Review

Blood Loss in Pancreatic Resections: Definitions, Risk Factors and Strategies for Intra- and Postoperative Bleeding Prevention – A Narrative Review

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AIM: Pancreatic resections are among the most complex procedures in general surgery and are associated with high morbidity. Intraoperative blood loss and post-pancreatectomy hemorrhage (PPH) are clinically relevant yet inconsistently defined and reported, limiting comparability across studies. This narrative review integrates current evidence on definitions, risk factors, and preventive approaches for bleeding in pancreatic surgery.
METHODS: A selective PubMed literature review was conducted without restrictions on publication date or study design, limited to full-length English-language articles. Multiple targeted searches addressed definitions of blood loss, PPH, patient- and procedure-related risk factors, patient blood management, tranexamic acid, surgical techniques, and perioperative outcomes.
RESULTS: Blood loss estimation is highly heterogeneous across studies. Key risk factors for increased blood loss and/or PPH include obesity, antithrombotic therapy, preoperative anemia, vascular resection, and prolonged operative time. Higher intraoperative blood loss correlates with higher reoperation rates, prolonged intensive care unit (ICU) stay, and increased 90-day mortality. While perioperative transfusions are associated with shorter long-term survival in observational studies, causal interpretation remains limited by confounding, suggesting that blood loss and preoperative anemia rather than transfusion itself drive adverse outcomes. Effective preventative approaches include Patient Blood Management (PBM) programs, preoperative intravenous iron supplementation, the artery-first approach, and minimally invasive surgical techniques, which may reduce blood loss and/or transfusion requirements; prophylactic falciform ligament wrapping may reduce the risk of PPH.
CONCLUSIONS: Systematic preoperative risk assessment, structured PBM protocols, and tailored surgical strategies are necessary to minimize hemorrhagic complications in pancreatic surgery.

Keywords: pancreatic resection; blood loss; post-pancreatectomy hemorrhage; patient blood management; transfusion; pancreatoduodenectomy

Introduction

Pancreatic resections are among the most complex procedures in general surgery, and despite reduced mortality, they are still associated with high morbidity rates. Furthermore, post-pancreatectomy hemorrhage (PPH) is rare but one of the most life-threatening complications, with significantly higher mortality and a substantial impact on postoperative outcome [1,2,3,4]. Despite its clinical significance, intraoperative blood loss is inconsistently and poorly reported across studies, limiting the comparability of evidence and the effective quantification of this important risk factor. Transfusion rates following pancreatic resections range from approximately 15% to 30% [5,6], varying considerably by procedure type, institution, and country, yet standardized guidance on optimal transfusion thresholds as well as timing remains scarce. This narrative review integrates current evidence on the definitions, risk factors, and prophylactic measures relevant to both intraoperative blood loss and post-pancreatectomy hemorrhage. Patient-related risk factors, including obesity and anticoagulation therapy, as well as procedure-related factors, such as vascular involvement and operative time, are discussed alongside surgical strategies, including minimally invasive approaches, the artery-first technique, and perioperative blood management concepts. Finally, the impact of blood loss and transfusions on outcomes is examined, and the remaining research gaps are identified.

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Methods

Based on a selective literature review, we discuss definitions, risk factors, and strategies for intra- and postoperative bleeding prevention in patients undergoing pancreatic resection. We conducted a selective literature review in PubMed between March and June 2026, without restrictions regarding time of publication or study design. Only full-length articles in English were selected. Studies were selected based on their relevance to the predefined review topics, with preference given to larger cohorts, randomized trials, systematic reviews, and recent or clinically influential studies. Multiple targeted searches were performed to address different subtopics of this review, using combinations of MeSH terms and free-text keywords combined with Boolean operators, including 'Pancreatectomy', 'Pancreaticoduodenectomy', 'Pancreatoduodenectomy', 'pancreatic resection', 'Whipple procedure', 'Blood loss, Surgical' and 'Postoperative Hemorrhage' for definitions and clinical impact of intraoperative blood loss and post-pancreatectomy hemorrhage; 'risk factors', 'Obesity', 'Anticoagulants', 'Neoadjuvant Therapy' and 'Operative Time' for patient-, disease- and procedure-related risk factors; 'Anemia', 'patient blood management', 'Tranexamic acid', 'Robotic Surgical Procedures' and 'Laparoscopy' for perioperative strategies to reduce intraoperative blood loss; 'Reoperation', 'Embolization, Therapeutic' and 'Radiology, Interventional' for prevention and management of post-pancreatectomy hemorrhage and 'Blood Transfusion' for the impact of blood loss and transfusions on perioperative outcome. Additional references were identified through manual screening of reference lists of relevant articles. Institutional websites were consulted where appropriate.

Results

Definitions and Clinical Impact

Intraoperative Blood Loss

Intraoperative blood loss during pancreatic resection is common and prognostically relevant, yet it is poorly and inconsistently defined and reported. A systematic review of 806 hepato-pancreato-biliary surgery studies demonstrated substantial heterogeneity in the assessment of intraoperative blood loss. Notably, a systematic review reported that 83% of the included studies did not report the method used for blood loss estimation, while nine different assessment techniques were identified among the remaining studies, most commonly suction volume measurement combined with surgical sponge weighing [7]. Another study showed that the estimated blood loss in distal pancreatectomy is often underestimated, though in open surgery, rather overestimated [8]. According to the European–African Hepato-Pancreato-Biliary Association (E-AHPBA) Delphi consensus, intraoperative blood loss should be estimated by subtracting the irrigation fluid volume from the total suction fluid volume and adding the weight difference between used and dry surgical gauze (1 g = 1 mL of blood). This recommendation achieved 95.5% agreement among the expert panel [9]. Standardized reporting of blood loss itself will not be an independent intervention to improve outcomes, but evidence shows that greater blood loss impairs short- and long-term outcomes following pancreatic resection, and that current inconsistent estimation methods reduce the effective utilization of this potent risk factor.

Reported transfusion rates typically differ between about 15% to 30% [5,6], with higher rates observed in complex pancreatoduodenectomy (PD) and venous resection [10]. Pancreatoduodenectomy is associated with higher transfusion rates than distal or total pancreatectomy [10]. Nevertheless, there is considerable variability across countries, institutions, and surgeons regarding policies and transfusion triggers [11,12,13,14].

Post-Pancreatectomy Hemorrhage (PPH)

PPH is a rare but serious complication after pancreatic resection [15,16]. The International Study Group of Pancreatic Surgery (ISGPS) defined PPH in 2007 (Table 1) [17]. Early PPH occurs within 24 hours postoperatively, while late PPH occurs after 24 hours. Bleeding is classified as intraluminal or extraluminal, and severity is categorized as mild (minor clinical impact) or severe (requiring invasive intervention) [17]. After infective complications from anastomotic failure (postoperative pancreatic fistula (POPF)), PPH is the second leading cause of perioperative mortality [18] and a major reason for reintervention in PD patients [19]. The grading system can be summarized as a simple escalation pathway: Grade A → observation only; Grade B → diagnostic work-up (computed tomography (CT)/angiography) with transfusion and intensive care unit (ICU)/intermediate care unit (IMC) care; Grade C → emergency embolization or relaparotomy with ICU support.

Impact of Blood Loss and Transfusions on Outcomes

When it comes to pancreatic resections, intraoperative blood loss and perioperative transfusions are closely linked to the rate of complications and survival. Higher intraoperative blood loss clearly correlates with an increase in perioperative complications, prolonged ICU treatment, and a longer total duration of hospital stay. In a multicenter propensity score matching study from 2021, high blood loss was defined as an estimated loss of more than 700 mL. Patients with higher estimated blood loss had significantly higher rates of reoperations (9.2% vs. 4.0%, $p < 0.001$), ICU transfers (9.9% vs. 4.8%, $p < 0.001$) and 90-day mortality (4.7% vs. 2.0%, $p < 0.001$) compared with those with lower estimated blood loss [6]. Another study with over 5000 performed PDs confirms these findings, stating that in the 301–750 mL group, the rate of severe complications (defined as Accordion ≥3 [20], which equals

Table 1. Grading system for post-pancreatectomy hemorrhage: clinical characteristics and therapeutic implications. Adapted from [17].

Grade	Time of onset, location, severity, and clinical impact of bleeding	Clinical condition	Diagnostic consequence	Therapeutic consequence
A	Early, intra- or extraluminal, mild	Well	Observation, blood count, ultrasonography and, if necessary, computed tomography	No
B	Early, intra- or extraluminal, severe Late, intra- or extraluminal, mild	Often well/ intermediate, very rarely life-threatening	Observation, blood count, ultrasonography, computed tomography, angiography, endoscopy	Transfusion of fluid/blood, intermediate care unit (or ICU), therapeutic endoscopy, embolization, relaparotomy for early PPH
C	Late, intra- or extraluminal, severe	Severely impaired, life-threatening	Angiography, computed tomography, endoscopy	Localization of bleeding, angiography and embolization, (endoscopy) or relaparotomy, ICU

Abbreviations: ICU, intensive care unit; PPH, post-pancreatectomy hemorrhage.

Table 2. Characteristics and survival outcomes of studies reporting the impact of perioperative blood transfusion on long-term survival following pancreatic resection.

Reference	Year	Study type	Sample size	Survival	*Effect estimate and p*-value
Spore et al. [23]	2024	Nationwide analysis from Denmark	473	5-year survival: 8.8% transfused vs. 28.0% non-transfused	HR: 2.53 $p = 0.005$
Javed et al. [21]	2022	Retrospective cohort study	546	Median overall survival in months: patients receiving PBT 17.2 months vs. patients without PBT 24.7 months	$p < 0.001$
Newhook et al. [22]	2021	Retrospective cohort study	312	Median overall survival in months: patients receiving PBT 35 months vs. patients without PBT 53 months	$p = 0.006$

Abbreviations: HR, hazard ratio; PBT, perioperative blood transfusion.

Clavien-Dindo ≥III) was 19.6%, whereas in the 751–1300 mL group, the rate was 24.4%. The 90-day mortality rate also rose from around 2.0% in the 301–750 mL group to 3.5% in the 751–1300 mL group (all p-values < 0.001) [5].

Several studies have reported an association between perioperative blood transfusions (PBT) and adverse postoperative outcomes following pancreatic resection (Table 2, Ref. [21,22,23]). In a large national cohort comprising 26,175 patients, perioperative transfusions were associated with increased 5-year mortality (hazard ratio (HR): 1.4, 95% CI: 1.3–1.6), with the strongest effect observed in patients undergoing pancreatoduodenectomy [24]. Similar results have been reported in multiple institutional cohorts [21,22] and a nationwide Danish analysis [23], demonstrating reduced overall survival among transfused patients and a dose-dependent relationship between transfusion volume and outcome [22].

However, interpreting these outcomes is difficult. A systematic review of pancreatic ductal adenocarcinoma (PDAC) surgery found only a weak, uncertain link between perioperative transfusion and long-term survival. The authors noted major methodological limits, especially confounding by indication, since transfused patients had more comorbidities, higher blood loss and underwent more complex surgery [25]. Another single-center retrospective study confirms this: blood transfusions were not an independent risk factor for reduced overall survival after a propensity-matched Cox regression analysis (hazard ratio (HR) = 0.79, 95% CI: 0.28–2.20, p = 0.647) [26]. New analyses with more rigorous adjustment suggest that blood loss and anemia are the actual drivers of morbidity, whereas transfusion itself, even after adjustment, is not always an independent risk factor [26,27]. These data show that perioperative blood transfusions are better viewed as indicators of operative complexity and patient physiological status rather than as a direct cause of adverse postoperative outcomes or impaired survival.

Risk Factors (for Blood Loss)

Patient-related

Obesity. Studies have demonstrated an association between obesity and pancreatic cancer that should be considered. In particular, a higher BMI at a younger age (16–29 years) increases the risk of PDAC (HR: 1.21, 95% CI: 1.13–1.31), as a nationwide registry-based cohort study from Norway reported [28,29]. As global obesity rates continue to rise [29], an increasing proportion of patients undergoing pancreatic resection are obese, potentially affecting blood loss. Mechanistically, obesity is thought to increase surgical bleeding risk through greater visceral fat volume complicating dissection and vessel identification [30] and a pro-inflammatory adipokine profile that impairs wound and anastomotic healing [31].

A meta-analysis published in 2025 reported a modest increase in the risk of PPH among patients with obesity (in this study, obesity was defined as BMI >25 kg/m^2 for Asian populations and >30 kg/m^2 for United States and Western countries) (OR: 1.44, 95% CI: 1.07–1.94), based on 4446 patients. When analyzing the subgroups, open PD, robotic PD, and laparoscopic PD, no statistically significant increase in PPH risk was observed for robotic (OR: 1.79, 95% CI: 0.8–3.9) or laparoscopic procedures (OR: 1.05, 95% CI: 0.5–2.3) [32]. Nevertheless, obesity remains an important risk factor, particularly because it is associated with a higher incidence of POPF (OR: 1.98, 95% CI: 1.59–2.47) [32], which in turn increases the likelihood of PPH (OR: 31.7, 95% CI: 8.94–112.2) [33]. Because obesity thresholds and their clinical consequences differ by ethnicity, region-specific data are particularly relevant. Lower BMI cutoffs used in Asian populations underscore that obesity cannot be defined solely by absolute BMI values and highlight the importance of considering visceral adiposity when assessing perioperative risk.

Anticoagulation. The use of antithrombotic agents (ATA), such as acetylsalicylic acid, clopidogrel, warfarin and others before pancreatic resection is an independent risk factor for post-pancreatectomy hemorrhage (PPH) in several large cohorts. In a multicenter study (n = 1297), PPH occurred in 8.3% of patients receiving ATA compared with 2.0% of those not receiving it ($p < 0.001$). This was also confirmed by a multivariate analysis, where ATA use was an independent risk factor for PPH (OR: 3.58, 95% CI: 1.29–9.91, $p = 0.014$) [34]. Fujikawa et al. [35] reported on 334 ATA-treated patients undergoing digestive surgery, including pancreatectomy, and found that direct oral anticoagulant therapy with heparin bridging was the most significant risk factor for postoperative bleeding complications (OR: 11.60, $p = 0.028$), while patients who continued preoperative acetylsalicylic acid showed no significant increase in postoperative bleeding complications (OR: 1.46, 95% CI: 0.49–4.38, $p = 0.5$). These studies indicate that perioperative heparin bridging could elevate the risk of bleeding after surgery.

Neoadjuvant Therapy. Several studies have examined the impact of neoadjuvant chemotherapy on the risk of PPH, but their findings have been inconsistent (Table 3, Ref. [36,37,38]). A 2026 study analyzed risk factors for late PPH in patients with POPF. Neoadjuvant chemotherapy emerged as an independent predictor of late PPH (OR: 8.28, 95% CI: 2.41–28.44, $p < 0.001$) [36]. However, this analysis focused solely on PPH in the context of pre-existing postoperative pancreatic fistulas. Since late-onset PPH often results from local inflammatory processes or vascular erosions within a fistula, these results may not be widely applicable to the overall risk of PPH after pancreatic resection. In contrast, a multicenter randomized trial with 164 patients showed no significant effect (Risk Difference: 4.0%, 95% CI: –4.2% – 12.2%, $p = 0.352$) [37]. Similarly, a systematic review and meta-analysis found no significant association between neoadjuvant chemotherapy and PPH (OR: 0.73, 95% CI: 0.39–1.37, $p = 0.3$) [38]. These studies evaluated unselected surgical populations without stratifying patients according to POPF status. Furthermore, the retrospective design and limited sample size of the fistula-specific study increase the potential for residual confounding. Taken together, current evidence does not support a generalizable causal effect of neoadjuvant chemotherapy on the risk of PPH outside the context of postoperative pancreatic fistula, though the absence of stratification by treatment modality and disease stage limits the interpretive depth of this conclusion for clinical decision-making.

Disease- and Procedure-Related

Vascular Involvement. Even when tumor infiltrations necessitate vascular resection during pancreatic surgery, a careful assessment of the oncological necessity of extended resection against the associated increased surgical complexity is required. In particular, an elevated risk of bleeding necessitates continuous intraoperative vigilance and appropriate precautions by the surgical team. Propensity score-matched analysis demonstrated that vascular resection significantly increased the need for blood transfusion (42.2% vs. 18.1%, $p < 0.01$) [39]. A prospective, multicenter international study on pancreatic surgery was conducted in 2021 across 52 countries and 317 centers. The study found that vascular involvement significantly increased the need for intraoperative blood transfusion. Patients who underwent vascular resection were about twice as likely to require transfusion (OR: 2.06, 95% CI: 1.69–2.51). However, vascular involvement was not significantly associated with clinically relevant postoperative bleeding (OR: 0.87, 95% CI: 0.60–1.26) [40]. There is also a significant difference between arterial and venous resection. The rate of postoperative bleeding (PPH B or C) following arterial resection was significantly greater at 36.8% compared with the 7.9%

Table 3. Characteristics and odds ratio of studies reporting the association between neoadjuvant chemotherapy and PPH.

Reference	Year	Study type	Sample size	OR (or risk difference), 95% CI, and p-value for PPH with neoadjuvant chemotherapy
Pan et al. [36]	2026	Retrospective multicenter case-control study (pre-existing pancreatic fistula)	100 patients	OR: 8.28 95% CI: 2.41–28.44 $p < 0.001$
Van Dongen et al. [37]	2022	Multicenter randomized trial	164 patients	Risk difference: 4.0% 95% CI: –4.2 % – 12.2% $p = 0.35$
Kamarajah et al. [38]	2020	Systematic review and meta-analysis	9 studies (of 24 studies with 19,893 patients)	OR: 0.73 95% CI: 0.39–1.37 $p = 0.3$

Abbreviation: OR, odds ratio.

observed after venous resection (χ^2 test, $p = 0.01$) [41]. The higher bleeding risk associated with arterial compared with venous resection likely reflects the higher intraluminal pressure and greater technical complexity of arterial reconstruction [41]. Adjusted multivariable regression analysis indicated that pancreatoduodenectomy with vein resection, whether performed with direct or graft repair, was associated with higher rates of overall morbidity (OR: 1.50 for direct, 1.74 for graft, $p < 0.05$) and bleeding (OR: 2.18 for direct, 3.26 for graft, $p < 0.05$) [42]. To sum up, the results indicate that while vascular resections are often necessary in pancreatic surgery to achieve complete resection, they come with a higher risk of needing transfusions during the operation and facing complications afterward. Careful indication and watchful perioperative management are central to treatment success.

Operative Time. A longer operative time tends to indicate more complex pancreatic resections, which are associated with higher blood loss and a higher risk of complications such as POPFs [33]. In an analysis of 500 major pancreatic resections, longer operative time was significantly associated with severe PPH (ISGPS Grade C) (OR: 1.003, 95% CI: 1.001–1.006 per additional minute, $p = 0.018$) in multivariate analysis. At the same time, POPF was the most important cofactor [43]. The influence of the operative time on bleeding and transfusions was also investigated in a multicenter, retrospective cohort of 1188 elective distal pancreatectomies (2014–2018). Patients with PPH had a median operating time of 240 minutes compared to 185 minutes in uncomplicated patients ($p < 0.001$). In the multivariate analysis, operating time remained an independent risk factor (OR: 1.006 per minute, 95% CI: 1.004–1.010, $p < 0.001$) [44]. Overall, prolonged operative time is unlikely to be an independent causal driver of bleeding; rather, it most plausibly serves as a surrogate marker for surgical complexity and evolving intraoperative complications such as fistula, which independently predispose to bleeding through tissue trauma and localized inflammation.

Strategies to Reduce Intraoperative Blood Loss

Preoperative

Patient Blood Management. Preoperative anemia is an adjustable factor in pancreatic surgery. The treatment of preoperative anemia plays an important role in blood loss, transfusion requirements and short- and long-term outcomes. Approximately one-third of the patients are anemic prior to pancreatic surgery [27,45,46]. Affected patients undergo perioperative red blood cell transfusions at higher rates compared to non-anemic patients [27,45,47]. Moreover, preoperative anemia has been independently associated with increased postoperative morbidity and with shorter short-and long-term survival, effects that remain partially independent of transfusion [27,45,47,48]. Importantly, preoperative anemia, and iron deficiency anemia in particular, is amenable to targeted treatment prior to surgery. Intravenous iron supplementation in iron-deficient patients has been shown to increase preoperative hemoglobin levels, reduce surgical site infection rates and potentially decrease transfusion requirements [46]. When administered three to seven days before pancreatoduodenectomy, intravenous iron is associated with faster postoperative recovery of hemoglobin and iron stores, notably even in patients without preoperative anemia. This was associated with a shorter intensive care unit stay, suggesting a benefit beyond correction of anemia itself [49]. Preoperative anemia therefore represents a modifiable risk factor that warrants systematic assessment and treatment within a structured patient blood management (PBM) protocol, which prepares patients for surgery and minimizes blood transfusion requirements. A 10-year retrospective cohort study comparison between mature-PBM and pre-PBM cohorts revealed a reduction in transfused units per 100 discharged patients, with a 53% decrease for packed red blood cells (from 155 to 73, $p < 0.0001$), an 81% decrease for plasma (from 79 to 15, $p < 0.038$) and a 75% decrease for platelets (from 10 to 2.5, $p < 0.005$). Clinical outcomes improved, with a decrease in composite morbidity events from 16.4% to 7.4% ($p < 0.0001$). Mortality and length of hospitalization stay were unchanged [50]. An Italian single-center study with 1302 abdominal tumor surgeries confirms this trend after the introduction of PBM [51]. In practice, a structured PBM pathway could reasonably comprise three elements: preoperative iron or anemia screening with correction where feasible, intraoperative measures, such as ensuring proper blood clotting, processing wound blood back to the patient and a restrictive approach to transfusion in hemodynamically stable patients and postoperative restriction of transfusions with early reassessment of hemoglobin status [52].

Tranexamic Acid. Tranexamic acid (TXA) is a synthetic derivative of the amino acid lysine that acts as an antifibrinolytic by inhibiting plasminogen activation. The efficacy of TXA administration in reducing blood loss and transfusion requirements has been demonstrated. In a variety of surgical procedures across different surgical disciplines, particularly orthopedics and cardiac surgery, TXA reduced the probability of receiving a blood transfusion (OR: 0.62, 95% CI: 0.58–0.65) [53]. A meta-analysis from 2022 showed that TXA reduces the need for perioperative blood transfusions in liver resections and transplants (OR: 0.09, 95% CI: 0.01–0.72) [54]. Furthermore, another study showed that tranexamic acid (TXA) reduced combined bleeding events in hepatopancreatobiliary surgery (OR: 0.55, 95% CI: 0.34–0.91, n = 332) [55]. However, another study showed that TXA did not reduce blood transfusions or bleeding in liver resections, but was associated with more severe bleeding complications, which calls into question its routine use and necessitates further research on its use in HPB cancer surgeries [56]. Nevertheless, the benefit of TXA in the context of pancreatic surgery has so far been scarcely investigated [53]. It is postulated that cancer patients are at increased risk of thromboembolic events due to their underlying disease, as well as immobilization and surgical interventions [57]. Among solid malignancies, patients with PDAC have the highest risk of venous thromboembolism [58], reflecting a hypercoagulable state characterized by increased procoagulant activity, reduced anticoagulant function and impaired fibrinolysis [59]. However, there is no evidence for an actual increase in the incidence of thromboembolic events with the use of TXA. A systematic review and meta-analysis found no association between TXA use and the risk of thromboembolic events at the recommended dose [60]. Dosing in pancreatic surgery has not been specifically established and would likely need to draw experience from other surgical fields. Given some uncertainty around its safety profile in hepatobiliary procedures, routine use in pancreatic surgery does not currently appear warranted outside a study setting.

Surgical and Technical Approaches

Vascular Control: Prophylactic Falciform Ligament Wrapping Around the Hepatic and Gastroduodenal Arteries.. The prophylactic falciform ligament wrapping consists of placing the mobilized falciform ligament around the hepatic artery and fixing it with sutures, so that it acts as a protective cuff to shield the artery from postoperative complications like POPF or abscess formation [61]. It may be particularly worth considering in patients judged to be at elevated risk of POPF. A prophylactic falciform ligament wrap around the hepatic artery may reduce the risk of PPH (Table 4, Ref. [61,62]). In a randomized clinical trial (PANDA trial), 407 patients were examined in the per-protocol analysis. While the modified ITT with 417 patients was not able to show significance (OR 0.39, 95%CI: 0.15–1.02, $p = 0.071$), the per-protocol analysis showed a significant reduction from 7.2% to 2.0% (OR: 0.26, 95% CI: 0.09–0.80) in PPH [61]. However, the significant benefit was observed only in the per-protocol analysis, while the modified ITT analysis was not statistically significant. In contrast, a retrospective single-center analysis of 196 pancreatoduodenectomies (39 with falciform ligament wrapping) reported a PPH incidence of 7.7% in the wrapping group versus 9.6% without wrapping, a difference that was not statistically significant [62].

Artery-First Approach Versus Standard Pancreatoduodenectomy. The "artery-first" approach is a surgical technique that involves exposing and dissecting the superior mesenteric artery before dividing the pancreas and nearby tissue. The aim is to improve assessment of resectability, minimize intraoperative blood loss, optimize mesopancreatic clearance and increase the probability of achieving R0 resection [63]. Two meta-analyses looked at this topic using very similar primary studies. Because of this overlap, only the more recent analysis was chosen for the main evaluation, while the other was used for context. In 13 studies involving 1261 patients, the mean intraoperative blood loss was significantly reduced in the artery-first group, with a mean difference of –389 mL (95% CI: –542 to –237, $p < 0.001$). Additionally, in ten studies with 972 patients, fewer patients in this group needed intraoperative transfusions, 10.6% (54 of 508) compared to 40.1% (186 of 464) in the control group. The risk ratio was 0.27 (95% CI: 0.16–0.46, $p < 0.001$) [64]. The second meta-analysis also demonstrated this trend, showing a blood loss of –345 mL (95% CI: –477 to –213 mL) [65]. Both meta-analyses are consistent, indicating that an artery-first approach significantly improves perioperative blood management and reduces transfusion needs [64,65]. Standardized implementation of this technique is, in our view, best suited to centers with adequate case volume and experience given its technical demands.

Table 4. Characteristics and odds ratios of studies reporting the effect of falciform ligament wrapping on PPH incidence.

Reference	Year	Study type	Sample size	PPH incidence (wrap)	PPH incidence (control)	OR and 95% CI, *p*-value
Welsch et al. [61]	2021	Randomized clinical trial	407 (per protocol population)	2.0% (Grade B or C)	7.2% (Grade B or C)	OR: 0.26 95% CI: 0.09–0.80 p = 0.017
Müssle et al. [62]	2017	Retrospective	196	7.7%	9.6%	p = 1.000

Open vs Minimally vs Robotic Surgery

Distal Pancreatectomy. A network meta-analysis [66] examined perioperative outcomes of different surgical approaches to distal pancreatectomy, particularly robotic, laparoscopic and open. Both robotic distal pancreatectomy (RDP) and laparoscopic distal pancreatectomy (LDP) resulted in significantly less blood loss compared with open distal pancreatectomy (ODP). The mean blood loss was reduced by 279.45 mL (95% CI: –318.23 to –240.61) for RDP versus ODP and by 248.99 mL (95% CI: –283.41 to –214.57) for LDP versus ODP. In this analysis, no significant difference in blood loss was detected between RDP and LDP [66]. Furthermore, both minimally invasive techniques were associated with significantly lower transfusion rates than ODP. The likelihood of requiring a transfusion was substantially reduced for RDP versus ODP (OR: 0.25, 95% CI: 0.19–0.34) and for LDP versus ODP (OR: 0.30, 95% CI: 0.24–0.37) [66]. Another network meta-analysis from 2019 confirmed these results [67]. Nevertheless, the demographic differences that patients must meet to be assigned to the respective groups are discussed: "significantly younger patients with smaller size tumors were included in the RDP and LDP cohorts compared to the ODP cohort" [67]. Overall, minimally invasive distal pancreatectomy appears to be associated with lower blood loss and transfusion needs compared with open surgery, but these benefits should be interpreted with caution because patients in the RDP and LDP groups generally had more favorable baseline characteristics.

Pancreatoduodenectomy. A systematic review from 2020 states that relative to open pancreatoduodenectomy (OPD), both laparoscopic pancreatoduodenectomy (LPD) and robotic pancreatoduodenectomy (RPD) were associated with a significantly lower estimated intraoperative blood loss (29 studies) (mean difference –148.5 mL, 95% CI: –156.5 to –140.5 and –158.5 mL, 95% CI: –169.2 to –147.9, respectively) and a reduced incidence of postoperative bleeding (23 studies) (RR: 0.64, 95 % CI: 0.48–0.81 and RR: 0.67, 95% CI: 0.42–0.82, respectively) [68]. Further meta-analyses confirmed reduced blood loss and transfusion requirements with RPD vs OPD [69]. Similar selection bias may also affect studies evaluating minimally invasive pancreatoduodenectomy.

In summary, network meta-analyses and systematic reviews indicate that, for both distal resections and pancreatoduodenectomy, minimally invasive approaches (laparoscopic and robotic) are associated with lower blood loss and reduced transfusion requirements compared with open surgery. Robotic surgery may offer particular advantages, but these appear strongest in high-volume centers [66] and in carefully selected, less complex cases, as many studies included younger patients with smaller tumors.

Prevention and Management of PPH

Early Hemorrhage

Reoperation. Reoperations after pancreatic resections frequently occur due to bleeding or anastomotic leaks, often resulting in a complicated clinical course [70]. More than half of all reoperations are due to postoperative bleeding [71,72]. Reoperations are clearly associated with greater intraoperative blood loss and higher transfusion rates during the initial surgery, identifying significant blood loss during the first operation as an independent risk factor for the need for reoperation [70]. Reoperation itself does not cause the increased initial blood loss but rather reflects its consequences: greater blood loss leads to more complications, resulting in a higher reoperation rate and increased transfusion requirements [5]. Additionally, early revision is associated with a significantly better outcome than delayed reoperation [73,74]. Minimizing blood loss during the initial surgery is therefore crucial to reducing the need for reoperation and transfusions.

Late Hemorrhage

Interventional Radiology. Endovascular procedures such as embolization or stent grafts are currently the standard for delayed PPH. The technical success and hemostasis rates are high with both embolization and stent grafts. The procedures differ significantly in terms of their complication profiles and effects on organ perfusion.

In hemodynamically stable patients with predominantly arterial rebleeding, CT angiography is performed first, followed by preferred endovascular therapy via embolization or stent graft [75]. In a retrospective study, the technical success of interventional radiology was reported to range from 82% to 100% [76]. In a meta-analysis, the mortality rate for delayed PPH treated with interventional radiology was 22%, compared with 47% when treated with operative intervention (p = 0.02) [75], a trend supported by other reviews [3]. However, radiological interventions are not always possible: not every source of bleeding is angiographically visualizable and reinterventions are required in approximately 20–30% of cases [77,78]. Moreover, ischemic complications may occur following embolization. While stent grafts preserve organ perfusion more effectively, they too are associated with a risk of reintervention [78,79]. In contrast, in hemodynamically unstable patients or those presenting with massive early bleeding, relaparotomy typically remains the primary therapeutic option, potentially supplemented by intraoperative angiography or hybrid procedures [75,77]. Overall, prognosis is determined less by hemostasis alone than by associated complications, such as sepsis or fistula [78,80].

Discussion

International data indicate a trend toward lower transfusion rates during pancreatic resections, with a study of more than 19,000 patients reporting a significant 6.1% decrease in transfusion rate over the study period. The mentioned study even shows that the transfusion rate decreased despite decreasing preoperative hematocrit levels and increasing patient comorbidities. This is attributed, among other factors, to developments in surgical technique, improved perioperative management and the increasing implementation of PBM strategies [13]. Nevertheless, this trend is not uniform, as recent research shows. In some countries, transfusion rates have stagnated or even show signs of rising again. Furthermore, these studies indicate that social and structural differences in healthcare can affect whether a patient receives a transfusion, with regional and socioeconomic factors sometimes playing a role [11,24]. A major limitation of the current literature is the difficulty in establishing relationships between perioperative blood transfusions and long-term survival. Because transfusions are typically administered in response to clinical necessity, randomized trials directly comparing transfused and non-transfused patients are impossible to conduct for ethical and pragmatic reasons. Consequently, the current evidence is derived largely from observational studies and it remains unclear to what extent adverse outcomes are actually caused by the transfusion itself versus the severity of the underlying disease and the surgical procedure [23,25,81]. Propensity-score-matched analyses support this interpretation by reducing bias inherent to observational transfusion data. In our view, this reflects the fact that transfusion may often mediate rather than independently cause the association between risk factors. A distinction with direct implications for transfusion thresholds: rather than relying on fixed hemoglobin cutoffs alone, perioperative strategies should prioritize prevention and correction of anemia and minimization of blood loss upstream. Similarly, uncertainty remains about optimal transfusion thresholds, which are heterogeneous between regions, surgeons, and institutions, as well as the ideal timing of transfusion. In particular, there are currently no standardized recommendations for pancreatic surgical procedures, such as pancreatoduodenectomy, total pancreatectomy, or distal pancreatectomy [10,22,24]. Another research area concerns the efficacy of PBM programs, especially in pancreatic surgery. Although PBM concepts are well-established in many surgical fields, few prospective studies currently assess their use in pancreatic operations [82,83]. Key future steps include prospective PBM studies, for instance, evaluating optimal timing of preoperative intravenous iron supplementation relative to surgery date, procedure-specific transfusion thresholds that differentiate pancreatoduodenectomy from distal and total pancreatectomy, cost-effectiveness analyses of PBM implementation in high-volume centers, and randomized trials that better distinguish between cause and effect. This review was designed as a narrative synthesis from the outset, rather than a systematic review. No formal risk-of-bias assessment or certainty-of-evidence grading was performed, consistent with this narrative approach. Reported associations should therefore be interpreted as descriptive trends drawn from the individual studies cited, rather than as pooled effect estimates.

Conclusions

Blood loss and transfusion-related complications are associated with perioperative outcomes after pancreatic resection. Despite advances in surgery and perioperative management, studies still inconsistently define and report intraoperative blood loss. This inconsistency limits comparability across institutions, yet blood loss continues to be consistently associated with worse short- and long-term outcomes. For clinicians, preoperative identification and correction of modifiable risk factors, including anemia, anticoagulation and, if applicable, obesity, should be routinely integrated into perioperative planning. Patient blood management programs provide a structured and evidence-supported framework to reduce transfusion requirements and may improve selected clinical outcomes. Where oncologically feasible, minimally invasive approaches, the artery-first technique and prophylactic falciform ligament wrapping may reducte hemorrhagic risk. From a practical standpoint, management may reasonably be risk-adapted, although this stratification reflects clinical reasoning rather than validated risk scores. In patients without significant comorbidities, anticoagulation or planned vascular involvement, standard PBM screening and correction of anemia would likely be sufficient in most cases. In patients with additional risk factors such as obesity, antithrombotic therapy or planned venous resection, a more structured preoperative approach, including iron supplementation, individualized anticoagulation management and consideration of techniques such as the artery-first approach or falciform ligament wrapping, may be worth considering. In patients with the highest risk profile, such as those undergoing arterial resection or presenting with multiple combined risk factors, closer multidisciplinary coordination, including earlier involvement of interventional radiology and a lower threshold for early reoperation, could plausibly reduce the consequences of major bleeding, although this remains an area warranting further prospective evaluation. Future research needs to focus on prospective trials on PBM in this setting, as well as randomized designs capable of distinguishing the independent effect of transfusion from that of surgical complexity and disease burden.

Availability of Data and Materials

Not applicable.

Author Contributions

CT and AR conceptualized the review and performed the literature search. EN, LD, UR, and JK extracted data from the included studies and contributed to the synthesis of the literature. UR and JK additionally provided expert interpretation of the findings within their respective areas of expertise. CT drafted the manuscript. EN, LD, AR, UR, and JK critically revised the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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