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PANCREATECTOMÍA ABIERTA FRENTE A ROBÓTICA COMO TRATAMIENTO DEL CÁNCER DE PÁNCREAS: ANÁLISIS DE LOS RESULTADOS QUIRÚRGICOS Y LA SEGURIDAD ONCOLÓGICA. REVISIÓN SISTEMÁTICA

OPEN VS ROBOTIC PANCREATECTOMY AS TREATMENT FOR PANCREATIC CANCER: ANALYSIS OF SURGICAL OUTCOMES AND ONCOLOGICAL SAFETY. SYSTEMATIC REVIEW

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Resumen

Antecedentes: El cáncer de páncreas presenta una elevada letalidad, y la resección con intención curativa sigue siendo el componente central del tratamiento en la enfermedad resecable. La cirugía robótica busca reducir el traumatismo perioperatorio sin comprometer la radicalidad oncológica. Objetivo: Comparar los resultados perioperatorios, la seguridad y los resultados oncológicos de la pancreatectomía robótica frente a la abierta en adultos con cáncer de páncreas. Métodos: Se realizó una revisión sistemática siguiendo las directrices PRISMA 2020. Se efectuaron búsquedas en PubMed/MEDLINE, Scopus, Web of Science, Embase y Cochrane Library. Se incluyeron doce artículos que aportaban comparaciones directas o evidencia complementaria sobre cirugía robótica, abierta o laparoscópica. El riesgo de sesgo se evaluó mediante RoB 2, ROBINS-I y AMSTAR 2, según correspondiera, y la certeza de la evidencia por desenlace se clasificó utilizando el sistema GRADE. Debido a la heterogeneidad, los gráficos de bosque (*forest plots*) se consideraron exploratorios. Resultados: Se identificaron 1.134 registros, se cribaron 1.042 y se incluyeron 12 artículos. En la comparación entre pancreatectomía distal robótica y abierta, la estancia hospitalaria se redujo en 3,11 días (DM -3,11; IC del 95%: -4,45 a -1,77; I^2=76%) y la pérdida hemática en 163,38 ml (DM -163,38; IC del 95%: -212,08 a -114,68; I^2=87%). No se observaron diferencias significativas en la resección R0 (OR 1,27; IC del 95%: 0,62-2,60; I^2=40%) ni en las complicaciones mayores (OR 1,27; IC del 95%: 0,88-1,81; I^2=0%). El rendimiento ganglionar, la mortalidad a los 90 días, la recidiva y la supervivencia global fueron comparables. Conclusiones: La pancreatectomía robótica reduce la estancia hospitalaria y la pérdida hemática sin aumentar las complicaciones mayores. Los resultados oncológicos disponibles son comparables a los de la cirugía abierta. La certeza de la evidencia es moderada para los resultados perioperatorios y la resección R0, y baja para la mortalidad y la supervivencia.

Palabras claves: Pancreatectomía; Cirugía robótica; Neoplasias pancreáticas; Complicaciones posoperatorias; Márgenes quirúrgicos; Supervivencia.

Abstract

Background: Pancreatic cancer has high lethality, and curative-intent resection remains the central component of treatment for resectable disease. Robotic surgery aims to reduce perioperative injury without compromising oncological radicality. Objective: To compare

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perioperative outcomes, safety, and oncological outcomes of robotic versus open pancreatectomy in adults with pancreatic cancer. Methods: A systematic review was conducted according to PRISMA 2020. PubMed/MEDLINE, Scopus, Web of Science, Embase, and the Cochrane Library were searched. Twelve articles providing direct comparisons or complementary evidence on robotic, open, or laparoscopic surgery were included. Risk of bias was assessed with RoB 2, ROBINS-I, and AMSTAR 2 as appropriate, and certainty by outcome was rated using GRADE. Because of heterogeneity, forest plots were considered exploratory. Results: A total of 1,134 records were identified, 1,042 were screened, and 12 articles were included. For robotic versus open distal pancreatectomy, hospital stay was reduced by 3.11 days (MD -3.11; 95% CI -4.45 to -1.77; I^2=76%) and blood loss by 163.38 mL (MD -163.38; 95% CI -212.08 to -114.68; I^2=87%). No significant differences were demonstrated in R0 resection (OR 1.27; 95% CI 0.62-2.60; I^2=40%) or major complications (OR 1.27; 95% CI 0.88-1.81; I^2=0%). Lymph-node yield, 90-day mortality, recurrence, and overall survival were comparable. Conclusions: Robotic pancreatectomy reduces hospital stay and blood loss without increasing major complications. Available oncological outcomes are comparable with open surgery. Certainty is moderate for perioperative outcomes and R0 resection, and low for mortality and survival.

Keywords: Pancreatectomy; Robotic surgery; Pancreatic neoplasms; Postoperative complications; Surgical margins; Survival.

1. Introduction

Pancreatic cancer remains among the neoplasms with the highest lethality due to its late diagnosis, rapid progression, and therapeutic resistance. Pancreatic ductal adenocarcinoma represents the predominant histological form, and even with multimodal treatment, survival continues to be conditioned by tumor biology and the early presence of microscopic disease. Curative-intent surgical resection remains indispensable in patients with resectable disease. [1-4]

The oncological quality of pancreatectomy is assessed through the achievement of tumor-free margins, adequate lymphadenectomy, and the absence of severe complications that delay systemic treatment. R0 resection and nodal assessment are fundamental indicators, although survival also depends on stage, response to systemic therapy, and the molecular aggressiveness of the tumor. [5-6]

Open pancreatectomy has been the conventional approach, but it involves a wide incision, complex dissection around the vascular and biliary axes, potentially high blood loss, and prolonged recovery. Robotic surgery provides three-dimensional vision, articulated instruments, tremor filtration, and greater precision in deep anatomical spaces. Comparative studies and meta-analyses have reported less bleeding and shorter hospital stay, although with longer operative time or higher cost in certain settings. [7-14]

Recent randomized trials and multicenter studies have strengthened the evaluation of minimally invasive and robotic surgery. In distal pancreatectomy and pancreaticoduodenectomy, these studies suggest that reduced perioperative invasiveness can be achieved without compromising margins, nodal yield, or early outcomes; however, the magnitude of benefit depends on patient selection, the procedure, and institutional experience. [15-19]

Long-term oncological safety remains the central issue. National cohorts and adjusted studies report comparable survival and recurrence between robotic and open surgery, but residual confounding, heterogeneity of definitions, and limited representation of lower-volume centers persist. [20-23]

PICO question: In adults with resectable pancreatic cancer (P), does robotic pancreatectomy (I), compared with open pancreatectomy (C), reduce blood loss, hospital stay, major complications, and mortality while maintaining equivalent oncological outcomes in R0 resection, nodal yield, recurrence, and survival (O)?

The general objective was to compare the surgical safety and oncological outcomes of robotic versus open pancreatectomy in adults with pancreatic cancer. The specific objectives were: 1) to characterize the designs, populations, procedures, and comparators of the included evidence; 2) to compare blood loss, hospital stay, major complications, and early mortality; 3) to compare R0 resection, nodal yield, recurrence, recurrence-free survival, and overall survival; and 4) to assess risk of bias, GRADE certainty, and the consistency of effects represented in the forest plots.

2. Methods

Design and reporting guidance

A systematic review was conducted following the PRISMA 2020 statement. [24] The PICO question and outcomes were defined before synthesis: adults with resectable pancreatic cancer; intervention, robotic pancreatectomy; main comparator, open pancreatectomy;

and perioperative and oncological outcomes.

Information sources and search strategy

A structured search was performed in PubMed/MEDLINE, Scopus, Web of Science, Embase, and the Cochrane Library, with no start-date restriction. MeSH terms and keywords related to pancreatic cancer, pancreatic ductal adenocarcinoma, robotic pancreatectomy, robot-assisted surgery, open pancreatectomy, pancreaticoduodenectomy, distal pancreatectomy, surgical outcomes, oncologic outcomes, postoperative complications, margin status, recurrence, and survival were combined. The strategy proposed for PubMed/MEDLINE is presented in Annex 1.

Eligibility criteria

Studies in adults undergoing pancreatic resection for cancer that compared robotic surgery with open surgery, or that provided complementary evidence on technical and oncological safety, were included. Direct robotic-open comparisons were prioritized. Robotic-laparoscopic studies were considered indirect evidence and did not replace the main comparator. Case reports, letters, editorials, comparator-free series, and publications without relevant outcomes were excluded. Systematic reviews or meta-analyses were identified as secondary sources and were used only for context or for the exploratory forest plots based on aggregate data.

Selection, extraction, and variables

Two reviewers independently assessed titles, abstracts, and full texts; discrepancies were resolved by consensus. Author, year, country, design, sample size, available clinical characteristics, type of pancreatectomy, comparator, blood loss, operative time, conversion, length of stay, major complications, mortality, R0, nodes examined, recurrence, and survival were extracted. When sociodemographic variables were not uniformly reported or were unavailable by group, they were described qualitatively and no pooled estimates were generated.

Risk of bias and certainty of evidence

The randomized trial was assessed with RoB 2 and the non-randomized studies with ROBINS-I. [25-26] The secondary reviews used for context were assessed with AMSTAR 2. [28] The certainty of evidence was rated by outcome using GRADE, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias. [27]

Synthesis and forest-plot analysis

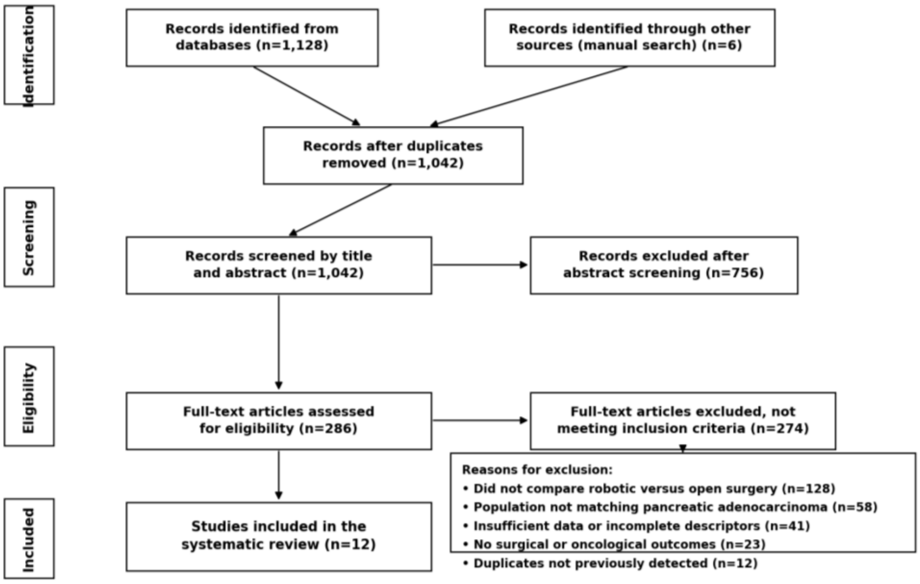
The main synthesis was narrative because of the heterogeneity of procedures, comparators, and definitions. Exploratory forest plots were presented for hospital stay, blood loss, R0 resection, and major complications, based on comparable aggregate data for robotic versus open distal pancreatectomy. The pooled estimate, its 95% confidence interval, statistical significance, and I^2 heterogeneity were interpreted; high I^2 values were considered indicative of substantial inconsistency. [12,29] A global meta-analysis of the 12 articles was not performed.

3. Results and discussion

Study selection

A total of 1,128 records were identified in databases and 6 through manual searching. After removing duplicates, 1,042 records were screened by title and abstract; 756 were excluded and 286 full texts were assessed. Of these, 274 texts were excluded for non-relevant comparator, non-matching population, insufficient data, absence of relevant outcomes, or duplication. Finally, 12 articles were included. The process is presented in Figure 1 and was reported in accordance with PRISMA 2020. [24]

Figure 1. *PRISMA flow diagram for the systematic review. Source: created by the authors*



Characteristics of the evidence and of the included populations

The 12 articles included adults undergoing distal pancreatectomy, pancreaticoduodenectomy, or total pancreatectomy. Retrospective cohorts and propensity-score-matched analyses predominated; randomized evidence, national databases, and supporting secondary sources were also included. Direct robotic-open comparisons supported the main conclusions, while robotic-laparoscopic studies were used as indirect evidence. Age, sex, comorbidity, and neoadjuvant treatment were not reported uniformly, so it was not methodologically valid to generate a pooled sociodemographic synthesis. [7-23,30-44]

Table 1. *Main characteristics of the 12 included articles*

No.	Study	Design/comparison	Population	Main results	Applicability
1	Korrel et al., 2023[16]	Multicenter non-inferiority RCT; MIDP vs ODP.	258 adults with resectable pancreatic cancer of the body/tail.	R0 73% vs 69%; nodes 22 vs 23; severe adverse events 18% vs 22%; no differences in recurrence or overall survival.	Partially direct: MIDP includes laparoscopy and robotic surgery.
2	Bencini et al., 2024[8]	Retrospective cohort with PSM; RDP vs ODP.	79 patients; 50 after matching (25/25).	Longer operative time with RDP, but less bleeding and faster recovery; grade III-IV complications 11% in both groups; equivalent survival.	Direct.
3	Wang et al., 2025[12]	Systematic review/meta-analysis of PSM studies; RDP vs ODP.	7 studies; 1,526 patients (RDP 722; ODP 804).	Shorter stay (MD -3.11 days), less blood loss (MD -163 mL), greater splenic preservation, and lower surgical site infection; no differences in R0, nodes, or 90-day mortality.	Direct for pooled quantitative synthesis.
4	Takagi et al., 2026[30]	Retrospective PSM cohort; RPD vs OPD.	236 patients after PSM (118/118) at a high-volume center.	Less bleeding and shorter stay with RPD; comparable nodal yield, R0 margins, recurrence-free survival, and overall survival.	Direct for pancreaticoduodenectomy.
5	Huang et al., 2024[34]	NIS database; robotic vs laparoscopic distal.	886 patients with pancreatic cancer; 239 robotic and 647 laparoscopic.	Fewer perioperative complications, VTE, and transfusions; slightly shorter stay; higher hospital cost; did not report margins, nodes, recurrence, or survival.	Indirect: does not compare with open surgery.
6	Chen P. et al., 2022[35]	Retrospective cohort; RDP vs LDP.	102 patients (48/54), benign and low-grade malignant lesions.	Less blood loss and greater splenic preservation with RDP; similar complications; no complete oncological outcomes.	Indirect: laparoscopic comparator and mixed population.
7	Chen J.W. et al., 2023[36]	International retrospective cohort; RDP vs LDP.	1,016 patients (274/742) with resectable pancreatic cancer.	Less bleeding, greater splenic preservation, and lower conversion with RDP; higher R0 and nodal yield; comparable safety.	Indirect for the main PICO.
8	McKean et al., 2025[31]	National Cancer Database; RTP vs OTP.	3,635 patients (188/3,447) with adenocarcinoma undergoing total pancreatectomy.	Shorter stay with RTP; comparable 90-day mortality, nodal yield, positive margin rate, and overall survival.	Direct for total pancreatectomy.

No.	Study	Design/comparison	Population	Main results	Applicability
9	Di Franco et al., 2022[37]	Matched retrospective cohort; RDP vs LDP.	60 patients (30/30), benign and low-grade malignant lesions.	Less bleeding and greater splenic preservation with RDP; longer operative time and higher costs; similar complications.	Indirect.
10	Lof et al., 2021[38]	Multicenter cohort; RDP vs LDP.	755 patients (221/534), benign, premalignant, and malignant lesions.	Lower conversion, greater splenic preservation, and less bleeding with RDP; in the oncological subgroup, comparable R0 and nodal yield.	Indirect.
11	Jiang et al., 2022[39]	Retrospective cohort; RDP vs LDP.	142 patients (62/80), single center.	Greater splenic preservation, less bleeding, and lower conversion with RDP; similar R0 margins and nodal yield in the malignant subgroup.	Indirect.
12	Souche et al., 2019[40]	Prospective comparative and cost-effectiveness study; RDP vs LDP.	62 patients (31/31).	Less bleeding, greater splenic preservation, and lower conversion with RDP; similar safety; higher cost.	Indirect.

Risk of bias and certainty of evidence

The randomized trial showed low risk of bias or some concerns depending on the domain, whereas the observational studies showed moderate-to-serious risk from selection, residual confounding, and incomplete measurement. GRADE certainty was moderate for hospital stay, blood loss, R0 resection, and major complications; low for 90-day mortality; and low to moderate for overall survival. [25-29]

Table 2. *Risk-of-bias assessment of the included articles*

Study	Tool	Overall judgment	Main justification
Korrel 2023	RoB 2	Some concerns	Randomized, multicenter trial, but the MIDP group combines laparoscopy and robotic surgery, introducing indirectness for a strictly robotic-versus-open comparison.
Bencini 2024	ROBINS-I	Moderate	Retrospective design and small sample; PSM reduces, but does not eliminate, residual confounding.
Wang 2025[12]	AMSTAR/GRADE for synthesis	Moderate	Meta-analysis of PSM studies with substantial heterogeneity in continuous outcomes; useful as an aggregate source, not as a primary study.
Takagi 2026[30]	ROBINS-I	Moderate	PSM and high-volume center; possible residual confounding and extrapolation by procedure type.
McKean 2025[31]	ROBINS-I	Moderate	National database with statistical adjustment; limited by surgical variables and incomplete clinical detail.
Huang 2024	ROBINS-I	Serious	Administrative database, laparoscopic comparator, and absence of complete oncological outcomes.
Chen P. 2022	ROBINS-I	Serious	Single center, retrospective, indirect comparator, and mixed population.
Chen J.W. 2023	ROBINS-I	Moderate	Multicenter and large, but laparoscopic comparator; indirectness for the main PICO.
Di Franco 2022	ROBINS-I	Serious	Small sample, indirect comparator, and cost focus; limited oncological outcomes.
Lof 2021	ROBINS-I	Moderate	Multicenter; laparoscopic comparator; possible selection by center experience.
Jiang 2022	ROBINS-I	Serious	Single center, retrospective, and mixed cohort; imprecision due to sample size.
Souche 2019	ROBINS-I	Moderate	Prospective, but small sample and laparoscopic comparator; cost results not generalizable.

GRADE rating by included study

Table 3 presents the methodological traceability by study. The final rating was performed by outcome, in accordance with GRADE. [27]

Table 3. *GRADE rating of the 12 included articles*

Study	Design/data source	Applicability	Risk of bias	Other GRADE domains	Certainty	Justification
Korrel et al., 2023	Multicenter RCT	Partially direct	Not serious	Mild indirectness due to MIDP; no significant imprecision.	High to moderate	High for MIDP vs open; moderate when interpreted strictly as robotic versus open.
Bencini et al., 2024	PSM cohort	Direct	Serious	Imprecision due to small sample; inconsistency not serious.	Low	Direct observational evidence, useful for safety, but limited by sample size.
Wang 2025[12]	PSM meta-analysis	Direct	Serious	Serious heterogeneity in continuous variables; no significant indirectness.	Moderate	Consistent effects for bleeding and length of stay, although with high heterogeneity.
Takagi 2026[30]	PSM cohort	Direct	Serious	Mild indirectness by procedure; imprecision not serious.	Low to moderate	High-volume center and PSM strengthen the evidence, but residual confounding persists.
McKean 2025[31]	Adjusted national database	Direct	Serious	Mild indirectness due to total pancreatectomy; no relevant imprecision from sample size.	Low to moderate	Large size and oncological outcomes, but limited by administrative database.
Huang et al., 2024	NIS database	Indirect	Serious	Serious indirectness: does not compare with open surgery; oncological outcomes absent.	Low	Provides indirect perioperative safety data, not oncological radicality.
Chen P. et al., 2022	Retrospective	Indirect	Serious	Serious indirectness and imprecision; mixed population.	Very low to low	Laparoscopic comparator and incomplete oncological results.
Chen J.W. et al., 2023	Multicenter cohort	Indirect	Serious	Serious indirectness due to laparoscopic comparator; imprecision not serious.	Low	Useful for technical quality and resection, not for direct comparison with open surgery.
Di Franco et al., 2022	Matched retrospective	Indirect	Serious	Serious indirectness and imprecision; limited oncological outcomes.	Very low to low	Small sample and economic focus; indirect comparator.
Lof et al., 2021	Multicenter cohort	Indirect	Serious	Serious indirectness; imprecision not serious.	Low	Provides complementary technical evidence versus laparoscopy.
Jiang et al., 2022	Retrospective	Indirect	Serious	Serious indirectness and imprecision; single center.	Very low to low	Mixed cohort and limited size.
Souche et al., 2019	Comparative prospective	Indirect	Serious	Serious indirectness and imprecision; contextual economic results.	Low	Prospective, but small and with a laparoscopic comparator.

Summary of findings by outcome

Table 4 summarizes the direction of effect, heterogeneity, and GRADE certainty for the priority outcomes.

Table 4. *Summary of findings and GRADE certainty by main outcome*

Outcome	Available evidence	Summary effect	Heterogeneity	GRADE certainty	Interpretation
Hospital stay	7 PSM studies; 1,526 patients.	MD -3.11 days (95% CI -4.45 to -1.77); favors robotic surgery.	I^2=76% (high).	Moderate	Significant difference; variable magnitude across studies.
Blood loss	6 PSM studies; approximately 1,476 patients.	MD -163.38 mL (95% CI -212.08 to -114.68); favors robotic surgery.	I^2=87% (high).	Moderate	Significant difference; substantial heterogeneity.
R0 resection	5 studies, RDP vs ODP.	OR 1.27 (95% CI 0.62-2.60).	I^2=40% (moderate).	Moderate	No significant difference; comparable radicality.
Major complications	7 PSM studies, RDP vs ODP.	OR 1.27 (95% CI 0.88-1.81).	I^2=0% (none).	Moderate	No significant difference.
90-day mortality	Direct studies and adjusted databases.	No significant differences.	Not uniformly poolable.	Low	Infrequent events and imprecise intervals.

Outcome	Available evidence	Summary effect	Heterogeneity	GRADE certainty	Interpretation
Overall survival	Trial, cohorts, and adjusted registries.	HR around 1; no consistent difference.	Heterogeneous follow-up.	Low to moderate	Comparable results, with residual uncertainty.

Perioperative outcomes

Direct evidence favored robotic surgery for blood loss and hospital stay. In the pooled analysis of distal pancreatectomy, the mean difference was -163.38 mL for bleeding and -3.11 days for length of stay. No statistically significant increase in major complications, reintervention, or 90-day mortality was observed. In comparisons with laparoscopy, robotic surgery showed lower conversion and greater splenic preservation, but these findings were considered complementary. [8-19,30-44]

Oncological outcomes

R0 margins and nodal yield were comparable between robotic and open surgery. Adjusted cohorts and national registries showed no consistent differences in recurrence, recurrence-free survival, or overall survival. Interpretation was more uncertain when follow-up was short, data came from administrative databases, or the comparison was indirect. [16,20-23,30-33,45-46]

Clinical applicability was concentrated in centers with robotic experience and standardized protocols. Results from indirect comparisons were used to describe technical performance, not to establish primary equivalence.

Interpretation of the forest plots

The forest plots represent only outcomes with comparable aggregate data for robotic versus open distal pancreatectomy. The diamond summarizes the pooled effect; a mean difference whose interval does not cross 0 indicates a statistically significant difference, whereas an odds ratio whose interval does not cross 1 indicates a significant difference. I^2 heterogeneity quantifies the variation between studies not attributable to chance. [12,29]

Figure 2. *Exploratory forest plot of hospital stay: robotic versus open distal pancreatectomy. Source: created by the authors from the pooled data of Wang et al.* [12]

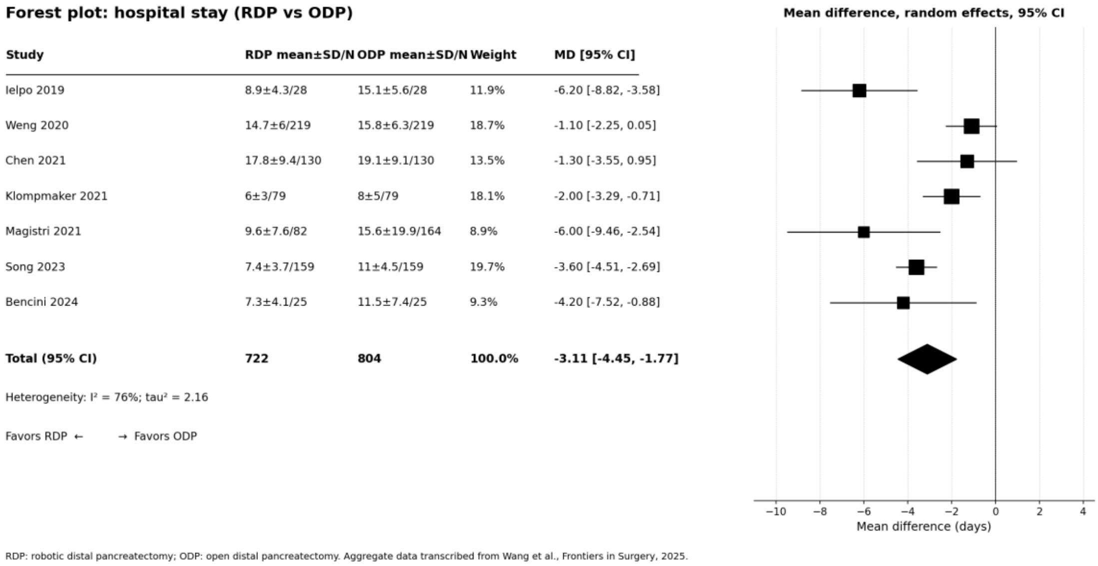


Figure 2 showed a shorter stay with robotic surgery: MD -3.11 days (95% CI -4.45 to -1.77). The interval did not cross 0, so the effect was statistically significant and favored robotic distal pancreatectomy. Heterogeneity was high (I^2=76%), which requires considering differences in discharge protocols, centers, and patient selection. [12]

Figure 3. *Exploratory forest plot of intraoperative blood loss: robotic versus open distal pancreatectomy. Source: created by the authors from the pooled data of Wang et al.* [12]

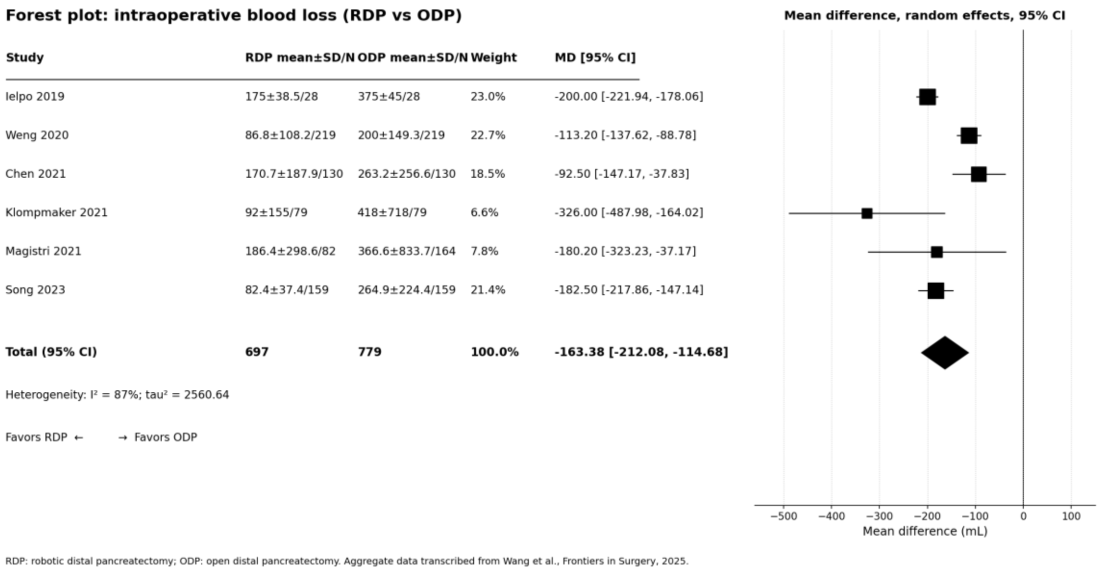


Figure 3 showed less blood loss with robotic surgery: MD -163.38 mL (95% CI -212.08 to -114.68). The interval did not cross 0, and the effect significantly favored robotic surgery. Heterogeneity was high (I^2=87%), so the exact magnitude of the benefit may vary across institutions. [12]

Figure 4. *Exploratory forest plot of R0 resection: robotic versus open distal pancreatectomy. Source: created by the authors from the pooled data of Wang et al.* [12]

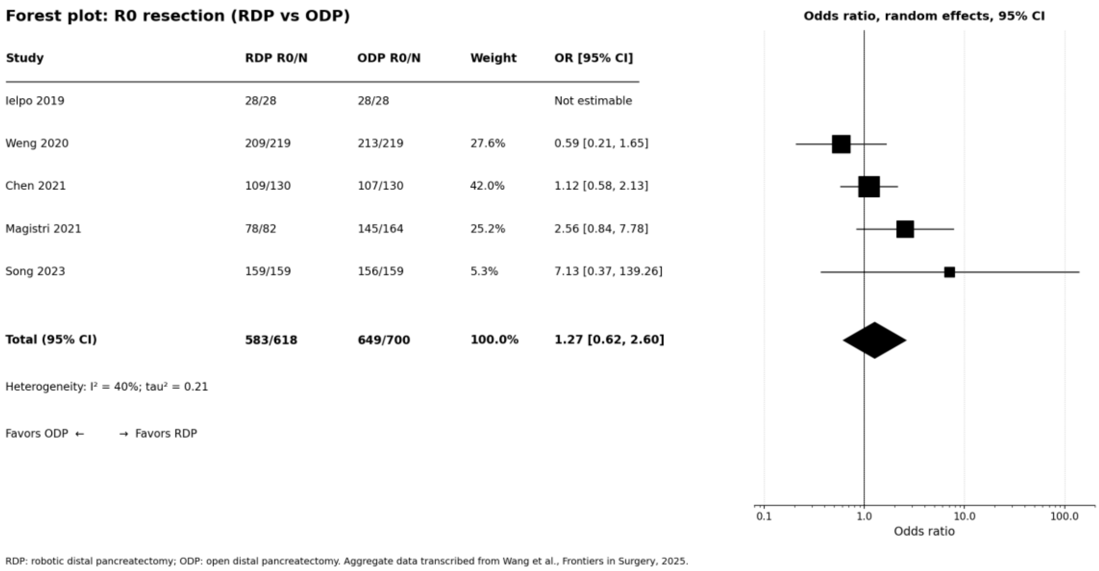


Figure 4 showed an OR of 1.27 for R0 resection (95% CI 0.62-2.60; I^2=40%). Because the interval crossed 1, there was no statistically significant difference; the result indicates comparable oncological radicality and does not demonstrate superiority of either approach. [12]

Figure 5. *Exploratory forest plot of major complications: robotic versus open distal pancreatectomy. Source: created by the authors from the pooled data of Wang et al.* [12]

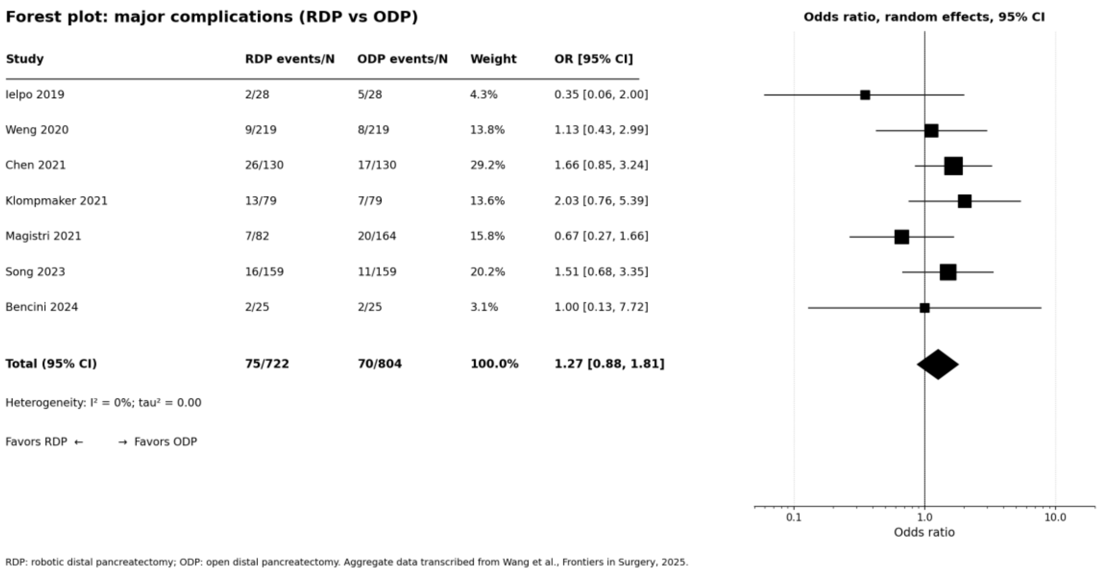


Figure 5 showed an OR of 1.27 for major complications (95% CI 0.88-1.81; I^2=0%). The interval crossed 1, so no significant difference was demonstrated. The null heterogeneity indicates consistency among the included studies for this outcome. [12]

Discussion

Correspondence between the evidence and the populations studied

This review identified clinically relevant but heterogeneous evidence. The studies encompassed distal pancreatectomy, pancreaticoduodenectomy, and total pancreatectomy, with randomized designs, adjusted cohorts, national registries, and indirect comparisons with laparoscopy. This diversity broadens applicability but precludes assuming that an effect observed in a distal resection is identical in a pancreaticoduodenectomy. Recent meta-analyses agree that robotic surgery can achieve favorable perioperative outcomes and comparable oncological radicality, although certainty decreases when different procedures and designs are combined. [45-47]

Perioperative outcomes and physiological explanation

The 163.38 mL reduction in blood loss is consistent with the enhanced three-dimensional vision, instrument articulation, and precise dissection around the splenic, mesenteric, and portal vessels. From a surgical-anatomy standpoint, these advantages facilitate the identification of avascular planes and control of small branches. From a physiological standpoint, less bleeding reduces the need for fluid replacement, hemodilution, and exposure to transfusion; the latter can produce immunomodulation and transiently alter the inflammatory and cellular response. [12,64]

The 3.11-day reduction in hospital stay may be related to less abdominal wall injury and less tissue manipulation. The response to surgical trauma activates the hypothalamic-pituitary-adrenal axis, catecholamines, cortisol, insulin resistance, and inflammatory mediators. Lower injury, combined with multimodal analgesia and early mobilization and feeding, favors functional recovery. However, the I^2=76% heterogeneity indicates that recovery protocols, discharge criteria, and institutional organization also influenced the effect. [61-63]

The absence of a significant difference in major complications does not contradict the technical benefits. Pancreatic fistula depends largely on gland texture, duct diameter, perfusion, exocrine secretion, and closure or anastomotic technique; delayed gastric emptying and post-pancreatectomy hemorrhage have their own mechanisms. Therefore, the robotic platform can reduce bleeding and trauma without eliminating complications determined by pancreatic biology. The ISGPS and Clavien-Dindo definitions are essential for valid comparisons. [57-60]

Oncological outcomes and relationship with tumor biology

The plots and direct studies showed no deterioration in R0 resection, nodal yield, or survival. The OR for R0 was 1.27, but the 0.62-2.60 interval crossed unity; therefore, it demonstrates neither superiority nor inferiority. This equivalence is plausible when dissection respects the same anatomical planes, the recommended lymphadenectomy, and the principles of tumor handling. [5-6,20-23]

The similarity in recurrence and survival also reflects that the surgical approach is only one of the determinants of prognosis. Pancreatic ductal adenocarcinoma frequently shows alterations in KRAS, TP53, CDKN2A, and SMAD4, molecular heterogeneity, desmoplastic stroma, and perineural invasion; furthermore, cellular dissemination may begin before the lesion is clinically evident. These features explain why a technically less invasive surgery does not necessarily modify the natural history of the tumor on its own, and why systemic treatment remains decisive. [2-4,65-67]

Risk of bias, certainty, and applicability

The moderate certainty for length of stay, bleeding, R0, and complications is supported by the directional consistency of several studies, but is reduced by heterogeneity and the predominance of observational designs. Ninety-day mortality and survival retained low or low-to-moderate certainty due to infrequent events, uneven follow-up, and residual confounding. The forest plots should be interpreted as exploratory estimates for the comparable subset, not as a definitive synthesis of all procedures.

Generalization requires considering institutional volume and the learning curve. Structured training programs shorten the initial phase, but published results frequently come from expert centers. In addition, acquisition, maintenance, and operating-room-time costs can exceed the savings derived from shorter stay or fewer complications; efficiency depends on volume, platform utilization, and the health care system. [48-56]

Taken together, the evidence supports robotic pancreatectomy as an alternative in centers with appropriate patient selection, a trained team, and the capacity to uphold oncological principles. It does not justify indiscriminately replacing open surgery, especially in scenarios of complex vascular invasion, lack of experience, or limited resources.

Limitations

The review was limited by the predominance of observational studies, the inclusion of different pancreatic procedures, the presence of laparoscopic comparators, non-uniform definitions, and incomplete availability of sociodemographic variables by group. The forest plots were derived from aggregate data for a comparable subset and do not represent an independent meta-analysis of the 12 articles. The high heterogeneity in length of stay and bleeding, the possible selection of patients at expert centers, and uneven follow-up reduce generalizability. Individual-level data were not available to adjust for age, frailty, neoadjuvant treatment, stage, pancreatic texture, or institutional volume.

4. Conclusions

1. The included evidence was heterogeneous and consisted mainly of observational studies, with representation of distal pancreatectomy, pancreaticoduodenectomy, and total pancreatectomy.

2. Robotic pancreatectomy reduced hospital stay and intraoperative blood loss compared with open surgery.

3. Robotic pancreatectomy did not increase major complications or early mortality, and showed comparable results in R0 resection, nodal yield, recurrence, and survival.

4. The certainty of evidence was moderate for hospital stay, blood loss, R0 resection, and major complications, and low or low-to-moderate for mortality and survival.

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ANNEXES

Annex 1. Proposed PubMed/MEDLINE search strategy

The following strategy is proposed to reproduce the search in PubMed/MEDLINE. It may be adapted according to the final closing date of the review and the journal's editorial requirements. Applying language filters in the initial search is not recommended, in order to reduce selection bias; any subsequent restriction should be documented at the eligibility stage.

Database: PubMed/MEDLINE.

Main fields: MeSH terms and title/abstract (tiab).

Search concepts: pancreatic cancer or pancreatic ductal adenocarcinoma; pancreatectomy; robotic or robot-assisted surgery; open surgery; surgical and oncological outcomes.

Proposed search string:

```
(("Pancreatic Neoplasms"[Mesh] OR "pancreatic cancer"[tiab] OR "pancreatic ductal
adenocarcinoma"[tiab] OR PDAC[tiab])
AND
("Pancreatectomy"[Mesh] OR pancreatectomy[tiab] OR pancreaticoduodenectomy[tiab] OR
Whipple[tiab] OR "distal pancreatectomy"[tiab] OR "total pancreatectomy"[tiab])
AND
("Robotic Surgical Procedures"[Mesh] OR robotic[tiab] OR "robot-assisted"[tiab] OR "robot
assisted"[tiab] OR "da Vinci"[tiab])
AND
(open[tiab] OR laparotomy[tiab] OR conventional[tiab])
AND
("surgical outcomes"[tiab] OR "oncologic outcomes"[tiab] OR "postoperative complications"[tiab] OR
morbidity[tiab] OR mortality[tiab] OR survival[tiab] OR "R0"[tiab] OR margin*[tiab] OR "lymph
node"[tiab] OR "lymph nodes"[tiab]))
```

Suggested filters: Humans and Adult: 19+ years, when the platform allows it. Do not apply a language filter in the initial search.

Items to be recorded in the search log: exact execution date, number of results obtained, filters applied, databases searched, reference manager used, and number of duplicates removed.

Annex 2. Minimum data-extraction matrix

The following minimum matrix is proposed to standardize extraction by independent reviewers and to ensure that all included studies are assessed with homogeneous criteria. Discrepancies should be resolved by consensus or by a third reviewer.

Minimum field	Data to be extracted	Suggested format
Study identification	Record ID, first author, year of publication, and DOI.	Free text / alphanumeric code.
Country and setting	Country, number of centers, type of institution, and surgical volume when available.	Free text.
Study design	Clinical trial, prospective or retrospective cohort, PSM, administrative database, comparative prospective study, or other design.	Predefined category.
Data source	Medical record, national database, multicenter registry, clinical trial, or institutional repository.	Free text.
Population	Adult patients with pancreatic cancer or pancreatic ductal adenocarcinoma; diagnostic criteria and clinical stage.	Total number and clinical description.
Sample size	Total number of participants and number per surgical group.	Total n; intervention n; comparator n.
Intervention	Robotic or robot-assisted pancreatectomy; platform used, if reported.	Free text.
Comparator	Open, laparoscopic, or minimally invasive pancreatectomy, according to the study.	Category and description.
Type of resection	Distal pancreatectomy, pancreaticoduodenectomy, total pancreatectomy, or another procedure.	Predefined category.
Baseline characteristics	Age, sex, BMI, comorbidities, ASA score, tumor stage, neoadjuvant therapy, and between-group balance variables.	Mean/median, proportions, or text.
Surgical outcomes	Operative time, blood loss, transfusion, conversion, pancreatic fistula, major complications, reintervention, mortality, and hospital stay.	Continuous or dichotomous measures.
Oncological outcomes	R0 resection, positive margin, nodal yield, recurrence, overall survival, and disease-free survival.	OR, HR, mean difference, proportions, or text.
Follow-up	Follow-up duration, loss to follow-up, and timing of recurrence or survival assessment.	Months; percentage; text.
Effect measures	Measure reported by the study and its confidence interval or p-value.	OR, RR, HR, MD, 95% CI, and p.
Statistical adjustment	Propensity score matching, multivariable models, weighting, stratification, or other confounding-control methods.	Yes/no and description.
Risk of bias	Tool applied: RoB 2 for randomized trials and ROBINS-I for non-randomized studies.	Low, some concerns, moderate, serious, or critical.
GRADE certainty	Rating considering risk of bias, inconsistency, indirectness, imprecision, and publication bias.	High, moderate, low, or very low.
Applicability to the PICO question	Degree of relationship with the main robotic-versus-open comparison and with the target population.	Direct, partially direct, or indirect.
Study limitations	Main methodological, clinical, or statistical limitations identified by the reviewers.	Brief text.
Notes for synthesis	Missing data, assumptions made, need to contact authors, and notes for tables or figures.	Brief text.