, 1.76	0.436	31.5%	8	0.94	0.56, 1.60	0.832	0%
Operative time (min)	6	**67.3**	**42.2, 92.5**	**<0.001**	90%	7	**55.5**	**35.8, 75.3**	**<0.001**	73%
Intraoperative bowel injuries	6	**0.59**	**0.42, 0.85**	**<0.001**	0%	3	0.70	0.19, 2.51	0.581	0%
Intraoperative blood loss (mL)	0	–	–	–	–	2	**− 95.3**	**− 125.6, − 65.0**	**<0.001**	0%
Conversion to open surgery	7	**0.51**	**0.43, 0.60**	**<0.001**	0%	–	–	–	–	–
LOS (days)	7	− 0.2	− 0.6, 0.3	0.423	81.5%	6	**− 3.4**	**− 5.1, − 1.7**	**<0.001**	96.9%
30-day mortality	2	4.69	0.49, 45.17	0.181	0%	3	0.59	0.21, 1.62	0.306	0%
30-day reoperation rate	4	0.34	0.10, 1.16	0.086	0%	5	0.48	0.18, 1.22	0.123	0%
30-day readmission rate	7	1.10	0.52, 2.34	0.802	85.2%	9	**0.66**	**0.44, 0.99**	**0.046**	24.7%
Opioid use (yes)	2	0.72	0.48, 1.08	0.113	16.1%	2	0.76	0.46, 1.26	0.287	54.5%
Time to return to normal activities (days)	2	− 1.5	− 7.0, 4.0	0.592	94.5%	2	− 1.6	− 7.1, 3.9	0.571	95.1%
Time to return to work (days)	2	− 0.8	− 2.3, 0.7	0.303	13.7%	2	− 1.7	− 10.6, 7.2	0.712	95.9%

Statistically significant results are shown in bold characters

CI confidence interval, *LOS* length of stay, *OR* odds ratio, *SSI* surgical site infections, *WMD* weighted mean difference

Nowadays, open IHR represents one of the most performed procedures in general surgery. Although there was no significant difference between open and robotic IHR, except for a longer OT and lower opioid use in the robotic group, the greater financial costs associated with robotic IHR over open IHR represent a major barrier to its widespread adoption. The choice of the surgical technique should be made on a case-by-case basis, taking into account the surgeon's and patient's preference, the patient's characteristics, and the national/hospital healthcare system regulations.

Focusing on VHR, pooled data analyses indicate that robotic VHT is associated with a decreased rate of conversion to open surgery and lower intraoperative bowel injuries compared to laparoscopy, but no difference was found in terms of postoperative complications. Thus, the advantages of robotic surgery may be greater intraoperatively than on the postoperative outcomes. These findings are in agreement with those reported by Mohan et al. [85], who found a reduction in conversions to open surgery, similar postoperative complications, and equivalent hernia recurrence between robotic and laparoscopic VHR. Conversely, according to Goettman et al. [86], robotic technology allows to optimize the overlap between the mesh and the ventral hernia defect, conceivably reducing the risk of hernia recurrence compared to both laparoscopic and open VHR. Similarly, Dixit et al. [87] reported a 4% reduction of hernia recurrence after robotic procedure compared to laparoscopy. Nevertheless, previous meta-analyses did not consider data from the most recent RCTs [66–68, 70] published since their publication.

When compared to open VHR, robotic VHR is associated with 39% less odds of postoperative complications, 53% less SSI, less intraoperative blood loss (− 95 mL), 3.4 day shorter LOS and 34% less odds of hospital readmissions, supporting the clear advantages of performing VHR by a robotic approach. These results are in accordance with those reported by Bracale et al. [88] concerning overall complications, LOS, and operative time, despite their analysis was focused only on transversus abdominis release. Similarly, the study by Goettman et al. [86] showed less postoperative SSI occurrence for robotics. The decreasing incidence of overall postoperative complications and SSIs, the shorter LOS, the reduced blood loss, and the lower readmission rate after robotic VHR may be attributed to MIS, which reduces tissue trauma and promotes faster recovery. Indeed, the lack of significant differences between robotic and laparoscopic VHR for most of the aforementioned outcomes might be explained by the MIS nature of these two techniques. However, the lower need for conversion to open surgery and the decreased blood loss associated with robotic-assisted procedures, probably highlights once again the several technical drawbacks of laparoscopy. No statistically significant difference in terms of opioids use, time to return to work or time to return to normal activities emerged from the present pooled analysis, regardless of the type of repair and the surgical approach.

Patients' preferences and perspectives on the diverse aspects of the health status, such as pain, mesh-related symptoms, sexual dysfunction, health-related quality of life and physical function [89], represent Patient Reported Outcome Measures (PROMs) that are of upmost importance in the evaluation of low-risk elective surgical procedures, such as IHR and VHR [90, 91]. A recent meta-analysis based on 8 studies and focused on PROMs, showed that time to return to activities of daily living and time to return to work were significantly shorter for the robotic group than the laparoscopic one, whereas no difference were found concerning postoperative pain, quality of life, body image, and patient satisfaction [87]. The present results confirmed these findings and support the use of PROMS to evaluate laparoscopic and robotic hernia repair. Nowadays, the selection of the most appropriate approach for hernia repair relies on the surgeon's expertise and caseload in MIS, but it should also be tailored on the patient's characteristics and medical history. Further evidence is awaited to elucidate the criteria upon which define personalized surgery in order to achieve the maximum efficiency from robotic, laparoscopic, and open approach in the field of abdominal wall surgery.

For both IHR and VHR, robotic surgery was associated with significantly longer OT than laparoscopy and open surgery. This result was expected and consistently reported. Indeed, robotic docking and use is likely to prolong the OT, irrespective to the type of procedure performed and particularly during the learning curve of the surgical team. Prolonged OT has been seen as one of the main drawbacks of robotic surgery, together with the increased costs. The impact of surgery duration is obviously important from a clinical and practical perspective, potentially leading to medical risks and generating additional costs. However, the impact of OT was not systematically assessed in the selected studies and cannot be deemed from the present data. Similarly, the impact of complication rate, readmission and reoperation need on healthcare costs have not been estimated. Thus, it was not possible to further evaluate this aspect and to provide a cost-effectiveness analysis considering the differences across centers, healthcare systems, and countries. This represents a limitation of the current literature and the present systematic review. Moreover, findings must be interpreted bearing in mind the clinical and statistically heterogeneity observed among the included studies. In some studies, there were significant imbalance between the groups concerning demographic and clinical characteristics (e.g., BMI) that can represent selection criteria for the surgical approach, which was not randomized. Moreover, intraoperative and postoperative outcomes on IHR were not reported separately for unilateral and bilateral procedures, thus the pooled analysis was not conditioned depending on
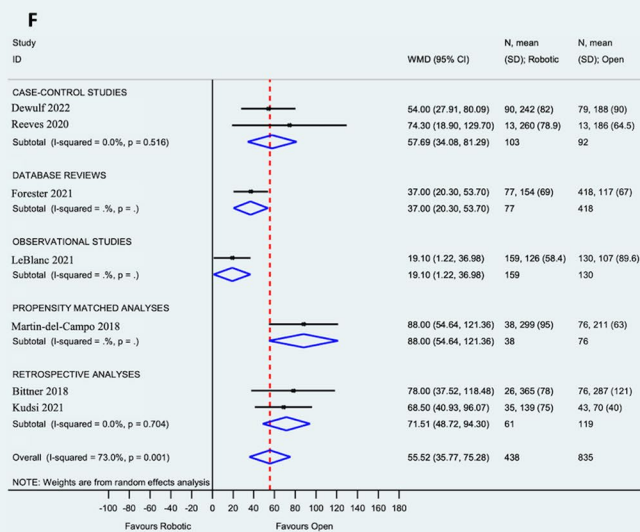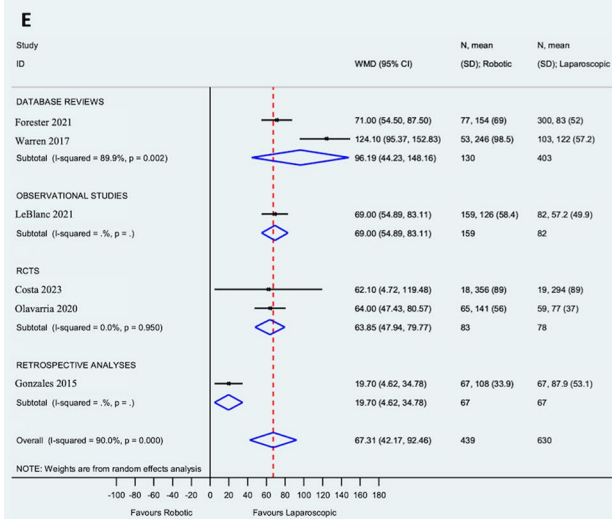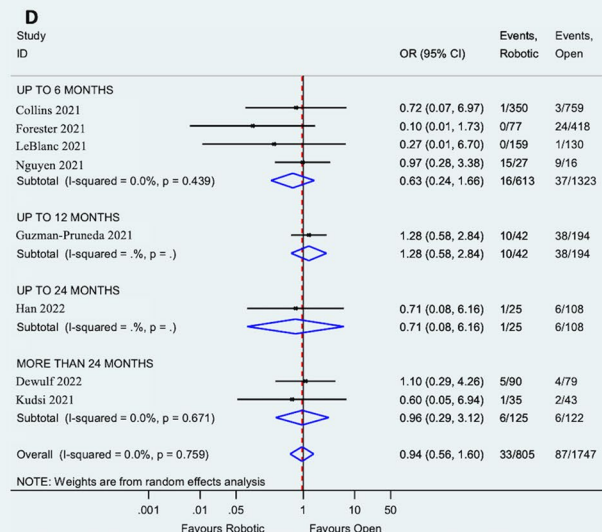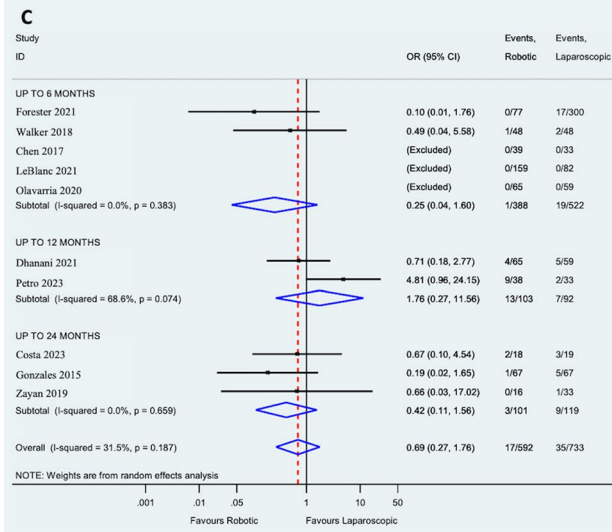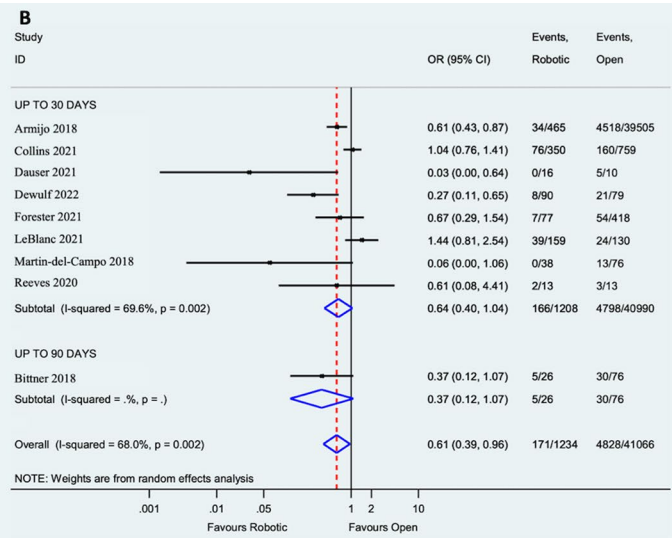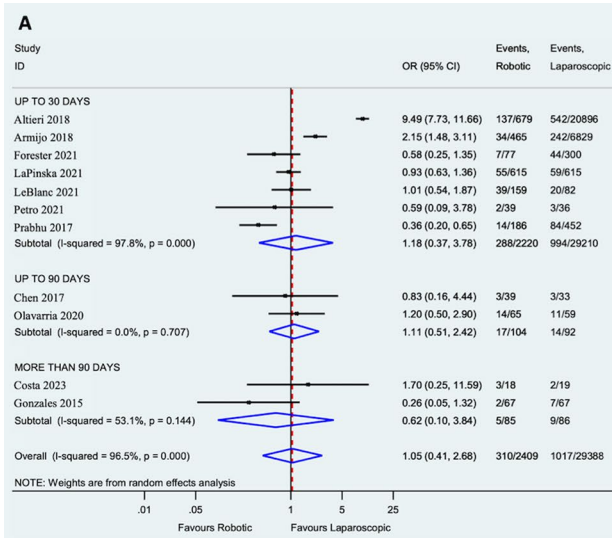
◀**Fig. 3** Forest plots for VHR. **A** Overall complications for robotic vs. laparoscopic VHR. **B** Overall complications for robotic vs. open VHR. **C** Hernia recurrence for robotic vs. laparoscopic VHR. **D** Hernia recurrence for robotic vs. open VHR. **E** Operative time for robotic vs. laparoscopic VHR. **F** Operative time for robotic vs. open VHR

the type of procedure (unilateral or bilateral repair). Several other factors may impact on the pooled results, namely the type of surgical technique (i.e. extraperitoneal or intraperitoneal IHR, transversus abdominis release, intraperitoneal onlay or retromuscular mesh placement), the type of mesh used, the closure versus non-closure of the fascia defect, and the mesh fixation technique. Finally, a high variability

of complications detection metrics was observed among the included studies (e.g. post-discharge follow-up as clinical examination or telephone calls). As suggested by Bittner JG, there is a compelling need for standardized definitions and uniform reporting metrics allowing to unequivocally analyze and understand the burden of hernia-specific outcomes across different studies and different healthcare systems [92].

In conclusion, the present systematic review and meta-analysis supports the use of robotic surgery for abdominal wall hernia repair. Pooled data analyses show improved outcomes for robotic surgery over laparoscopy and open surgery, particularly for VHR. Overall, these results, based on 64 studies, support robotic surgery as a safe, effective, and

Table 5 Summary of reported costs associated with robotic, laparoscopic, and open inguinal and ventral hernia repair

First Author, Year	Direct (fixed) costs per case (mean)[a]			Total hospital costs per case (mean)		
	ROB	LAP	OPEN	ROB	LAP	OPEN
Inguinal hernia repair						
Waite et al. (2016) [41]	3479 $	3216 $	–	–	–	–
Charles et al. (2018) [11]	–	–	–	7162 $	4527 $	4264 $
Abdelmoaty et al. (2019) [33]	4584 $	2164 $	–	5517 $	3269 $	–
Pokala et al. (2019) [35]	9431 $	6502 $	8837 $	–	–	–
Zayan et al. (2019) [18]	5017 $[b]	4638 $[b]	–	7832 $[b]	8605 $[b]	–
Aghayeva et al. (2020) [26]	2275 $	1008 $	–	4778 $	3852 $	–
Gundogdu et al. (2020) [48]	–	–	–	3968 $	2506 $	–
Janjua et al. (2020) [31]	–	–	–	18,494 $	13,581 $	13,595 $
Khoraki et al. (2020) [51]	–	–	–	9993 $	5994 $	–
Prabhu et al. (2020) [40]	–	–	–	3258 $	1421 $	–
Glasgow et al. (2021) [47]	2454 $[c]	25 $[c]	–	–	–	–
Muysoms et al. (2021) [49]	–	–	–	2612 $	1963 $	–
Quilici et al. (2022) [29]	Outpatient: 6780 $ Inpatient: 13,131 $	Outpatient: 3468 $ Inpatient: 6597 $	Outpatient: 2138 $ Inpatient: 6251 $	Outpatient: 11,932 $ Inpatient: 23,391 $	Outpatient: 5841 $ Inpatient: 11,547 $	Outpatient: 4097 $ Inpatient: 11,226 $
Ventral hernia repair						
Warren et al. (2017) [64]	19,532 $	13,943 $	–	–	–	–
Armijo et al. (2018) [62]	10,000 $	7000 $	9000 $	–	–	–
Zayan et al. (2019) [18]	5017 $[b]	4638 $[b]	–	7832 $[b]	8605 $[b]	–
Olavarria et al. (2020) [70]	–	–	–	15,865 $	12,955 $	–
Dauser et al. (2021) [60]	5397 €	–	1989 €	8109 €	–	8650 €
Petro et al. (2021) [69]	0.97[d]	1.00[d]	–	1.13[d]	0.97[d]	–

ROB robotic surgery, *LAP* laparoscopic

[a]The direct costs considered were the variable costs of the surgery, such as mesh, disposable laparoscopic equipment, and disposable robotic equipment. Capital costs, such as the robotic system itself, laparoscopic towers, operating room time, recovery room time, length of stay, and non-disposable equipment, were not included

[b]The authors reported costs for robotics and laparoscopy without distinction between inguinal and ventral hernia

[c]Assuming a 5-year straight line depreciation and allocation to an average of 247 per year for robotic and 540 cases per year for laparoscopy in which this equipment is used

[d]The values for cost are reported as ratios, because the institution did not permit reporting of cost in dollars

	D1	D2	D3	D4	D5	Overall
Olavarria 2020	+	+	+	+	+	+
Prabhu 2020	+	!	+	!	+	!
Dhanani 2021	+	-	+	+	+	-
Petro 2021	+	+	+	!	+	!
Miller 2023	+	!	-	!	+	-
Petro 2022	+	+	+	!	+	!
Costa 2023	+	!	+	!	+	!

+ Low risk
! Some concerns
- High risk

D1 Randomisation process
D2 Deviations from the intended interventions
D3 Missing outcome data
D4 Measurement of the outcome
D5 Selection of the reported result

Fig. 4 Risk of bias according to the Cochrane ROB-II tool for RCTs

viable alternative to traditional open and laparoscopic surgery for IHR and VHR, and they may contribute to dismiss the residual skepticism and increase the interest towards this minimally-invasive surgical technique.

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Author contributions All authors made substantiable contributions to the conception of the work, the acquisition, analysis, interpretation of data, drafted the work and revised it critically for important intellectual content, approved the version to be published and agree to be accountable for all aspects of the work in ensuring that questions to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Declarations

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