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Commentary

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Is robotic pancreaticoduodenectomy (PD) a valid alternative to open pancreaticoduodenectomy?

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Abstract
In recent years, minimally invasive pancreatic surgery (MIPS) has become increasingly popular and is now considered an important part of pancreatic surgery practice. Nevertheless, MIPS is feasible and safe only in high-volume centres, with good training of surgeons and good patient selection. This commentary aims to focus on the role of MIPS, in particular robotic pancreaticoduodenectomy, highlighting the advantages of the robotic approach in terms of early postoperative recovery, reduced postoperative complications, and comparable oncological outcomes.

Keywords: Robotic pancreaticodudoenectomy, minimally invasive surgery, pancreatic tumours

INTRODUCTION
In recent years, the role of minimally invasive pancreatic surgery (MIPS) has become increasingly popular, now representing an important part of pancreatic surgery practice. While the role of minimally invasive surgery (MIS) has been demonstrated and standardised for distal pancreatectomy[1], the role of minimally invasive pancreaticoduodenectomy (PD) is nowadays still debated, and this approach is reserved only for selected patients in highly specialised centres.

DISCUSSION

The first laparoscopic PD (LAP-PD) was performed in 1994 by Gagner *et al.*[2]. However, despite the increasing adoption of minimally invasive approaches in pancreatic surgery, LAP-PD still represents only a minority of pancreatic procedures. As a result, open pancreatoduodenectomy (OPD) remains the gold standard and the preferred technique in most centres, particularly for vascular and multivisceral resections. One of the main reasons for this reluctance compared to LAP-PD was the difficulty associated with this technique, characterised by a steep learning curve and requiring advanced skills in laparoscopic dissection and reconstruction. Lately, with the advent of robotic techniques, the number of PD procedures performed using a minimally invasive approach has increased. The robotic technique offers several advantages over laparoscopy, including improved precision through three-dimensional visualisation, seven degrees of motion, and elimination of hand tremors. On the other hand, the robotic approach involves high service and maintenance costs. Over the years, various randomised studies[3-5] have compared the outcomes of OPD and LAP-PD, with contrasting results. Some studies reported shorter hospital stays but longer operative times in the laparoscopic group, while others revealed higher complication rates with the laparoscopic approach [Table 1].

Following the publication of the laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours (LEOPARD-2) trial results[4], which showed that LAP-PD was associated with a higher rate of complication-related mortality compared to OPD, with no significant difference in time to functional recovery between the two groups, interest in LAP-PD slowed. Conversely, the interest in robotic PD (RPD) increased, leading to the publication of several trials.

The minimally invasive versus open pancreatoduodenectomy for pancreatic and peri-ampullary neoplasm (DIPLOMA-2) trial[6], an international randomised controlled study, was conducted in 14 high-volume pancreatic centres in Europe with a minimum annual volume of 30 minimally invasive pancreatico duodenectomy (MIPD) and 30 OPD. A total of 288 patients with an indication for elective PD for pre-malignant and malignant disease, eligible for both open and minimally invasive approaches, were randomly allocated for MIPD or OPD in a 2:1 ratio. Contrary to the LEOPARD-2, the DIPLOMA-2 trial demonstrated the non-inferiority of MIPD *vs.* OPD for overall complications and the superiority of MIPD regarding time to functional recovery[7]. This trial underlined the tight relationship between the outcomes of the patients and the high-volume centres. Moreover, the participating surgeons were required to have a minimum of 60 MIPDs and 60 OPDs of experience to participate in the trial.

At the same time, at the University Hospital Heidelberg in Germany, the robotic versus open partial pancreatoduodenectomy (EUROPA) trial was conducted[8].

The EUROPA trial confirmed that RPD was as safe as open surgery [90-day comprehensive complication index (CCI) of 34 *vs.* 36, respectively, $P = 0.713$]. However, this study did not demonstrate the usual benefits of minimally invasive approaches, such as reduced blood loss and shorter hospital stays.

In the same year (2024), Liu *et al.* published a multicentre, open-label, randomised controlled trial (RCT) conducted at three high-volume hospitals in China, showing that the postoperative length of hospital stay was significantly shorter in the RPD *vs.* the OPD group (11 *vs.* 13.5 days; median difference of 2 days; $P = 0.029$), as were times to functional recovery in robotic group (e.g., removal of nasogastric tube and off-bed activities: 2 *vs.* 3 days; $P < 0.001$)[9].

Table 1. Summary of RCTs comparing laparoscopic *vs.* open partial pancreatoduodenectomy

Studies	Type RCT	*N*	Hospital stay	POPF B/C	Mortality	Year published
PLOT	Monocentric	64	7 *vs.* 13 days (*P*: 0.001)	6% *vs.* 12% (*P*: 0.311)	1 *vs.* 1 (*P*: -)	2017
PADULAP	Monocentric	66	13.5 *vs.* 17 days (*P*: 0.024)	12.5% *vs.* 27.6% (*P*: 0.14)	0% *vs.* 6.9% (*P*: 0.29)	2018
LEOPARD-2	Multicentric	105	12 *vs.* 11 days (*P*: 0.86)	28% *vs.* 24% (*P*: 0.69)	10% *vs.* 2% (*P*: 0.20)	2019

RCTs: Randomised controlled trials; POPF: postoperative pancreatic failure; LEOPARD-2: laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours.

These results were confirmed in the PORTAL trial[10], which showed a shorter time to functional recovery (11.3 *vs.* 15.4, *P*: 0.029), less blood loss (*P*: 0.053), and lower rates of postoperative pancreatic failure (POPF) grade B/C (8.9% *vs.* 20.2%, *P*: 0.014) in the robotic group.

Therefore, almost all trials reported in the literature have affirmed the non-inferiority of RPD compared to OPD, supporting the use of MIS also for PD [Table 2].

Almost all the selected studies consider surgeries performed by trained surgeons, emphasising that the learning curve is essential for performing RPD. As reported by Jones *et al.*, RPD was feasible after 30-45 procedures, with proficiency achieved after 90 procedures. Moreover, the number of procedures performed was inversely correlated with major morbidity[11].

Furthermore, the phase 3 studies mentioned above demonstrated a statistically significant reduction in the incidence of clinically relevant (grade B/C) postoperative pancreatic fistula (CR-POPF)[7,10]. This finding was corroborated by subsequent studies, which also indicated that RPD is associated with a lower incidence of CR-POPF[11-13].

Specifically, Fuji *et al.*, in their retrospective study involving 204 patients, demonstrated that RPD was significantly linked to a lower incidence of CR-POPF in high-risk anastomoses[14].

The reason for the reduced incidence of CR-POPF in RPD still has to be assessed. However, it may be related to the technical advantages of the robotic platform. The robotic system provides enhanced magnified three-dimensional visualisation of small pancreatic ducts and wristed instruments can offer superior dexterity and manoeuvrability in a stable operating field with tremor filtration. These features facilitate more precise suturing during pancreatic anastomosis, potentially improving the quality of reconstruction, reducing the pancreatic tissue manipulation and thereby reducing the risk of CR-POPF.

Moreover, RPD has recently been demonstrated to be a suitable approach even for patients with locally advanced pancreatic adenocarcinoma following neoadjuvant treatment (NAT) as shown in the retrospective analysis by Kim *et al.*, which also reported comparable survival outcomes to OPD, along with shorter postoperative hospital stays and a lower incidence of postoperative complications[15,16].

On the other hand, one of the main factors currently limiting the adoption of robotic techniques is the high cost associated with this technology. Indeed, as reported in the EUROPA trial[8], RPD was more expensive than OPD in terms of both procedure-related and total hospital costs up to postoperative day 90. However, this finding has not been confirmed by other studies. In fact, as reported in the DIPLOMA 2 trial[7], the reduction of postoperative complications and hospital stay can offset the costs associated with the robotic platform, making the robotic approach a viable and affordable alternative to OPD in high-volume centres.

Table 2. Summary of RCTs: robotic *vs.* open partial pancreatoduodenectomy

Studies	Type RCT	*N* Total	Hospital stay	POPF B/C	Mortality	Year published
EUROPA	Monocentre	81	17 *vs.* 13 days (*P*: 0.177)	38% *vs.* 21% (*P*: 0.148)	0% *vs.* 9.1% (NS)	2024
Liu	Multicentre	164	11 *vs.* 14 days (*P*: 0.029)	14% *vs.* 13% (*P*: 0.84)	1% *vs.* 1% (*P*: 1)	2024
DIPLOMA-2	Multicentre	288	7 *vs.* 8 days (*P*: 0.02)	23% *vs.* 36% (*P*: 0.03)	4,6% *vs.* 2% (*P*: 0.26)	2023
PORTAL	Multicentre	237	11 *vs.* 15 days (*P*: 0.029)	9% *vs.* 20% (*P*: 0.014)	NA	2021

RCTs: Randomised controlled trials; POPF: postoperative pancreatic failure; EUROPA: robotic versus open partial pancreatoduodenectomy; DIPLOMA-2: minimally invasive versus open pancreatoduodenectomy for pancreatic and peri-ampullary neoplasm; NS: not significant; NA: not applicable.

This finding was also confirmed by Wakabayashi *et al.*, who supported the feasibility and potential advantages of adopting RPD for the management of periampullary neoplasms in clinical practice[12].

In conclusion, in high-volume centres with experienced and well-trained surgeons, RPD can be considered a viable alternative to OPD, offering reduced intraoperative blood loss, fewer postoperative complications, shorter hospital stays, and a lower incidence of CR-POPF. Nevertheless, robust long-term oncological data are still lacking, and further studies with extended follow-up are required to confirm these results. Emerging evidence also indicates a potential benefit in terms of postoperative quality of life and earlier return to daily activities, although these areas remain under-investigated. Furthermore, the robotic platform may play a significant role in surgical training, offering improved ergonomics, simulation modules, and support for complex reconstructions. Looking forward, the integration of ongoing RCTs, international registries, and new technologies, including next-generation robotic systems and artificial intelligence-based intraoperative support, will be crucial to fully establish the role of RPD in standard surgical practice.

DECLARATIONS

Authors' contributions

Data collection, review analysis, and manuscript writing: Belli A, Cutolo C
Study concept, design, and manuscript review: Belli A, Cutolo C, Izzo F, Valeriani M
Critical revision of the manuscript for important intellectual content: Izzo F
All authors have read and approved the final version of the manuscript.

Availability of data and materials

All data and materials are available online, corresponding to the cited references.

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Conflicts of interest

Belli A is both an Editorial Board Member of the journal *Mini-invasive Surgery* and a Guest Editor for the Special Issue *Pancreatic Surgery: From Minimally Invasive Techniques to Robotic Assistance*. Belli A was not involved in any steps of the editorial process, notably including reviewers' selection, manuscript handling, or decision-making. The other authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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