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# Minimally invasive approaches in pancreatic cancer surgery

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**Summary** This literature review reflects the present evidence on minimally invasive pancreatic surgery, differentiating between distal pancreatic resection and pancreatoduodenectomy for pancreatic cancer. The review analyzed studies comparing minimally invasive and open pancreatic surgery in PubMed, the Cochrane Library, and the WHO Trial Register according to the following MeSH search strategy: MeSH items: pancreatic surgery, minimally invasive surgery, robotic surgery, laparoscopic surgery, pancreatoduodenectomy, and distal pancreatic resection. In systematic reviews and meta-analysis, minimally invasive distal pancreatectomy (MI-DP) has been shown to result in shorter hospital stays, less blood loss, and better quality of life than open distal resection (ODP) with similar morbidity and mortality. Meta-analyses have suggested similar oncological outcomes between the two approaches. Minimally invasive pancreatoduodenectomy (MI-PD) has been shown to offer advantages over open surgery, including shorter length of stay and less blood loss, by expert surgeons in several studies. However, these studies also reported longer operative times. As the procedure is technically demanding, only highly experienced pancreatic surgeons have performed MI-PD in most studies, so far limiting widespread recommendations. In addition, selection of cases for minimally invasive operations might currently influence the results. Registry studies from dedicated groups such as the European Consortium on Minimally Invasive Pancreatic Surgery (E-MIPS) and randomized controlled trials currently recruiting (DIPLOMA-1 and 2, DISPACT-2) will bring more reliable data in the coming years. In conclusion, both MI-DP and MI-PD have shown some advantages over open surgery in terms of shorter hospital stays and reduced blood loss, but their effectiveness in terms of oncological outcomes is uncertain due to limited evidence. The study highlights the need for further randomized controlled trials with larger sample sizes and registry studies to further evaluate the safety, efficacy, and oncological outcomes of minimally invasive pancreatic resections.

**Keywords** Minimally invasive pancreatic surgery · Pancreatoduodenectomy · Distal pancreatic resection · Pancreatic ductal adenocarcinoma · Robotic pancreatic surgery

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## Introduction

The pancreas was for a long time considered unsuitable for minimally invasive surgery (MIS), until Michel Gagner described the first laparoscopic pancreatic head resection (LPD) in 1994 [1]. Three years later, Alfred Cuschieri performed laparoscopic distal pancreatic resection (LDP) for chronic pancreatitis (CP) [2]. In recent years, there has been an increasing interest in the use of minimally invasive approaches in pancreatic surgery, and several studies have investigated their feasibility, safety, and efficacy [3–10]. Laparoscopic techniques have gained wide acceptance for distal pancreatic resections with/or without splenectomy. For pancreatic head resections, laparoscopic techniques were slowly adapted due to the complexity of the resection, but first and foremost due to the complexity of the reconstruction. Today, there is still limited evidence comparing laparoscopic approaches to open surgery in terms of long-term outcomes such as survival and quality of life. Furthermore, the described technical challenges and limitations associated with these approaches, such as the need for specialized equipment and expertise, have not led to widespread adaption of the techniques even though specialized centers have reported excellent results [4, 8, 11, 12]. Consequently, the use of a minimally invasive approach to pancreatic surgery has remained a controversial and debated topic.

The operating procedures, complexity, and demand for distal pancreatic resection (DP), central pancreatic resection (CP), and pancreatic head resection (PD) vary significantly. Pancreatic left-sided resection does not require reconstruction after the resection phase, while central resection requires one anastomosis and pancreatic head resection requires three to four anastomoses, making reconstruction particularly demanding. Unlike in colorectal or upper gastrointestinal surgery, where technical aids such as staplers can simplify minimally invasive reconstruction, there are no such aids available for pancreatic surgery. The pancreatic and biliodigestive anastomosis still requires manual suturing of complex anastomoses, which is a demanding task that necessitates meticulous skills.

The aim of oncological surgery for pancreatic cancer differs from that of other types of pancreatic surgery. The focus lies on achieving a radical approach that ensures sufficient removal of lymph nodes and an R0 resection margin to achieve the best oncological outcomes. Due to the varying locations and stages of tumor diseases, oncological resection for pancreatic cancer may involve vessel resection or reconstruction and multivisceral resections. The feasibility of minimally invasive pancreatic surgery (MI-PS) in achieving these outcomes needs to be demonstrated in such cases.

Our literature review aims to examine the current evidence regarding minimally invasive pancreatic surgery, with a particular focus on distinguishing between distal pancreatic resection and pancreatoduodenectomy, with applications specifically for pancreatic cancer.

## Methods

To provide a comprehensive summary of the current evidence on minimally invasive pancreatic surgery (MIPS), we conducted a narrative review of the literature using PubMed, the Cochrane Library, and the WHO Trial Register as the main sources. We compared studies that evaluated minimally invasive and open pancreatic surgery for pancreatic cancer, using the following keywords in various combinations: pancreatic surgery, minimally invasive surgery, robotic surgery, laparoscopic surgery, pancreatoduodenectomy, distal pancreatic resection. This review presents an overview of the current literature, including relevant randomized controlled trials, registry studies, observational studies, meta-analyses, and expert group consensus guidelines on the topic of minimally invasive pancreatic surgery for pancreatic cancer.

Since the first laparoscopic pancreatic resection was performed, there has been a steady increase in the number of studies investigating this procedure. However, due to significant differences in surgical techniques, particularly in the reconstruction phase, we believe that a combined analysis of the surgical methods for pancreatoduodenectomy and distal pancreatectomy would not be clinically or scientifically meaningful. Therefore, we have conducted separate technical analyses and evaluations of the data on each surgical method, to provide a more accurate and meaningful comparison.

## Results

### *Minimally invasive distal pancreatic resection (MI-DP)*

Several systematic reviews and meta-analyses of single-center retrospective studies have demonstrated the benefits of minimally invasive distal pancreatic resection over open surgery [3, 13, 14]. These benefits include a shorter hospital stay and reduced blood loss. Currently, three randomized controlled trials have been published comparing MI-DP to ODP (Table 1).

The LEOPARD trial published in 2019 is a large multicentric RCT that supported the findings from non-randomized single-center experiences. In this multicenter patient-blinded randomized controlled trial, MI-DP was compared to ODP. In summary, 108 patients from 14 centers with all kinds of pancreatic tumors (benign, premalignant, malignant) were included. The authors demonstrated faster functional recovery by 2 days (4 days [interquartile range (IQR) 3–6] vs. 6 days [IQR 5–8]; $p < 0.001$), less operative blood loss (150 ml vs. 400 ml; $p < 0.001$), and less serious delayed gastric emptying (DGE; grade B/C 6% vs. 20%; $p = 0.04$), but longer operative times (217 min [IQR 135–277] vs. 179 min [IQR 129–231]; $p = 0.005$) in the MI-DP group. The quality of life (QoL) within the first 3–30 days was better in the MI-DP group. There was no evaluation of oncological parameters like overall survival (OS) and disease-free survival (DFS), or of pathological parameters like resection margin (R) und lymph node harvest [15].

In a randomized single-center study by Björnsson et al., the duration of hospital stay after MI-DP and ODP was evaluated. This trial confirmed the findings of the other studies, with a shorter hospital stay after MI-DP (5 days [IQR 4–5] vs. 6 days [IQR 2–6]; $p = 0.002$). Oncological parameters (OS and DFS) and pathological parameters (R and lymph nodes) were also not sufficiently investigated this trial [16]. In 2021, Korrel et al. published the long-term data from the LEOPARD trial again with a focus on QoL of the pa-

**Table 1** Table of published randomized controlled trials comparing laparoscopic to open surgery for distal pancreatic resection and pancreatoduodenectomy

| Author | Date | Title | Publication |
|---|---|---|---|
| *Published on minimally invasive distal pancreatic resection* | | | |
| Korrel et al | 2021 | Long-Term Quality of Life after Minimally Invasive vs Open Distal Pancreatectomy in the LEOPARD Randomized Trial | [13] |
| Björnsson et al | 2020 | Comparison of the duration of hospital stay after laparoscopic or open distal pancreatectomy: randomized controlled trial | [12] |
| De Rooij et al | 2019 | Minimally Invasive Versus Open Distal Pancreatectomy (LEOPARD) | [11] |
| *Published on minimally invasive pancreatoduodenectomy* | | | |
| Wang et al | 2021 | Laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours: a multicentre, open-label, randomised controlled trial | [31] |
| Van Hilst et al | 2019 | Laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours (LEOPARD-2): a multicentre, patient-blinded, randomised controlled phase 2/3 trial | [30] |
| Van Hilst et al | 2019 | The inflammatory response after laparoscopic and open pancreatoduodenectomy and the association with complications in a multicenter randomized controlled trial | [29] |
| Poves et al | 2018 | Comparison of Perioperative Outcomes Between Laparoscopic and Open Approach for Pancreatoduodenectomy | [28] |
| Palanivelu et al | 2017 | Randomized clinical trial of laparoscopic versus open pancreatoduodenectomy for periampullary tumours | [27] |

tients. Interestingly, the authors could demonstrate that there were no significant differences in QoL between the groups in the long run. On closer evaluation, it seemed that the effect of MI-DP on QoL dissolves at day 30. Only the cosmetic satisfaction was higher in the MI-DP group [17].

Sulpice et al. conducted a study using French healthcare databases in 2015 and found that only a small percentage (12.6%) of PDAC patients underwent minimally invasive surgery [18]. These findings were further supported by a propensity score-matched analysis of the German Pancreas Register by Wellner et al., who found that in Germany, only 13% of PDAC patients underwent MI-DP [19].

A large meta-analysis and review of five case–control studies by Ricci et al. comprising 261 patients compared MI-DP to ODP for PDAC and found no significant differences in terms of R0 resection rates, harvested lymph nodes, overall morbidity, and eligibility for adjuvant treatment. Furthermore, the study confirmed the previously reported benefits of MI-DP, such as shorter hospital stay and less blood loss [20]. To evaluate the effectiveness of MI-DP for PDAC treatment, a subsequent Cochrane Review was conducted. This review included 11 non-randomized studies with a total of 1506 patients, all of which were retrospective cohort-like or case–control studies. The Cochrane Group found no statistically significant differences in terms of short- and long-term mortality, serious adverse events, pancreatic fistula (POPF), recurrence at maximal follow-up, or positive resection margins. Mean length of hospital stay was reduced by 2.4 days in the laparoscopic group. However, the overall quality of evidence was very low because of the high number of observational studies in the collective and the consequently high risk of confounding bias [7].

The most current landmark study for evaluation of minimally invasive distal pancreatic resection in comparison to open resection is the DIPLOMA trial. This pan-European study compared MI-DP to ODP for PDAC using propensity score matching and involved 1212 patients from 34 centers in 11 countries. After matching, 340 patients underwent MI-DP, and 340 patients underwent ODP. The results of the study showed that both procedures had similar overall survival rates, but MI-DP had the advantage of less blood loss (200 ml vs. 300 ml; $p = 0.001$) and a shorter hospital stay (8 days vs. 9 days; $p < 0.001$). The pathological outcomes, however, showed higher R0 resection rates (67% vs. 58%; $p = 0.019$) for the MI-DP group. The authors also found that the MI-DP group had fewer harvested lymph nodes (14 vs. 22; $p < 0.001$) and less frequent resection of Gerota's fascia compared to ODP [21]. Long-term results and survival data are pending.

Currently, two meta-analyses have been published comparing robotic distal pancreatic resection (RDP) with LDP for PDAC. The first metanalysis included six retrospective studies out of which five were single-center studies and one was a multicenter study. A total of 572 patients (152 RDP, 420 LDP) were analyzed. In summary, the results indicated that the RDP group exhibited higher R0 resection rates compared to the LDP group (OR: 2.96; 95% CI 1.78–4.93; $I^2 = 36\%$; $p < 0.00001$). However, there were no significant differences between the two groups in terms of operative time, tumor size, and harvested lymph nodes [22].

A recent international study conducted by members of the E-MIPS compared 542 patients (103 RDP, 439 LDP) from 33 centers in 11 countries. They found that RDP and LDP had comparable R0 resection rates (75.7% vs. 69.3%; $p = 0.404$). However, RDP was associated with a longer operative time (290 vs. 240 min; $p < 0.001$) more vascular resections (7.6% vs. 2.7%; $p = 0.030$), a lower conversion rate (4.9% vs. 17.3%; $p = 0.001$), more major complications (26.2% vs. 16.3%; $p = 0.019$), improved lymph node yield (18 vs. 16; $p = 0.021$), and longer hospital stay (10 vs. 8 days; $p = 0.001$) than LDP [23].



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**Table 2** Table of ongoing randomized controlled trials comparing minimal invasive (MI) to open surgery for distal pancreatic resection (DP) and pancreatoduodenectomy (PD)

| Trial Number | Title | Expected end |
|---|---|---|
| *Ongoing MI-DP* | | |
| NCT03957135 | Laparoscopic versus Open Distal Pancreatectomy for Pancreatic Cancer: a Multicenter Randomized Controlled Trial | November 30, 2025 |
| NCT04483726 | Distal Pancreatectomy, Minimally Invasive or Open, for Malignancy (DIPLOMA) | July 9, 2025 |
| ISRCTN44897265 | Distal pancreatectomy, minimally invasive or open, for malignancy | May 1, 2024 |
| KCT0004176 | Multicenter Prospective Randomized Controlled Clinical Trial for Comparison between Laparoscopic and Open Distal Pancreatectomy for Ductal Adenocarcinoma of the Pancreatic Body and Tail | November 30, 2023 |
| NCT03792932 | Laparoscopic vs Open Pancreatectomy for Body and Tail Pancreatic Cancer | January 31, 2022 |
| ChiCTR1900024648 | A randomized controlled study for the short-term oncologic outcomes of robot-assisted radical and open antero-grade modular pancreaticosplenectomy | November 30, 2020 |
| ISRCTN26912858 | Laparoscopic versus open distal pancreatectomy (LAPOP): study protocol for a single center, nonblinded, random-ized controlled trial | January 31, 2020 |
| DRKS00014011 | Distal Pancreatectomy of a randomised controlled trial to compare open versus laparoscopic resection (DISPACT 2-TRIAL) | Not reported |
| ChiCTR2000038933 | Robotic versus open radical antegrade modular pancreatosplenectomy for pancreatic cancer of the body and tail: a multicenter, randomized controlled trial | Not reported |
| NCT03770559 | The Therapeutic Evaluation (Both Short-term and Long-term Outcome) of Minimal Invasive Radical Antegrade Modu-lar Pancreatosplenectomy for Left-sided Pancreatic Cancer Patients (MIRROR) | Not reported |
| *Ongoing MI-PD* | | |
| NCT03785743 | Comparising Laparoscopic and open surgery for pancreatic carcinoma | March 1, 2026 |
| NCT04171440 | Comparison of Perioperative Outcomes Between Minimally Invasive and Open Pancreaticoduodenectomy | July 1, 2024 |
| ChiCTR1900024788 | Robotic Pancreaticoduodenectomy (RPD) versus Open Pancreaticoduodenectomy (OPD) in the long-term oncologic outcomes (LR301PD1): a randomized controlled trial | September 1, 2021 |
| NCT03870698 | Comparison of Functional Recovery Between Laparoscopic and Open Pancreaticoduodenectomy | July 1, 2021 |
| NCT03747588 | The Comparision of Laparoscopic and Open Pancreaticoduodenectomy for Pancreatic Cancer (LOPA) | December 30, 2020 |
| NCT03138213 | Comparing Total Laparoscopic Versus Open Pancreaticoduodenectomy | September 1, 2020 |
| NCT03722732 | Comparison of Blood Loss in Laparoscopic vs Open Pancreaticoduodenectomy in Patients With Periampullary Carci-noma | December 1, 2019 |
| DRKS00020407 | Evaluation of robotic versus open partial pancreaticoduodenectomy of a randomised controlled trial (EUROPA) | Not reported |
| NCT04400357 | Robotic Versus Open Pancreaticoduodenectomy for Pancreatic and Periampullary Tumors (PORTAL) | Not reported |
| ChiCTR1900028686 | A prospective randomized controlled trial for the effects of laparoscopic and non-laparoscopic surgery on pancreas islet function | Not reported |
| ChiCTR2000038932 | Robotic versus open pancreatoduodenectomy for pancreatic or periampullary tumours: a multicentre, patient-blinded, randomised controlled trial | Not reported |
| NCT05463328 | Open Versus Laparoscopic Assisted Pancreaticoduodenectomy | Not reported |

### Minimal invasive pancreatoduodenectomy (MI-PD)

Several studies have shown that expert surgeons can successfully and safely perform the technically demanding MI-PD procedure (feasibility) [24–30]. Currently, there are many ongoing randomized controlled studies comparing MI-PD with OPD (see Table 2). In a comprehensive meta-analysis of 19 comparative studies and two register studies with a total of 19,996 patients, the E-MIPS consortium found that MI-PD resulted in shorter hospital stays, less blood loss, and delayed gastric emptying (DGE) compared to OPD. However, the quality of the included cohort studies was low, which introduces potential biases [6]. Currently, five randomized controlled trials evaluating laparoscopic pancreatoduodenectomy have been published on the topic (Table 1; [31–35]). The second study conducted by van Hilst, which investigated the inflammatory response after LPD and OPD, is a sidearm study of the LEOPARD-2 patient cohort and was therefore excluded from most subsequent meta-analysis [33].

The first randomized clinical trial from Palanivelu was published in 2017 (PLOT trial). The PLOT trial was a single-center study which compared LPD to OPD. In total, 64 patients were randomized, 32 to each group. Only patients with resectable periampullary (cholangiocarcinoma, duodenal, ampullary, and pancreatic head cancer) were included. All procedures were performed by only two very experienced surgeons with more than 25 minimally invasive procedures. The follow-up was 90 days. The trial showed a shorter hospital stay (7 days vs. 13 days; $p=0.001$), less blood loss (250 ml vs. 401 ml; $p<0.001$), and less blood transfusion (3 vs. 7; $p=0.034$) for the LPD procedure. Postoperative complications were comparable for both procedures except for fewer surgical site infections in the LPD group (12.5% vs. 25%; $p=0.015$). Histopathological analysis showed comparable results for resection margins, number of harvested lymph nodes, and tumor size, but the LPD group had a lower incidence of perineural invasion (19% versus 28%; $p=0.002$) [31].

Poves et al. conducted the second RCT, which was published in 2018. This trial, the PADULAP study, was also a prospective single-center RCT that compared the perioperative outcomes of LPD to OPD for patients with various histologies, including benign, premalignant, and malignant disease. The LPD procedures were performed by only one single expert surgeon. The primary endpoint of this study was the length of hospital stay (LOS). A total of 66 patients were included in the study, with 34 in the LPD group and 32 in the OPD group. The study found no statistically significant differences between the two groups in terms of pathological findings such as resection margin, number of lymph nodes, tumor size, grade of differentiation, perineural invasion, and lymphovascular invasion. The majority of patients in both groups had a malignant diagnosis, with 75% in the LPD group and 86.2% in the OPD group, although this difference was not statistically significant ($p=0.88$). Regarding the primary endpoint, LPD showed a shorter LOS compared to OPD (13.5 days vs. 17 days; $p=0.024$). In addition, LPD demonstrated benefits in terms of fewer severe postoperative complications compared to OPD (Clavien-Dindo classification [CDC] grade 3–5: 15.6% vs. 37.9%; $p=0.048$). Pancreas-specific complications, including pancreatic fistula (POPF), delayed gastric emptying (DGE), and postpancreatectomy hemorrhage (PPH) were not significantly different. Consistent with other studies, the LPD group had a significantly longer operative time compared to the OPD group (460 min vs. 365 min; $p=0.000$) [32].

Van Hilst et al. in 2019 performed the first multicentric randomized controlled trial (LEOPARD-2) that was defined to evaluate levels of inflammatory cytokines after open or laparoscopic PD. The LEOPARD-2 trial was performed in four centers in the Netherlands that each performed a total 20 or more PDs annually. All participating surgeons had performed more than 50 advanced laparoscopic gastrointestinal procedures, including a dedicated training program for laparoscopic distal and pancreatic head resection (LAELAPS). Prior to inclusion, the surgeon had to have performed 20 or more LPDs. This trial was designed as a phase 2/3 study. For the phase 2 component the primary outcome was cytokine IL-6 levels after surgery. The primary outcome of the phase 3 component was time to functional recovery, defined as a composite endpoint of adequate pain control (only oral analgetic), independent mobility, daily oral food intake greater than 50% of required daily calories, no fluid administration, and no signs of infection. The follow-up was 90 days. The trial enrolled a total of 105 patients, including 42 in phase 2 and 63 in phase 3, with 54 patients undergoing LPD and 51 undergoing OPD. 15% (3 of 20) of the patients in the LPD group died within 90 days in phase 2, while none of the patients in the OPD group died. Discussion of these discrepancies in the safety and monitoring board still led to a continuation of the study to phase 3. Due to a higher mortality rate within 90 days in the laparoscopic group (mortality LPD: 5/50; 10%) compared to the open group (mortality OPD: 1/49; 2%) and a risk ratio of 4.90 (95% CI 0.59–40.44; $p=0.20$), the trial was recommended for premature termination by the data and safety monitoring board. The evaluation of the available data indicated no significant difference between the LPD and OPD groups in terms of histopathological results such as resection margin and number of lymph nodes. It is worth noting, however, that the proportion of resected PDAC was 28% in the LPD group and 31% in the OPD group.

In 2021, Wang et al. published the latest and second multicenter randomized controlled trial, which compared LPD and OPD across 14 Chinese pancreatic centers for periampullary tumor entities (including malignant, premalignant, and benign cases). This study involved highly experienced surgeons with a minimum of 104 LPDs performed. The primary outcome was LOS. A total of 656 patients were randomized, with 328 patients in each group. The LPD group had a significantly shorter LOS than the OPD group by one day (15 days vs. 16 days; $p=0.02$). There were no significant differences between the two groups in terms of 90-day mortality, morbidity, and pancreas-specific complications.

## Discussion

The present review evaluates the evidence for the effectiveness and safety of minimally invasive surgery (MIS) for distal pancreatectomy (DP) and pancreatoduodenectomy (PD) in the treatment of pancreatic cancer. The results of this review suggest that MIS for DP and PD is a safe and feasible approach that provides advantages over open surgery. The question of the oncological safety of MIS for pancreatic cancer cannot be answered to a high level of evidence and requires further investigation.

The advantages of minimally invasive surgery (MIS) in pancreatic left-sided resection are well established but cannot be simply transferred to pancreatic head resection (PD). One of the major challenges in adopting MI-PD is the complexity of the reconstruction phase. Unlike in colorectal surgery, where circular staplers can be used for anastomosis, and in pancreatic left resection, where no reconstruction is necessary, PD requires at least two anastomoses to be sutured manually, namely pancreatic anastomosis and biliodigestive anastomosis. This technically demanding task requires a high level of expertise and manual skill in open and especially in MIS surgery. In addition, a high level of proficiency in pancreatic surgery is required. As a result, MI-PD by laparoscopic techniques has not yet gained widespread acceptance in the surgical community, despite the proven benefits of MIS in other types of surgery in expert hands. Expert surgeons have successfully performed the technically demanding MI-PD procedure in several studies. Although four published randomized controlled trials (RCTs) have compared LPD to OPD, there are currently no published RCTs comparing the robotic approach to OPD or LPD. However, studies are ongoing and the results from RCTs comparing robotic pancreatoduodenectomy (RPD) with OPD such as the EUROPA trial are still running and will provide further insights into the benefits and risks of RPD [36].

Pfister et al. conducted a meta-analysis comparing MI to open pancreatic surgery, which included six RCTs (four to PD and two to DP) with a total of 984 patients. The results showed similar mortality, morbidity, and pancreas-specific complications between the MI and open surgery groups. For all groups (MI-PD and MI-DP), this metanalysis demonstrated a shorter LOS and less blood loss but longer operative time in the MI group. The subgroup analysis that looked at PD and DP separately put the benefits into perspective: MI-PD showed fewer surgical site infections (OR 0.35 [95% CI: 0.12–0.96]; $p = 0.04$) and blood loss (131 ml [95% CI: 173–89]; $p < 0.00$) but no difference in LOS. However, the operative time was significantly longer in MI-PD (75 min, 95% CI: 42–108; $p < 0.000$) while there was no difference in the MI-DP group [37]. The clinical relevance of the benefits observed in MI-PD herein remains uncertain to date. While many studies report lower blood loss, the median values of the difference reported are between 100 and 150 ml, and may therefore not be clinically significant [31, 32, 34, 35]. Currently, there is a lack of studies that establish the threshold at which blood loss becomes clinically significant. Only in the study from Palanivelu et al. was a difference in the number of transfused blood packages demonstrated. Fewer blood cell packages were transfused in the LPD group (3 vs. 7; $p = 0.034$) [31]. The remaining previously reported RCTs did not specify the amount of transfused blood packages [32, 34]. In summary, the RCTs show a slight advantage for MI-PD. However, it remains questionable whether this advantage justifies the long learning curve with increased risk and prolonged surgery time. It is important to note that the study situation is based solely on the results from experienced pancreas specialists. Therefore, recommending broad application based on these results is not advisable.

Pancreatic resection is known to have a negative impact on patients' quality of life after the operation and in the postoperative period [38–43]. Minimally invasive approaches are believed to offer potential im-

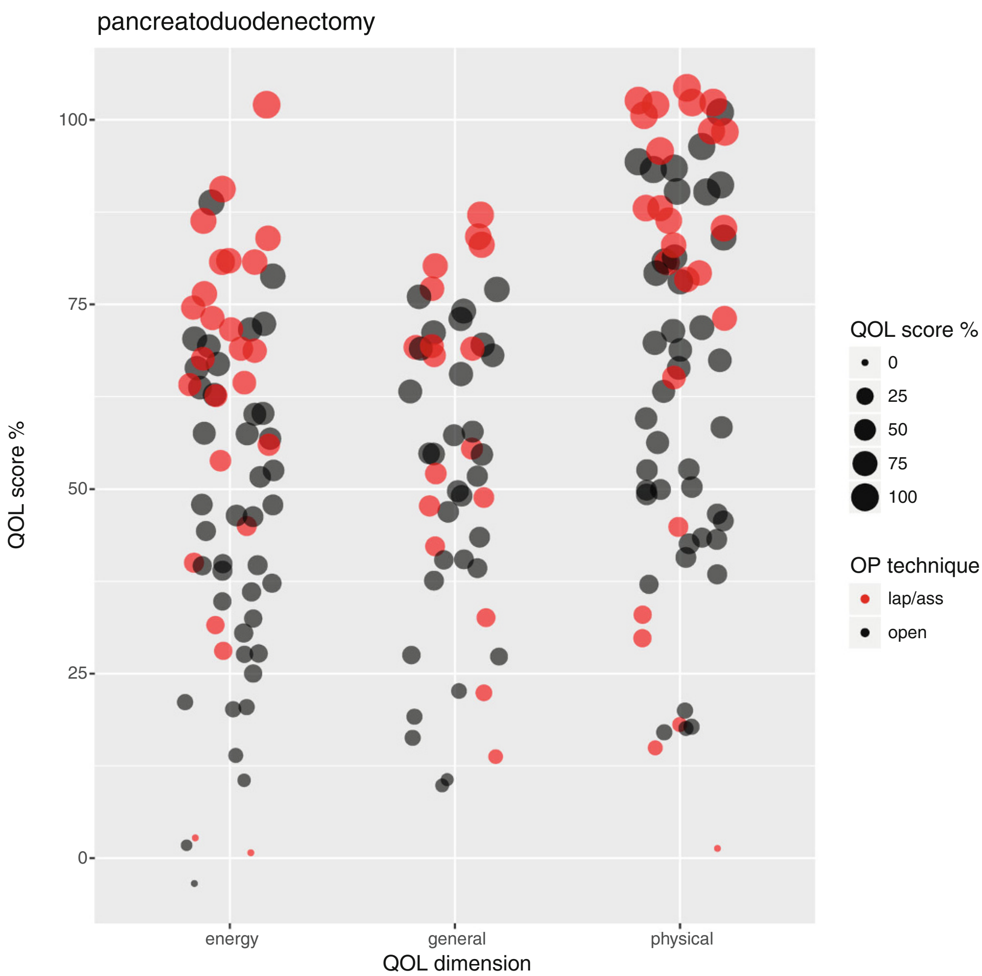


**Fig. 1** Bee swarm bubble plot: comparison of the quality of life analysis (*QOL*) between the operative access laparoscopic (*lap/ass*) versus open. Three of nine dimensions of the SF-36 are shown. Energy (emotional well-being); general (general health); physical (role limitations due to physical health); lap/ass: hybrid technique for LPD: laparoscopic resection and open reconstruction via minilaparotomy

provements, similar to what has been seen in colorectal surgery. In a study by Torphy et al., the quality of life for patients who underwent minimally invasive pancreatic resection was compared to those who underwent open resection. The study showed that both procedures had comparable quality of life outcomes [12]. This confirms the findings of Korrel et al., who compared the long-term QoL after MI-DP to ODP in the LEOPARD trial. The authors reported better QoL in the MI-DP group during the first 30 days postsurgery, but this effect was no longer observed in the long term [17]. Also, our own experience shows better quality of life after MI-PD in three of nine dimensions of QoL observed (Fig. 1; [39]).

Robotic surgery is a promising development in MI-PS due to its ability to improve dexterity and range of motion, facilitating the technically demanding anastomosis required during MI-PD and resulting in easier, more accurate, and more skillful procedures. Robotic pancreatic surgery is therefore seeing a much faster adaption than has laparoscopic pancreatic surgery. Although there are currently no published RCTs comparing RPD to LPD or OPD approaches, there are four ongoing RCTs (Table 2).

Despite the lack of RCTs, there are four consensus guidelines providing statements on laparoscopic, minimally invasive, and robotic pancreatic surgery, based on the available evidence [44–47]. The latest consensus meeting on pancreatic surgery took place in Brescia in 2022, but results have not been published to date. The latest available consensus data therefore originate from the Miami guidelines in 2020. These guidelines recommend that both MI-PD and OPD are valid approaches for selected patients with periampullary and pancreatic ductal adenocarcinoma. Several studies have shown similar oncological outcomes, and there have been no differences in 30- and 90-day mortality rates. However, no recommendations could be given for the use of MI-PD in cases of advanced pancreatic head cancer with vascular resection, or after neoadjuvant treatment, due to the lack of comparative data [44]. Due to the complexity, the Miami guidelines also addressed the learning curve. These guidelines not only emphasized the importance of implementing training programs but also defined the relationship between center volume and the number of surgical procedures performed. The study observed improvements in the LPD learning curve after 10–50 cases and for RPD after 20–40 cases. Moreover, a decreased complication rate was seen in centers performing >20 PD/year. Mortality rates decreased from a volume >10 PD/year [44].

Several studies provide strong evidence that MI-DP results in a shorter LOS compared to ODP [7, 15, 16, 21]. In two RCTs, it was shown that MI-DP had shorter LOS, less blood loss, and better early postoperative QoL compared to ODP, with similar morbidity and mortality [15, 16]. The primary outcome of these studies was LOS or functional recovery. All periampullary entities were included and so a direct statement on the oncological outcome for PDAC could not be made without selection bias. Furthermore, there were no statements about surgical approaches like the radical antegrade modular pancreatosplenectomy (RAMPS).

The RAMPS technique has been shown to increase the R0 resection rate for left-sided pancreatic resections [48]. Minimally invasive RAMPS techniques are also possible in experienced hands [49, 50]. In the LEOPARD study, all MI-DP resections for malignant diagnoses were performed using the RAMPS method, demonstrating broad applicability [51].

The 2020 Miami consensus meeting on evidence-based guidelines recommended use of MI-DP for benign and premalignant entities, while PDAC cases were recommended only for expert hands [44]. At the time of the consensus, the DIPLOMA trial had not been published, but it later supported the consensus by showing higher R0 resection rates but lower lymph node harvest and less frequent resected Gerota's fascia in the MI-DP [21]. The lower resection rate of Gerota's fascia in the MI-DP group may be due to the parallel introduction of the standardized RAMPS method with MI-DP. A subgroup analysis of the DIPLOMA study showed an increase in the resection of Gerota's fascia from 18 to 30% during the study [21].

A meta-analysis by the E-MIPS consortium including of 21 studies with 11,246 patients also supported these findings, demonstrating similar overall survival, R0 resection rate, and use of adjuvant chemotherapy in both groups. MI-DP, however, resulted in a lower lymph node yield and patients with earlier staged disease (smaller tumors, less perineural and lymphovascular invasion), likely due to treatment allocation bias [52]. Two other meta-analyses have also suggested similar oncological outcomes between the two approaches [7, 53]. In summary, while MI-DP may be recommended for PDAC, there is still a selection bias for smaller tumors without vascular or other organ involvement. Additionally, there is currently no evidence on the use of MI-DP for vascular resection, and no studies have been identified to address this issue. Therefore, Therefore, further studies, in the best case RCTs, are needed to gather more information on this topic. Notably, there are two meta-analyses that specifically investigate the comparison between RPD and LDP for PDAC.

## Conclusion

Minimally invasive surgery (MIS) for pancreatic surgeries offers advantages over open surgery. However, it is important to consider the MI approach for DP and PD separately. MI-PD is technically challenging, and its widespread use limited due to the complexity of its reconstruction phase. Current literature suggests that MI-PD is feasible and safe in selected patients, but there are insufficient data to recommend it over OPD for widespread use. MI-PD should be limited to experienced surgeons in high-volume centers due to the long learning curve and the difficulty of the procedure.

Numerous studies have shown that MI-DP is associated with a shorter LOS and improved QoL compared to ODP. However, the evidence supporting the use of MI-DP in larger tumors involving vascular or other organs is limited, and further research is needed. Nonetheless, MI-DP is considered a viable option for smaller tumors without vascular or organ involvement.

Robotic surgery is a promising development of minimally invasive pancreatic surgery, enabling the technically demanding anastomosis required during MI-PD. Currently there are no published randomized controlled studies comparing robotic pancreatoduodenectomy (RPD) to laparoscopic (LPD) or open (OPD) approaches, but relevant and large RCTs are ongoing.

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