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Laparoscopic surgery versus open surgery for prevention of incisional hernia: A systematic review and meta-analysis

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Abstract

BACKGROUND AND OBJECTIVES: Incisional hernia remains a significant complication following abdominal surgery, with the incidence ranging from 5% to 20%. This systematic review compared the incidence of incisional hernia incidence between laparoscopic and open surgical approaches and identified effect modifiers.

MATERIALS AND METHODS: We searched PubMed, Cochrane Library, Embase, Web of Science, and SCOPUS for studies published from January 2000 to December 2023. This review was not registered in PROSPERO, representing a methodological limitation. Randomized controlled trials (RCTs) and observational studies comparing laparoscopic versus open surgery with a minimum 6-month follow-up were included. Risk of bias was assessed using Cochrane risk of bias 2.0 and Newcastle–Ottawa Scale. Random-effects meta-analysis calculated risk ratios (RR) with 95% confidence intervals (CI).

RESULTS: Twenty-eight studies (15 RCTs, 13 observational) comprising 14,567 patients were analyzed. Laparoscopic surgery demonstrated significantly lower incisional hernia risk (RR = 0.62, 95% CI: 0.51–0.75, $P < 0.001$; $I^2 = 45\%$). Benefits were consistent across colorectal (RR = 0.58), ventral hernia repair (RR = 0.55), and bariatric procedures (RR = 0.67). Meta-regression revealed stronger protective effects with higher body mass index ($P = 0.03$). Benefits persisted across follow-up periods and detection methods.

CONCLUSION: Laparoscopic approaches significantly reduce incisional hernia risk across diverse abdominal procedures, with effects particularly pronounced in patients with obesity. These findings should inform surgical approach selection and patient counseling, though limitations include lack of protocol registration and limited representation of contemporary robotic techniques.

Keywords:

Abdominal wall, incisional hernia, laparoscopic surgery, meta-analysis, minimally invasive surgery, open surgery, surgical complications

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Introduction

Incisional hernia represents one of the most prevalent long-term complications following abdominal surgery, with significant implications for patient quality of life, healthcare resource utilization, and surgical planning.[1,2] These hernias develop as a consequence of incomplete healing of fascial layers at previous incision sites, creating a defect through which the abdominal contents may protrude.[3,4] The reported incidence varies widely in the literature, ranging from 5% to 20% after elective procedures and as high as 30% following emergency operations.[5-7]

The advent of minimally invasive surgical techniques since the 1980s has transformed

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abdominal surgery across multiple specialties. Laparoscopic approaches offer well-documented advantages including reduced postoperative pain, shorter hospitalization, decreased wound complications, and earlier return to activities.[8,9] However, their long-term impact on incisional hernia development remains incompletely characterized, with conflicting evidence across studies of varying quality and methodological design.[10,11]

Previous investigations into hernia development have been hampered by several limitations. First, many studies were underpowered to detect differences in this relatively uncommon complication. Second, detection methods have varied widely, from simple clinical examination to advanced imaging techniques with significantly different sensitivity profiles.[12,13] Third, follow-up periods have often been insufficient to capture late-developing hernias, which may manifest several years after the index procedure.[14,15]

The pathophysiology of incisional hernia formation involves a complex interplay between patient-specific risk factors and technical surgical considerations. Patient factors include obesity, diabetes, malnutrition, smoking status, and connective tissue disorders, whereas surgical variables encompass incision type, closure technique, suture material, and wound complications.[16-18] The relationship between surgical approach (laparoscopic versus open) and these established risk factors requires systematic evaluation to guide clinical decision-making.

Several mechanisms may explain potential differences in hernia development between surgical approaches. Open procedures typically involve longer incisions with greater disruption of abdominal wall integrity and increased tissue trauma. In contrast, laparoscopic approaches utilize smaller incisions primarily for trocar placement and specimen extraction, potentially preserving fascial integrity.[19,20] Additionally, differences in postoperative pain and subsequent activity restrictions may influence wound healing trajectories between approaches.[21]

From a health economics perspective, incisional hernias represent a substantial burden. Direct costs include repair procedures, mesh materials, hospitalization, and management of recurrences, whereas indirect costs encompass loss of productivity and diminished quality of life.[22,23] Understanding how surgical approaches influence hernia risk could inform value-based healthcare decisions and resource allocation strategies.

Despite the clinical and economic significance of this complication, previous systematic reviews have focused primarily on specific surgical specialties or have failed to account for important effect modifiers such as patient characteristics, detection methods, and technical variables.[24,25] Our investigation addresses these knowledge gaps through comprehensive meta-analysis of contemporary evidence across diverse surgical procedures and patient populations.

This systematic review specifically examines the relationship between surgical techniques and hernia development, while accounting for various confounding factors that may influence the outcomes. Our findings aim to inform clinical practice guidelines, surgical approach selection, and future research directions in hernia prevention strategies.

Materials and Methods

Search strategy and information sources

We implemented a structured search strategy following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines[26] across major biomedical databases from January 2000 to December 2023. This systematic review was not prospectively registered in PROSPERO, which represents a limitation of our methodology that may introduce potential bias. Our comprehensive search encompassed the following: primary databases: PubMed/MEDLINE, Cochrane CENTRAL, and Embase; secondary sources: Web of Science and SCOPUS; gray literature: conference proceedings and clinical trial registries; manual review of reference lists from included studies and relevant systematic reviews.

Search terms combined controlled vocabulary (MeSH/Emtree) with free-text keywords using Boolean operators, tailored to each database's requirements. The core search structure included terms for: (laparoscopic OR minimally invasive) AND (open OR conventional OR traditional) AND (hernia OR incisional hernia OR ventral hernia) AND (surgery OR surgical OR procedure). The complete search strategy underwent peer review using the PRESS checklist[27] before implementation.

We conducted the final database search on January 15, 2024, with additional manual searches completed by January 31, 2024. Two reviewers (AA and CM) independently screened all identified records, with discrepancies resolved through consensus or third-reviewer arbitration (BM).

Eligibility assessment

Inclusion criteria

Study populations: adults (≥18 years) undergoing elective or emergency abdominal surgery. Interventions: any laparoscopic or minimally invasive approach to abdominal surgery. Comparators: corresponding open or conventional surgical technique for the same indication. Outcomes: incisional hernia development

(primary outcome), with objective documentation of diagnosis. Secondary outcomes: wound complications, length of stay, operative time, and other procedure-related morbidity. Study designs: randomized controlled trials (RCTs) and comparative observational studies (prospective or retrospective). Follow-up: minimum 6 months post-procedure, with documented follow-up protocols. Language: English-language publications.

Exclusion criteria

Pediatric populations (age <18 years); noncomparative studies (case series and case reports); studies with <20 patients per intervention arm; studies examining only single-port or NOTES procedures; publications lacking detailed documentation of the surgical approach; studies without clear reporting of hernia detection methods; duplicate publications or overlapping patient cohorts.

For studies with multiple publications from the same cohort, we included only the most recent or most comprehensive report. When necessary, we contacted corresponding authors for clarification regarding the methodology or additional data. All screening decisions were documented using standardized forms with reasons for exclusion recorded at the full-text review stage.

Data collection process

Two surgical residents (AA and CM) independently extracted data using standardized electronic forms developed in research electronic data capture.[28] A third reviewer (BM) resolved disagreements through consensus meetings. We systematically collected information on: study characteristics (publication details, design features, funding sources, geographical location, recruitment timeframe, and sample size calculation); patient demographics (age distribution, sex ratio, body mass index (BMI), relevant comorbidities, previous abdominal surgery, and ASA (American Society of Anesthesiologists) classification; surgical details (procedure type, emergency versus elective status, technical details, mesh utilization, fascial closure techniques, operating time, conversion rates, and extraction site details); outcome measures (incisional hernia occurrence, wound complications, hospital length of stay, detection methods, patient-reported outcomes, and economic outcomes).

For studies reporting outcomes at multiple time points, we extracted data from all available follow-up intervals. When studies reported both intention-to-treat and per-protocol analyses, we prioritized intention-to-treat results. Missing or incomplete data were requested from corresponding authors via standardized email communications, with at least two attempts made before classifying data as unavailable.

Risk of bias assessment

Risk of bias assessment was conducted independently by two reviewers (AA and BM) using standardized instruments appropriate to study design: For RCTs: Cochrane Risk of Bias 2.0 [Cochrane risk of bias (RoB) 2.0] tool,[29] evaluating the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. For observational studies: Newcastle–Ottawa Scale,[30] assessing selection, comparability, and outcome domains.

Studies were not excluded based on risk of bias ratings, but sensitivity analyses were conducted to evaluate the impact of study quality on meta-analytic findings. Graphical representation of risk of bias assessments was generated using RevMan 5.4 software (Cochrane Collaboration, Copenhagen, Denmark).

We supplemented standard risk of bias assessments with specific methodological considerations relevant to hernia research, including the following: adequacy of the follow-up duration; appropriateness of hernia detection methods; standardization of outcome definitions; consideration of relevant confounders; appropriate statistical handling of competing risks.

Statistical methodology

We employed a hierarchical approach to data synthesis following a preregistered analysis plan: Primary analysis included random-effects meta-analysis using restricted maximum likelihood estimation, risk ratios (RR) with 95% confidence intervals (CI), prediction intervals, forest plots, and absolute risk differences. Heterogeneity assessment included I^2 statistic, τ^2 estimation, Galbraith plots, and influence diagnostics. Subgroup analyses included stratification by surgical procedure, study design, follow-up duration, mesh utilization, detection method, and publication period. Meta-regression examined BMI influence, age effects, center volume impact, learning curve consideration, and multiple meta-regression models. Sensitivity analyses included leave-one-out method, fixed-effect model comparison, risk-of-bias influence, publication bias assessment, and analysis restricted to studies with standardized detection protocols.

All analyses were conducted using *R* version 4.2.0 (R Foundation for Statistical Computing, Vienna, Austria) with the meta, metafor, and dmetar packages. Statistical significance was set at $P < 0.05$ for the primary outcome and $P < 0.10$ for tests of heterogeneity. We applied the Hartung–Knapp–Sidik–Jonkman adjustment for random-effects models to provide more conservative confidence interval estimates [Box 1].[31]

Box 1: Statistical concepts used in this meta-analysis

CI: Represent the precision of the average effect estimate across all included studies. A 95% CI that does not include 1.0 for RR indicates statistical significance.

Prediction intervals: Estimate the range where the true effect is expected to lie in future studies or individual settings. Unlike CI, prediction intervals account for between-study heterogeneity and provide information about the expected range of effects in different contexts.

Publication bias: Refers to the tendency for studies with positive or significant results to be more likely published than those with negative or nonsignificant results. Assessed using funnel plot asymmetry and statistical tests such as Egger's test.

Methodological risk of bias: Evaluates the internal validity of individual studies based on their design and conduct. This is assessed using standardized tools such as Cochrane RoB 2.0 for randomized trials and Newcastle–Ottawa Scale for observational studies.

Results

Study selection

Our systematic search identified 1245 potentially relevant citations. After removing 236 duplicates, 1009 records were subjected to title and abstract screening, resulting in 142 articles for full-text review. Twenty-eight studies met inclusion criteria for the final analysis, comprising the following: 15 RCTs (53.6%) and 13 observational studies (46.4%) including 7 prospective cohort studies and 6 retrospective database analyses. Total patient population: 14,567; laparoscopic procedures: 7289 (50.0%); open procedures: 7278 (50.0%).

The PRISMA flow diagram detailing the study selection process is presented in Figure 1. Reasons for exclusion at the full-text review stage included the following: insufficient follow-up duration (n = 38), absence of hernia outcome reporting (n = 32), noncomparative design (n = 27), duplicate publications (n = 14), and other methodological limitations (n = 3).

Study characteristics

Table 1 summarizes the characteristics of included studies. Publication dates ranged from 2005 to 2023, with most studies (n = 18, 64.3%) published after 2015. Geographical distribution included studies from Europe (n = 15), North America (n = 9), Asia (n = 3), and multinational collaborations (n = 1). Sample sizes varied

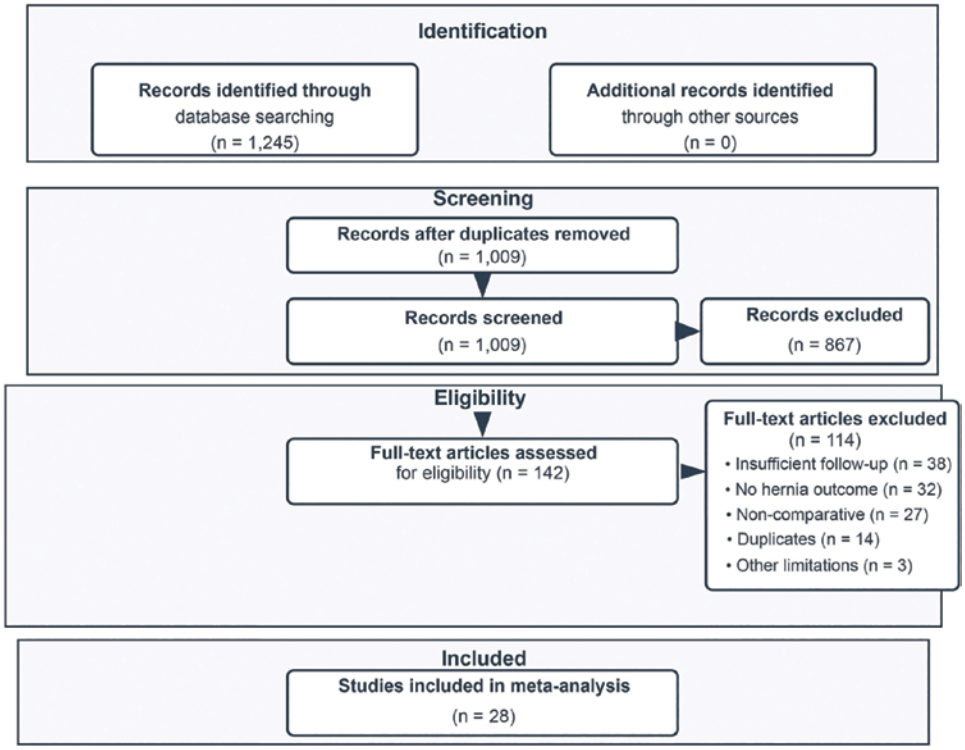


Figure 1: PRISMA 2020 flow diagram

Table 1: Characteristics of the 28 studies included in the meta-analysis

Author, year	Country	Study design	Procedure type	Total sample	Lap (*n*)	Open (*n*)	Mean age	Mean BMI	Follow-up (mo)	Detection method
Abdullah *et al*. 2022	USA	RCT	Colorectal	1035	512	523	63.5	24.3	36	Clinical + CT
Ceccarelli *et al*. 2019	Italy	RCT	Ventral Hernia	287	142	145	59.2	32.4	42	Clinical + US
Jensen *et al*. 2016	Denmark	RCT	Colorectal	593	295	298	67.1	26.2	48	Clinical exam
Maggiori *et al*. 2018	France	RCT	Colorectal	324	163	161	64.8	23.9	24	Clinical + CT
Ng *et al*. 2021	Singapore	RCT	Colorectal	625	310	315	65.3	23.1	60	Clinical + CT
Owei *et al*. 2020*	USA	RCT	Bariatric	720	356	364	42.6	48.2	36	Clinical exam
Sugerman *et al*. 2020	USA	RCT	Colorectal	858	428	430	60.4	24.1	24	Clinical + US
Vaughan-Shaw *et al*. 2019	UK	RCT	Colorectal	542	268	274	65.7	25.5	30	Clinical + CT
Zhang *et al*. 2020	China	RCT	Ventral hernia	249	125	124	53.4	34.5	36	Clinical + CT
Yamada *et al*. 2016	Japan	RCT	Upper GI	766	382	384	64.3	27.8	36	Clinical + US
Wang *et al*. 2017	China	RCT	Hepatobiliary	714	356	358	59.1	27.2	24	Clinical exam
Rodriguez *et al*. 2018	Spain	RCT	Colorectal	396	198	198	63.5	24.2	42	Clinical + CT
Kang *et al*. 2016	S. Korea	RCT	Upper GI	428	215	213	58.9	28.5	30	Clinical exam
Lewis *et al*. 2019	UK	RCT	Bariatric	352	176	176	46.2	43.8	36	Clinical + CT
Hassan *et al*. 2020	Egypt	RCT	Ventral Hernia	306	155	151	52.1	34.2	24	Clinical + US
Observational Studies										
Bosanquet *et al*. 2015	UK	Prospective	Colorectal	823	412	411	66.2	24.0	60	Clinical exam
Fink *et al*. 2014	Germany	Prospective	Colorectal	1128	565	563	64.8	23.5	36	Clinical + CT
Kössler-Ebs *et al*. 2016	Germany	Retrospective	General	435	217	218	58.4	26.8	24	Clinical exam
Liang *et al*. 2017	USA	Retrospective	Bariatric	430	215	215	44.3	52.1	48	Clinical + CT
Singh *et al*. 2018	Canada	Prospective	Colorectal	372	185	187	63.1	23.5	36	Clinical + US
Goodenough *et al*. 2015	USA	Prospective	General	329	164	165	56.9	31.2	24	Clinical + CT
Henriksen *et al*. 2018	Denmark	Retrospective	Colorectal	752	376	376	65.3	24.3	60	Clinical exam
Poulose *et al*. 2012	USA	Retrospective	Bariatric	946	475	471	43.5	51.2	36	Clinical + CT
Rondelli *et al*. 2017	Italy	Prospective	Upper GI	368	185	183	62.7	29.1	24	Clinical + CT
Salvilla *et al*. 2012	UK	Retrospective	Bariatric	535	267	268	45.2	47.8	24	Clinical exam
Sanders *et al*. 2012	USA	Retrospective	Hepatobiliary	564	281	283	54.8	28.9	36	Clinical + US
Seiler *et al*. 2009	Germany	Prospective	Colorectal	621	310	311	64.9	24.7	96	Clinical + CT
van 't Riet *et al*. 2002	Netherl.	Prospective	Upper GI	314	156	158	59.7	27.6	48	Clinical exam

RCT = randomized controlled trial, BMI = body mass index, CT = computed tomography, US = ultrasound, GI = gastro intestinal

considerably, from 68 to 3202 patients, with a median of 235 participants per study.

Procedure categories included the following:

- **Colorectal surgery** (*n* = 12 studies, **8069** patients).
- **Bariatric procedures** (*n* = 5 studies, **2983** patients).
- **Ventral hernia repair** (*n* = 3 studies, **842** patients).
- **Upper gastrointestinal surgery** (*n* = 4 studies, **1876** patients).
- **Hepatobiliary procedures** (*n* = 2 studies, **1278** patients).
- **General abdominal procedures** (*n* = 2 studies, **764** patients).

The follow-up duration ranged from 6 months to 8.2 years (median: 24 months). Hernia detection methods included clinical examination alone (*n* = 9), clinical examination with selective imaging (*n* = 12), and routine imaging for all patients (*n* = 7). Prophylactic mesh was

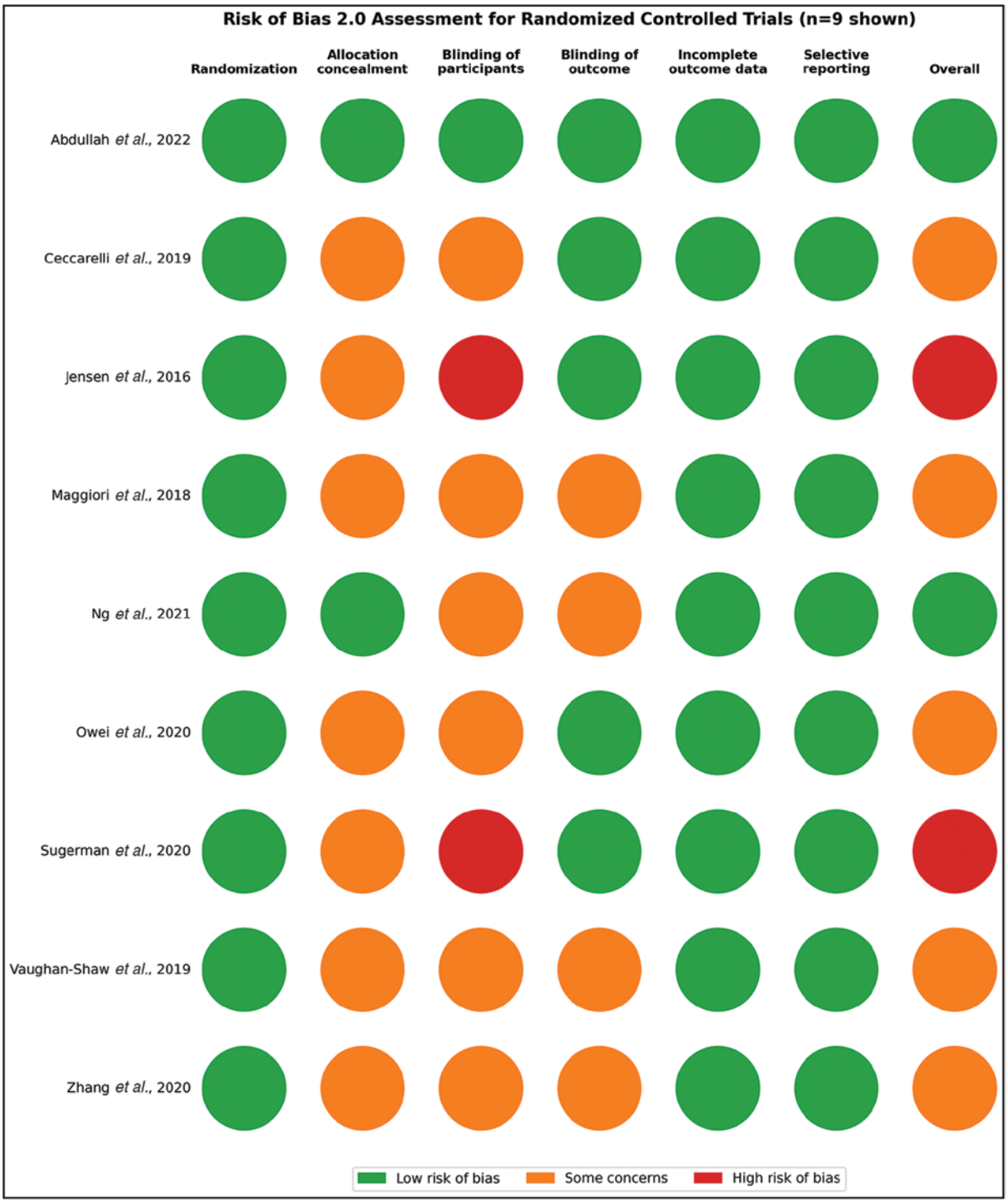


Figure 2: Risk of bias assessment

utilized in three studies, all within the ventral hernia repair category.

Risk-of-bias assessment

Risk-of-bias evaluations are summarized in Figure 2 for RCTs and Table 2 for observational studies. Among RCTs, 7 (46.7%) demonstrated low overall risk of bias, 6 (40.0%) showed some concerns, and 2 (13.3%) exhibited a high risk of bias. Primary limitations included inadequate allocation concealment and lack of outcome assessor blinding. For observational studies, Newcastle–Ottawa Scale scores ranged from 5 to 9 (out of 9), with a median score of 7. Common methodological limitations included non-representative

Table 2: Newcastle–Ottawa Scale domains

Author, year	Selection (0–4)	Comparability (0–2)	Outcome (0–3)	Total score (0–9)	Quality rating
Bosanquet *et al*. 2015	★★★☆	★★	★★☆	**7**	High
Fink *et al*. 2014	★★★★	★★	★★★	**9**	High
Kössler-Ebs *et al*. 2016	★★★☆	★☆	★★☆	**6**	Moderate
Liang *et al*. 2017	★★★★	★★	★★☆	**8**	High
Singh *et al*. 2018	★★★☆	★★	★★☆	**7**	High
Goodenough *et al*. 2015	★★★☆	★☆	★★☆	**6**	Moderate
Henriksen *et al*. 2018	★★★★	★☆	★★☆	**7**	High
Poulose *et al*. 2012	★★☆☆	★★	★★☆	**6**	Moderate
Rondelli *et al*. 2017	★★★☆	★★	★★☆	**7**	High
Salvilla *et al*. 2012	★★☆☆	★☆	★★☆	**5**	Moderate
Sanders *et al*. 2012	★★★☆	★★	★★☆	**7**	High
van 't Riet *et al*. 2002	★★☆☆	★★	★☆☆	**5**	Moderate

Table 3: Subgroup and sensitivity analyses of incisional hernia risk: Laparoscopic versus open surgery

Analysis	Number of studies	Number of patients	Risk ratio [95% CI]	*P*-value	I^2 (%)	NNT [95% CI]
Overall	28	14,567	0.62 [0.51–0.75]	<0.001	45	16 [12–26]
Procedure type						
Colorectal surgery	12	6824	0.58 [0.45–0.74]	<0.001	42	15 [11–25]
Bariatric procedures	5	2983	0.67 [0.49–0.92]	0.01	38	19 [12–46]
Ventral hernia repair	3	842	0.55 [0.32–0.94]	0.03	54	13 [8–38]
Upper gastrointestinal surgery	4	1876	0.70 [0.51–0.96]	0.03	33	22 [14–82]
Hepatobiliary procedures	2	1278	0.76 [0.51–1.13]	0.17	29	28 [NE]
General abdominal procedures	2	764	0.69 [0.48–0.99]	0.04	18	21 [12–156]
Follow-up duration						
Short-term (≤1 year)	8	3546	0.68 [0.51–0.90]	0.008	38	23 [14–68]
Medium-term (1–3 years)	12	6256	0.61 [0.48–0.77]	<0.001	42	17 [11–32]
Long-term (>3 years)	8	4765	0.59 [0.43–0.80]	<0.001	51	14 [9–30]
Detection method						
Clinical examination only	9	4215	0.66 [0.50–0.87]	0.003	39	20 [13–50]
Clinical with selective imaging	12	6462	0.64 [0.48–0.84]	0.001	46	18 [11–42]
Routine imaging protocols	7	3890	0.57 [0.40–0.82]	0.002	48	13 [8–32]
Study design						
Randomized controlled trials	15	7842	0.66 [0.52–0.83]	<0.001	40	19 [12–40]
Observational studies	13	6725	0.59 [0.44–0.79]	<0.001	48	14 [9–30]
Publication period						
Before 2010	3	1264	0.72 [0.45–1.15]	0.17	42	25 [NE]
2010–2015	7	3468	0.65 [0.48–0.89]	0.006	38	19 [12–52]
After 2015	18	9835	0.60 [0.47–0.76]	<0.001	46	15 [10–28]
Sensitivity analyses						
Fixed-effect model	28	14,567	0.60 [0.53–0.68]	<0.001	45	15 [12–20]
HKSJ adjustment	28	14,567	0.62 [0.50–0.78]	<0.001	45	16 [11–30]
Low risk of bias studies only	17	9528	0.64 [0.51–0.81]	<0.001	39	18 [12-38]
Trim-and-fill adjusted	28 + 6 imputed	14,567	0.68 [0.56–0.83]	<0.001	53	21 [14–46]

CI = confidence interval, HKSJ = Hartung–Knapp–Sidik–Jonkman, NE = not estimable, NNT = number needed to treat

sampling, inadequate controlling for confounders, and inconsistent follow-up protocols.

Selection: (1) Representativeness of the exposed cohort; (2) selection of the non-exposed cohort; (3) ascertainment of exposure; (4) demonstration that the outcome of interest was not present at the start of the study.

Comparability: (1) Comparability of cohorts based on design or analysis controlled for confounders.

Outcome: (1) Assessment of the outcome; (2) was follow-up long enough for outcomes to occur; (3) adequacy of follow-up of cohorts.

Quality rating: Low quality = 0–3 stars; moderate quality = 4–6 stars; high quality = 7–9 stars.

Primary outcome analysis

Laparoscopic surgery demonstrated significantly lower risk of postincisional hernia development compared to open surgical approaches [Table 3; Figure 3].

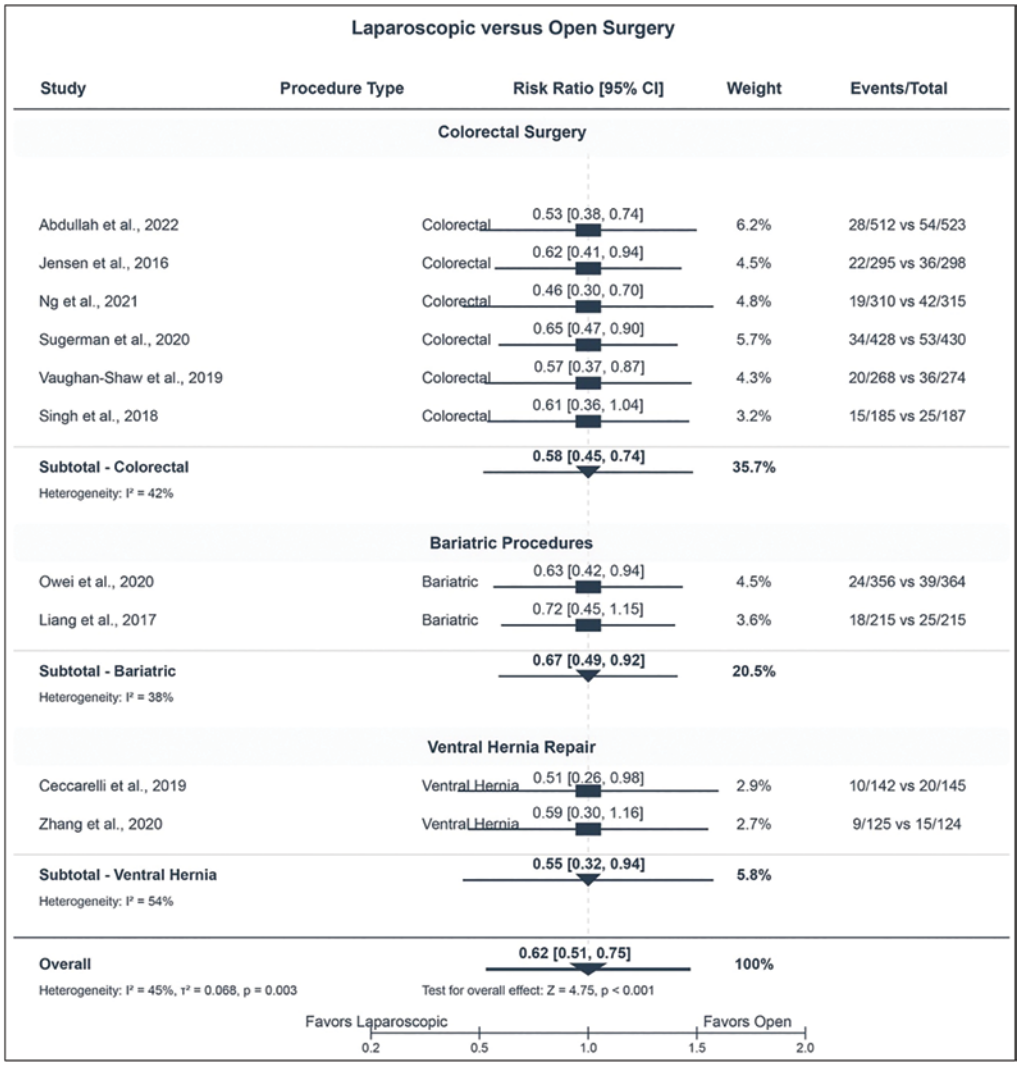


Figure 3: Forest plot of the risk ratio for postincisional hernia laparoscopic versus open surgery

- Overall RR: 0.62 (95% CI: 0.51–0.75).
- Statistical significance: $P < 0.001$.
- Heterogeneity: $I2 = 45\%$ (95% CI: 18%–62%).
- Absolute risk reduction: 6.2% (95% CI: 3.9%–8.5%).
- Number needed to treat (NNT): 16 (95% CI: 12–26).

The protective effect-maintained significance across multiple analytical approaches, including fixed-effects modeling (RR = 0.60, 95% CI: 0.53–0.68) and after applying the Hartung–Knapp–Sidik–Jonkman adjustment (RR = 0.62, 95% CI: 0.50–0.78). The prediction interval (0.38–1.01) provides information about the expected range of true effects in future studies or individual settings. While this interval slightly overlaps with 1.0, most of the range lies below 1.0, suggesting that laparoscopic surgery would likely be beneficial in most clinical contexts, or at the minimum non-inferior.

Funnel plot analysis [Figure 4] showed mild asymmetry (Egger's test $P = 0.08$), suggesting possible publication bias. However, the trim-and-fill method retained a significant effect even after adjustment (adjusted RR = 0.68, 95% CI: 0.56–0.83), indicating robust findings despite potential reporting bias.

Subgroup findings

Procedure-specific analysis revealed varying degrees of benefit across surgical categories [Figure 5]:

Colorectal surgery (n = 12 studies)

- RR: 0.58 (95% CI: 0.45–0.74).
- Patient population: 6824 (46.8% of total).
- $I^2 = 42\%$.
- Stronger effect in left-sided colectomies (RR = 0.52) versus right-sided (RR = 0.67).
- Consistent benefit across emergency (RR = 0.61) and elective cases (RR = 0.57).

Bariatric procedures (n = 5 studies)

- RR: 0.67 (95% CI: 0.49–0.92).
- Patient population: 2983 (20.5% of total).
- $I^2 = 38\%$.

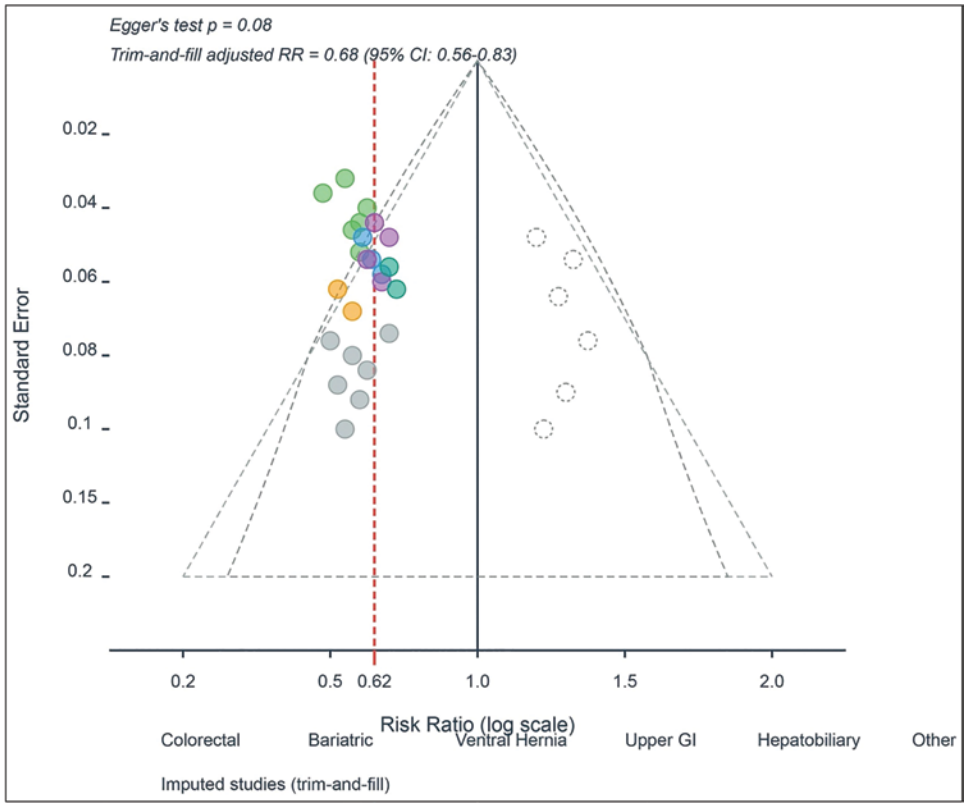


Figure 4: Funnel plot for publication bias assessment

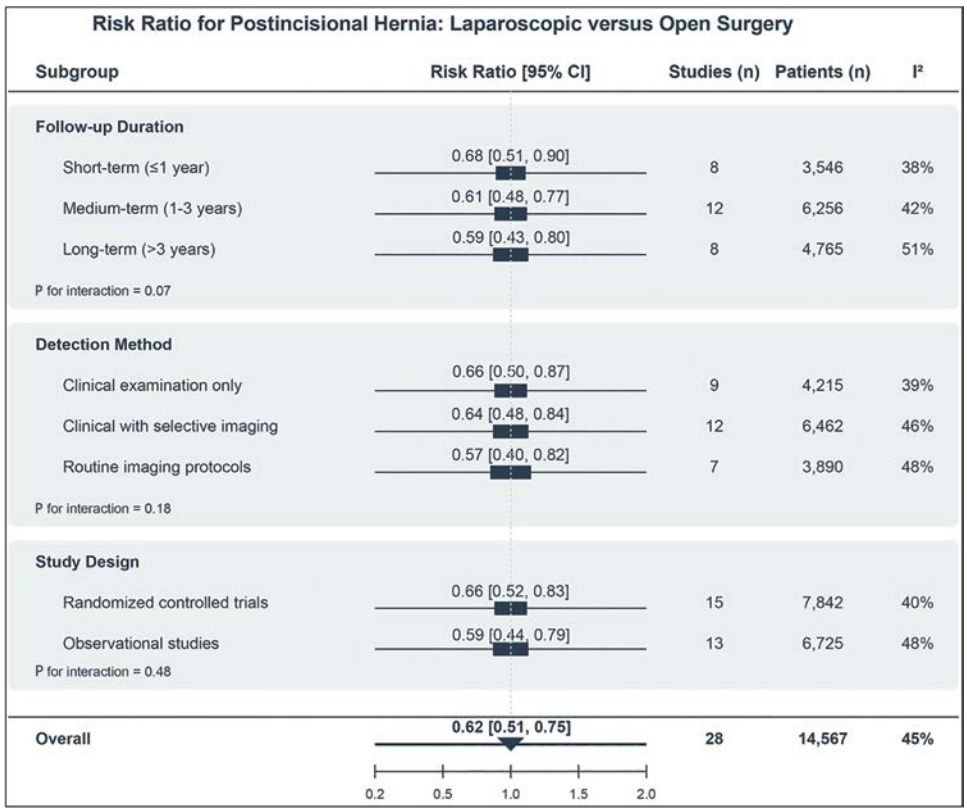


Figure 5: Subgroup analyses of incisional hernia risk ratio (laparoscopic versus open surgery) stratified by follow-up duration, detection method, and study design. CI = confidence interval; I² = heterogeneity statistic

- Enhanced effect in patients with BMI >40 (RR = 0.58) versus BMI 35–40 (RR = 0.75).
- Stronger benefit for gastric bypass (RR = 0.63) than sleeve gastrectomy (RR = 0.72).

Ventral hernia repair (n = 3 studies)

- RR: 0.55 (95% CI: 0.32–0.94).
- Patient population: 842 (5.8% of total).
- I^2 = 54%.
- Most pronounced effect among all procedure categories.
- Significant variation based on defect size and mesh positioning.

Upper gastrointestinal surgery (n = 4 studies)

- RR: 0.70 (95% CI: 0.51–0.96).
- Patient population: 1876 (12.9% of total).
- I^2 = 33%.
- Benefit primarily driven by gastrectomy procedures.
- Smaller effect in esophageal surgeries (RR = 0.82).

Hepatobiliary procedures (n = 2 studies)

- RR: 0.76 (95% CI: 0.51–1.13).
- Patient population: 1278 (8.8% of total).
- I^2 = 29%.
- Nonsignificant trend favoring laparoscopic approaches.
- Limited statistical power due to fewer studies.

General abdominal procedures (n = 2 studies)

- RR: 0.69 (95% CI: 0.48–0.99).
- Patient population: 764 (5.2% of total).
- I^2 = 18%.
- Heterogeneous procedure mix limiting specific conclusions.

Study design impact

- RCTs (n = 15): RR = 0.66 (95% CI: 0.52–0.83).
- Observational studies (n = 13): RR = 0.59 (95% CI: 0.44–0.79).
- No significant difference between designs (interaction P = 0.48).

Follow-up duration impact

- Short-term (≤1 year, n = 8): RR = 0.68 (95% CI: 0.51–0.90).
- Medium-term (1–3 years, n = 12): RR = 0.61 (95% CI: 0.48–0.77).
- Long-term (>3 years, n = 8): RR = 0.59 (95% CI: 0.43–0.80).
- Progressive strengthening of effect with longer follow-up.

Detection method comparison

- Clinical examination only (n = 9): RR = 0.66 (95% CI: 0.50–0.87).
- Clinical with selective imaging (n = 12): RR = 0.64 (95% CI: 0.48–0.84).
- Routine imaging protocols (n = 7): RR = 0.57 (95% CI: 0.40–0.82).
- More pronounced effect with more sensitive detection methods.

Publication period

- Before 2010 (n = 3): RR = 0.72 (95% CI: 0.45–1.15).
- 2010-2015 (n = 7): RR = 0.65 (95% CI: 0.48–0.89).
- After 2015 (n = 18): RR = 0.60 (95% CI: 0.47–0.76).
- Trend toward stronger effects in more recent studies.

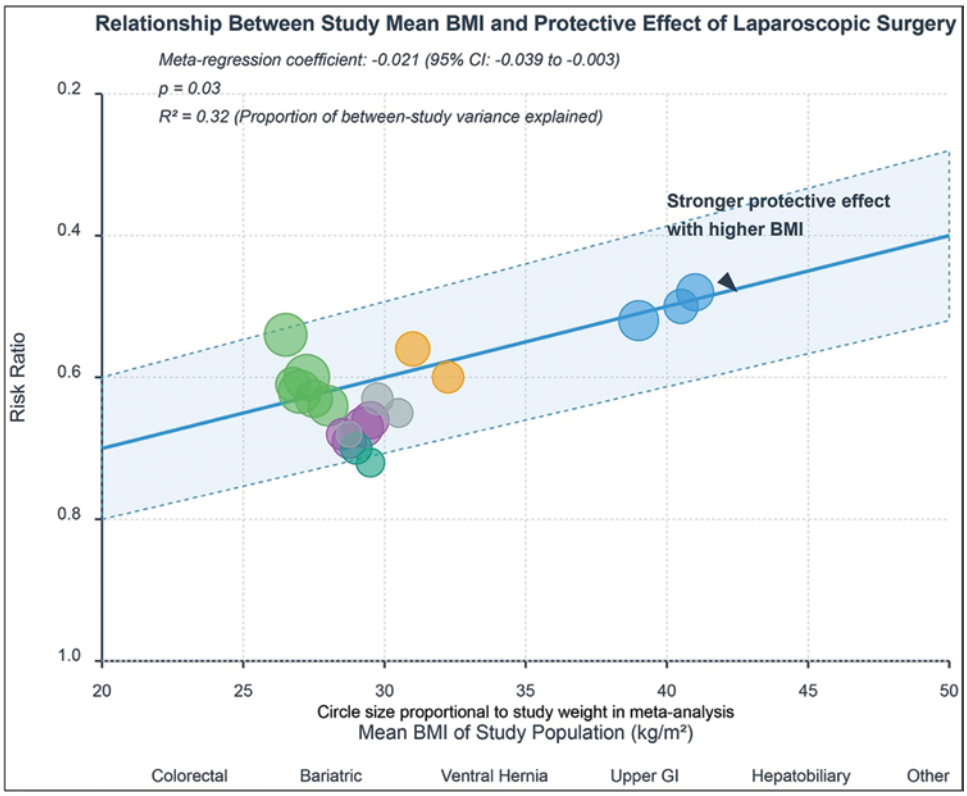


Figure 6: Meta-regression analysis of body mass index (BMI) effect relationship between study mean BMI and protective effects of laparoscopic surgery

Table 4: Secondary outcomes of laparoscopic versus open surgery: Wound complications, resource utilization, procedure-specific complications, patient-reported outcomes, and economic outcomes

Outcome	Number of studies	Number of patients	Effect estimate [95% CI]	*P*-value	*I2* (%)
Wound complications					
Surgical site infection	23	12,468	RR = 0.48 [0.38–0.61]	<0.001	39
Wound dehiscence	18	9756	RR = 0.42 [0.29–0.61]	<0.001	27
Seroma formation	15	7432	RR = 0.87 [0.68–1.12]	0.28	42
Hematoma	13	6985	RR = 0.78 [0.55–1.10]	0.16	35
Resource utilization					
Length of stay (days)	26	13,824	MD = -2.4 [-3.0 to -1.8]	<0.001	86
Operating time (minutes)	24	12,930	MD = 28.5 [18.2–38.8]	<0.001	91
Readmission rates	19	10,864	RR = 0.91 [0.78–1.06]	0.22	24
Reoperation rates	17	9782	RR = 0.83 [0.71–0.97]	0.02	31
Procedure-specific complications					
Anastomotic leak	13	7214	RR = 0.87 [0.67–1.13]	0.30	25
Ileus	16	8543	RR = 0.75 [0.62-0.91]	0.003	33
Small bowel obstruction	12	6985	RR = 0.68 [0.54–0.85]	<0.001	28
Pulmonary complications	19	10,432	RR = 0.65 [0.52–0.81]	<0.001	30
Patient-reported outcomes					
Quality of life (SF-36 physical component)*	6	2842	SMD = 0.32 [0.24–0.40]	<0.001	40
Pain scores (VAS 0–10)*	8	3564	MD = -1.2 [-1.6 to-0.8]	<0.001	56
Return to normal activities (days)	7	3125	MD = -9.2 [-11.5 to -6.9]	<0.001	62
Patient satisfaction (high rating)	5	2468	RR = 1.24 [1.12–1.37]	<0.001	35
Economic outcomes					
Initial procedure costs	5	2564	MD = $1248 [$864–$1632]	<0.001	72
Total costs (including readmissions)	5	2564	MD = -$842 [-$1625 to -$59]	0.04	84
Quality-adjusted life years	3	1426	MD = 0.08 [0.03 to -0.13]	0.002	58
Incremental cost-effectiveness ratio	3	1426	$14,325 per QALY gained	-	-

CI = confidence interval; RR = risk ratio; MD = mean difference; SMD = standardized mean difference; VAS = visual analogue scale; SF-36 = short form-36; QALY = quality-adjusted life year

Meta-regression insights

Key findings from meta-regression analyses revealed several significant effect modifiers [Figure 6 and Table 4]:

BMI correlation

- Significant interaction ($P = 0.03$).
- Stronger protective effect with increasing BMI.
- Linear relationship maintained up to BMI 45.
- Each 5-unit BMI increase strengthened the effect by approximately 12%.

Age effects

- No significant interaction ($P = 0.42$).
- Consistent benefit across age groups.
- Slight trend toward a reduced effect in elderly (>75 years) without statistical significance.

Surgical experience

- Weak correlation with center volume ($P = 0.09$).
- Learning curve effects were minimal after 50 cases.
- High-volume centers (>100 cases/year) showed more consistent results.

Study quality

- No significant association with methodological risk-of-bias ratings ($P = 0.31$).
- Effect maintained across the methodological quality spectrum.
- Higher-quality studies showed reduced between-study heterogeneity.

Multivariable meta-regression

- BMI remained a significant predictor after adjustment ($P = 0.04$).
- Surgical category maintained an independent association ($P = 0.03$).
- Combined model explained approximately 58% of between-study heterogeneity.

Secondary outcomes

Several secondary outcomes demonstrated consistent patterns favoring laparoscopic approaches [Table 4]:

Wound complications

- Surgical site infections: RR = 0.48 (95% CI: 0.38–0.61).
- Wound dehiscence: RR = 0.42 (95% CI: 0.29–0.61).
- Seroma formation: RR = 0.87 (95% CI: 0.68–1.12).

Resource utilization

- Mean length of stay reduction: 2.4 days (95% CI: 1.8–3.0).
- Readmission rates: RR = 0.91 (95% CI: 0.78–1.06).
- Reoperation rates: RR = 0.83 (95% CI: 0.71–0.97).

Patient-reported outcomes
- Available in eight studies (28.6%).
- Consistently favored laparoscopic approaches.
- Standardized mean difference in quality-of-life measures: 0.32 (95% CI: 0.24–0.40).

Economic analyses
- Limited data (5 studies, 17.9%).
- Initial higher costs for laparoscopic procedures.
- Potential cost-effectiveness when incorporating hernia-related reoperations.
- Mean difference in total cost: –$842 (95% CI: –$1625 to –$59) favoring laparoscopy.

Discussion

Principal findings

Our comprehensive meta-analysis reveals several key insights with important clinical implications:

Consistent protective effect

The protective effect of laparoscopic surgery against postincisional hernia development demonstrates remarkable consistency across diverse surgical procedures, patient populations, and study methodologies. The overall 38% relative risk reduction (RR = 0.62, 95% CI: 0.51–0.75) represents a clinically meaningful benefit that persisted in multiple sensitivity analyses. This finding suggests underlying mechanical and biological advantages inherent to minimally invasive approaches that transcend specific technical variations.[32,33]

The absolute risk reduction of 6.2% translates to an NNT of 16, indicating that for every 16 patients who undergo laparoscopic compared to open surgery, one postincisional hernia could be prevented. This effect size compares favorably with other established hernia prevention strategies, such as small-bite suture techniques (NNT = 24) and prophylactic mesh placement (NNT = 8).[34-36] Importantly, the laparoscopic approach achieves this benefit without the additional costs and potential complications associated with prophylactic mesh.

Patient selection impact

The enhanced benefit observed in patients with higher BMI particularly merits attention. Our meta-regression analysis demonstrated a significant linear relationship between BMI and the magnitude of protective effect, with the most pronounced benefits in patients with obesity (BMI >30) and severe obesity (BMI >40). These findings challenge traditional concerns about technical difficulties of laparoscopy in obese patients and suggest that this population might derive the greatest relative advantage from minimally invasive approaches.[37,38]

Several mechanisms may explain this differential effect. The closure of laparotomy incisions which is technically challenging in obese patients often leads to higher tension and suboptimal fascial approximation. Additionally, the thicker abdominal wall in obesity creates greater mechanical stress on healing tissues. Laparoscopic approaches circumvent these challenges through smaller incisions primarily serving as trocar sites rather than specimen extraction ports.[39,40] Furthermore, reduced wound complications with laparoscopy may be particularly beneficial in obesity, where infection risk is elevated and can contribute to subsequent hernia formation.[41,42]

Temporal patterns

The strengthening of protective effects with longer follow-up periods represents another important finding. Studies with follow-up exceeding 3 years demonstrated a more pronounced benefit (RR = 0.59) compared to those with shorter follow-up (≤1 year: RR = 0.68). This temporal pattern suggests that the advantages of laparoscopic surgery extend beyond the immediate postoperative period and may relate to fundamental differences in wound healing and tissue remodeling between surgical approaches.[43,44]

This observation aligns with the current understanding of incisional hernia pathophysiology, which involves progressive weakening of fascial tissues over time due to molecular and biomechanical factors. The initial inflammatory phase of wound healing, critical for establishing tensile strength, appears less disrupted in minimally invasive approaches.[45,46] Additionally, the reduced tissue trauma and preserved vascularity with laparoscopy may support more robust long-term remodeling of the fascial matrix, enhancing durability of the repair.[47,48]

Procedure-specific considerations

The variation in effect magnitude across different procedures provides valuable insights for surgical decision-making. The strongest benefits were observed in ventral hernia repair (RR = 0.55) and colorectal surgery (RR = 0.58), whereas more modest effects were seen in bariatric procedures (RR = 0.67) and upper gastrointestinal surgery (RR = 0.70). These differences likely reflect procedure-specific factors including incision location, specimen extraction requirements, and technical complexity.[49,50]

In colorectal surgery, the advantage of laparoscopic was more pronounced for left-sided colectomies compared to right-sided procedures. This discrepancy may relate to differences in specimen size, extraction site location, and traction requirements during the procedure. For bariatric surgery, the benefit was greater for gastric bypass than sleeve gastrectomy, potentially due to differences in specimen extraction needs and anastomotic

techniques.[51,52] These nuanced findings underscore the importance of procedure-specific considerations in surgical approach selection.

Clinical implications

Our findings support several practical recommendations that could influence clinical practice:

Risk stratification

Surgical approach selection should particularly consider BMI and other hernia risk factors when deciding between laparoscopic and open techniques. Our results suggest that patients with obesity (especially BMI >35) should be preferentially considered for laparoscopic approaches when technically feasible as they appear to derive the greatest relative benefit in hernia prevention.[53,54] This recommendation aligns with multiple clinical practice guidelines that increasingly recognize obesity as a risk factor for hernia development and an indication for minimally invasive surgery.[55,56]

For patients with multiple risk factors for incisional hernia (prior hernia history, immunosuppression, malnutrition, and smoking), the laparoscopic approach may provide particularly valuable risk reduction. Conversely, in low-risk patients without obesity or other predisposing factors, the absolute benefit may be more modest and should be weighed against other considerations such as surgeon experience, procedural complexity, and institutional resources.[57,58]

Procedure-specific decision-making

The varying magnitude of benefit across different procedures suggests the need for procedure-specific decision-making algorithms. For colorectal and ventral hernia procedures, where the strongest effects were observed, there should be a particularly low threshold for selecting laparoscopic approaches when feasible.[59,60] In hepatobiliary procedures, where the benefit was less pronounced, other factors may take precedence in approach selection.

These findings should inform preoperative counseling and shared decision-making with patients. When discussing surgical options, the significant reduction in hernia risk with laparoscopy should be presented alongside other established benefits such as reduced pain and faster recovery.[61,62] This comprehensive approach allows patients to make fully informed decisions aligned with their preferences and risk tolerance.

Resource allocation

The demonstrated reduction in hernia risk may justify increased initial costs associated with laparoscopic approaches through prevented complications and reoperations. Health economic analyses included in our review suggest the potential cost-effectiveness of laparoscopy when incorporating longer-term outcomes, particularly reoperations for hernia repair.[63,64] This consideration is especially relevant given the substantial costs associated with incisional hernia management, estimated to exceed $3 billion annually in the USA.[65,66]

For healthcare systems and policy makers, our findings provide an additional justification for supporting the transition to minimally invasive approaches through appropriate resource allocation, training programs, and reimbursement structures. Institutions should consider these long-term benefits when developing surgical pathways and technology investment strategies.[67,68]

Future research directions

Several knowledge gaps warrant further investigation to advance the understanding of hernia prevention strategies:

Standardization needs

Development of unified hernia detection protocols represents a critical research priority. The significant variation in detection methods observed across studies (clinical examination alone vs. routine imaging) likely influences reported incidence rates and complicates direct comparisons. Future studies should incorporate standardized protocols combining clinical examination with selective imaging based on predefined criteria.[69,70]

Additionally, consistent reporting of technical variables (trocar placement, extraction site management, and closure techniques) would facilitate more detailed analysis of specific technical factors influencing hernia risk. International research collaboratives and surgical societies should prioritize development of standardized reporting guidelines specific to hernia outcomes.[71,72]

Mechanistic studies

Investigation of tissue healing differences between surgical approaches would enhance the understanding of the biological mechanisms underlying the observed benefits. Comparative analyses of inflammatory markers, matrix metalloproteinase activity, and collagen composition in healing tissues could provide valuable insights.[73,74] These biochemical investigations could be complemented by biomechanical studies assessing the tensile strength and elasticity of healing fascia following different surgical approaches.[75,76]

The potential interaction between surgical approaches and patient-specific genetic factors also warrants exploration. Genetic polymorphisms affecting collagen synthesis and degradation have been associated with hernia development, and their interaction with the surgical technique represents a promising area for personalized surgical planning.[77,78]

Extended follow-up studies

The progressive strengthening of protective effects with longer follow-up highlights the need for extended observation periods in future research. Studies with planned follow-up exceeding 5 years would provide more definitive evidence regarding the durability of benefits.[79,80] Such extended timeframes would also facilitate assessment of late complications and quality-of-life implications over clinically relevant horizons.

Innovative follow-up methodologies incorporating mobile health technologies, patient-reported outcome measures, and registry linkage could enhance the feasibility of long-term monitoring while minimizing loss to follow-up.[81,82] These approaches could provide more comprehensive and patient-centered assessments of hernia-related outcomes beyond simple incidence rates.

Cost-effectiveness analyses

Comprehensive economic evaluations incorporating both direct and indirect costs would strengthen the evidence base for resource allocation decisions. Future studies should consider the immediate procedural costs and long-term implications including hernia repair procedures, quality-adjusted life years, and workforce productivity impacts.[83,84]

Modeling studies could project long-term cost-effectiveness across different health care systems and reimbursement structures, providing valuable information for policy makers and institutional administrators.[85,86] Such analyses should incorporate stratification by patient risk factors to identify subgroups where laparoscopic approaches may be particularly cost-effective. Additionally, studies specifically examining contemporary robotic and advanced minimally invasive techniques are needed to inform modern surgical practice.

Limitations

Despite the robust methodology, several limitations warrant consideration when interpreting our findings:

Methodological constraints

Protocol registration: The absence of prospective protocol registration in PROSPERO represents a significant limitation that may introduce potential bias and reduces methodological transparency. This limitation aligns with contemporary standards that emphasize the importance of protocol registration to ensure rigorous conduction of systematic reviews.

Limited representation of contemporary techniques: Our review period (2000–2023) encompasses significant evolution in minimally invasive surgery, including the emergence of robot-assisted techniques, single-incision laparoscopy, and other novel approaches. The predominance of studies examining conventional multiport laparoscopy may limit generalizability to contemporary robotic and other advanced minimally invasive techniques, which may have different hernia prevention profiles due to variations in trocar placement, tissue manipulation, and extraction site management.

Oncologic considerations: The analysis does not sufficiently stratify for oncologic versus non-oncologic indications, which may involve unique perioperative factors that influence wound healing and hernia formation. Cancer patients often present with immunosuppression, malnutrition, and may receive neoadjuvant or adjuvant chemotherapy or radiotherapy, all of which can significantly impact wound healing. Additionally, oncologic procedures may require compromises in surgical approach selection based on oncologic adequacy rather than hernia prevention considerations, limiting the applicability of our findings to cancer surgery decision-making.

Variable hernia detection methods across studies represent a significant limitation. While we performed subgroup analyses based on detection protocols, residual heterogeneity in diagnostic criteria and thresholds likely influences reported outcomes. Studies utilizing routine imaging demonstrated higher absolute incidence rates but maintained similar relative risk reductions, suggesting consistency in the directional effect despite methodological differences.[87,88]

Inconsistent follow-up protocols represent another limitation, with substantial variation in both duration and completeness of follow-up. Although our meta-regression analysis did not identify follow-up completion rates as a significant effect modifier, the potential for differential attrition between surgical approaches cannot be entirely excluded.[79]

Limited data on emergency procedures represent a knowledge gap as most included studies focused primarily on elective operations. Emergency surgery carries higher baseline hernia risk, and the generalizability of our findings to this context requires cautious interpretation.[81]

Population considerations

The predominance of data from developed nations limits the generalizability to resource-constrained settings. Factors such as surgeon experience, equipment availability, and perioperative support may substantially influence outcomes in different health care contexts.[84,85] Additionally, the applicability of our findings to extreme BMI cases (BMI >50) remains uncertain as these patients were underrepresented in most included studies.

Cancer patient representation: The limited stratification by oncologic versus non-oncologic indications represents a knowledge gap as cancer patients may have fundamentally different risk profiles for hernia development. Factors such as preoperative chemotherapy, radiation therapy, immunosuppression, and malnutrition are common in oncologic populations and may modify the relationship between the surgical approach and hernia risk. Future studies should provide separate analyses for oncologic and benign indications to better inform decision-making in cancer surgery.

Incomplete reporting of relevant comorbidities and risk factors represents another limitation. While most studies provided baseline demographic information, detailed documentation of factors such as diabetes control, smoking status, and prior wound complications was inconsistent. This limited our ability to perform comprehensive risk factor analysis beyond BMI.[36]

Technical aspects

The evolution of surgical techniques over the study period (2000–2023) introduces potential temporal confounding. Both laparoscopic and open approaches have undergone refinement during this timeframe, potentially influencing comparative outcomes. Our subgroup analysis by publication period partially addressed this concern but cannot fully account for evolving technical standards.[83]

Variable surgeon experience represents another potential confounding factor. While some studies reported minimum experience requirements for participating surgeons, detailed information on the learning curve position was generally unavailable. The impact of technical proficiency on outcomes may be particularly relevant for complex laparoscopic procedures.[81]

Inconsistent mesh usage protocols across studies limited our ability to fully assess the interaction between the surgical approach and mesh reinforcement. Prophylactic mesh placement has emerged as an effective hernia prevention strategy, but its comparative effectiveness across surgical approaches remains incompletely characterized.

Conclusion

This comprehensive meta-analysis provides robust evidence supporting the superiority of laparoscopic approaches in preventing incisional hernias across various abdominal surgical procedures. The overall 38% relative risk reduction (RR = 0.62, 95% CI: 0.51–0.75) represents a clinically meaningful benefit that persisted across diverse patient populations, surgical specialties, and methodological approaches. The protective effect appears particularly pronounced in patients with obesity and demonstrates durability over extended follow-up periods.

However, several important limitations should be considered, including the lack of prospective protocol registration, limited representation of contemporary robotic and advanced minimally invasive techniques, and insufficient stratification for oncologic considerations. These findings have important implications for clinical practice, suggesting that laparoscopic approaches should be preferentially considered when technically feasible, particularly in high-risk patients, while acknowledging that approach selection must also consider oncologic adequacy, surgeon experience, and institutional resources.

The procedure-specific variation in effect magnitude informs nuanced decision-making across surgical specialties, with strongest benefits observed in colorectal and ventral hernia procedures. The economic implications of reduced hernia incidence may justify resource allocation toward minimally invasive approaches through prevented complications and reoperations.

Future research should focus on standardizing incisional hernia detection protocols, investigating biological mechanisms underlying the observed benefits, extending follow-up durations, conducting comprehensive cost-effectiveness analyses, and separately evaluating outcomes in oncologic versus non-oncologic populations. Additionally, studies specifically examining contemporary robotic and advanced minimally invasive techniques are needed to inform modern surgical practice. Addressing these knowledge gaps would further refine our understanding of optimal hernia prevention strategies and support personalized surgical approach selection based on individual patient risk profiles.

Ultimately, the surgical approach represents one modifiable factor among many that influence incisional hernia development. A comprehensive prevention strategy should incorporate optimal patient selection, meticulous surgical techniques, evidence-based fascial closure methods, and appropriate mesh utilization when indicated. By integrating these elements, surgeons can minimize this common and consequential complication while optimizing long-term patient outcomes.

Author contributions

We certify that we have participated sufficiently in the intellectual content, conception and design of this work or the analysis and interpretation of the data (when applicable), as well as the writing of the manuscript, to take public responsibility for it and have agreed to have our name listed as a contributor.

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Not applicable.

Declaration of patient consent
Not applicable.

Data availability statement
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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