Abstract. Distal pancreatectomy with splenectomy is the gold-standard surgery for the treatment of left-sided pancreatic cancer. Margin negative resection accompanied by effective lymphadenectomy are the deciding factors affecting the outcome of tail-body pancreatic adenocarcinoma. Radical antegrade modular pancreatosplenectomy (RAMPS) is considered as a reasonable approach for margin-negative and systemic lymph node clearance. Herein, we aim to present all existing data regarding this novel approach including surgical technique and comparison with standardized procedures. RAMPS has shown oncological superiority comparing to distal pancreatectomy with splenectomy due to radical lymphadenectomy and improved dissection of the posterior pancreatic aspects. Robotic-assisted RAMPS has recently been described as a valuable alternative to open RAMPS. With this novel technique, anterior, posterior or modified approaches can be achieved; favorable clinical and oncological outcomes have been reported in the current literature, with reduced conversion rates compared to other minimally invasive approaches, as well as vastly improved maneuverability, accuracy and vision. Robotic-assisted RAMPS is not only technically feasible but also oncologically safe in cases of well-selected, left-sided pancreatic cancer.

Pancreatic cancer is the seventh leading cause of cancer-related morbidity worldwide, with annually increasing incidence. Despite all the advances in management and detection of pancreatic cancer, the reported 5-year survival rate still does not exceed 10% across all stages (1). Complete surgical resection remains the mainstay of treatment for local and loco-regional disease; it is often combined with neoadjuvant or perioperative chemotherapy with or without radiotherapy (2).

Left-sided pancreatic tumors are often considered more lethal compared to those of the pancreatic head, due to lack of specific clinical symptoms and delayed diagnosis (3). Distal pancreatectomy and splenectomy (DPS) are considered the gold-standard surgical approach for the treatment of left-sided pancreatic adenocarcinoma. Radical antegrade modular pancreatosplenectomy (RAMPS) is a novel variation of DPS, described by Strasberg et al. in 2003, which attempts to achieve wider tangential retroperitoneal resection margins (4).
Minimally invasive surgery for pancreatic cancer is on the rise worldwide. Since the first report of laparoscopic-assisted pancreaticoduodenectomy in 1994 by Gagner et al. (5), laparoscopic distal pancreatectomy was firstly performed in 1996 by Cushiery et al. (6). Subsequent reports of laparoscopic distal pancreatectomy during the 1990s presented its safety and efficacy for the treatment of chronic pancreatitis and benign tumors (7). In 1998, Cushiery et al. concluded that laparoscopic distal pancreatectomy can provide favorable outcomes, reduce postoperative complications, as well as a shorten the length of hospital stay (8); Park et al. in 1999 commented that patients undergoing laparoscopic distal pancreatectomy have significant benefits compared to those undergoing open surgery (9).

Following that, and during the first decade of the 20th century, laparoscopic DPS was established as an effective surgical therapy for the treatment of left-sided pancreatic malignancies (10-12).

In 2003, Melvin et al. published the first report of the first robotic distal pancreatectomy (13); subsequently, Guilianotti et al. presented the first series of robotic-assisted distal pancreatectomies (14). They concluded that utilization of robotic-assisted DPS provided acceptable rates of post-operative morbidity (20%) with no reported mortality in their cohort of eight patients. Numerous publications that followed compared laparoscopic DPS to robotic-assisted DPS and showed similar profiles of safety and feasibility for the two methods, with oncological adequacy (15-18).

In 2012, Choi et al. first reported their novel technique of robotic-assisted RAMPS for the treatment of tail-body pancreatic adenocarcinoma as an effective alternative to LDPS to overcome all limitations and technical difficulties for improved outcomes (19). Ever since, there has been a growing interest in this approach and all the benefits that it has to offer, combining all the advantages of robotic-assisted surgery with radical resection and the favorable oncological profile of RAMPS.

Herein, we aimed to present and discuss all current evidence on robotic RAMPS, including surgical technique and comparison with standardized techniques such as open and laparoscopic RAMPS. This novel approach is safe and feasible, offering all the advances and accuracy of robotic surgery compared to other approaches, and may lead to a paradigm shift regarding the radical treatment of left-sided pancreatic tumors.

**RAMPS**

Left-sided pancreatic cancers (i.e., of the tail and body of the pancreas) are conventionally treated with standard, open, retrograde DPS. DPS is performed in a left-to-right direction with mobilization of the spleen followed by resection of the posterior aspect of the pancreas, directing from the pancreatic tail to the body (20). On the contrary, DPS has been associated with high rates of positive tangential resection margins, devoid of lymph node drainage of the organ. To overcome these problems, Strasberg et al. in 2003 introduced a modified technique of DPS named rRAMPS (4), in which transection of the pancreas and dissection of the splenic vessels and a celiac lymph node dissection are performed first, followed by dissection in one of the two posterior dissection planes (anterior or posterior) proceeding from medial-to-lateral fashion, depending on the depth of invasion and extent of the tumor as presented by Zhou et al. (21).

R0 resection is the deciding factor determining survival in patients with pancreatic cancer. The posterior margin is the predominant site of margin invasion in left-sided pancreatic tumors (22). In 2010 Kooby et al. (23), followed by de Rooij et al. (24) in 2016, reported R0 resection rates between 50 and 74%, including both open and laparoscopic DPS for tail-body pancreatic cancer. On the contrary, Zhou et al. presented a R0 resection rate up to 88% following RAMPS in their meta-analysis (17), providing significantly superior oncological outcomes compared to standard DPS.

While no survival benefit of a more extensive lymphadenectomy has been observed for patients with left-sided pancreatic cancer, thorough pathological examination of lymph nodes may contribute to more accurate disease staging (21). The rationale for performing a more extensive dissection and lymphadenectomy had a significant impact following pancreatic resection with curative intent, according to Huebner et al. (25). In their study, patients with node-negative (N0) resection in whom the total number of resected lymph nodes was less than 11 had a significantly worse 3-year survival rate compared to patients with more than 11 lymph nodes excised (32% versus 50%, respectively). As a result, we can assume that metastasis to the loco-regional lymph nodes can be missed by sampling an insufficient number of lymph nodes. This can be attributed to the fact that during conventional DPS, the lymph nodes along the root of superior mesenteric artery (SMA) are not resected. On the contrary, RAMPS permits routine resection of these nodes as presented by Strasberg et al. (3).

**Surgical Procedures**

_Anterior approach._ The anterior approach for RAMPS involves entering the lesser sac through dividing the gastrocolic ligament and removing the omentum. The inferior pancreatic border is dissected, and the area above the superior mesenteric vein (SMV) is approached; tunneling under the pancreas and above the SMV (inferior aspect of the pancreas and anterior aspect of the SMV) is then performed, until the pancreas is dissected completely free from the portosplenic confluence (4). At this time, entrance to the lesser sac through the foramen of Winslow is achieved, and the common and
proper hepatic arteries, as well as the gastroduodenal arteries, are dissected free. The pancreas is then taped using either an umbilical tape or a vessel loop to facilitate stapler insertion and transection of the pancreatic parenchyma (10, 11, 25). Pancreatic transection should be performed slowly and into small sections of up to 3–4 mm each time in order to minimize pancreatic laceration and to minimize bleeding. Following pancreatic transection, the splenic artery and splenic vein are identified, dissected and divided at their origins. Lymph nodes along the superior border of the pancreas and the anterior border of the common hepatic artery beside the left gastric artery and the left border of the celiac axis are dissected. The plane of dissection is then headed vertically, beneath the posterior aspect of the pancreas, dividing all the adipose tissue until the SMA is identified. Following that, after exposure of the left border of the SMA is completed, the dissection plane is turned to the left, in an oblique plane that slopes posteriorly to the left. The superior border of the left renal vein and the anterior aspect of the aorta are then assessed, defining the inferior border of dissection. This inferior plane dissection from the medial to the lateral side is completed with identification and preservation of the adrenal vein and left adrenal. The dissection then continues laterally, with removal of Gerota’s fascia. The lienorenal ligament and spleno-phenic ligaments are then divided. The operation is then completed with en-bloc resection of the spleen, after ligation of the short-gastric vessels and mobilization of the spleen from its lateral attachments (4, 25, 26).

*Posterior approach.* The posterior RAMPS technique is similar to anterior RAMPS but includes more extensive dissection. Specifically, after exposure of the SMA the anterior border of the aorta is dissected, followed by the posterior border of the left renal vein. The procedure is continued with deeper into the abdomen, reaching up to the diaphragm and the retroperitoneal muscle layer. At this point, identification of the left renal artery is possible; left renal vein is fully dissected and exposed. From the medial to the lateral side, all adipose tissue behind the left adrenal gland and Gerota’s fascia are resected. The excised specimen includes the pancreas, spleen, omentum, left adrenal gland and most of the retroperitoneal adipose lymphovascular tissue (4, 26).

*Robotic RAMPS.* Patients are placed supine, in a split-leg step-reverse Trendelenburg position. The operation begins with a laparoscopy to rule out peritoneal or metastatic disease and to estimate the extent of the tumor (19). Five trocars are routinely placed, a 12 mm sub-umbilical port for the endoscope, a 12 mm port at the mid-clavicular line under the right hypogastrium, and three additional 5 mm ports at the left- and right-subcostal positions, as well as in the left hypogastrium. The stomach is lifted cranially, while the gastro-colic and gastro-splenic ligaments are divided using on energy device, followed by exposure of the pancreas. An extended Kocher maneuver is performed for mobilization of the transverse duodenum from the ligament of Treitz and above the superior mesenteric vessels (27). The superior and inferior pancreatic borders are recognized and dissected. Through the avascular plane below the posterior aspect of the pancreas and above the SMV, a tunnel is created for the division of the pancreas; a vessel loop or an umbilical tape is placed to facilitate a lift-up from the porto-mesenteric confluence (superior mesenteric vein-portal vein-splenic vein). The celiac axis is then identified and dissected, alongside lymphadenectomy around the common hepatic artery, left gastric artery and the origin of splenic artery. At this time, the coronary vein is dissected. Using endoscopic linear staplers, the pancreas can be transected with continuous firings. Ligation of the splenic artery at its origin is then performed, while the splenic vein is divided at the porto-mesenteric confluence. Dissection is then continued in a medial-to-lateral direction, including all the adipose tissue around the celiac trunk and the splenic vessels. The left renal vein is then identified and followed to the left (28). The anterior Gerota’s facia is removed, while the perirenal soft tissue and left adrenal gland are left intact. Consequently, the spleen is mobilized from its lateral attachments and the specimen is resected en-bloc.

**Discussion**

Bloodless and margin-negative resection is the deciding factor in the treatment of left-sided pancreatic cancer according to Kang et al. (29). Using this technique, the negative tangential margin rate was reported at between 80 to 94%, compared with 72 to 85% in standardized DPS in the recent study by Liu et al. (27). RAMPS showed a trend for improved oncological outcomes, compared to DPS (30).

Generally, the retroperitoneal dissection line in DPS can be divided into three levels according to Takagi et al. (31). At the first level, posterior dissection proceeds in front of the anterior Gerota’s fascia, a plane referred to in standard DPS. On the contrary, RAMPS facilitates retroperitoneal dissection posterior to the anterior Gerota’s fascia, as well as above (second level, anterior RAMPS) or behind (third level, posterior RAMPS) the left adrenal gland (31). Which approach of RAMPS is chosen should be determined based on the preoperative radiological images and depth of invasion. Yonsei criteria for resectability via minimally invasive RAMPS were introduced and adopted, as firstly stated by Lee et al., including tumors confined within the pancreas, with no invasion of the anterior Gerota’s fascia and with a distance of more than 2 cm from the celiac trunk (32). In recent years, development of minimally invasive surgery has made the application of laparoscopy in DPS for
left-sided pancreatic cancer feasible, which is associated with reduced intra-operative blood loss and length of hospital stay compared to standard open DPS (33, 34). It is well known that robotic surgery overcomes many inherent limitations of laparoscopic surgery, with its improved three-dimensional visualization and flexible manipulation (28). While there are numerous reports of robotic distal pancreatectomy for pancreatic cancer, scarce evidence exists regarding robotic-assisted RAMPS; only few reports have been published and from high-volume referral cancer centers (35).

Liu et al. first showed that robotic RAMPS is safe and effective for the treatment of tail-body pancreatic adenocarcinoma, with a reduced rate of conversion to open surgery (27). Lee et al., in their series of minimally invasive RAMPS including eight cases of laparoscopic RAMPS and four cases of robotic RAMPS, reported that robotic-assisted RAMPS was technically feasible and provided an oncological safe profile in cases of well-selected left-sided pancreatic cancer (33). In 2020, Napoli et al. described the detailed surgical technique for robotic RAMPS, which can facilitate the standardization and wider application of this novel procedure (36).

Recently, Takagi et al. presented their modified technique of anterior robotic RAMPS, with SMA approach; in their study, they concluded that this approach in performing robotic RAMPS offers a ventral view for determining the posterior margin of the pancreas in a relatively easy and safe way, allowing resectability to be assessed prior to the division of the pancreas as in other approaches (31). They proposed that robotic RAMPS has specific indications (31), including left-sided pancreatic tumors staged T1-3 and without distant metastasis. On the contrary, patients with tumor invasion to the arterial wall of celiac axis, superior mesenteric artery, or superior mesenteric vein, as well as of the common hepatic artery are not considered as candidates for robotic RAMPS.

Optimization of the surgical sequence and standardization of this approach can improve reproducibility, offering obvious anatomical landmarks guiding the resection. Patients should be wisely chosen; those with invasion to the superior mesenteric or celiac trunk will not be benefit from RAMPS; however, patients with tumor infiltration to the posterior pancreatic border or the anterior Gerota’s fascia or the adrenal gland may have a significant benefit from robotic-assisted RAMPS and radical resection.

Conclusion

To date, only limited data exist regarding robotic-assisted RAMPS, which reflects the novelty of this surgical technique. Consequently, and while it is too early to draw definite conclusions regarding the safety and efficacy of this approach, it can be considered a valuable alternative to well-established open or minimally invasive procedures. It may become the new norm in the near future, with the expansion of surgical innovation in the treatment of left-sided pancreatic adenocarcinoma. Patients with such tumors amenable to RAMPS have the valuable alternative of a robotic-assisted approach, which offers all the advantages of minimally invasive surgery. Due to a limited number of studies in the current literature and the lack of methodologically valid studies, such as randomized control trials, further evidence is needed to elucidate the role of robotic-assisted RAMPS and create a standardized, step-by-step, safe, and feasible technique that may lead to a paradigm shift in pancreatic cancer surgery.

Conflicts of Interest

All Authors declare they have no potential conflicts of interest.

Authors’ Contributions

Study conception and design: EK, SD, AC, GT, AP, EF, and NK. Acquisition of data: EK, SD, AC, EF, and NK. Analysis and interpretation of data: EK, SD, AC, GT, AP, EF, and NK. Drafting of article: EK, SD, AC, GT, AP, EF, and NK. Critical revision: EK, SD, AC, GT, AP, EF, and NK. All Authors approved the final version of the article.

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