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Comparative Analysis of Robotic- and Endoscopic-Assisted Minimally Invasive Nipple–Areola Complex–Sparing Mastectomy for Breast Cancer: A Meta-Analysis with Subgroup Analyses

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Abstract

Objective

To compare robotic or endoscopic minimally invasive nipple-sparing mastectomy with conventional open nipple-sparing mastectomy in breast cancer patients.

Methods

Studies comparing minimally invasive and open nipple-sparing mastectomy were searched in PubMed, Embase, Web of Science, and the Cochrane Library. Data on operative outcomes, complications, cosmetic-related indicators, and recurrence were extracted and pooled.

Results

Twelve studies were analyzed. Minimally invasive surgery required a longer operative time but was associated with less blood loss, shorter incisions, and shorter reconstruction time. It also showed lower rates of overall complications, skin necrosis, seroma, and hematoma or bleeding. Delayed wound healing, nipple–areola complex complications, nipple necrosis, flap necrosis, and recurrence did not differ significantly between the two groups.

Conclusion

Robotic and endoscopic minimally invasive nipple-sparing mastectomy may provide selected advantages over open surgery, particularly in surgical trauma and postoperative complications. However, evidence for recurrence and long-term safety remains limited.

Clinical Trial Registration

Not applicable.

1. INTRODUCTION

As a prevalent malignancy affecting women, breast cancer accounts for a substantial proportion of cancer fatalities across the world and remains a critical issue in global health [1, 2]. With the widespread implementation of early screening programs and advances in multimodal treatment strategies, survival outcomes for breast cancer patients have improved considerably. Consequently, contemporary breast surgery has evolved beyond the traditional focus on oncologic radicality alone, shifting toward a more comprehensive, patient-centered paradigm that integrates tumor control, aesthetic reconstruction, perioperative management, and psychosocial rehabilitation [3, 4]. The surgical outcomes are no longer evaluated solely by oncologic safety, but also by their impact on cosmetic appearance and functional preservation. In parallel, perioperative care-including complication prevention, incision management, flap perfusion monitoring, psychological support, and rehabilitation guidance-has become an indispensable component in optimizing clinical outcomes and enhancing recovery. The integration of reconstructive principles with high-quality perioperative nursing care has thus emerged as a central theme in modern breast cancer management [5–7].

Nipple–areola complex–sparing mastectomy (NSM), when performed within strict oncologic safety margins, preserves the native skin envelope and nipple–areola complex, thereby providing a favorable anatomical foundation for breast reconstruction. This technique enables improved restoration of breast contour and aesthetic appearance, contributing to better postoperative psychosocial outcomes [8–10]. However, conventional open NSM is associated with several inherent limitations, including extensive incision length, substantial flap dissection, and disruption of skin perfusion. These conditions can negatively affect cosmetic results and elevate the likelihood of postoperative issues, including skin tissue death and delayed healing. From a clinical perspective, these challenges not only elevate the complexity of perioperative management but also impose a greater burden on nursing care. Moreover, the occurrence of complications and suboptimal cosmetic results may negatively affect patients' psychological status, potentially leading to anxiety, depression, and delayed functional recovery. Such limitations underscore the need for surgical innovations that can simultaneously address oncologic safety, aesthetic expectations, and perioperative care optimization [11, 12].

In recent years, minimally invasive surgical approaches, including robot-assisted and endoscopic-assisted techniques, have undergone rapid technological advancements and have been increasingly incorporated into clinical practice for NSM [13, 14]. These techniques offer several potential advantages, such as enhanced operative precision, improved visualization, reduced surgical trauma, and more concealed incisions, which may contribute to better preservation of soft tissue integrity and vascular perfusion. Minimally invasive NSM has the potential to achieve adequate oncologic resection while minimizing disruption to the skin envelope and flap vascularity. This may translate into reduced incision length, improved aesthetic outcomes, and lower rates of postoperative complications. Furthermore, by decreasing surgical invasiveness, these approaches may facilitate perioperative management, reduce the intensity of nursing interventions, and promote faster postoperative recovery, thereby providing both functional and cosmetic benefits for patients with breast cancer [15]. Despite these promising attributes, current evidence regarding minimally invasive NSM remains limited and inconclusive. Most available studies are retrospective, single-center analyses with relatively small sample sizes. Consequently, the comparative effectiveness of minimally invasive versus conventional NSM—particularly with respect to operative efficiency, perioperative safety, aesthetic outcomes, and oncologic prognosis—has not been definitively established. Therefore, the present study systematically identifies and analyzes comparative clinical studies of minimally invasive and

conventional NSM in breast cancer. Through a meta-analytic approach, we aim to comprehensively evaluate differences in operative parameters, perioperative complications, aesthetic outcomes, and recurrence rates.

2. MATERIALS AND METHODS

The study followed PRISMA 2020 guidance and was prospectively registered (CRD420261352495) [16].

2.1 Eligibility criteria

Studies were selected using predefined PICOS-based eligibility criteria [17]. The population of interest included female patients with histopathologically confirmed primary breast cancer who met established clinical indications for NSM. The intervention comprised minimally invasive NSM techniques, specifically robot-assisted or endoscopic-assisted procedures, while the comparator was conventional open NSM. We considered randomized and cohort-based comparative studies for inclusion, provided they were peer-reviewed and focused primarily on nipple-sparing mastectomy. Studies were required to report at least one relevant outcome, including operative parameters, perioperative complications, aesthetic outcomes related to the nipple–areola complex, or oncologic outcomes such as recurrence, with sufficient data available for extraction. Exclusion criteria encompassed review articles, systematic reviews, basic experimental studies, duplicate publications, and studies with incomplete data or inappropriate statistical analyses. Additionally, studies involving mixed surgical techniques other than NSM or those deemed to have insufficient methodological rigor were excluded.

2.2 Search strategy

PubMed, Embase, Web of Science, and the Cochrane Library were searched up to February 2026. The search terms covered breast cancer, nipple-sparing mastectomy, and minimally invasive surgery. Additional studies were identified by checking the reference lists of relevant articles.

2.3 Study selection and data extraction

After deduplication, two reviewers screened the records by title and abstract, then examined the full texts of potentially relevant studies. Any disagreement was settled by discussion, with a third reviewer involved if needed.

Two reviewers also extracted study details independently, including author, year, country, design, sample size, surgical method, follow-up time, and outcome data. When necessary, missing or unclear information was checked against the original report, and inconsistencies were resolved by consensus.

2.4 Quality assessment

Different quality assessment tools were used according to study type: Cochrane for randomized trials, NOS for cohort studies, and ROBINS-I for non-randomized comparisons [18].

2.5 Statistical analysis

Statistical analyses were conducted in RevMan 5.4. Mean differences were used for continuous outcomes, whereas odds ratios were applied to dichotomous outcomes, both with 95% confidence intervals..

3. RESULTS

3.1 Study selection and characteristics

After applying the inclusion and exclusion criteria, a total of 12 comparative clinical studies were included in the final analysis [19–30]. All included studies evaluated NSM as the primary surgical approach, specifically comparing minimally invasive NSM with conventional open NSM. The detailed study selection process is illustrated in Fig. 1.

Among the 12 studies, three investigated combined robot-assisted and endoscopic-assisted techniques, while nine focused exclusively on robot-assisted NSM. The overall sample sizes were considered adequate, and all studies provided extractable data suitable for quantitative synthesis. Key features of the included studies are presented in Tables 1 and 2.

Table 1
Demographic and design characteristics of the studies meeting the inclusion criteria. (RA: Robot-Assisted, CF: Conventional Freehand, N: Number, NR: N
Reported)

Publication year		Joo Heung Kim	Jeea Lee	Wenling Kuo	Jiyoung You	Hungwen Lai	Antonio Toesca	Jeea Lee	Chai Won Kim	Yu Gui	Hungwen Lai	Hungwen Lai	J M
		2024	**2025**	**2025**	**2025**	**2025**	**2021**	**2021**	**2026**	**2022**	**2024**	**2020**	**2**
Cases (n)	RA	227	162	123	8	317	40	41	148	292	76	54	4
	CF	1356	239	123	49	588	40	270	148	205	73	62	4
BMI, kg/m^2 (mean ± SD)													
	RA	22.52 ± 3.04	22.17 ± 3.00	23.43 ± 4.16	22.52 ± 6.6	23.4 ± 3.4	NR	21.7 ± 2.3	22.09 ± 2.77	NR	NR	NR	2 ±
	CF	22.71 ± 3.15	22.51 ± 3.11	23.09 ± 3.86	24.22 ± 15.98	23.3 ± 3.8	NR	22.5 ± 3.1	22.31 ± 2.96	NR	NR	NR	2 ±
Age (years) (mean ± SD)													
	RA	45.41 ± 7.99	44.76 ± 7.81	45.01 ± 6.99	49.58 ± 19.66	50.7 ± 10.2	44.85 ± 23.07	44 ± 10.0	46.18 ± 8.21	43.05 ± 32.04	48.2 ± 9.5	48 ± 9.3	4 8
	CF	45.47 ± 8.56	46.75 ± 8.34	45.37 ± 8.83	47.03 ± 29.79	48.9 ± 9.6	45.5 ± 25.37	46 ± 8.0	46.90 ± 9.24	43.35 ± 30.61	46.1 ± 8.0	49 ± 11	4 1
follow-up time (months) (mean ± SD)													
	RA	3	24.5(mean)	36	NR	65.4 ± 38.8	28.6(mean)	1 ~ 28	NR	78.91 ± 116.22	28.4 ± 8.0	14.6 ± 8.8	3
	CF	3	42(mean)	36	NR	78.4 ± 46.2	28.6(mean)	1 ~ 28	NR	71.66 ± 129.16	25.5 ± 8.5	47.3 ± 19.6	3
Study design		RCS	RCS	RCS	RCS	RCS	RCT	RCS	RCS	RCS	RCS	RCS	R

Table 2
Perioperative indicators and postoperative outcomes reported in the 12 controlled studies.

		Joo Heung Kim	Jeea Lee	Wenling Kuo	Jiyoung You	Hungwen Lai	Antonio Toesca	Jeea Lee	Chai Won Kim	Yu Gui	Hungwen Lai	Hungwen Lai	Jiae Moon
1. Operative time (min) (mean ± SD)													
	RA		370.63 ± 157.11			290.8 ± 149.3	3.6 ± 0.8	308.9 ± 75.5	153 ± 53.7	220.65 ± 60	202.4 ± 42.3	224 ± 61	279 ± 63
	CF		319.34 ± 203.48			203 ± 109.1	2.3 ± 0.8	303.9 ± 195.9	98.9 ± 37.1	206.17 ± 81.55	190.2 ± 64	197 ± 19.9	207 ± 46
2. Breast reconstruction time (min) (mean ± SD)													
	RA		182.29 ± 148.1					140.5 ± 52.5					
	CF		213.41 ± 190.16					196.8 ± 182.5					
3. Intraoperative blood loss (ml) (min) (mean ± SD)													
	RA	136.24 ± 178.17					202 ± 98			70.15 ± 52.5	33.8 ± 18.3	35 ± 28.2	
	CF	170.55 ± 195.72					209 ± 146			91.8 ± 68.41	43.4 ± 57.2	97.3 ± 73.4	
4. Incision length (cm)	RA										4.1 ± 0.9		4.4 ± 0.7
	CF										8.3 ± 2.4		8.8 ± 2.2
5. Overall complication rate (n)													
	RA	73	8	67	1	67	12	19	31	31	31	18	14
	CF	465	70	66	9	145	20	157	36	18	36	29	24
6. Incidence of delayed wound healing (n)													
	RA					15					1	5	
	CF					58					12	5	
7. Incidence of nipple–areolar complex involvement (n)													
	RA		0	0	0		0				0		
	CF		1	1	1		2				1		
8. Incidence of nipple necrosis (n)													
	RA		1			3				2			
	CF		4			5				3			
9. Incidence of skin ischemia (n)													
	RA	1	0						0				
	CF	18	5						2				
10. Incidence of skin necrosis (n)													
	RA		4	12	0				1			8	
	CF		32	32	7				5			4	

		Joo Heung Kim	Jeea Lee	Wenling Kuo	Jiyoung You	Hungwen Lai	Antonio Toesca	Jeea Lee	Chai Won Kim	Yu Gui	Hungwen Lai	Hungwen Lai	Jiae Moon
1. Operative time (min) (mean ± SD)													
11. Incidence of seroma formation (n)													
	RA	25		5					12	1		3	2
	CF	245		6					18	3		5	2
12. Incidence of bleeding or hematoma (n)													
	RA					3	4					1	0
	CF					20	7					1	2
13. Tumor recurrence rate (n)													
	RA		6			1							
	CF		14			12							
14. Incidence of flap necrosis (n)													
	RA	12		4		14	0					5	2
	CF	60		0		13	5					8	6

3.2 Quality assessment of included studies

The methodological quality of the included studies is presented in Fig. 2. Overall, most studies showed acceptable quality, although several common limitations were identified

3.3 Comparison of operative outcomes

3.3.1 Total operative time

Overall operative time was reported in nine studies, including two in the robot-/endoscopy-assisted subgroup and seven in the robot-assisted subgroup. The pooled analysis showed that the minimally invasive approach required a significantly longer operation than conventional NSM (MD = 35.77, 95% CI 13.46–58.09, $P < 0.05$).

In the robot-assisted subgroup, minimally invasive NSM remained associated with significantly prolonged operative time (MD = 31.34, 95% CI 6.96–55.73, $P < 0.05$), with similarly high heterogeneity ($I^2 > 50\%$) (Fig. 3A).

3.3.2 Reconstruction time

Two robot-assisted studies provided data on breast reconstruction time. Combined analysis indicated that reconstruction was completed significantly faster in the minimally invasive group than in the conventional group (MD = − 46.25, 95% CI − 67.22 to − 25.27, $P < 0.05$). These findings suggest that robot-assisted NSM may improve efficiency during the reconstructive stage (Fig. 3B).

3.3.3 Intraoperative blood loss

A total of five studies reported intraoperative blood loss, including two in the robot-/endoscopy-assisted subgroup and three in the robot-assisted subgroup. The pooled results demonstrated significantly less blood loss with minimally invasive NSM than with the conventional procedure (MD = − 28.66, 95% CI − 47.91 to − 9.42, $P < 0.05$).

Subgroup analysis further showed that in the robot-/endoscopy-assisted subgroup, intraoperative blood loss was significantly reduced in the minimally invasive arm (MD = − 23.69, 95% CI − 33.89 to − 13.49, $P < 0.05$), with low heterogeneity ($I^2 < 50\%$) (Fig. 3C).

3.3.4 Incision length

Two robot-assisted studies assessed incision length, an objective indicator closely related to postoperative cosmetic evaluation. Meta-analysis revealed that the minimally invasive technique produced significantly shorter incisions than the conventional approach (MD = − 4.28, 95% CI − 4.73 to − 3.83, $P < 0.05$) (Fig. 4A).

3.4 Perioperative complications and aesthetic-related outcomes

3.4.1 Overall complication rate

All 12 studies reported overall complications, including three in the robot-/endoscopy-assisted subgroup and nine in the robot-assisted subgroup. The combined analysis indicated that minimally invasive NSM significantly decreased the overall complication rate compared with open NSM (OR = 0.66, 95% CI 0.49–0.89, P < 0.05).

Subgroup analysis showed that the robot-assisted subgroup demonstrated a significantly lower risk of complications in the minimally invasive arm (OR = 0.53, 95% CI 0.35–0.82, P < 0.05), despite persistent heterogeneity (I^2 > 50%) (Fig. 4B).

3.4.2 Delayed wound healing

Three studies reported delayed wound healing, including one in the robot-/endoscopy-assisted subgroup and two in the robot-assisted subgroup. The pooled estimate showed no significant difference between the minimally invasive and conventional groups (OR = 0.42, 95% CI 0.13–1.35, P > 0.05) (Fig. 4C).

3.4.3 Nipple-areola complex complications

Outcomes related to nipple–areola complex (NAC) complications were available from four robot-assisted studies. Pooled analysis showed that the incidence of NAC-related events did not differ significantly between minimally invasive and conventional NSM (OR = 0.30, 95% CI 0.06–1.47, P > 0.05). No heterogeneity was detected (I^2 = 0%), indicating consistency across studies. These data suggest that minimally invasive NSM does not increase the risk of NAC complications (Fig. 5A).

3.4.4 Nipple necrosis

Three studies evaluated nipple necrosis, including two from the robot-/endoscopy-assisted subgroup and one from the robot-assisted subgroup. The pooled result showed no statistically significant difference between the two surgical strategies (OR = 0.65, 95% CI 0.24–1.76, P > 0.05).

A similar result was observed in the robot-/endoscopy-assisted subgroup (OR = 0.79, 95% CI 0.26–2.43, P > 0.05) (Fig. 5B).

3.4.5 Skin ischemia

Skin ischemia was reported in three studies, including one in the robot-/endoscopy-assisted subgroup and two in the robot-assisted subgroup. The pooled analysis suggested that minimally invasive NSM was associated with a lower rate of skin ischemia than conventional NSM (OR = 0.23, 95% CI 0.05–0.99, P = 0.05), with no heterogeneity observed (I^2 = 0%).

Although this finding points toward a possible benefit of minimally invasive surgery in preserving skin perfusion, the borderline level of statistical significance suggests that the result should be interpreted carefully (Fig. 5C).

3.4.6 Skin necrosis

Five studies reported skin necrosis, including one in the robot-/endoscopy-assisted subgroup and four in the robot-assisted subgroup. This complication is clinically important because of its direct relevance to reconstructive success and cosmetic appearance.

Skin necrosis occurred less often after minimally invasive NSM than after conventional NSM (OR = 0.32, 95% CI: 0.20–0.52; P < 0.01; I^2 < 50%). This finding was also significant in the robot-assisted subgroup (OR = 0.24, 95% CI: 0.14–0.42; P < 0.01; Fig. 6A).

3.4.7 Seroma formation

Six studies reported seroma formation, including two in the robot-/endoscopy-assisted subgroup and four in the robot-assisted subgroup. The overall pooled estimate showed that the minimally invasive group had a significantly lower rate of seroma than the conventional group (OR = 0.59, 95% CI 0.42–0.83, P < 0.01).

Subgroup analysis found a significant reduction in the robot-/endoscopy-assisted subgroup (OR = 0.54, 95% CI 0.35–0.84, P < 0.01), without heterogeneity (I^2 = 0%) (Fig. 6B).

3.4.8 Hematoma/bleeding

The incidence of hematoma or bleeding was reported in four studies, including one in the robot-/endoscopy-assisted subgroup and three in the robot-assisted subgroup. The pooled analysis indicated that minimally invasive NSM significantly lowered the risk of hematoma/bleeding compared with conventional NSM (OR = 0.37, 95% CI 0.16–0.81, P < 0.05) (Fig. 6C).

3.4.9 Flap necrosis

Six studies provided data on flap necrosis, including two in the robot-/endoscopy-assisted subgroup and four in the robot-assisted subgroup. The pooled results showed no significant difference between minimally invasive and conventional NSM (OR = 1.09, 95% CI 0.73–1.65, P > 0.05) (Fig. 7A).

3.5 Oncologic outcome: recurrence

Only two studies provided recurrence data: one evaluated robot-/endoscopy-assisted NSM and the other focused on robot-assisted NSM. The pooled result favored minimally invasive NSM over conventional NSM for recurrence (OR = 0.42, 95% CI: 0.18–0.98; P < 0.05), with low heterogeneity (I^2 < 50%).

This finding should be viewed cautiously because the evidence was limited. Whether minimally invasive NSM offers any true oncologic advantage remains uncertain, and longer-term, high-quality studies are needed for confirmation (Fig. 7B).

4. DISCUSSION

In this meta-analysis of 12 comparative studies focusing exclusively on NSM, we observed that minimally invasive NSM was associated with several potential advantages over the conventional open approach. Although operative time was generally longer, minimally invasive techniques were linked to reduced intraoperative blood loss, shorter reconstruction time, smaller incision length, and lower rates of several perioperative complications, including skin necrosis, seroma formation, and hematoma/bleeding.

The evolution of breast cancer surgery has shifted toward a multidisciplinary and patient-centered paradigm that emphasizes not only oncologic safety but also functional preservation, aesthetic outcomes, and perioperative recovery [31, 32]. NSM represents a critical surgical approach in this context, as it preserves the native skin envelope and NAC, thereby facilitating superior reconstructive outcomes and improved patient-reported satisfaction [33, 34]. Nevertheless, conventional open NSM is associated with inherent limitations, including longer incisions, more extensive flap dissection, and disruption of skin perfusion. These factors may contribute to suboptimal cosmetic outcomes and an increased risk of complications such as skin necrosis and delayed wound healing [35, 36]. Beyond their direct clinical impact, such complications can prolong recovery, increase the complexity of perioperative management, and negatively affect patients' psychological well-being. Minimally invasive approaches, particularly robot-assisted and endoscopic-assisted techniques, offer enhanced visualization and greater precision in tissue dissection, which may contribute to improved preservation of vascular integrity and reduced surgical trauma. In the present analysis, the observed reductions in incision length and skin ischemia/necrosis rates may reflect these technical advantages. From a clinical perspective, these improvements are likely to translate into less demanding postoperative wound care, more favorable scar outcomes, and improved aesthetic satisfaction. Importantly, the comparable incidence of NAC-related complications between the two approaches suggests that minimally invasive NSM does not compromise the safety of this critical anatomical structure. This finding is clinically relevant, as preservation of NAC integrity is closely associated with aesthetic outcomes and patient satisfaction. Furthermore, maintaining structural integrity may facilitate more standardized perioperative care pathways and reduce variability in postoperative management. From a perioperative care perspective, the reduction in complication rates observed in the minimally invasive group may have broader implications. Lower rates of wound-related complications and improved tissue preservation may decrease the intensity of nursing interventions, reduce the need for prolonged monitoring of flap perfusion, and facilitate earlier functional recovery.

Perioperative complications represent a critical determinant of aesthetic outcomes, postoperative recovery, and the overall quality of perioperative care in breast surgery. Complications such as seroma formation, hematoma, and skin necrosis not only prolong hospital stay and increase the likelihood of secondary interventions, but also impose a substantial burden on nursing care, including intensified wound management, hemodynamic monitoring, and pain control. These factors may ultimately affect the efficiency of healthcare resource utilization. Minimally invasive approaches may mitigate these risks through more precise tissue dissection and refined instrument manipulation, thereby reducing disruption to the subcutaneous vascular and lymphatic networks. From a perioperative management perspective, the reduction in complication rates is likely to translate into decreased nursing workload and a more streamlined care process. This enables healthcare providers to allocate greater attention to key recovery-oriented interventions, such as early mobilization, psychological support, and structured rehabilitation, aligning with the principles of Enhanced Recovery After Surgery (ERAS) pathways [37]. In addition, the significantly shorter reconstruction time observed in the minimally invasive group may reflect improved surgical conditions during the reconstructive phase, potentially due to better preservation of anatomical planes and reduced tissue trauma. Shorter operative and anesthesia exposure may, in turn, attenuate postoperative physiological stress responses, thereby facilitating earlier initiation of postoperative care and accelerating recovery. These findings are consistent with the broader trend toward integrating surgical precision, reconstructive efficiency, and perioperative care optimization in contemporary breast cancer management.

Oncologic safety remains the fundamental prerequisite of breast cancer surgery and serves as the basis for both perioperative management and long-term follow-up care. In the present analysis, a lower recurrence rate was observed in the minimally invasive group. This finding may reflect the advantages of enhanced visualization and precise surgical manipulation, which could facilitate more standardized tumor resection and adherence to oncologic principles without compromising radicality. From a clinical perspective, the absence of an apparent increase in recurrence risk supports the feasibility of minimally invasive approaches in appropriately selected patients. This has important implications not only for surgical decision-making but also for postoperative management, including surveillance strategies, rehabilitation planning, and long-term care pathways. A stable oncologic profile enables clinicians and nursing teams to implement structured follow-up and patient-centered rehabilitation programs with greater confidence, thereby supporting sustained improvements in quality of life. In summary, minimally invasive NSM appears to offer a favorable balance between oncologic safety and surgical refinement. Among these approaches, robot-assisted techniques may provide additional technical advantages in selected settings.

5. LIMITATIONS

This meta-analysis has several limitations. Most included studies were retrospective, which may have introduced selection bias. Differences in surgical technique, reconstruction approach, surgeon experience, and follow-up length may also have affected the results. In addition, recurrence and cosmetic outcomes were reported in only a small number of studies, so these findings should be interpreted with caution. Longer follow-up and better-designed prospective studies are still needed.

6. CONCLUSION

Robotic and endoscopic nipple-sparing mastectomy may be considered for appropriately selected breast cancer patients. Although these techniques tend to prolong operative time, they are associated with less bleeding, smaller incisions, and fewer selected postoperative complications than open surgery.

Available data do not indicate a higher short-term recurrence risk, but evidence on long-term oncologic outcomes remains limited. Further prospective research with adequate sample size and extended follow-up is required.

Declarations

Author Contributions:

Xiaohan Wang and Hua Tian contributed equally to this work. They jointly conceived the study, developed the protocol, conducted the literature search and study selection, extracted and analyzed the data, and prepared the manuscript draft. Min Zhang and Yangxu Ding verified the extracted data, participated in methodological assessment, interpreted the statistical findings, and revised the manuscript. Jiangyong Shen and Huijuan Shi were involved in quality appraisal, clinical interpretation, and critical revision of the manuscript. Huijuan Shi and Yupei Dai supervised the study, provided methodological guidance, and approved the final version for submission

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Figures

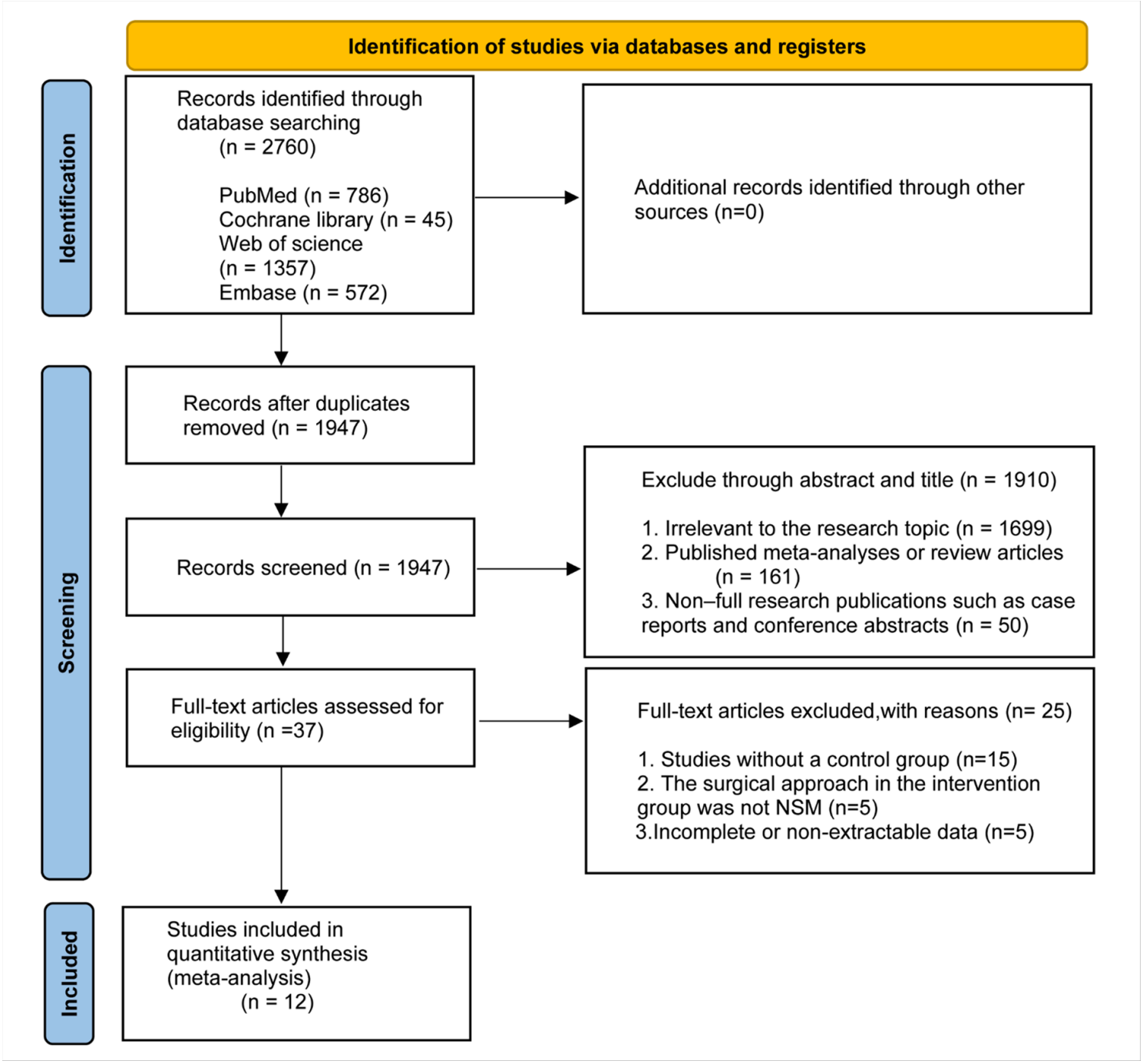


Figure 1

Flow diagram of study selection according to the PRISMA framework.

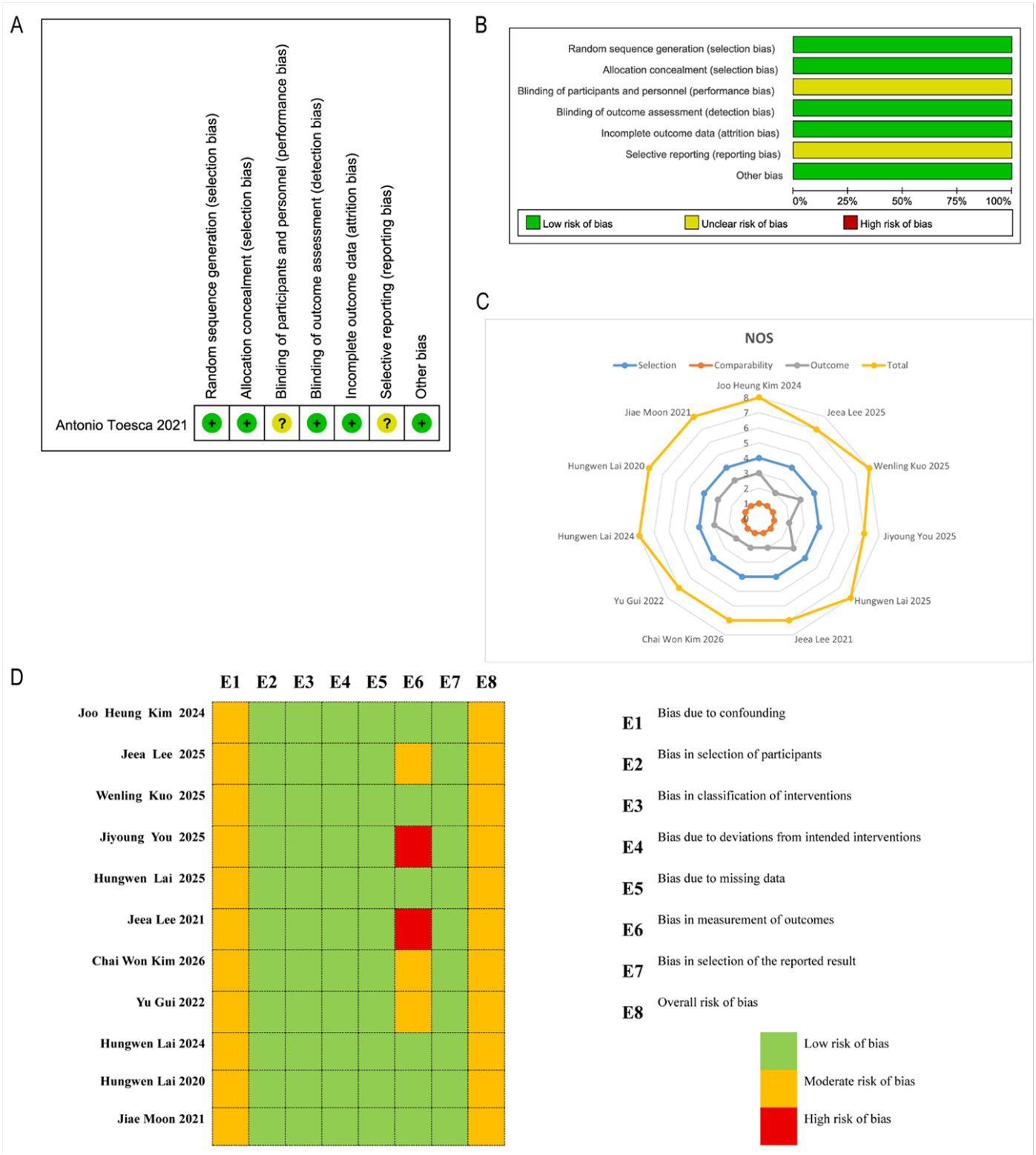


Figure 2

Quality assessment of included studies. (A) Risk of bias graph for randomized controlled trials; (B) Risk of bias summary for randomized controlled trials; (C) NOS assessment for cohort studies; (D) ROBINS-I assessment.

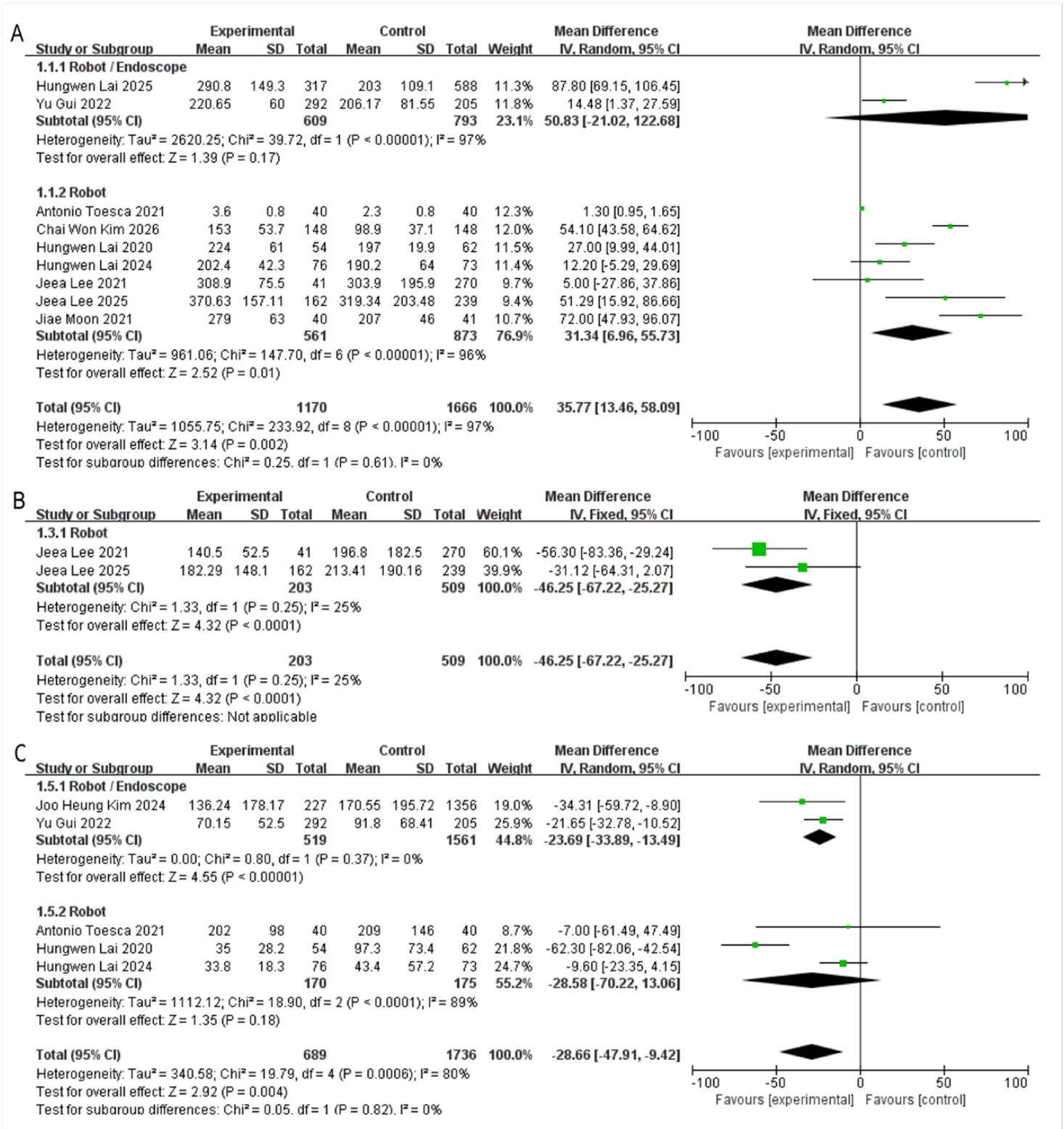


Figure 3

Forest plots of operative outcomes. (A) Total operative time; (B) Breast reconstruction time; (C) Intraoperative blood loss.

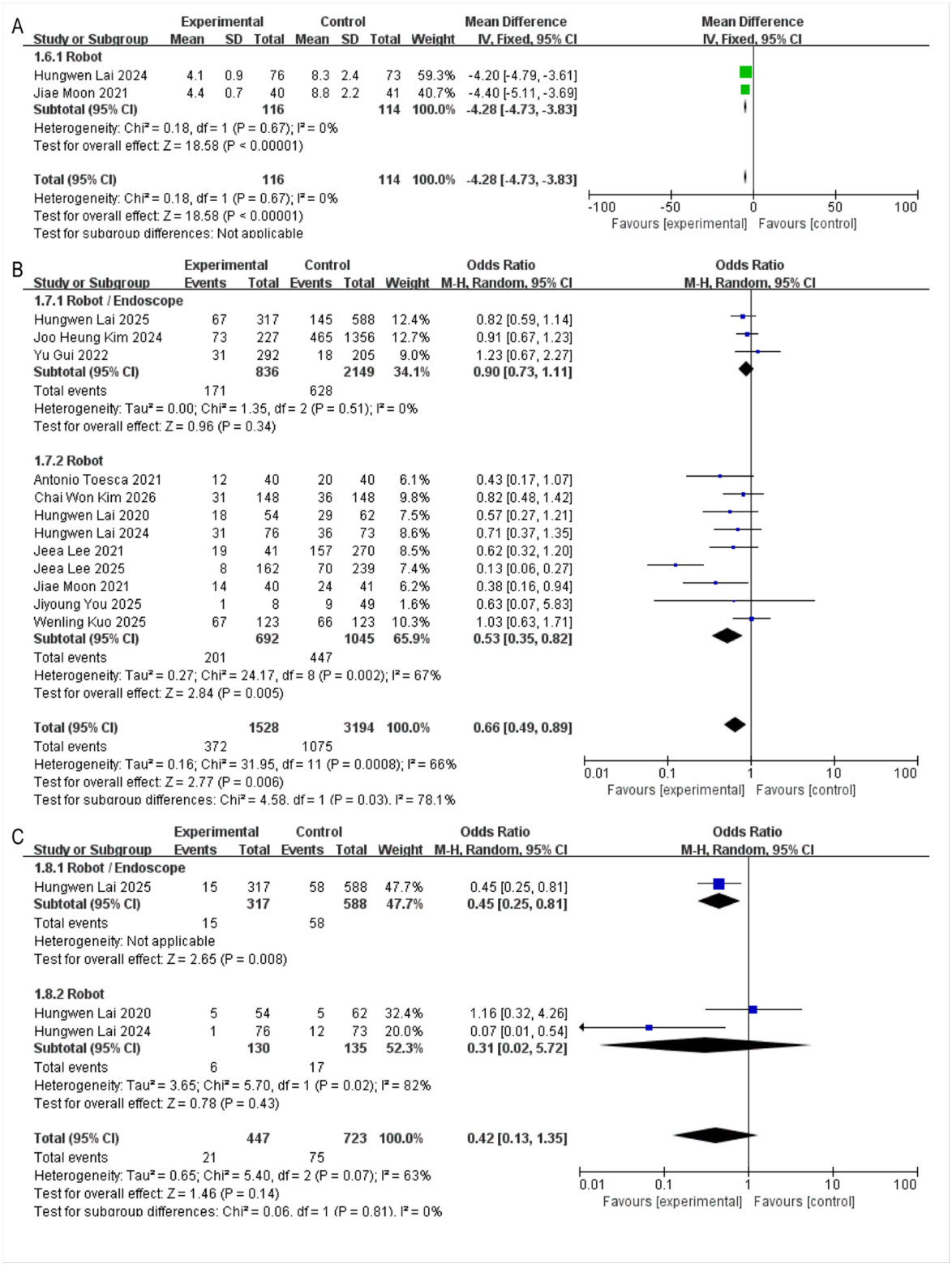


Figure 4

Forest plots of surgical and complication-related outcomes. (A) Incision length; (B) Overall complication rate; (C) Delayed wound healing.

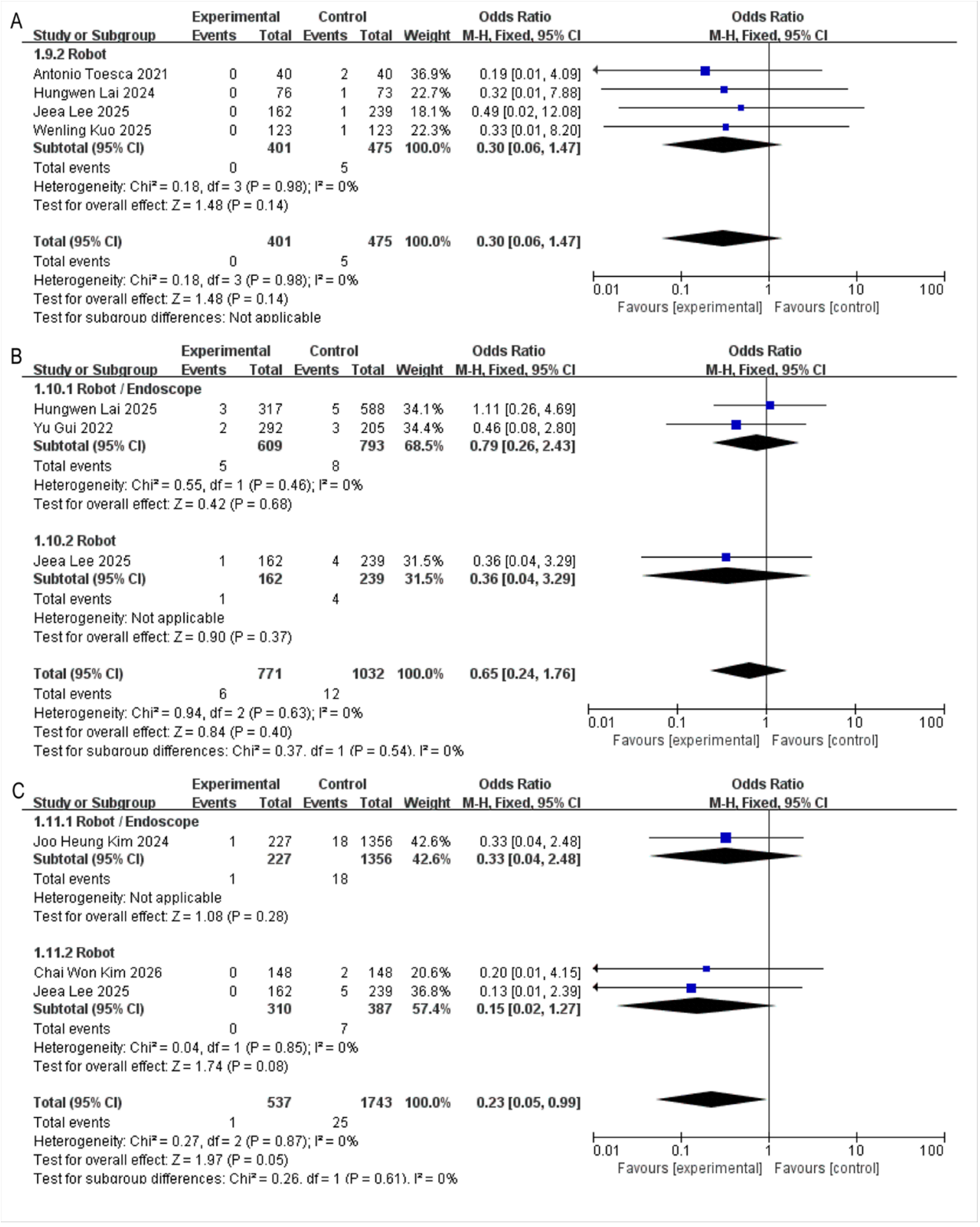


Figure 5

Forest plots of nipple–areola complex and skin-related outcomes. (A) Incidence of NAC complications; (B) Incidence of nipple necrosis; (C) Incidence of skin ischemia.

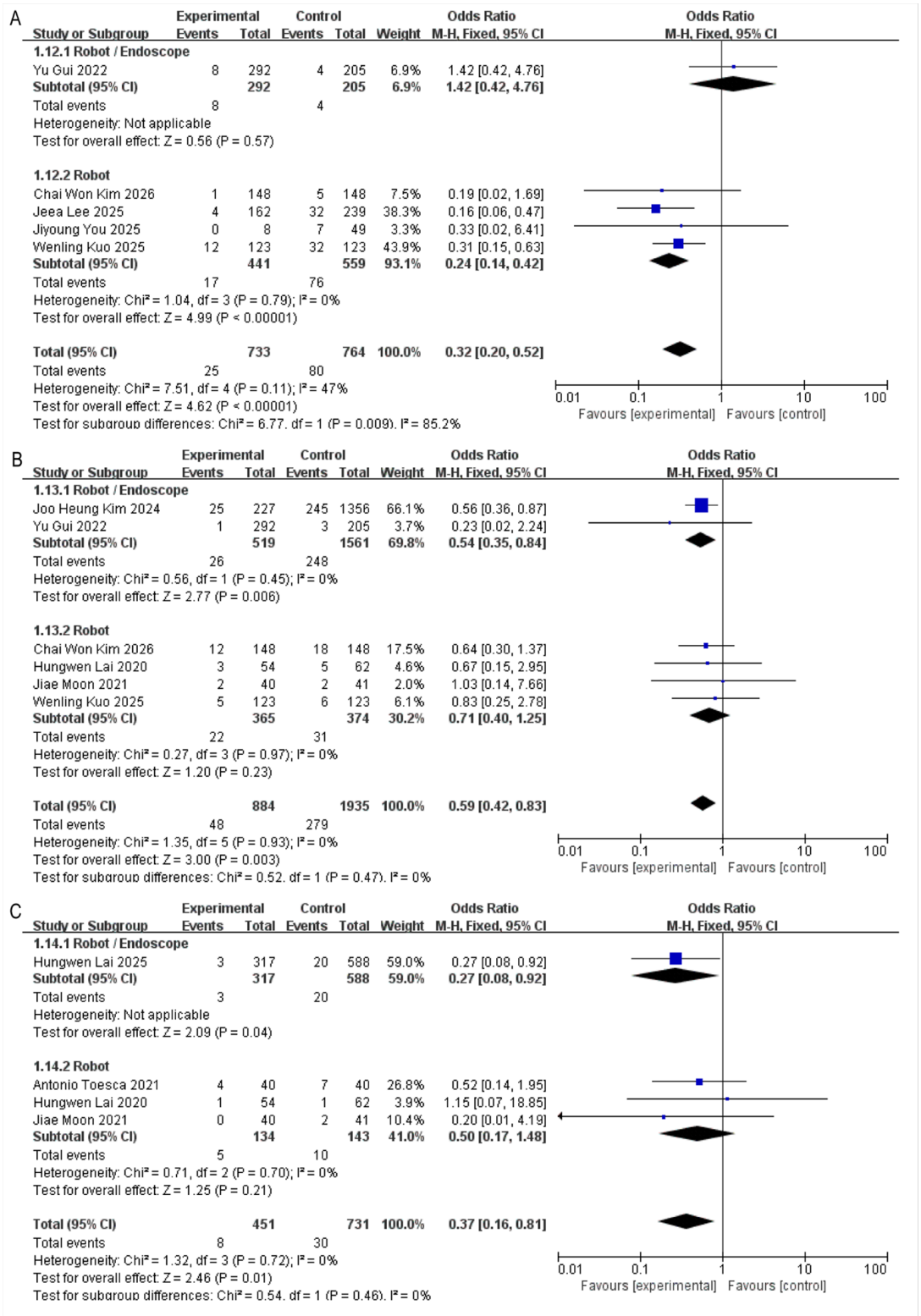


Figure 6

Forest plots of postoperative complication outcomes. (A) Skin necrosis; (B) Seroma formation; (C) Hematoma/bleeding.

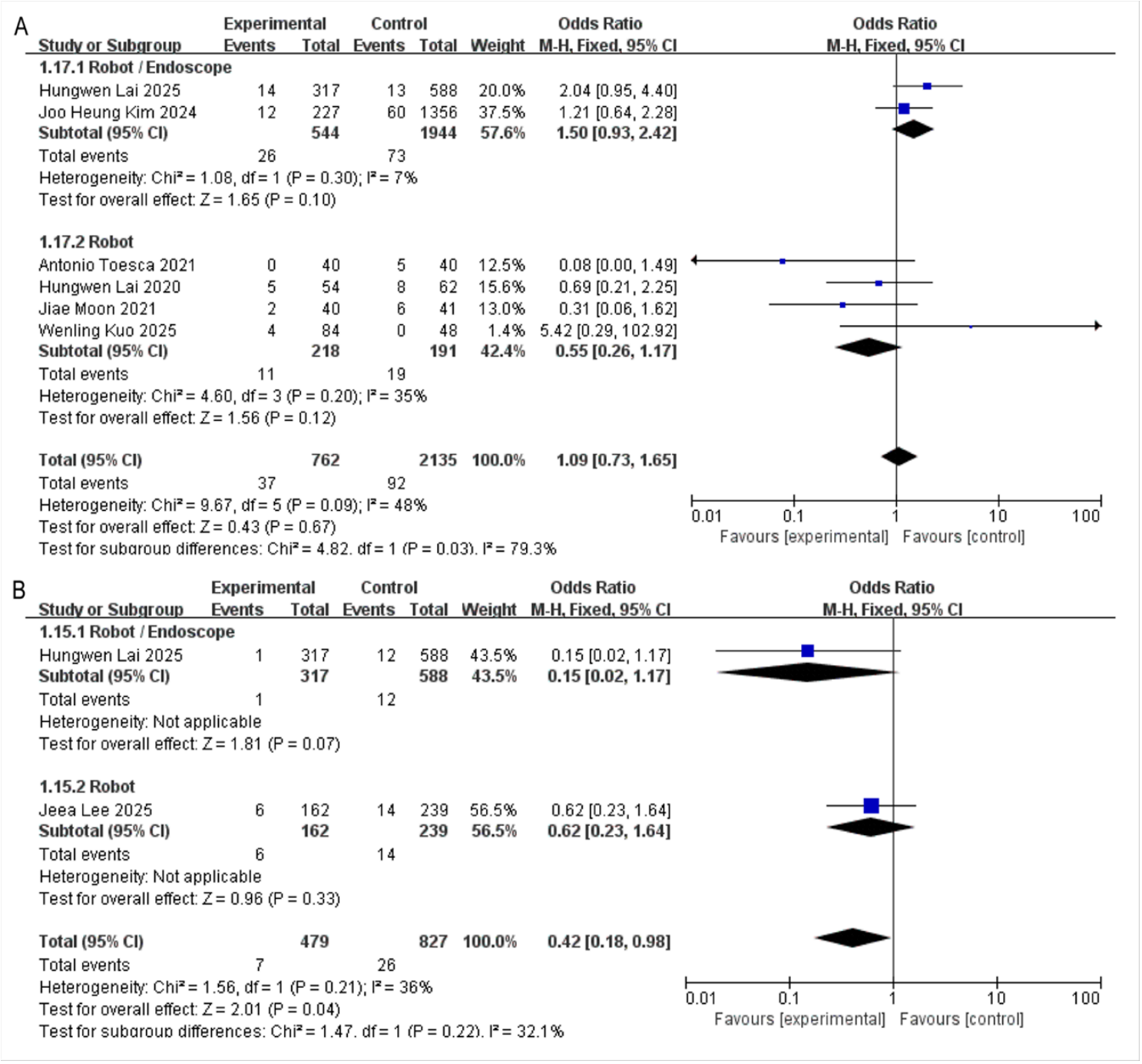


Figure 7

Forest plots of additional clinical outcomes. (A) Flap necrosis; (B) Tumor recurrence.

Supplementary Files

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