



Mapping global new-onset, worsening, and resolution of diabetes following partial pancreatectomy: a systematic review and meta-analysis

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Background and aims: Partial pancreatectomy, commonly used for chronic pancreatitis, or pancreatic lesions, has diverse impacts on endocrine and metabolism system. The study aims to determine the global prevalence of new-onset, worsening, and resolution of diabetes following partial pancreatectomy.

Methods: The authors searched PubMed, Embase, Web of Science, and Cochrane Library from inception to October, 2023. DerSimonian-Laird random-effects model with Logit transformation was used. Sensitivity analysis, meta-regression, and subgroup analysis were employed to investigate determinants of the prevalence of new-onset diabetes.

Results: A total of 82 studies involving 13 257 patients were included. The overall prevalence of new-onset diabetes after partial pancreatectomy was 17.1%. Univariate meta-regression indicated that study size was the cause of heterogeneity. Multivariable analysis suggested that income of country or area had the highest predictor importance (49.7%). For subgroup analysis, the prevalence of new-onset diabetes varied from 7.6% (France, 95% CI: 4.3–13.0) to 38.0% (UK, 95% CI: 28.2–48.8, $P < 0.01$) across different countries. Patients with surgical indications for chronic pancreatitis exhibited a higher prevalence (30.7%, 95% CI: 21.8–41.3) than those with pancreatic lesions (16.4%, 95% CI: 14.3–18.7, $P < 0.01$). The type of surgical procedure also influenced the prevalence, with distal pancreatectomy having the highest prevalence (23.7%, 95% CI: 22.2–25.3, $P < 0.01$). Moreover, the prevalence of worsening and resolution of preoperative diabetes was 41.1 and 25.8%, respectively.

Conclusions: Postoperative diabetes has a relatively high prevalence in patients undergoing partial pancreatectomy, which calls for attention and dedicated action from primary care physicians, specialists, and health policy makers alike.

Keywords: diabetes, epidemiology, pancreatectomy, risk factors

Introduction

Pancreatoduodenectomy (PD) and distal pancreatectomy (DP) are well-established treatment procedures used worldwide for chronic pancreatitis, benign or (potentially) malignant pancreatic lesions^[1–3]. However, the implementation of PD and DP is associated with the loss of upper gastrointestinal and pancreato-biliary

parenchyma, leading to impaired upper gastrointestinal functions^[4,5]. To mitigate the substantial decrease in functional capacity of the upper gastrointestinal tract, some organ-preserving pancreatectomy procedures have been developed, including duodenum-preserving pancreatic head resection (DPPHR), pancreatic head resection with segmental duodenectomy (PHRSD), central

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Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

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International Journal of Surgery (2024) 110:1770–1780

Received 17 October 2023; Accepted 4 December 2023

Supplemental Digital Content is available for this article. Direct URL citations are provided in the HTML and PDF versions of this article on the journal's website, www.ijournal-of-surgery.com.

Published online 21 December 2023

<http://dx.doi.org/10.1097/JS9.0000000000000998>

pancreatectomy (CP), and tumor enucleation (TEU)^[6–8]. These procedures aim to preserve pancreatic tissue, gastric antrum, duodenum, and common bile duct for maintaining the functionality of the residual pancreatic parenchyma and the upper gastrointestinal tract^[9].

It is widely acknowledged that partial pancreatectomy carries the potential of developing new-onset diabetes (referred to as type 3c diabetes) as well as exacerbating or resolving preexisting diabetes^[10]. However, the real-world dynamics of diabetes development, progression, and changes following partial pancreatic resection still require further investigation. Certain macro factors that may contribute to the emergence of new-onset diabetes such as regional variation, socioeconomic class, and medical level have not been taken into account in previous studies^[11,12]. Additionally, with regard to significant heterogeneity between different clinical studies, a comprehensive analysis of the preoperative, perioperative, and postoperative factors beyond indication and procedure of surgery is required to undertake. Moreover, the assessment of the worsening and resolution of diabetes following partial pancreatectomy has not been conducted in current systematic reviews^[9,13].

In this study, we aim to map the global new-onset, worsening, and resolution of diabetes following partial pancreatectomy. We performed a systematic review and meta-analysis through mining the existing data on postoperative diabetes after pancreatic resection. The study will broaden our knowledge of surgery-related postoperative changes of pancreatic endocrine function and provide evidence for clinical decision-making.

Methods

This systematic review follows the recommendations of the (Assessing the methodological quality of systematic reviews) AMSTAR (Supplemental Digital Content 1, <http://links.lww.com/JS9/B614>) guidelines and is consistent with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (Supplemental Digital Content 2, <http://links.lww.com/JS9/B615>), (Supplemental Digital Content 3, <http://links.lww.com/JS9/B616>)^[14,15].

Searching strategy and study selection

An extensive literature search was conducted using electronic database of PubMed, Embase, Web of Science, and the Cochrane Library. We searched articles with related terms ‘pancreatectomy’, ‘pancreatoduodenectomy’, ‘duodenum-preserving pancreatic head resection’, ‘pancreatic head resection with segmental duodenectomy’, ‘distal pancreatectomy’, ‘pancreatic left resection’, ‘spleno-pancreatectomy’, ‘central pancreatectomy’, ‘pancreatic middle segment resection’, ‘tumor enucleation’, ‘diabetes’, and ‘endocrine insufficiency’ (Supplementary Methods, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>).

We included studies for meta-analysis as follows: (1) a cohort study or case–control study fully published in English; (2) identified patients undergoing partial pancreatectomy; (3) reported number of preoperative and postoperative diabetes. We excluded studies for meta-analysis as follows: (1) individuals less than 18 years; (2) no sufficient information for data extraction.

HIGHLIGHTS

- Partial pancreatectomy carries the potential of triggering new-onset diabetes (referred to as type 3c diabetes).
- The global prevalence of new-onset diabetes after partial pancreatectomy was found to be 17.1% with significant heterogeneity influenced by macro factors such as regional variation, development, and income levels as well as micro factors including indication and procedure of surgery.
- Postoperative diabetes has a relatively high prevalence in patients undergoing partial pancreatectomy, which calls for attention and dedicated action.

Selection criteria

The studies were meticulously evaluated following predetermined criteria. The preliminary screening of titles and abstracts was performed by two reviewers independently. To ensure accuracy, an additional investigator critically reviewed a randomly selected 10% subset of the studies. Subsequently, the full texts of potentially relevant articles were thoroughly examined by any two of the authors, and any disparities were resolved through group discussion or, if necessary, by a fifth reviewer. Consensus was successfully attained in all cases, establishing a high level of agreement among the reviewers.

Data extraction

We extracted data at all levels reported in the study, including first author of the study, time of publication, study period, country or area, geographic region, income of country or area assessed by World Bank, the level of country development, study size, study population, indication of surgery, procedure and process of surgery, length of hospital stay, postoperative complications, duration of follow-up, diabetes diagnosis and the prevalence of new-onset, worsening and resolution of diabetes. Two authors independently reviewed and extracted data from the included studies by utilizing a custom-designed data extraction form tailored to the requirements of this investigation. Data were then cross-validated to guarantee accuracy by any of two authors. In cases where duplicate data were identified, the entry with the smaller sample size or shorter follow-up duration was excluded to prevent redundancy.

Quality assessment and statistical analysis

The quality assessment of the 82 included studies was conducted using the Newcastle–Ottawa Scale (NOS) (Supplementary Table 1, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>). No studies were excluded based on their quality scores to ensure transparency and encompass all available evidence in this domain. Consistency checks were conducted and the Metaprop module within the R-4.2.2 statistical software package was employed for meta-analysis. A 95% CI was estimated using the Wilson score method, and the pooled prevalence was calculated using the DerSimonian-Laird random-effects model with Logit transformation. The heterogeneity among the included studies was evaluated through the Cochran Q statistics and I^2 statistics. Estimates with a P -value less than .05 for the Q-statistic and an I^2 value of 50% or higher were considered to indicate moderate heterogeneity. Given the anticipated heterogeneity in global data, a random-effects model was employed to pool the

prevalence of new-onset, worsening and resolution of diabetes. Focusing on the significant heterogeneity associated with new-onset diabetes, we employed a meticulous sensitivity analysis approach by conducting a comprehensive series of leave-one-out diagnostic tests. Furthermore, the results were validated using a dedicated function within the metafor package to enhance the reliability and validity of our findings. As no outliers were identified through the sensitivity analysis, meta-regression was then conducted using a mixed-effects model. The considered covariates included country or area, geographic region, income of country or area, development level of country, study size, and study quality score. Subsequently, multivariable meta-regression (multimodel inference) was carried out using the 'dmetar' package to determine the best-fitting predictor combinations and identify the most significant overall predictors. Subgroup analyses were performed to assess potential confounding effects of heterogeneity. The difference between groups was assessed using a *P*-value, with a threshold of *P* < 0.05 indicating a statistical significance.

Results

Literature search and study characteristics

A total of 8736 records were identified. After eliminating duplicates, 5259 records remained. We screened the titles and abstracts and excluded 5116 ineligible records. The full texts of the remaining 143 records were evaluated for eligibility, with 61 being excluded. Ultimately, the analysis comprised 82 eligible studies involving 13 257 patients undergoing partial pancreatectomy, with 11 064 allocated to examine new-onset diabetes, 607 for worsening diabetes, and 1233 for resolution of diabetes (Fig. 1, Supplementary Table 1, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>)^[16–97]. The quality assessment scores for the included studies were presented in Supplementary Table 1 (Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>).

Global new-onset, worsening, and resolution of diabetes prevalence in patients following partial Pancreatectomy

We identified 1827 patients developing new-onset diabetes after partial pancreatectomy with an overall pooled prevalence of 17.1% (95% CI: 15.0–19.5, $I^2 = 84.0\%$, Table 1, Fig. 2).

To gain a deeper understanding of the heterogeneity, we conducted a sensitivity analysis by performing a set of leave-one-out diagnostic tests (Supplementary Table 2, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>) and the results were further verified using a build-in function in metafor (Supplementary Figure 1, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>). Regrettably, neither approach identified the outliers. To further explore the source of heterogeneity, meta-regression analysis was performed. Our univariate meta-regression model indicated that country or area ($R^2 = 0$, *P* = 0.8), geographic region ($R^2 = 0$, *P* = 0.9), income of country or area ($R^2 = 0$, *P* = 0.9), development level of country ($R^2 = 0$, *P* = 0.9), study quality score ($R^2 = 0$, *P* = 0.9) were not significantly associated with heterogeneity (Supplementary Table 3, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>). The source of heterogeneity across the studies, identified by univariate meta-regression analyses, was study size ($R^2 = 0.6$, *P* < 0.01, Supplementary Table 3, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>).

By performing multivariable meta-regression, we found that income of country or area exhibited the highest predictor importance of 49.7% (Fig. 3).

Subgroup analysis was conducted to validate the findings obtained from the meta-regression analysis. Regarding the geographic region with a minimum of five studies, the prevalence of new-onset diabetes ranged from 11.6% (Southern Europe, 95% CI: 7.1–18.2) to 23.4% (Central Europe, 95% CI: 14.7–35.0, *P* = 0.1, Table 1). Among countries with at least three studies, UK exhibited the highest prevalence (38.0%, 95% CI: 28.2–48.8), followed by Germany (23.3%, 95% CI: 14.2–35.7), USA (17.7%, 95% CI: 12.7–24.1), Korea (17.3%, 95% CI: 12.5–23.4), Japan (16.6%, 95% CI: 10.7–24.8), China (12.0%, 95% CI: 9.1–15.8), Italy (10.6%, 95% CI: 5.3–20.1), and France (7.6%, 95% CI: 4.3–13.0, *P* < 0.01, Table 1). When considering the income level, countries or areas with high-income displayed a greater prevalence of 18.0% (95% CI: 15.0–21.4) compared to those with upper-middle income (12.2%, 95% CI: 9.5–15.6, *P* = 0.01, Table 1). Besides, developed countries (17.2%, 95% CI: 14.2–20.6) shared a higher postoperative diabetes prevalence than that of developing countries (12.4%, 95% CI: 9.6–15.7, *P* = 0.03, Table 1). Studies included with fewer than 100 patients (18.1%, 95% CI: 15.0–21.8) exhibited significantly higher prevalence of diabetes than those with more than 100 patients (13.6%, 95% CI: 11.0–16.7, *P* = 0.04, Table 1). Considering the study period, studies conducted before 2010 (18.7%, 95% CI: 15.7–22.0) had a slightly higher prevalence of diabetes than those performed after 2010 (14.6%, 95% CI: 7.7–25.9, *P* = 0.2, Table 1). The quality assessment revealed 46 studies with a rating below 7 points (17.5%, 95% CI: 15.2–20.1), and 36 studies with a rating above 7 points (14.4%, 95% CI: 8.5–23.4, *P* = 0.5, Table 1). In terms of the duration of follow-up, 11 studies reported less than 6 months (9.5%, 95% CI: 6.0–14.8), while 25 studies reported more than 6 months (15.6%, 95% CI: 11.7–20.6, *P* = 0.06, Table 1).

Additionally, we assessed the preoperative, perioperative, and postoperative risk factors contributing to the development of new-onset diabetes. It was observed that patients with surgical indications related to chronic pancreatitis exhibited a higher prevalence (30.7%, 95% CI: 21.8–41.3) compared to patients with surgical indications of benign or (potentially) malignant pancreatic lesions (16.4%, 95% CI: 14.3–18.7, *P* < 0.01, Table 2). Concerning the type of surgery, patients undergoing DP (23.7%, 95% CI: 22.2–25.3) had the highest prevalence, followed by DPPHR (22.8%, 95% CI: 12.8–37.4), PD (15.8%, 95% CI: 14.9–16.8), PHRS (10.6%, 95% CI: 4.0–25.3), CP (9.4%, 95% CI: 7.3–12.0) and TEU (6.9%, 95% CI: 2.9–15.6, *P* < 0.01, Table 2, Supplementary Table 4, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>). However, minimal differences were observed among age ($\leq 49/50–64 / \geq 65$, 17.8% vs. 20.1% vs. 20.9%, *P* = 0.5), sex (male/female, 20.4 vs. 17.6%, *P* = 0.4), BMI ($< 25 / \geq 25$, 20.7 vs. 24.5%, *P* = 0.7), hypertension (Yes / No, 18.0 vs. 14.3%, *P* = 0.3), dyslipidemia (Yes / No, 21.8 vs. 15.1%, *P* = 0.4), peptic ulcer (Yes / No, 19.7 vs. 17.9%, *P* = 0.7), kidney disease (Yes / No, 25.5 vs. 13.8%, *P* = 0.4), blood glucose levels (euglycemia / impaired fasting glucose or impaired glucose tolerance, 9.9 vs. 18.3%, *P* = 0.4), type of procedure (open/laparoscopic/robotic, 18.1% vs. 17.4% vs. 7.1%, *P* = 0.08), operation time ($< 250 \text{ min} / \geq 250 \text{ min}$, 20.1 vs. 10.8%, *P* = 0.2), blood loss ($< 100 \text{ ml} / \geq 100 \text{ ml}$, 7.3 vs. 15.7%, *P* = 0.2), blood transfusion (Yes / No, 16.7 vs. 24.0%, *P* = 0.3).

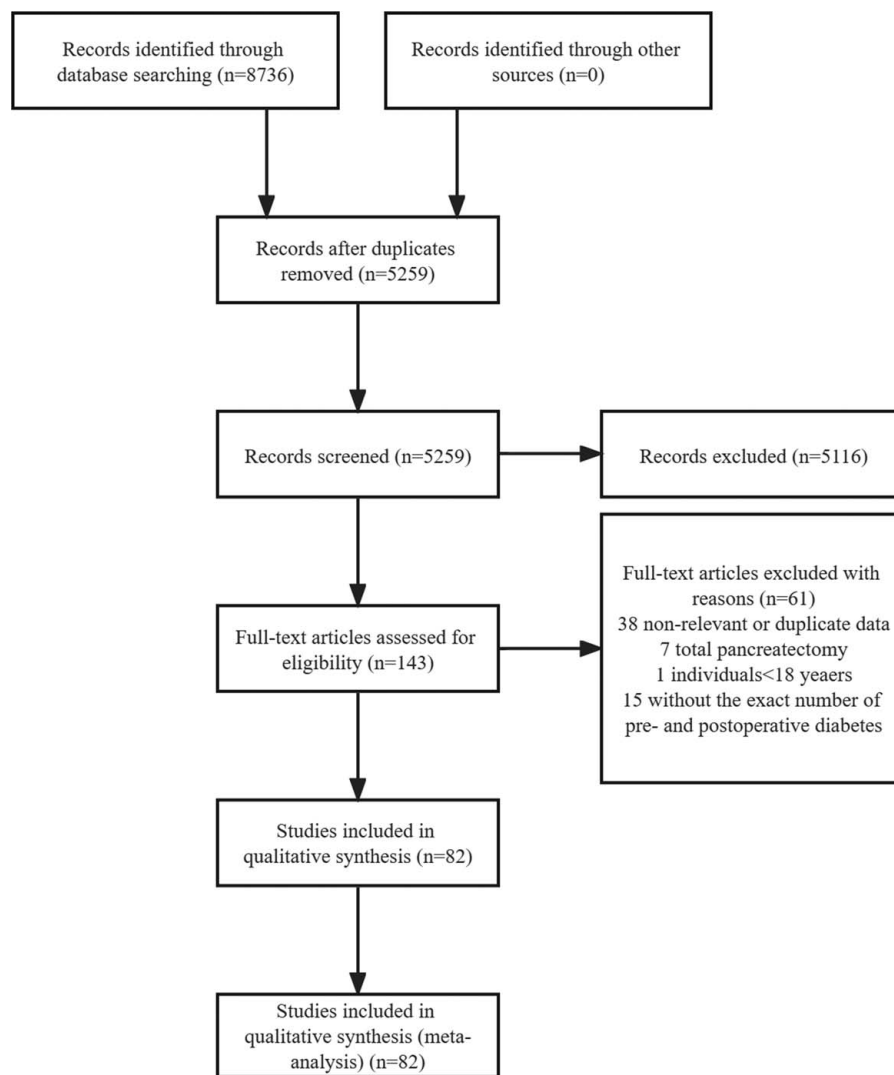


Figure 1. Study selection.

and postoperative complications (Yes / No, 16.4 vs. 14.8%, $P=0.7$, Table 2). We also conducted an evaluation of insulin utilization in patients with new-onset diabetes. The findings revealed that an impressive 52.9% (95% CI: 41.9–63.6) of patients relied on insulin therapy subsequent to the onset of diabetes (Supplementary Figure 2, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>).

Moreover, we estimated the pooled prevalence of worsening and resolution of diabetes in patients with preoperative diabetes. The results indicated that 277 patients (41.1%, 95% CI: 31.4–51.6) with preoperative diabetes experienced a deterioration in metabolic control and 255 patients (25.8%, 95% CI: 19.3–33.7) recovered from previously diagnosed diabetes (Supplementary Figure 3, Supplemental Digital Content 4, <http://links.lww.com/JS9/B617>).

Discussion

Partial pancreatectomy for chronic pancreatitis, benign or (potentially) malignant pancreatic lesions is associated with the

development, exacerbation, and resolution of diabetes. The global prevalence of new-onset diabetes was found to be 17.1% with significant difference between different countries. Univariate meta-regression indicated that study size was the causes of heterogeneity and multivariable analysis suggested that income of country or area has the highest predictor importance. Furthermore, a notable disparity of postoperative diabetes prevalence was identified with statistical significance due to the indication and type of surgery. Once developing diabetes, more than 50% of individuals required insulin therapy to effectively manage their blood glucose levels. It is noteworthy that pancreatic resection not only carried the potential to trigger new-onset or worsening diabetes but also held promise for ameliorating preexisting diabetes.

Recent systematic reviews have aimed to estimate the prevalence of new-onset diabetes following partial pancreatectomy^[9,11–13]. However, to our knowledge, this study represents the most comprehensive review to date, incorporating the largest number of studies on postoperative diabetes worldwide. Our investigation involved a series of rigorous and extensive analysis, first

Table 1
Subgroup analysis for new-onset diabetes following partial pancreatectomy.

	Studies	New-onset diabetes	Patients	Prevalence (95% CI)	P	I ² (%)
Overall population	82	1827	11064	17.1 (15.0–19.5)	–	84.0
By geographic regions					0.1	
Eastern Asia	31	1211	7392	15.3 (12.9–18.0)		75.8
Northern America	19	260	1782	17.7 (12.7–24.1)		84.6
Central Europe	11	183	807	23.4 (14.7–35.0)		88.9
Western Europe	10	124	592	19.6 (10.4–33.7)		88.5
Southern Europe	6	32	292	11.6 (7.1–18.2)		45.1
Oceania	1	11	95	11.6 (6.5–19.7)		–
Eastern Europe	1	2	49	4.1 (1.0–14.9)		–
Southern America	1	0	29	1.7 (0.1–21.7)		–
Southern Asia	1	2	14	14.3 (3.6–42.7)		–
Western Asia	1	2	12	16.7 (4.2–47.7)		–
By country or area					< 0.01	
USA	19	260	1782	17.7 (12.7–24.1)		84.6
China	11	1007	6075	12.0 (9.1–15.8)		84.2
Korea	10	139	894	17.3 (12.5–23.4)		72.6
Germany	10	180	793	23.3 (14.2–35.7)		90.0
Japan	10	65	423	16.6 (10.7–24.8)		66.1
France	5	9	188	7.6 (4.3–13.0)		0.0
Italy	4	18	188	10.6 (5.3–20.1)		50.7
UK	3	67	177	38.0 (28.2–48.8)		49.4
Netherlands	2	48	227	32.3 (4.7–82.0)		97.1
Romania	2	14	104	12.7 (5.2–28.0)		55.8
Australia	1	11	95	11.6 (6.5–19.7)		–
Russia	1	2	49	4.1 (1.0–14.9)		–
Brazil	1	0	29	1.7 (0.1–21.7)		–
Poland	1	3	14	21.4 (7.1–49.4)		–
India	1	2	14	14.3 (3.6–42.7)		–
Israel	1	2	12	16.8 (4.2–47.7)		–
By income					0.01	
High	67	804	4842	18.0 (15.0–21.4)		83.8
Upper-middle	15	1023	6222	12.2 (9.5–15.6)		79.6
By development					0.03	
Developed	67	801	4857	17.2 (14.2–20.6)		84.0
Developing	15	1026	6207	12.4 (9.6–15.7)		79.5
By study size					0.04	
< 100	63	491	2618	18.1 (15.0–21.8)		75.8
≥ 100	19	1336	8446	13.6 (11.0–16.7)		90.9
By study period					0.2	
Before 2010	53	1486	8689	18.7 (15.7–22.0)		86.1
After 2010	7	53	339	14.6 (7.7–25.9)		76.1
By study quality score					0.5	
< 7	16	129	922	17.5 (15.2–20.1)		83.1
≥ 7	66	1698	10142	14.4 (8.5–23.4)		86.5
By duration of follow-up					0.06	
< 6 months	11	50	842	9.5 (6.0–14.8)		50.0
≥ 6 months	25	186	1279	15.6 (11.7–20.6)		71.9

considering certain macro-level factors such as country and regional disparities, as well as economic development level, to examine their potential impact on the occurrence of postoperative diabetes. In addition, we conducted a comprehensive examination of pre-operative, perioperative, and postoperative variables, while also scrutinizing the global prevalence of worsening and resolution of diabetes following partial pancreatectomy. Our study has several limitations. First, despite its comprehensive nature, there is a notable scarcity of research studies from developing countries with lower-middle or low-income. This lack of representation hampers the generalizability of our findings. Second, the metabolic information in some studies were self-reported, and the diagnosis of

diabetes did not strictly adhere to WHO-criteria. This potential reporting bias may introduce uncertainties and affect the accuracy of the results. Third, it is reported that the proportion of pancreas removal was associated with postoperative diabetes^[38,67]. However, due to the limited availability of studies, we failed to further analyze these data. Lastly, because there was insufficient data from the included studies, our meta-analysis did not thoroughly examine the impact of preoperative diabetes types, surgical indications, and specific surgical procedures on the exacerbation and resolution of diabetes.

Our findings indicated that some western countries, including UK, Germany, and USA, exhibited higher prevalence of

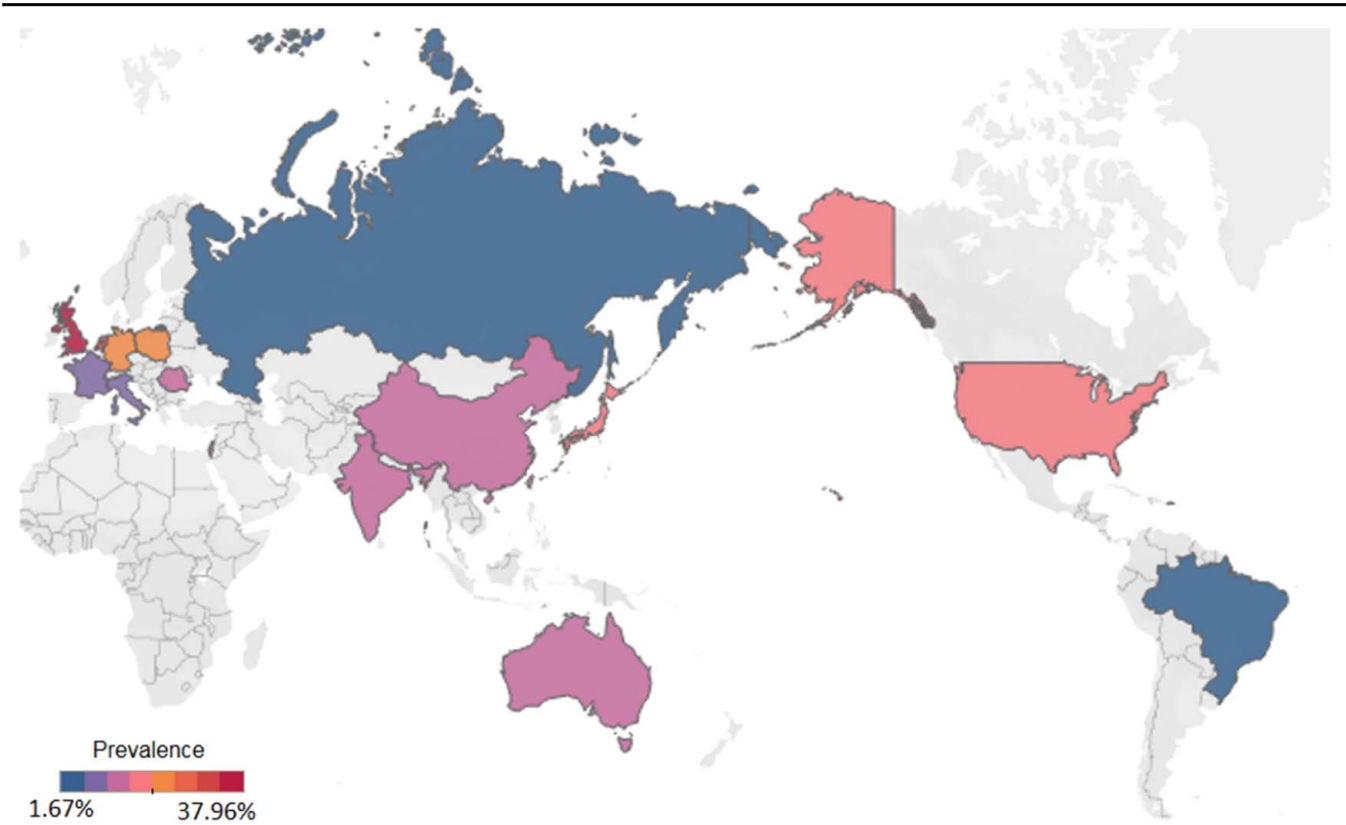


Figure 2. Global prevalence of new-onset diabetes following partial pancreatectomy.

postoperative diabetes compared to some eastern countries, such as China, Korea, and Japan. This observed disparity can be attributed to variations in dietary habits in different countries. Western countries often embrace a diet characterized by a greater consumption of processed foods, which are typically abundant in unhealthy fats, added sugars, and refined carbohydrates.

These dietary patterns may lead to an increased risk of developing diabetes^[98,99]. In contrast, eastern countries, particularly China, Korea, and Japan, traditionally prioritize diets rich in whole grains, vegetables, and seafood, which are generally regarded as healthier choices. These dietary preferences may contribute to a lower prevalence of postoperative diabetes in these regions^[100,101].

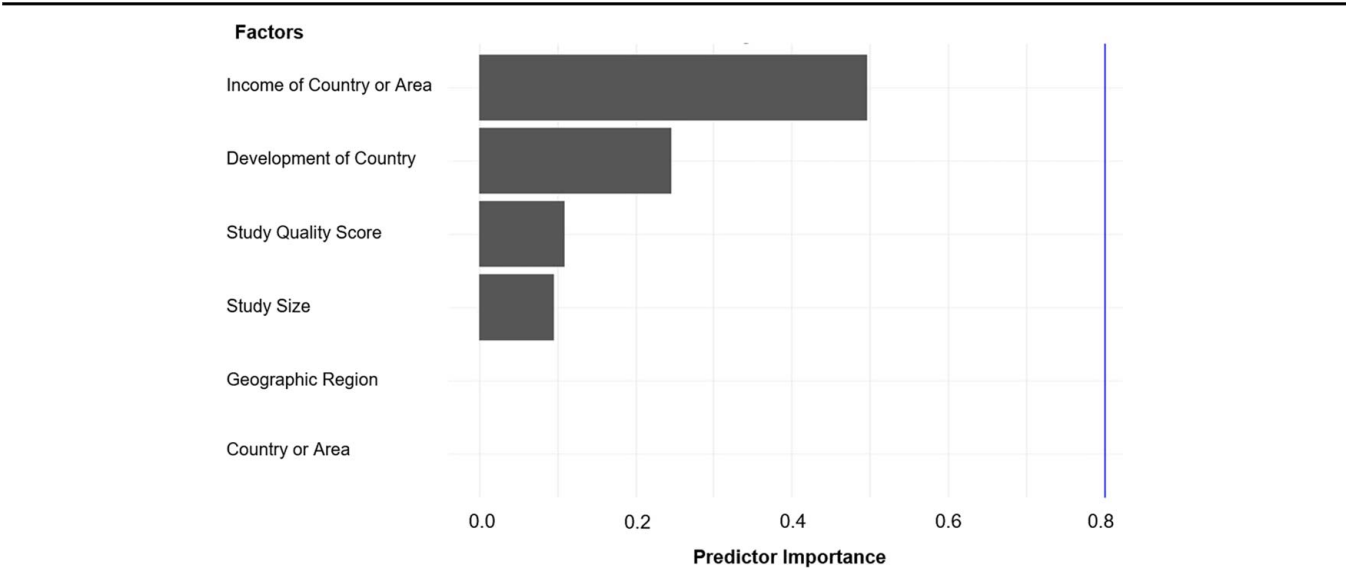


Figure 3. Results of multivariable meta-regression analysis.

Table 2
Pooled estimates of risk factors for new-onset diabetes following partial pancreatectomy.

	Studies	New-onset diabetes	Patients	Prevalence (95% CI)	P	P (%)
Preoperative risk factors						
Age					0.5	
≤ 49	9	257	1463	17.8 (15.3–20.6)		10.5
50–64	9	347	1828	20.1 (16.4–24.4)		26.3
≥ 65	8	348	2122	20.9 (14.7–28.8)		62.8
Sex					0.4	
Male	18	649	3556	20.4 (16.0–25.5)		69.2
Female	18	437	2707	17.6 (13.9–22.0)		58.1
BMI					0.7	
BMI < 25	3	27	134	20.7 (14.6–28.5)		0.0
BMI ≥ 25	3	11	50	24.5 (10.4–47.5)		52.3
Hypertension					0.3	
Yes	4	376	2050	18.0 (12.7–24.9)		81.1
No	4	594	3609	14.3 (10.0–20.1)		90.4
Dyslipidemia					0.4	
Yes	3	105	499	21.8 (9.3–43.0)		90.0
No	3	865	5148	15.1 (11.0–20.4)		93.8
Peptic ulcer					0.7	
Yes	2	529	2943	19.7 (12.8–29.2)		96.1
No	2	415	2381	17.9 (14.9–21.4)		73.6
Kidney disease					0.4	
Yes	2	11	38	25.5 (6.4–62.9)		39.2
No	2	327	1695	13.8 (5.0–32.9)		96.5
Blood glucose level					0.4	
Euglycemia	6	32	528	9.9 (2.9–28.9)		88.2
IFG/IGT	6	75	512	18.3 (8.2–36.1)		89.3
Indication of surgery					< 0.01	
Chronic pancreatitis	17	240	832	30.7 (21.8–41.3)		83.4
Benign or (potentially) malignant lesions	42	1027	6602	16.4 (14.3–18.7)		58.4
Perioperative risk factors						
Type of surgery					< 0.01	
PD	36	939	6392	15.8 (14.9–16.8)		80.2
DPPHR	11	93	389	22.8 (12.8–37.4)		82.7
PHRSD	3	9	98	10.6 (4.0–25.3)		49.5
CP	31	50	781	9.4 (7.3–12.0)		10.1
DP	37	715	3162	23.7 (22.2–25.3)		72.5
TEU	2	4	73	6.9 (2.9–15.6)		0.0
Type of procedure					0.08	
Open	6	6	61	18.1 (4.0–53.7)		61.3
Laparoscopic	11	49	314	17.4 (12.9–23.1)		10.4
Robotic	4	4	82	7.1 (3.2–14.9)		0.0
Operation time					0.2	
< 250 min	7	6	49	20.1 (10.9–34.2)		0.0
≥ 250 min	6	2	47	10.8 (4.5–23.7)		0.0
Blood loss					0.2	
< 100 ml	6	0	51	7.3 (2.3–20.7)		0.0
≥ 100 ml	7	14	120	15.7 (10.0–23.7)		0.0
Blood transfusion					0.3	
Yes	2	12	76	16.7 (10.0–26.7)		0.0
No	2	21	88	24.0 (16.2–34.0)		0.0
Postoperative risk factors						
Postoperative complications					0.7	
Yes	9	30	239	16.4 (9.1–27.6)		47.9
No	9	36	320	14.8 (9.0–23.2)		40.8

CP, central pancreatectomy; DP, distal pancreatectomy; DPPHR, duodenum-preserving pancreatic head resection; IFG, impaired fasting glucose; IGT, impaired glucose tolerance; PD, pancreaticoduodenectomy; PHRSD, pancreatic head resection with segmental duodenectomy; TEU, tumor enucleation.

Notably, countries such as Italy and France, renowned for their adherence to internationally acclaimed health-conscious dietary pattern known as the Mediterranean diet, showed the lowest prevalence of postoperative diabetes^[102].

Furthermore, our analysis revealed that higher prevalence of new-onset diabetes in developed and high-income countries compared to developing countries with upper-middle income. Indeed, it is acknowledged that significant strides have been

achieved in healthcare infrastructure in developing countries with an upper-middle income level over the past decade^[103]. In the realm of pancreatectomy, these countries have made noteworthy advancements in critical aspects, encompassing preoperative assessments, surgical techniques, and postoperative management, thereby bringing them into greater conformity with global standards^[104,105]. It is interesting that a considerable proportion of patients undergoing pancreatic resection in these countries often engage in physically demanding occupations due to their relatively underdeveloped economies. This specific employment setting could potentially operate as a mitigating factor, reducing the prevalence of postoperative diabetes^[106]. Although the lack of relevant data and the restricted rigor of research design prevented us from including data from developing with lower-middle or low incomes in our meta-analysis, we are able to present a general picture of the state of pancreatectomy in these areas. In comparison to high-income countries that possess cutting-edge medical infrastructure, such as state-of-the-art operating rooms, CT scanners, MRI machines, and robotic surgical systems, lower-middle and low-income countries often grapple with substantial challenges related to basic healthcare infrastructure^[107]. In addition, high-income countries benefit from a well-established cadre of highly proficient surgeons who specialize in the complexities of pancreatic surgery^[107]. Conversely, lower-middle and low-income countries frequently encounter the formidable obstacle of inadequate specialized training programs and a shortage of experienced surgeons possessing the necessary expertise to undertake intricate pancreatic resections^[107]. The insufficiency of healthcare infrastructure and the scarcity of specialized medical professionals have markedly increased the incidence of postoperative complications among patients undergoing pancreatic resection in these nations^[108,109]. It is possible that these factors have contributed to a dearth of research on the long-term outcomes of pancreatic resections within these nations, such as exocrine and endocrine insufficiency.

A potential explanation for the elevated occurrence of new-onset diabetes in patients undergoing partial pancreatectomy for chronic pancreatitis is likely attributed to the progressive destruction of pancreatic parenchyma^[110]. Conversely, in patients with benign or (potentially) malignant pancreatic lesions, the remaining pancreatic parenchyma is relatively healthy^[13]. Notably, following tumor resection, the impaired pancreatic β -cell function caused by tumor cells shows a remarkable improvement, as well as the degree of peripheral insulin resistance^[111–114]. Consequently, these patients have a lower risk of developing new-onset diabetes. In terms of different surgical procedures, it is widely acknowledged that the extent and location of pancreas removal are significantly associated with the development of diabetes^[10]. Our study, based on empirical data, demonstrated that specific pancreas-preserving techniques, such as CP and TEU, effectively reduced the risk of postoperative diabetes. Previous research has indicated that islet density and distribution are approximately two times higher in the tail region compared to that in the head and body regions, which may account for the highest risk of new-onset diabetes in patients undergoing the DP procedure^[115]. The impact of duodenal preservation on the emergence of postoperative diabetes remains a matter of controversy. The resection of the duodenum may induce alterations in incretin secretion, including a decrease in gastric inhibitory polypeptide secretion and an increase in

glucagon-like peptide 1 (GLP-1) secretion, which regulate β -cell function and insulin sensitivity in peripheral tissues^[10,116,117].

Another interesting finding was that there was no statistically significant disparity in postoperative diabetes prevalence between two BMI groups (BMI <25 and BMI $\geq$ 25). Although previous studies have suggested that overweight and obese individuals may exhibit a relatively compromised pancreatic parenchyma, commonly referred to as soft pancreatic tissue, we posit that the impairment in pancreatic β -cell function resulting from fatty infiltration is much less severe compared to the pancreatic diseases that necessitate surgical intervention^[118]. In fact, it appears that the degree of damage to the pancreatic parenchyma is nearly indistinguishable between both groups. Within these two groups, we still believed that the primary determinant for postoperative diabetes may be the insufficient insulin secretion resulting from the resection of pancreatic parenchyma. Furthermore, the relatively limited number of studies included in the subgroup analysis may contribute to the absence of statistically significant difference. Additional research efforts may be merited to conduct a more comprehensive exploration of this matter.

The concern is not groundless. First, diabetes exerts a profound impact on one's quality of life. Belyaev *et al.*^[42] provided evidence of patients enduring postoperative endocrine or exocrine insufficiency, or both, reporting significant declines in their physical well-being. In a comparative study examining the quality of life after partial pancreatic resection, postoperative diabetes exhibited the most detrimental effects on leisure activities and physical functioning^[85]. Second, a remarkable 52.9% of patients developing new-onset diabetes required insulin therapy to effectively manage their blood glucose levels, and 41.1% of individuals with preoperative diabetes experienced a deterioration in metabolic control. Furthermore, despite certain similarities between type 3c diabetes and type 2 diabetes, type 3c diabetes presents greater challenges in blood glucose management due to notable fluctuations associated with the deficiency of pancreatic polypeptide and exogenous insulin treatment^[119,120]. However, it is important to recognize that pancreatic resection does not solely yield negative outcomes. Notably, 25.8% of patients experienced a restoration from previously diagnosed diabetes, although the underlying mechanism needs further investigation.

In conclusion, postoperative diabetes has a relatively high prevalence in patients undergoing partial pancreatectomy and poses negative effects on their life. This calls for attention and dedicated action from primary care physicians, specialists, and health policy makers alike.

Ethical approval

Our research does not require ethical review.

Consent

Not applicable.

Sources of funding

This work is supported by the National Natural Science Foundation of China (82070846), EFSD and Lilly EXPLORING AND APPLYING NEW STRATEGIES IN DIABETES (EXPAND) Program, Sichuan Science and Technology Program

(2021ZYCD016, 2022YFS0308, 2023YFS0123), and Chengdu Science and Technology Program (2023-GH02-00083-HZ).

Author contribution

J.W., J.L., and X.Z.: designed the study; J.W., Y.O., J.C., and Z.Y.: carried out the research; J.W., Y.O., J.L., and X.Z. wrote the manuscript. Z.W., K.W., D.Y., Y.G., and Y.L.: critically revised the manuscript. All authors contributed and approved the final version of the manuscript.

Conflicts of interest disclosure

The authors declare no conflicts of interest.

Research registration unique identifying number (UIN)

1. Name of the registry: PROSEPRO.
2. Unique identifying number or registration ID: CRD4202-3457885.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): https://www.crd.york.ac.uk/prospetro/display_record.php?ID=CRD42023457885

Guarantor

The Guarantor is Prof Xiaofeng Zheng.

Data availability statement

Datasets generated during the current study are available upon reasonable request.

Provenance and peer review

Not commissioned, externally peer-reviewed.

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