Pushing the limits of pancreatic surgery; the quest for R0 resection through mesenteric principle and evolving vascular strategies

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Abstract

Background: Local recurrence is a major factor contributing to poor prognosis in pancreatic carcinoma, often driven by perineural invasion in the retro-pancreatic region. To improve R0 resection rates, surgical strategies have evolved toward more radical techniques, including total mesopancreatic excision, "triangle surgery," and routine consideration of vascular resection and reconstruction.

Objective: This review aims to elucidate the anatomical basis of mesopancreatic excision and to outline a comprehensive approach for incorporating vascular strategies into pancreatic cancer surgery, ensuring a balance between oncologic radicality and perioperative safety.

Methods: An extensive review of current anatomical data, recent clinical literature, and institutional surgical experience was performed. The analysis focuses on the role of the three fusion fascias (Treitz, Fredet, and Toldt), the concept of the mesopancreatic triangle, and the application of triangle surgery for complete mesopancreatic excision. It also examines the evolution of vascular resection and reconstruction from a previous contraindication to an essential component of modern oncologic surgery.

Results: Total mesopancreatic excision was found to be effective in removing retroperitoneal tissue containing potential microscopic disease. The planned use of vascular resection and reconstruction, supported by improved perioperative care, is now considered crucial in patients with venous or arterial involvement. Proper understanding and handling of fusion fascias during kocherization are vital to prevent tumor exposure, maintain oncologic planes, and define clear dissection boundaries. Advances in technique have also refined indications and execution of vascular reconstruction.

Conclusion: Expanding the limits of resectability in pancreatic cancer requires a shift from conventional methods to advanced mesopancreatic and vascular approaches. By integrating evidence-based knowledge with practical surgical expertise, this review offers a structured guide for residents and surgeons to manage the complexities of pancreatic oncology and achieve optimal R0 resection outcomes.

Keywords: Pancreatic cancer, mesopancreatic excision, vascular reconstruction, triangle surgery, R0 resection, fusion fascia.

Introduction

Pancreatic cancer treated with the Whipple procedure is frequently complicated by local recurrence remains the primary cause of poor outcomes in pancreatic carcinoma, often due to tumor spread through perineural invasion in the retro-pancreatic region.(1) To address this, surgeons have proposed total mesopancreatic excision and triangle surgery or the Heidelberg triangle (Büchler and Hackert). These techniques aim to clear retroperitoneal tissue that may harbor microscopic disease, potentially reducing recurrence rates.(2)

Historically, regional pancreatectomy involving vascular resection and reconstruction fell out of favor due to high morbidity and mortality. However, improved perioperative care has renewed interest in these extended resections. (3)While current guidelines (NCCN/ISGPS) classify porto-

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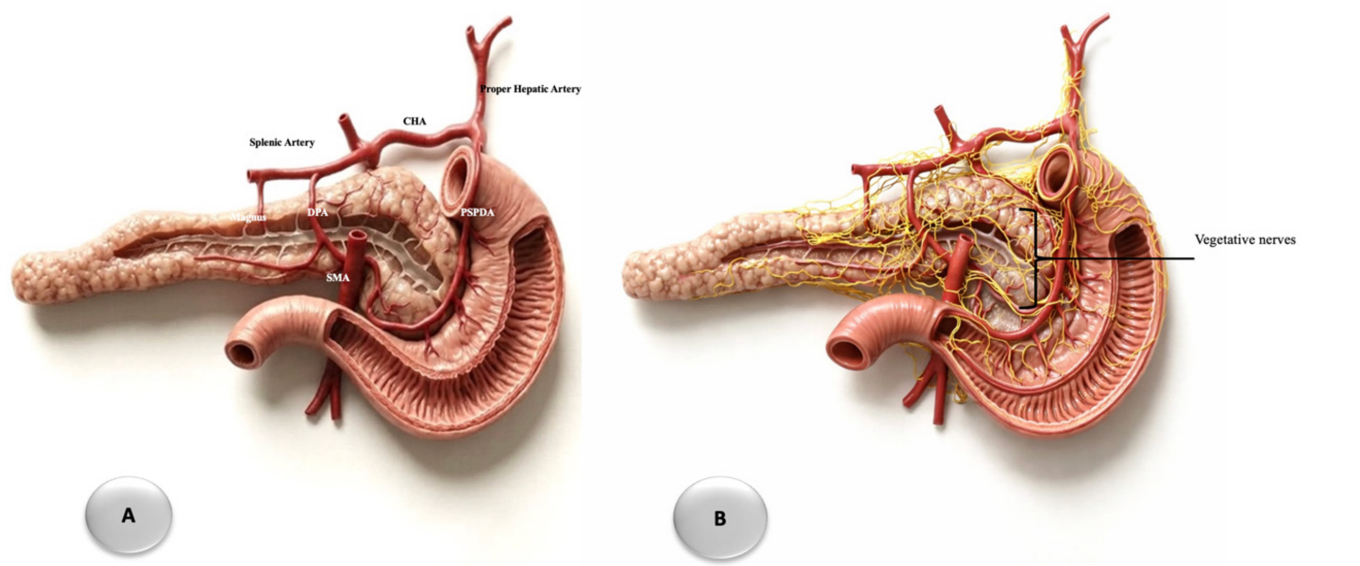

Figure 1: (A) Arteries of the pancreas and duodenum; (B) pancreatic and duodenal innervation, showing periarterial neuronal plexus along arteries and vegetative nerves traveling independently.

mesenteric venous resection as safe for borderline resectable cases, arterial resection is generally considered a criterion for unresectability.(4) Nevertheless, emerging evidence suggests carefully selected patients may benefit from arterial resection and reconstruction.

This review clarifies the concepts of mesopancreatic excision and triangle surgery, providing an overview of vascular management in pancreatic cancer surgery as a roadmap for residents and practicing surgeons.

FUSION FASCIA OF PANCREAS

Surgeons must understand the three fusion fascias around the pancreas—Fascia of Treitz, Fascia of Fredet, and Fascia of Toldt—which are a distinct entity from the mesopancreas. According to Kimura et.al. a sheet of fascia behind the head of the pancreas is called the Fusion Fascia of Treitz, while the fascia behind the body and tail is the Fusion Fascia of Toldt that becomes well-defined by 20 weeks of embryogenesis. Enveloping the parenchyma of posterior pancreas and lumphovascular structures, it forms a tough barrier for tumor to penetrate so, should be kept intact without breaching during kocherization.(5)

The Fusion Fascia of Fredet is a thin fascial sheet covering the anterior surface of the pancreas. It is thought to form during embryogenesis through the fusion of the dorsal mesogastrium with the dorsal mesocolon. Functionally, it serves as an adhesion plane between the visceral peritoneum of the mesocolon of the ascending colon and hepatic flexure and the visceral peritoneum of the duodenum and pancreas.(6)

CONCEPT OF MESOPANCREAS:

Pancreatic cancer is well known for its propensity for perineural invasion and lymphatic dissemination. Therefore, microscopic tumor deposits along the neural plexus of the pancreatic head, together with metastasis through surrounding lymphovascular tissue, are considered important contributors to local bed-site recurrence.

The term "mesopancreas" was first introduced by Gockel in 2002. This concept was based on the presence of a dense sheet of lymphovascular tissue and neural networks located posterior to the pancreas. This anatomical concept has been compared metaphorically to the mesorectum, a structure described in rectal cancer surgery by Bill Heald.(7)

In support of this concept, Gockel cited earlier anatomical work on the pancreatic neural network. The German anatomist H. Loweneck independently described this lymphovascular and neuronal tissue network in 1950 while studying the effects of vagotomy on pancreatic secretion.(7, 8) Similarly, the Japanese surgeon Yoshika independently reported a detailed study of the same neural network in 1957 in relation to the surgical management of chronic pancreatitis.(9) . According to H. Loweneck, pancreatic innervation arises from the vagus nerve

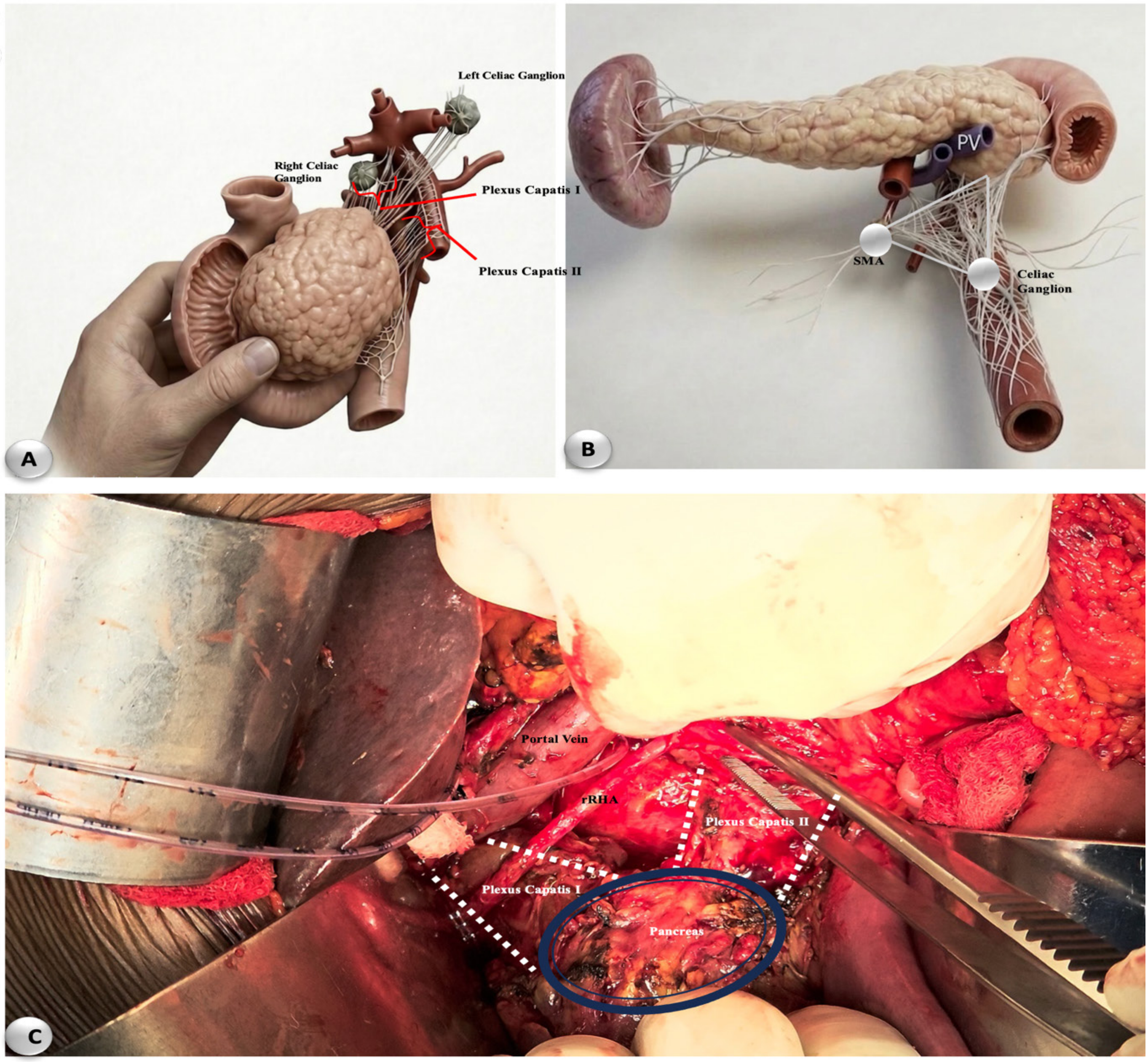

Figure 2: (A) Retraction of pancreatic head and duodenum during Whipple's surgery showing two plexuses as described by Yoshika et al.; (B) triangle illustration from the same publication hinting at its existence; (C) operative view of the plexus in one of our cases.

and mixed sympathetic fibers originating from the right and left celiac plexuses. These nerve fibers reach the head of the pancreas through three distinct pathways. The first group accompanies the arterial vessels and is termed periarterial nerves. The second group consists of nerves that travel independently (without accompanying vessel) for approximately 2–3 cm before entering the pancreas; these are referred to as the vegetative nerves. The third neural pathway runs along the bile duct and is known as the pericholedochal nerves.(8)

A similar description was later proposed by the Japanese surgeon Yoshika. He further subdivided the vegetative nerves into plexus 1 and plexus 2 where, Plexus 1 originates from the right celiac plexus and courses in a cranio-caudal direction toward the pancreatic head. In contrast, plexus 2 arises from the region of the superior mesenteric artery and travels within a sheet-like tissue plane extending to the posterior aspect of the pancreatic head before entering the pancreatic parenchyma. Thus, plexus 2 follows a horizontal, latero-medial trajectory.(9)

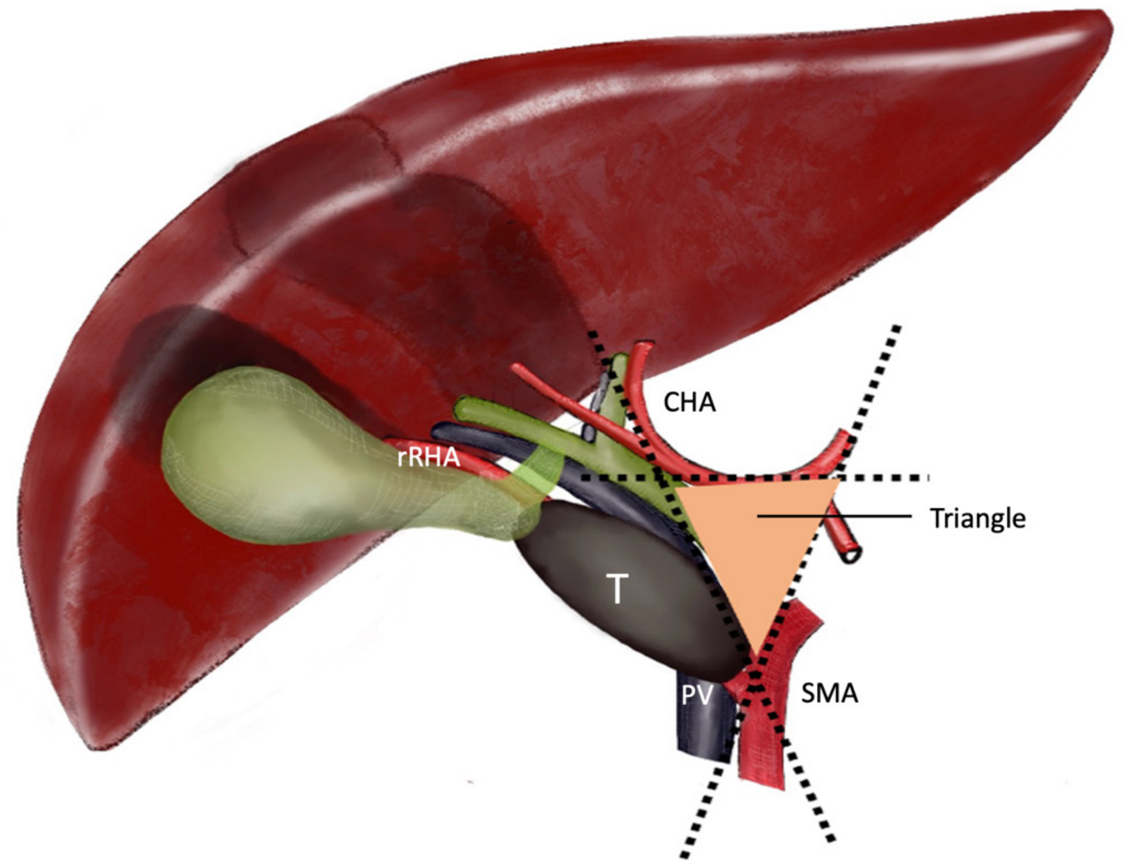

Figure 3: Boundaries for triangle operation formed by the common hepatic artery (CHA), portal vein (PV), and superior mesenteric artery (SMA); rRHA—replaced right hepatic artery., T-tumor invading rRHA.

This anatomical concept has been adopted by the Japan Pancreas Society and incorporated into both the 7th and 8th editions of its pancreatic cancer classification.(10) The sheet of tissue containing these neural plexuses, along with accompanying small vessels and lymphatic channels, is collectively regarded as the mesopancreas. Building on this concept, Gockel proposed that en bloc removal of this tissue, termed total mesopancreatic excision, may improve the likelihood of achieving an R0 resection in pancreatic cancer surgery.(7)

CONCEPT OF TRIANGLE OPERATION

With the introduction of the mesopancreas concept, many surgeons attempted to standardize total mesopancreatic excision (TMpE) by defining clear anatomical boundaries for en-bloc tissue removal. Early reports mainly focused on the feasibility, safety, and oncological outcomes of this procedure. In 2012, Michel Adham described the technique of mesopancreatic excision and proposed specific limits of dissection, introducing the concept of the mesopancreatic triangle.(11) According to this description, the triangle is inverted, with the porto-mesenteric vein (PV–SMV axis) forming its base and the apex located at the junction of the superior mesenteric artery (SMA) and the celiac trunk (CT). The mesopancreas is thus considered a triangular flap of tissue extending from the posterior surface of the pancreatic head behind the SMV/PV axis, forming an inverted triangle between the CT and SMA and covering their right semi-circumference.(11)

Later, in 2016, Markus W. Büchler and colleagues from Heidelberg University Hospital introduced the concept of “triangle surgery,” commonly referred to as the Heidelberg triangle. In this approach, the triangle is defined by the common hepatic artery (CHA), superior mesenteric artery (SMA), and portal vein (PV), and complete clearance of all tissues within this triangular space is considered essential.(12)

Conceptually, the mesopancreatic triangle described by Adham closely resembles the Heidelberg triangle. The main difference lies in the operative maneuver used to expose the triangle. In Adham's technique, the portal vein is lifted upward, creating an inverted triangular configuration, whereas in the Heidelberg approach the vessels are maintained in the same plane, with the portal vein retracted laterally toward the right, producing a flatter triangular operative field. Additionally, the Heidelberg triangle concept emphasizes systematic clearance of both neural plexus groups (Plexus I and Plexus II), whereas the Adham description does not clearly define the need for Plexus I dissection.

VENOUS MANAGEMENT

Moore et al. (1951) performed the first superior mesenteric vein resection and reconstruction during pancreaticoduodenectomy, demonstrating technical feasibility for locally advanced pancreatic cancer. Their work laid the foundation for modern vascular resections in pancreatic surgery.(13)

Child et al. (1952) and McDermott (1952) independently reported portal vein resection during pancreaticoduodenectomy. (14, 15) Child's study demonstrated both feasibility and physiological consequences using experimental monkeys and early human cases, while McDermott focused on the technical feasibility of a one-stage operation without evaluating physiological effects. Together, these studies laid the foundation for modern vascular resections in pancreatic cancer surgery.(14)

Porto-mesenteric vein resection has become standard practice in high-volume pancreatic centers, requiring pancreatic surgeons to have expertise in vascular surgery. Current guidelines state that tumor invasion of the porto-mesenteric vein can still be managed with venous resection and reconstruction with curative intent, and such cases are classified as borderline resectable disease.(16)

Table 1: Comparison of Borderline Resectable Pancreatic Cancer Definitions(4)

Vascular Structure	NCCN	AHPBA/SSO/SSAT	Alliance (Intergroup)	JPS (Japan Pancreas Society)
Superior Mesenteric Artery (SMA)	Tumor contact ≤180°	Tumor abutment ≤180°	Tumor–artery interface <180°	Tumor contact <180° without stenosis or deformity
Celiac Axis (CA)	Tumor contact ≤180° (especially for body/tail tumors)	No abutment or encasement	Tumor–artery interface <180°	Tumor contact <180° without stenosis
Common Hepatic Artery (CHA)	Tumor contact ≤180° or short-segment involvement without extension to CA or hepatic artery bifurcation; reconstruction feasible	Short-segment abutment or encasement amenable to reconstruction	Reconstructable short-segment involvement	Tumor contact without extension to CA or proper hepatic artery
SMV / Portal Vein	Tumor contact >180°, or ≤180° with contour irregularity or thrombosis if reconstruction feasible	Any abutment, encasement, or short-segment occlusion amenable to reconstruction	Tumor–vein interface ≥180° or reconstructable venous occlusion	Contact ≥180° or venous occlusion provided reconstruction feasible

Abbreviations: SMA – Superior Mesenteric Artery; CA – Celiac Axis; CHA – Common Hepatic Artery; SMV – Superior Mesenteric Vein; PV – Portal Vein, AHPBA – American Hepato-Pancreato-Biliary Association, SSO –

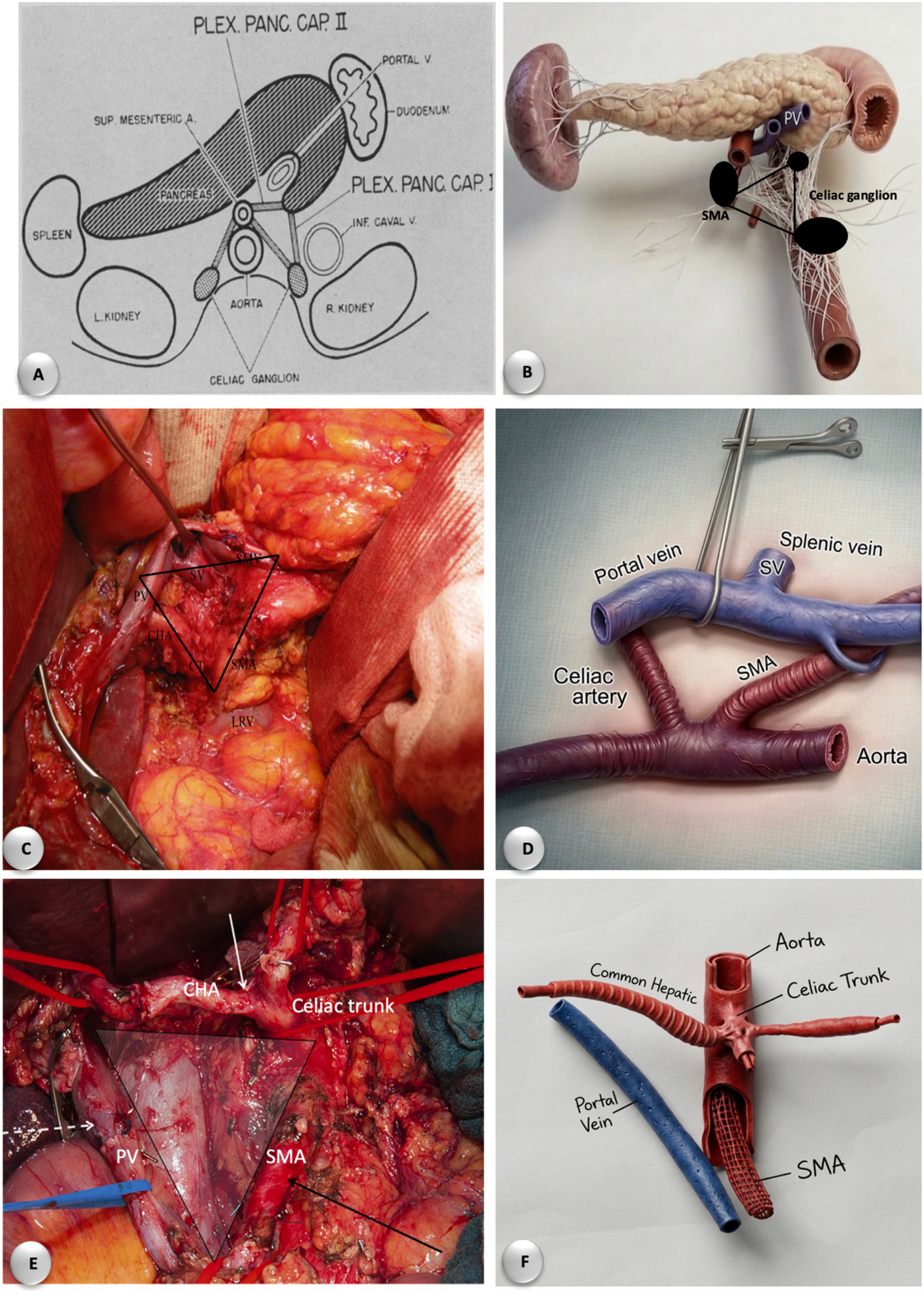

Figure 4: (A, B) Illustrations from Yoshika et al. (1950); (C, D) inverted mesopancreatic triangle described by Michael Adham et al. (2012); and (E, F) Heidelberg triangle as described by Büchler et al. (2017).

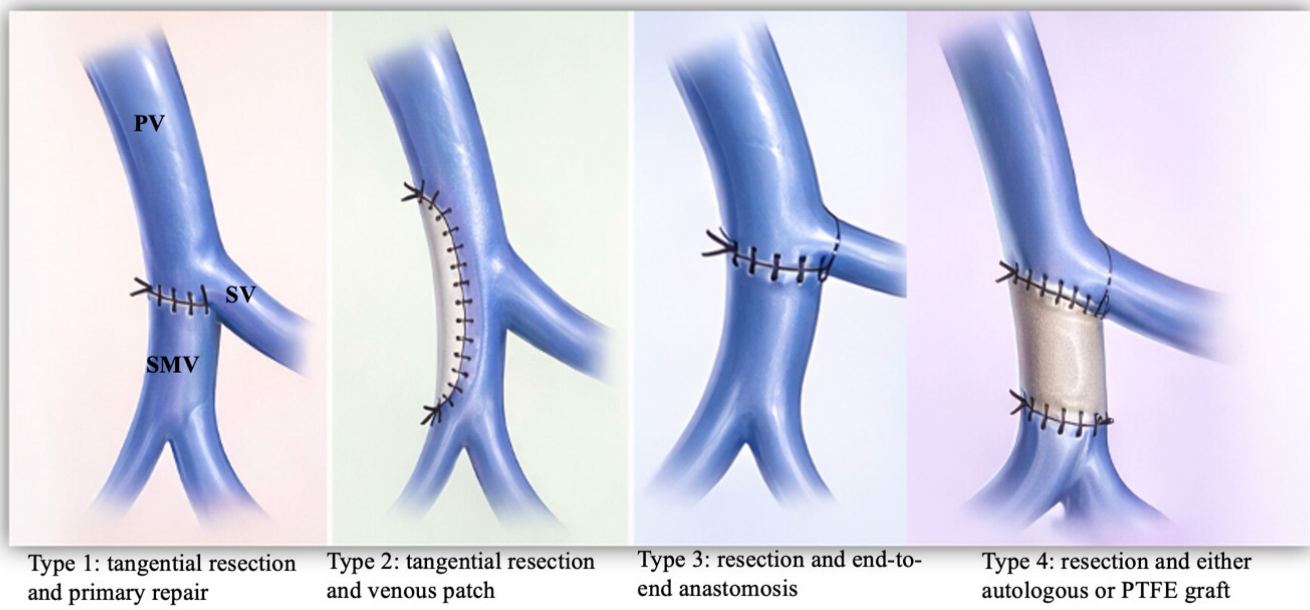

Figure: 5 Shows four different techniques of Venous resection and reconstruction as described by ISGPS

Society of Surgical Oncology, SSAT – Society for Surgery of the Alimentary Tract.

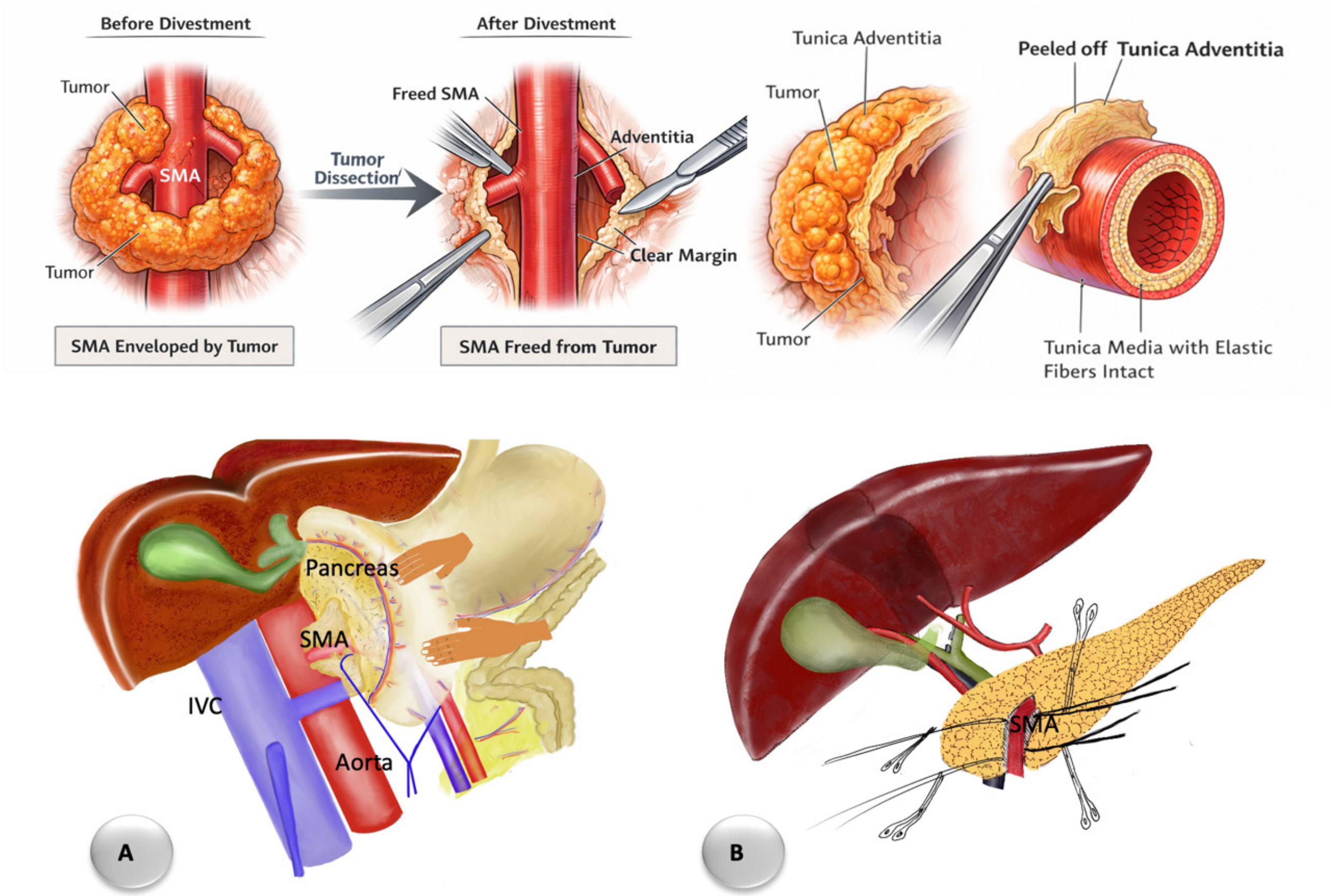

Figure 6: Upper panel shows SMA tumor encasement with peeling of tumor and adventitia; lower panel shows generous Kocherization to expose the SMA (A) and anterior divestment approach (B); IVC—inferior vena cava, SMA—superior mesenteric artery.

RADIOLOGICAL CLASSIFICATION OF VENOUS INVOLVEMENT

Isao Ishikawa and Atsushi Nakao described a detailed radiological classification of venous involvement in pancreatic carcinoma and proposed management strategies. Nakao and colleagues also developed an algorithmic approach for determining the indications for portal vein resection. Portal vein resection is recommended when it allows achievement of tumor-free surgical margins. However, it is not indicated if negative margins cannot be obtained despite resection. The procedure should also be performed safely without major perioperative complications while preserving postoperative quality of life.(17)

TYPES OF VENOUS RESECTION AND RECONSTRUCTION

The International Study Group of Pancreatic Surgery (ISGPS) categorizes venous resections into four types: Type 1 is partial resection with primary repair, Type 2 uses patch reconstruction, Type 3 involves segmental resection with end-to-end anastomosis, and Type 4 requires graft interposition for resections over 3 cm to avoid tension, using autologous or synthetic grafts.(18)

Splenic vein and first jejunal vein (J1) involvement adds complexity to porto-mesenteric venous resection. Chung-Yuan Tseng provided a detailed assessment of spleno-portal and J1 involvement, outlining criteria for pancreatoduodenectomy (PD). The extent of venous involvement alone did not preclude surgery. For splenic vein involvement, three strategies are described: first, primary reimplantation into the spleno-portal vein; second, simple ligation relying on collateral circulation via the gastroepiploic and other veins; and third, as a bailout, creating a lienorenal shunt or partial reimplantation into the inferior vena cava if venous congestion or bowel edema occurs. These approaches have been reported with variable outcomes.(19)

If vascular exclusion exceeds 20 minutes, it is advisable to intermittently clamp the SMA or perform a portal vein catheter bypass. Atsushi Nakao described using an antithrombogenic catheter, with the bypass routed to the femoral vein, to prevent portal congestion and hepatic ischemia during portal vein resection and reconstruction.(20)

IDEAL VENOUS RECONSTRUCTION(17, 20, 21)

1. The venous repair should be tension-free to avoid anastomotic narrowing or disruption.
2. Atraumatic handling of the tunica intima is essential, and the adventitia should be carefully trimmed to facilitate precise edge approximation.
3. The vessel lumen should be flushed with heparinized saline before completion of the anastomosis to remove debris and reduce thrombosis risk.
4. Topical lignocaine may be applied to relieve vasospasm and facilitate venous dilation when required.
5. The anastomosis should ensure accurate intima-to-intima apposition to maintain luminal continuity and minimize thrombogenicity.
6. As the porto-mesenteric venous system may dilate by up to approximately 150% after restoration of blood flow, a small growth allowance should be left in the anastomosis to accommodate this expansion.
7. Sequential release of vascular clamps should be performed after completing the anastomosis to allow flushing of air and possible thrombus.
8. If there is any concern regarding the adequacy of the anastomosis, the surgeon should not hesitate to revise or redo the reconstruction.
9. The procedure should only be concluded when the surgeon is fully satisfied with the integrity and patency of the venous reconstruction.

ARTERIAL MANAGEMENT

It is well established that achieving an **R0 resection** is essential for a curative pancreatectomy. When major arterial structures are involved, **arterial resection and reconstruction may be required** to obtain a margin-negative resection. In the classic textbook *Surgery of the Pancreas*, authored by Michael Trede and D. C. Carter, surgical strategies for periampullary carcinoma were historically categorized into three philosophical approaches: **nihilism, realism, and activism**.(22)

The nihilistic approach advocated a non-resectional strategy even for lesions considered operable at the time. This perspective was largely influenced by the historically high operative mortality associated with pancreaticoduodenectomy, which approached 30% in earlier eras. Some proponents of this view even suggested that legislative action whether "congress should pass a law making it illegal to perform Whipple surgery" and should be considered to prohibit the operation.(22)

At the opposite end of the spectrum was the activist approach, which supported aggressive surgical strategies whenever technically feasible. Advocates recommended extensive procedures, such as regional pancreatectomy and even cluster transplantation, in an effort to achieve radical oncologic clearance.

Between these extremes lay the realistic approach, which emphasized careful patient selection and attempted to define when surgical intervention was appropriate and when it was not.

With advances in surgical technique, perioperative care, and oncologic management, the philosophies of both the realistic and activist groups have evolved. Modern management has led to the stratification of pancreatic cancer into resectable, borderline resectable, and unresectable categories, with ongoing refinements as treatment strategies improve. As a result, certain patients previously considered unresectable are now being reclassified into the borderline resectable group, particularly with increasing experience in vascular, including arterial resection and reconstruction.(23)

Table 2: Regional pancreatectomy classification by Fortner et.al (22, 24)

Type 0	total pancreatectomy, including hemi gastrectomy, splenectomy, and retroperitoneal lymphadenectomy
Type I	As type 0, plus: resection of portal vein
Type II	
Type IIa	As type I, plus: resection of proximal SMA
Type IIb	As type I, plus: resection of celiac axis and hepatic artery
Type IIc	As type I, plus: resection of celiac axis and SMA

Because of the significant operative morbidity and mortality associated with arterial resection in earlier years, this approach failed to demonstrate a clear survival benefit for patients. Consequently, the activist philosophy gradually declined. Several systematic reviews and meta-analyses reported no significant improvement in overall survival, while highlighting the increased rates of perioperative complications and mortality. As a result, arterial

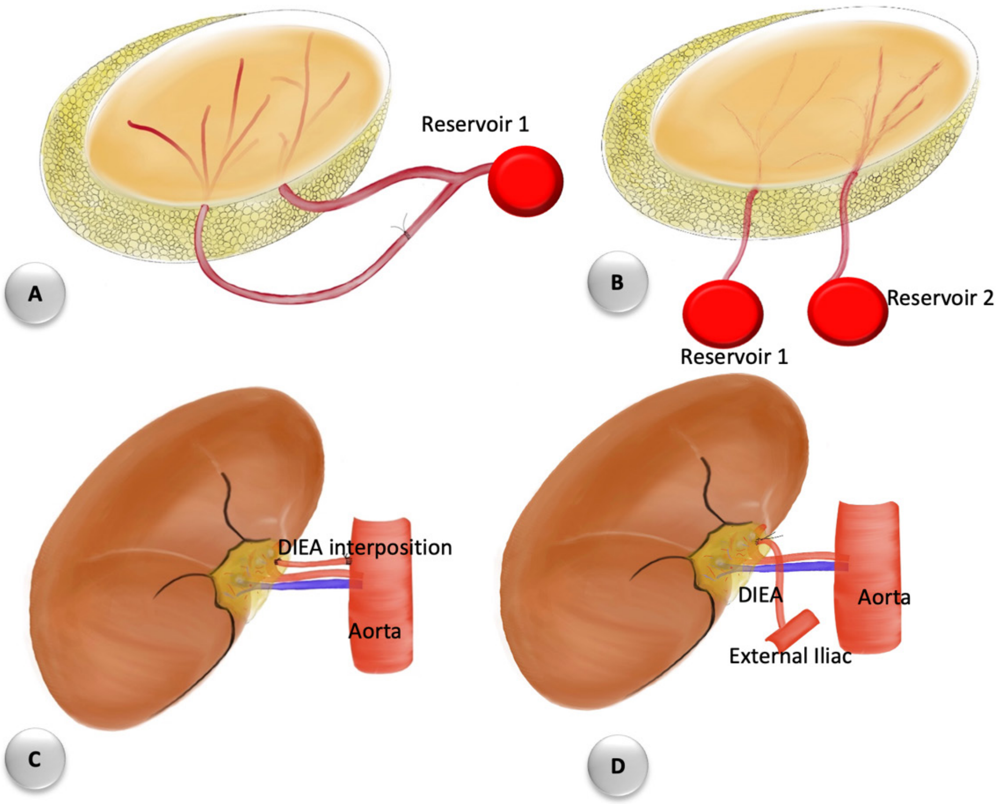

Figure 7: Concept of supercharging and turbocharging—(A) single-reservoir augmentation supplying two arteries, (B) dual-reservoir augmentation; (C) DIEA interposition graft for supercharging, and (D) DIEA augmenting kidney perfusion representing dual-reservoir (turbocharging).

involvement—even in cases where an R0 resection might have been technically achievable—was generally considered a criterion for unresectable disease, and such patients were managed non-surgically.(25-27)

However, the treatment landscape has evolved considerably in the modern era. Advances in neoadjuvant chemotherapy, including the introduction of nanoparticle albumin-bound chemotherapeutic agents, along with improvements in perioperative care and surgical expertise, have renewed interest in arterial resection. In carefully selected patients treated at high-volume centers, arterial resection and reconstruction are increasingly being performed with encouraging oncologic outcomes and acceptable morbidity. Consequently, the previously declining activist approach is gradually re-emerging in contemporary pancreatic surgery.(28)

CONCEPT OF DIVESTMENT:

In 2016, Miao et al. described arterial divestment, a technique that facilitates achieving tumor-free margins without requiring vascular reconstruction.(29, 30)This involves radical clearance of periarterial soft tissue and neuro-lymphatic tissue. Diener et al., from the University of Heidelberg, later provided a detailed description of this approach, reporting promising early outcomes.(31)

Arterial divestment is indicated when the superior mesenteric artery (SMA) is encased by tumor but maintains intact blood flow. The tumor is meticulously dissected off the SMA along its adventitia, effectively "freeing" the artery from tumor involvement without compromising arterial integrity. Divestment is carried out in patient who undergo neo adjuvant chemotherapy. Those patients who undergo pre-operative radiotherapy are usually contraindicated for divestment because of vascular fragility.(31)

RADIOLOGICAL EVALUATION FOR SELECTION OF DIVESTMENT

In patients with locally advanced, Stage III pancreatic cancer involving the superior mesenteric artery (SMA), high-quality preoperative imaging allows careful triage using the halo and string signs. A halo sign is present when there is >180° encasement of the SMA by tumor-infiltrated lymphatic and neural tissue, but the vessel itself remains fully patent without direct tumor invasion. The affected perivascular tissue forms a hypodense "halo" around the artery, with circumferential abutment but preservation of flow, making the patient a candidate for periadventitial dissection, where the neurolymphatic tissue is stripped while leaving a skeletonized artery. In contrast, the string sign occurs when >180° encasement leads to segmental narrowing or stenosis of the SMA due to true arterial invasion and/or mechanical compression, indicating that complete oncologic resection is unlikely to be achievable. This imaging-based approach moves beyond traditional circumferential encasement metrics, enabling more precise operative planning and potentially expanding curative options for patients historically considered unresectable.(32)

CONCEPT OF TURBO CHARGING AND SUPER CHARGING

The Concept of Turbo and Super charging generated from plastic surgery for vascular augmentation: Supercharging and turbocharging are surgical techniques for enhancing blood flow to the flaps. Supercharging connects one of the supply vessels of a flap to the vessels outside the flap.

In contrast, turbocharging involves interconnection of supplying vessels of a flap. Same concept is utilized during Renal transplantation where Deep inferior epigastric artery (DIEA) is used either for turbo charging or supercharging so as to increase the inflow to kidney. Similar concept can be utilized in pancreatic surgery too.

The replaced right hepatic artery (rRHA) originating from the SMA is very common—so much so that it is often assumed to be present unless proven otherwise. In our published study, we found its prevalence to be nearly 12%.(33) In cases of distal cholangiocarcinoma, the rRHA may be involved by the tumor, and achieving an R0 resection may require its resection. To preserve hepatic blood flow, the rRHA can be turbocharged using the gastroduodenal artery, or occasionally, the splenic artery can be rotated and anastomosed to the rRHA for hepatic perfusion.

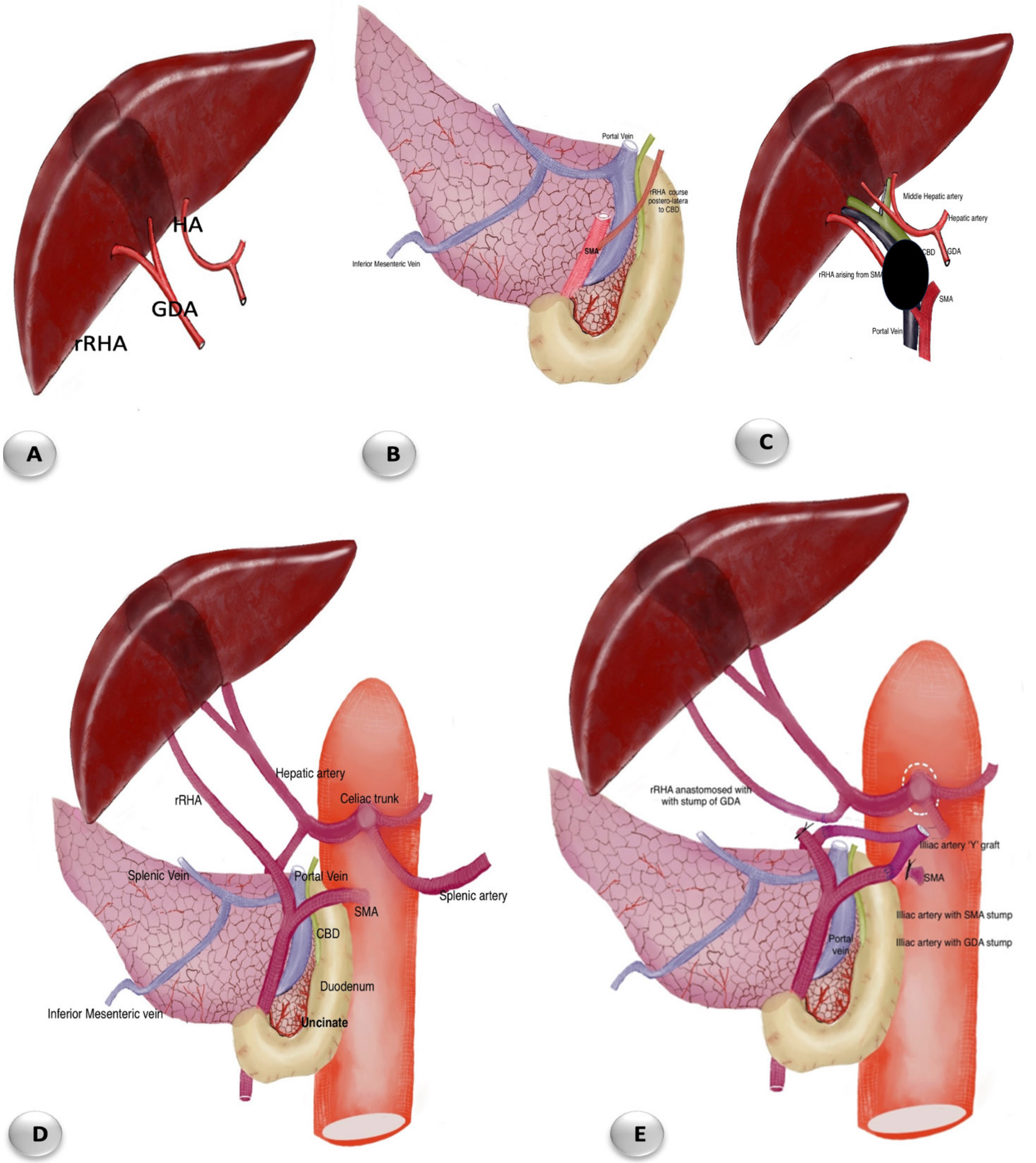

Figure 8: Michels type III replaced right hepatic artery (A), its course (B), and tumor encasement (C); overview of hepatic and peripancreatic vascular anatomy (D); and supercharging of rRHA using the gastroduodenal artery with Y-graft preparation and possible splenic vein rotation (E).

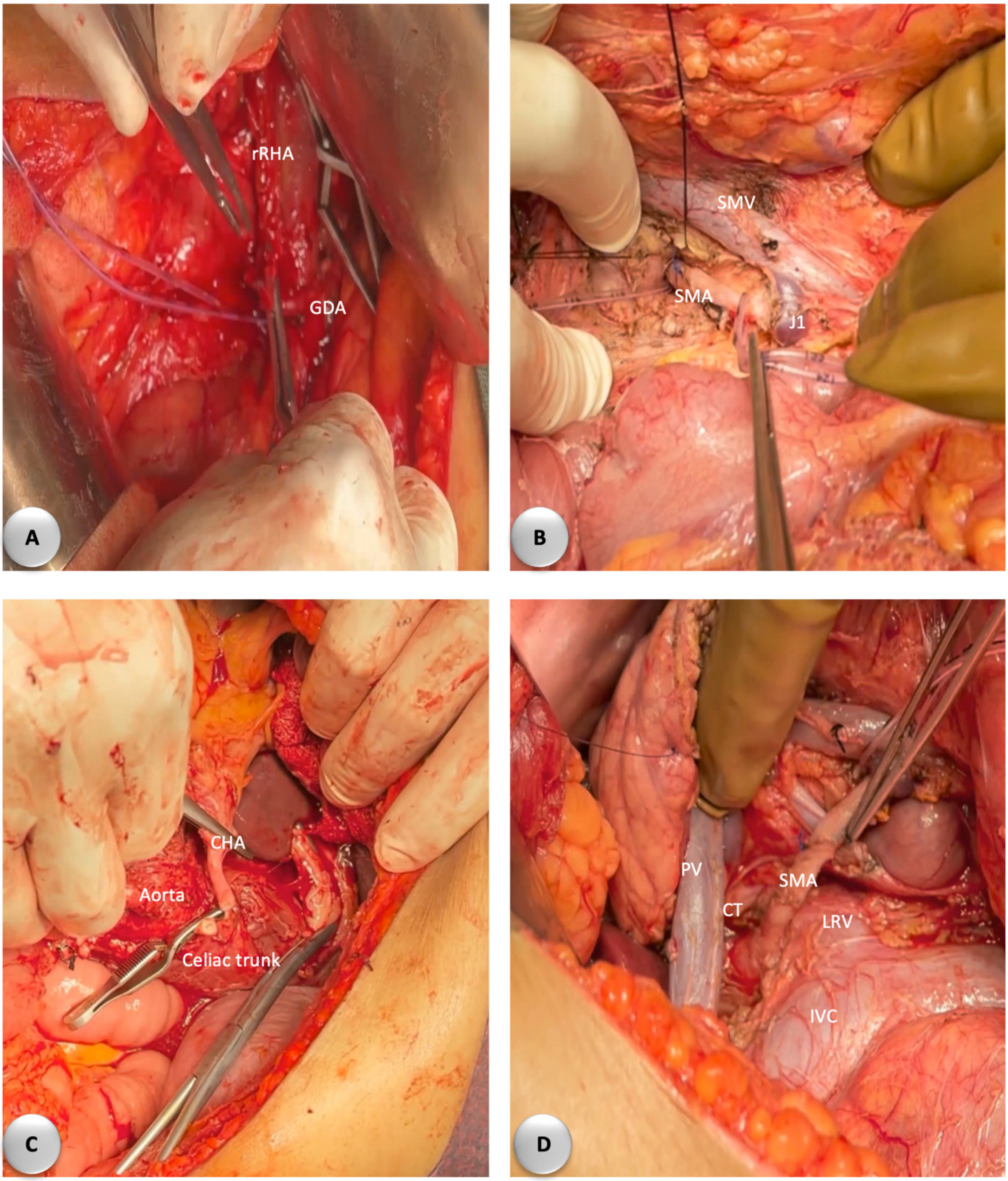

Figure 9: Operative images from our case series showing supercharging of the GDA with rRHA (A), SMA divestment (B), turbocharging of the CHA with the celiac trunk (C), and triangle dissection (D); SMV—superior mesenteric vein, LRV—left renal vein, CT—celiac trunk, IVC—inferior vena cava.

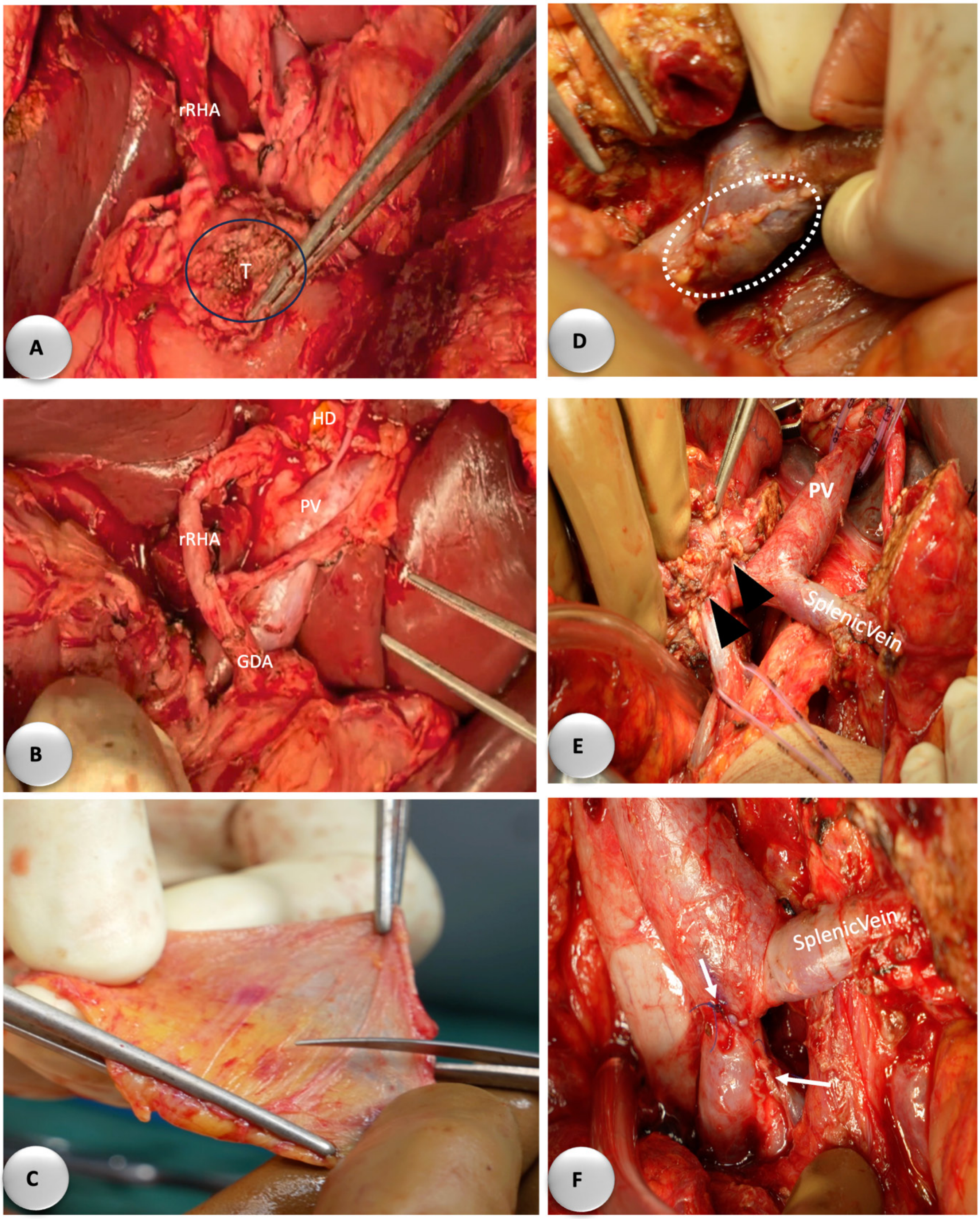

Figure 10: Replaced right hepatic artery invaded by tumor (A) with supercharging using the gastroduodenal artery (B); preparation and application of a peritoneal patch for portal vein reconstruction (C, D); and tumor invasion of the SMV and J1 vein with subsequent resection followed by SMV end-to-end and J1 end-to-side anastomosis (E, F).

DISCUSSION

Pancreatic carcinoma shows high local recurrence and frequent perineural invasion, raising concerns about the adequacy of standard Whipple's procedure. Residual microscopic disease in a distinct retro-pancreatic tissue plane—rich in lymphatics, vessels, and nerves—may contribute to recurrence if not completely excised.

In the 1950s, Loweneck and Yoshika described this retro-pancreatic sheet-like plane. Loweneck identified autonomic and periarterial nerves, while Yoshika classified them into plexus capitis I and II, a system still accepted. These studies provided the anatomical basis for later recognition of this region as a pathway for tumor spread.(8)

This led to the concept of the "mesopancreas" (Gockel, 2002), analogous to Heald's mesorectum. Although mesopancreatic dissection became important, its extent remained unclear, leading to the development of triangle surgery to standardize resection boundaries.(7)

In 2011, Adham et al. described the "inverted mesopancreatic triangle" (portal vein, SMA, celiac trunk), while the Heidelberg group defined a triangle surgery which mentioned removal of all tissues of the triangle formed by portal vein, SMA, common hepatic artery. The Heidelberg approach likely includes both neural plexuses I and II, but, Inverted triangle may not include Plexus I on disseciton. Despite variations, all aim for more complete oncological clearance.(11)

However, the triangle concept is essentially two-dimensional and does not adequately define 3D margins or account for the anterior and posterior fusion fasciae (Fredet, Treitz, Toldt), which should be preserved during dissection for oncological safety.(6)

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