The Role and Techniques of Vascular Resection

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Introduction

A "removable" tumor is one that can be surgically separated from a patient. A "resectable" tumor, in contrast, is one that can be removed within specific anatomic, biologic, and conditional constraints [1, 2]. Within this rubric, a borderline resectable tumor is one which can be surgically removed, but at "high risk" with respect to one or more of these constraints.

Although most patients presenting with a new diagnosis of pancreatic adenocarcinoma have various combinations of anatomic, biologic, and conditional factors that may influence the appropriate application of surgery, most of the literature and focus has been on anatomy alone. Based on specific imaging criteria, pancreatic cancers are classified according to their locoregional tumor extent and their involvement of critical vascular structures as anatomically resectable, anatomically borderline, or anatomically locally advanced/unresectable [3, 4]. Patients with anatomically borderline features have a higher risk of a positive margin resection in the absence of vascular resection. Furthermore, many of these patients with anatomically advanced cancers also have occult disseminated disease with a high risk for early recurrence making them biologically borderline, as well as conditionally borderline risk factors which place them at high risk for failure to receive recommended adjuvant therapy when surgery is used as primary therapy. A strong rationale therefore exists for the administration of preoperative therapy in such patients prior to resection.

When discussing the benefits of surgical resection for patients with pancreatic cancer, which is the only known modality that offers the possibility of cure or long-term survival (albeit in a small fraction of patients), one must assess the added benefit of resection compared to nonoperative therapies [5, 6]. Historically, comparisons have been made to patients receiving palliative procedures and supportive care. However, in light of advances in modern nonoperative treatment, this is no longer a valid comparison. Several recent studies looking specifically at patients with locally unresectable pancreatic cancer offer insight into what the modern comparison outcomes should be. Such patients who are treated with modern extended systemic chemotherapeutics followed by locoregional chemoradiation have been reported to live up to 18 months without surgery [7–10]. These nonoperative survival statistics rival those reported in many large surgery-first series. This suggests that in order to consider resection as a relevant modality for these patients we need to further improve upon this new thresh-

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old in long-term mortality—presumably using a combined multimodality approach [11, 12].

There is convincing scientific evidence that for the majority of patients with pancreatic cancer, the disease is systemic at diagnosis [13, 14]. For this reason, and given that "curative" surgical outcomes have had minimal improvements over the past few decades, a significant nihilism has developed and many patients are being denied resection as a potential life-extending modality as a result [15]. However, there does exist a significant proportion of patients that exhibit a "locally dominant phenotype," in that such cancers behave more in a locally invasive nature rather than a diffusely metastatic biology, perhaps due to divergent mutational evolution. Patients with locally dominant disease may truly benefit from aggressive locoregional surgical therapies. The best evidence for this stems from results of several autopsy studies and observational series of patients with locally advanced unresectable cancers. In these reports approximately 10–30 % of patients presenting with unresectable but localized disease ultimately died without evidence of metastatic disease [16–19]. Although a subset of patients may have this locally dominant phenotype, distant disease remains the most common pattern of recurrence or progression among patients who present with localized pancreatic cancer. The utilization of systemic therapies for all patients is therefore rational.

Elsewhere in this book is important discussion regarding the utilization of specific preoperative therapies to maximize surgical outcomes in patients with borderline resectable pancreatic cancer. Although some authors and centers utilize various preoperative modalities interchangeably, the author's personal preference has been for the use of extended induction systemic chemotherapy, followed by locoregional radiation treatment, prior to surgical resection in patients with anatomically borderline or locally advanced cancers. This allows patients to receive all the benefits of modern standard of care therapy prior to consideration of major resectional procedures, and maximizes probability of long-term survival by combining all effective available therapies in those patients most likely to benefit from aggressive operations.

Within this context, the concept of resectability continues to expand. Therefore, surgeons involved in the surgical care of patients with pancreatic cancer need to have significant experience in advanced techniques in order to render potentially life-extending surgical therapy. This chapter will focus on indications, techniques, and pitfalls of vascular resection in anatomically borderline resectable pancreatic cancer.

Venous Resection

An operation for pancreatic cancer is only of oncologic benefit if the following requisites are met: (1) the tumor can be resected with a negative margin—dependent on the extent of the local involvement of tumor, the complexity of the operation, and the experience and technical expertise of the surgeon; (2) no evidence or suspicion of metastatic disease exists—there is no survival benefit for surgery in such patients; and (3) the patient can tolerate the operation with limited and reversible perioperative complications and have a reasonably acceptable postoperative quality of life. In order to meet these requirements, the goals of an oncologically sound pancreatic cancer operation are specific. These include surgical extirpation of the primary tumor to negative margins, conduct of an appropriate regional lymphadenectomy for therapeutic and prognostic purposes, and minimization of perioperative complications that will allow receipt of adjuvant systemic therapy.

It has been well established that margin status after pancreatectomy for pancreatic cancer correlates with long-term survival and margin positive resections lead to worse overall survival [5, 20, 21]. Positive margin resections also correlate with local recurrences that can lead to significant symptoms and at times life-threatening complications if uncontrolled [22]. There is an inherent risk of a positive margin resection using a surgery-first approach, as supported by data from numerous pancreatic cancer surgery adjuvant trials [20, 23]. The actual survival benefit of surgery in the setting of a positive margin is essentially negated given the improved results of modern non-operative therapies. A negative surgical margin resection is the only specific variable that can potentially be surgeon controlled and it is therefore justifiably considered a metric of both surgeon and institutional quality of pancreatectomy for pancreatic cancer [24, 25].

The margin most frequently found to be positive following pancreatectomy is the retroperitoneal (SMA, uncinate) margin for head/uncinate/neck tumors. Microscopic involvement of this and other margins is clearly underreported as there is significant discrepancy between pathological assessment and clinical outcome, and identification of tumor cells at the margin depends both on the adequacy of resection and the quality of histopathologic processing [26, 27]. Obtaining a negative margin can be accomplished by either initial wide resection or with reexcision [28].

As venous involvement by pancreatic cancer is a frequent occurrence, all surgeons undertaking pancreatic resection, specifically pancreaticoduodenectomy, should be capable of performing venous resection and reconstruction as this finding may be unexpected and the extent of disease can only be fully determined once committed to resection. In patients with anatomically borderline resectable pancreatic cancer a negative margin may well not be possible without resection of the porto-mesenteric veins. Regional pancreatectomy with en bloc venous resection was shown to be feasible years ago, but was associated with high rates of morbidity and mortality and poor long-term survival. This has historically limited enthusiasm for such procedures [29]. Furthermore, concurrent venous resections can result in increased operating time, higher blood loss, and greater transfusion requirements, and some studies have suggested potentially increased perioperative morbidity [30]. However, numerous institutional series have since established that synchronous venous resection during pancreatectomy for cancer is safe and allows a larger proportion of patients to potentially benefit from surgical therapy by enabling a negative margin resection [31–34]. This appears also true for patients undergoing venous resection with more anatomically advanced tumors [35].

The strongest data available for concurrent venous resection are from recent systematic reviews evaluating over 2000 patients undergoing concurrent venous resection compared to over 8000 patients with pancreatectomy alone that have revealed that surgical morbidity and mortality and overall survival rates are comparable to standard pancreatic resections [36, 37]. As contemporary data support the use of venous resection at the time of resection for pancreatic cancer, any such techniques that may lead to a margin negative resection should be given consideration [33]. Some authors have even suggested routine segmental venous resection during pancreaticoduodenectomy regardless of actual anatomic involvement with data suggesting a potential survival benefit of such routine venous resections, however such a policy—although intriguing—is not readily supported [38].

In general terms, venous resection during pancreatectomy can be divided into three major types dependent on the location of tumoral involvement of the portomesenteric venous system: (1) Portal vein (PV) above the confluence; (2) PV/Superior Mesenteric Vein (SMV) involving the confluence; and (3) the SMV below the confluence. Various further classifications have been described based on the type and/or location of resection and reconstruction [39]. To date, the type of venous resection performed has not been included routinely in the published analyses of postoperative morbidity and mortality, and as a result, a recent proposed venous resection classification system has been described in order to more accurately detail these procedures for future study analyses: Type 1: partial venous excision with direct closure (venorrhaphy) by suture closure; Type 2: partial venous excision using a patch; Type 3: segmental resection with primary venovenous anastomosis; and Type 4: segmental resection with interposed venous conduit and at least two anastomoses [40].

The limiting factor for resectability in the case of venous involvement is the extent and complexity of the venous resection/reconstruction. This complexity is dependent both upon the surgeon and local tumor anatomy. Several anatomic and physiologic principles need to be considered including preservation of hepatopetal flow to the liver from the bowel, and reestablishment of venous outflow from the stomach and spleen, if necessary, to minimize the risk of postoperative sinistral hypertension.

In general terms, the limits of venous resection extend proximally to the origins of the right and left portal vein bifurcation of the main portal vein and distally to the first-order terminal ileal and jejunal branches of the SMV within the mesenteric root. Obtaining safe and adequate complete proximal and distal venous exposure and control prior to commitment to the resection is crucial when embarking on such operations in borderline or locally advanced cancers. Proximal portal vein resection and reconstruction is technically easier to perform, as the vessel diameter is large enough to create a sufficient anastomosis. However, very proximal portal venous involvement may also be associated with concurrent hepatic arterial involvement as discussed later in this chapter. In cases of distal tumor infiltration far below the portomesenteric venous confluence, the decreasing vascular diameter of the SMV can limit the technical success of a venous anastomosis. Sacrifice of one of the first-order terminal ileal or jejunal SMV branches can be performed as long as patency of one branch is maintained, however dissection and venous control deep in the mesenteric root may be difficult, particularly in obese individuals [41]. Furthermore, a distal anastomosis to one of these terminal branches is tenuous given the thin wall and fragility of these veins. The operative surgeon should therefore only commit to resection if success of such distal reconstructions has a high likelihood of technical success. Tumor infiltration of the confluence itself may be focal or extensive, and may extend posteriorly to involve the superior mesenteric artery (SMA). Furthermore confluence resections introduce concerns of gastric and splenic venous outflow that need to be considered that will be discussed later.

In cases of suspected need for venous resection, the author's approach is to first gain complete exposure and control of the portomesenteric venous structures, first distally then proximally, before committing to pancreatic resection. This is particularly germane in borderline and locally advanced tumors where assessment of technical resectability can sometimes only be accomplished intraoperatively. With tumors involving the infrapancreatic SMV, normal tissue planes can easily be distorted. Furthermore, significant desmoplastic changes, either from tumor infiltration or radiation, may exist. I have found the use of intraoperative ultrasound assists in the identification of vascular structures when this area is involved with significant inflammatory changes and thickened tissue to minimize venous injury during this dissection. The gastrocolic venous trunk and the middle colic vein, both of which lead to the anterior/lateral SMV, are identified early in the dissection. The gastrocolic trunk is ligated in continuity and the middle colic may be ligated as well if necessary. Control is obtained of the distal SMV. Further complete distal dissection of the primary first-order terminal ileal and jejunal SMV branches for distal venous control is then performed with in the root. If the inferior mesenteric vein (IMV) drains as a separate trunk into the lateral infrapancreatic SMV, it should also be controlled. If technically feasible, the peritoneum of the inferior border of the pancreatic neck and body lateral to the SMV is opened, dissection caudal to the pancreas is performed, and the splenic vein is identified and controlled. Hilar dissection ensues and control of the proximal portal vein is then performed. If the proximal portal vein is involved with tumor the right and left main trunks may need to be dissected initially proximally then the dissection proceeds distally after careful identification of possibly involved arterial structures. After the portal vein is controlled there is complete venous control and then dissection under the pancreatic neck can be performed safely. This approach of complete venous control, although time-consuming and tedious, is critical in the event of inadvertent venotomy and necessary repairs can then be performed under controlled conditions.

After pancreatic transection, formal assessment of the tumor/vessel interface can be made and the type and complexity of venous resection required can be specifically determined. Some surgeons attempt to tediously dissect as much of the specimen from the vein in order to minimize the complexity of the resection and reconstruc-

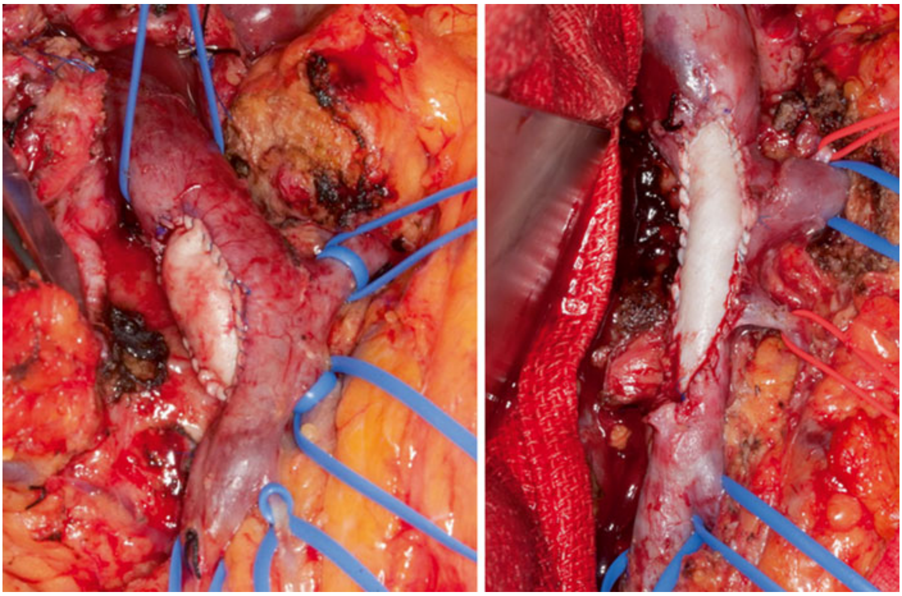

Fig. 13.1 Lateral tangential bovine patch venoplasty

tion. However, this can lead to inadvertent injury and/or a subsequent positive venous margin. In my practice any tissue that does not readily dissect off is considered at risk and removed en bloc with the specimen. This has resulted in a higher proportion of patients requiring more complex venous resections, however has significantly decreased intraoperative injury rates and subsequent venous margin positivity.

When tumor infiltration involves the right lateral circumference of the portomesenteric venous structures, a lateral tangential resection of the vein is possible. The tumor can be excised with a small en bloc segment of vein, and the vein can be repaired with either direct closure of the defect directly (if there is less than 25 % of the vein circumference involved) or with a patch venorrhaphy (using either autologous vein graft or bovine pericardial patch) without hemodynamically relevant stenosis (Fig. 13.1). We have found however that such lateral repairs or patches have led to subsequent significant stenosis with several patients requiring subsequent PV/SMV dilation and stenting due to developed mesenteric hypertension, gastrointestinal bleeding episodes, and ascites in long-term survivors. Thus we have moved towards formal segmental resection with either primary anastomosis or interposition grafts for most cases with any venous involvement. This practice also removes all "at risk" venous tissue and may potentially provide additional oncologic benefit.

If at all possible we prefer maximal attempts at full venous mobilization in order to construct a primary end-to-end anastomosis (Fig. 13.2). This can be performed with gaps up to 5 cm, and potentially more, depending on the specific patient anatomy. We perform full hepatic release and mobilization with right and left portal trunk dissection to gain additional length proximally and complete mobilization of the mesenteric root distally. The right colon should be completely mobilized inferiorly and medially from the retroperitoneal attachments of the anterior surface of the right kidney. This is continued dissecting the right and transverse mesocolon off the duodenum moving medially towards the groove between the uncinate of the pancreas and the mesenteric root. Our standard practice is to divide the splenic vein at the confluence not only to gain access to the SMA for the retroperitoneal dissection by allowing mobilization of the tumor and vein laterally,

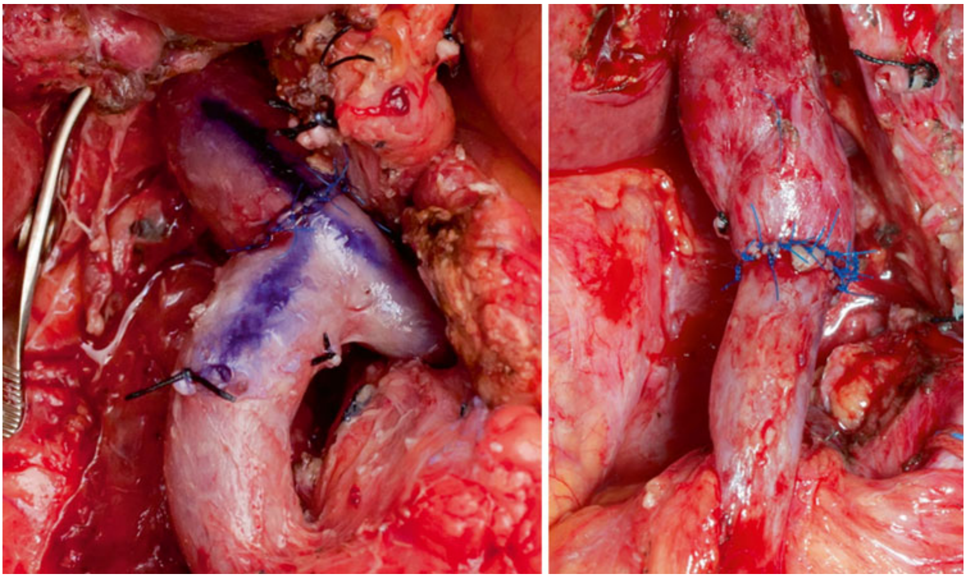

Fig. 13.2 Primary end-to-end venous anastomoses

but also for gaining additional centimeters of length for venous reconstruction. Such maneuvers allow significant added length and in most cases allow approximation of the distal and proximal resection vein margins without tension.

Reconstruction options for interposition grafts are variable and dependent on surgeon experience and comfort. Vein grafts such as left renal vein, internal jugular vein, saphenous vein, and deep femoral vein have all been described and the choice is surgeon- and experience-dependent (Fig. 13.3). We would caution the routine use of synthetic grafts, particularly in those patients predicted to have intermediate to high-risk postoperative pancreatic fistula, due to the life-threatening potential for post-pancreatectomy hemorrhage and/or difficult-to-treat long-lasting graft infection [42]. As pancreatectomy has a high risk of abdominal infection the use of synthetic venous prostheses might increase this complication [43]. One of the long-term risks of mesenteric venous reconstruction is subsequent thrombosis and occlusion with resulting complications and the use of synthetic grafts is a described risk factor for postoperative thrombosis [44].

We have recently increased the use of custom-fashioned bovine pericardial tube grafts created over a 28–32 Fr chest tube with an endovascular stapler to create tube grafts of various lengths (Fig. 13.4). These grafts are not only resistant to infection but this technique allows individual case tapering of the graft to the appropriate proximal and distal PV/SMV diameters. We have significant experience with such customized grafts with no significant detriment in patency or complications and this avoids harvest of other vascular conduits or use of synthetics for longer reconstructions. We orient the tube graft with the staple line either at the 12 or 6 o'clock position which allows the tube graft to assume a near perfect circular dimension once the viscera resumes normal position overlying the reconstruction. This provides ideal flow dynamics without the elliptical compression that might occur if oriented otherwise. In all cases of interposition grafts, care must be taken to avoid excess length and possible kinking of the graft or vein above and below that can lead to postoperative thrombosis and may require early operative revision.

Although the bulk of the literature and practice of venous resection in pancreatectomy is during pancreaticoduodenectomy, venous procedures may also be required during distal or total pancreatectomy. Tumors in the left neck or body of

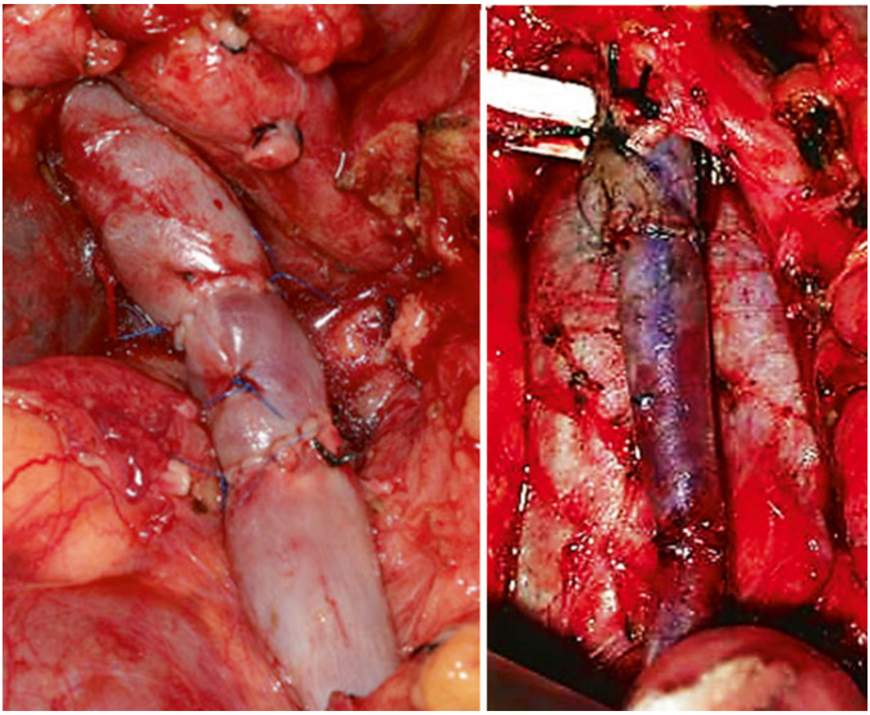

Fig. 13.3 Autologous vein interposition grafts (left renal vein and internal jugular conduits)

the pancreas can undergo subtotal extended distal pancreatic resection with the limits of proximal pancreatic resection determined at the level of the gastroduodenal artery (GDA), a natural anatomic landmark. This allows preservation of the duodenum and head of the pancreas. Care must be taken however as any resections beyond the GDA carry risk of inadvertent bile duct injury. In such extended resections with tumors arising in the pancreatic neck/body, often the splenic vein is occluded up to or involves the confluence and may extend into the PV/SMV. Such cases are reconstructed with either lateral patch grafting or formal segmental resection and anastomoses, either primarily or with conduit as described earlier.

In my practice I perform temporary SMA inflow occlusion during the venous reconstruction to prevent bowel wall congestion and edema that will hinder subsequent anastomoses. Soft plastic atraumatic bulldogs clamps are recommended to avoid intimal injury. Rummel tourniquet occlusion has also led to cases of arterial injury and is generally avoided. If the venous reconstruction can be performed in a rapid fashion, temporary SMA occlusion is optional. We prefer use of systemic heparin at the time of venous resection without reversal and continue postoperative heparin prophylaxis for 30 days. Finally we highly advocate the use of duplex ultrasound after every reconstruction to confirm patency and normal flow dynamics.

Sinistral Hypertension and Shunting Procedures

One of the most often unappreciated aspects of venous resection in pancreatectomy is the maintenance or re-establishment of gastrosplenic venous outflow. If the confluence including the splenic vein requires resection or is ligated for additional venous length and/or due to need for direct access to the SMA for the retroperitoneal dissection, postoperative acute sinistral hypertension may develop if adequate gastrosplenic

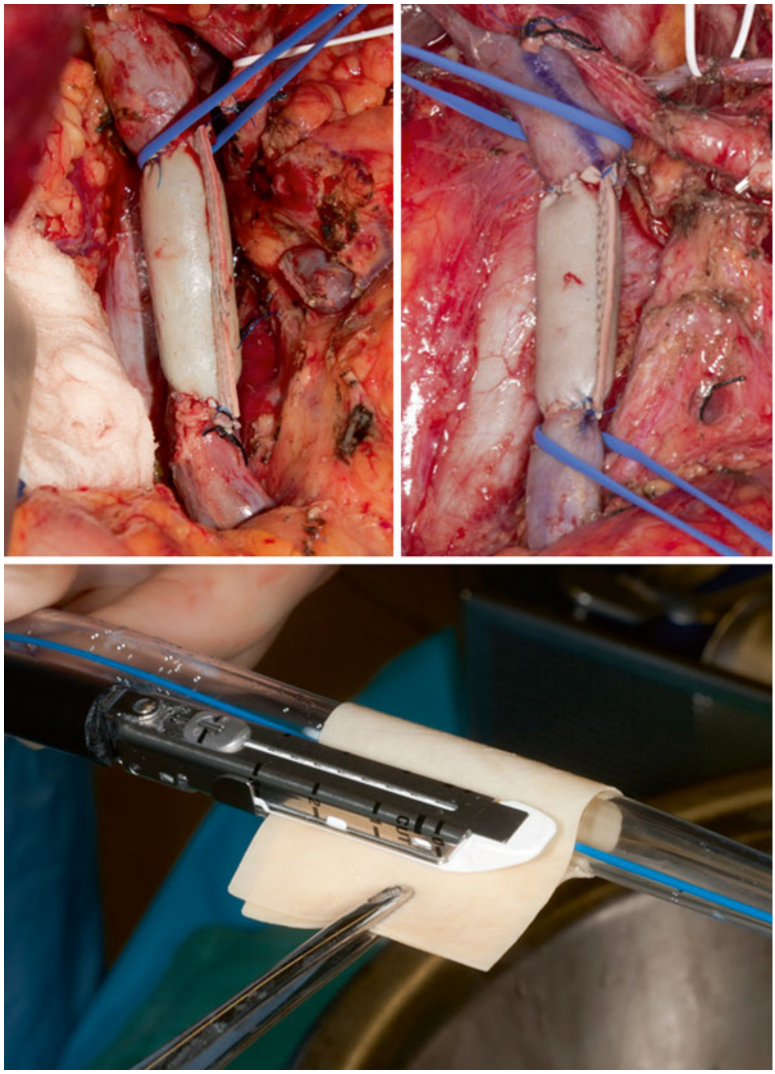

Fig. 13.4 Custom-fashioned bovine pericardial tube interposition grafts

retrograde outflow collaterals (IMV, coronary vein, gastroepiploic vein via gastrocolic trunk) are either anatomically unavailable or have been ligated as a result of the resection. In such circumstances our practice is to construct a distal splenorenal shunt (DSRS) to avoid the possibility of abrupt segmental left-sided venous hypertension that can result in splenomegaly with resultant acute hypersplenism, hypertensive gastropathy, varices, and subsequent postoperative hemorrhage that has occurred in several patients.

Recent reports have provided a proof of concept for the safety and efficacy of such venous decompressive techniques [41, 45, 46]. In the majority of cases the IMV terminates proximally into the inferior border of the splenic vein at its midpoint or near the splenoportal angle. The presence of this natural anatomic outflow pathway provides sufficient venous drainage of the spleen and gastric remnant and should be safely preserved and left in situ to provide retrograde sinistral outflow after splenic vein division. However, in up to one-third of patients, the IMV drains into the SMV as a separate trunk. Acute postoperative sinistral hypertension can thus develop after splenic vein division or resection.

For oncological necessity, particularly with microscopically invasive pancreatic adenocarcinoma, wide vascular resection of the portal venous confluence including the IMV is often necessary. Furthermore, ligation of the left gastric vein (coronary vein) performed during lymphadenectomy may also limit gastric remnant venous drainage. In such cases, splenic vein shunting can be particularly useful and may mitigate the risks of sinistral hypertension. The need for splenic venous shunting can be predicted preoperatively on coronal imaging based on the anatomical variant of IMV insertion, as well as intraoperatively estimated after splenic vein division by identification of dilated gastric veins, a dusky, boggy appearance to the stomach, and turgor in the divided splenic vein itself.

Construction of the anastomosis technically requires adequate visualization of the left renal vein, which is identified underneath and to the left of the SMA. The renal vein can be further mobilized, if additional length is needed, by ligation of the left gonadal and/or adrenal vein. We do not advocate reimplantation of the splenic vein to the newly created portomesenteric venous reconstruction as this may result in flow dynamic changes as a result of kinking of the anastomosis, and subsequent thrombosis can propagate from the splenic vein into the newly reconstructed PV/SMV and result in mesenteric outflow obstruction with resultant bowel congestion and possible venous ischemia and liver dysfunction in addition to gastrosplenic hypertension.

In patients undergoing total pancreatectomy, in whom the short gastric venous collaterals are typically divided as part of splenectomy, venous resection may lead to severe venous congestion of the remaining stomach that may require extended gastric resection to avoid ischemic complications. In these cases careful preservation of the coronary vein may allow adequate gastric venous drainage without need for formal gastric resection.

In patients with preoperative SMV/PV occlusion secondary to tumor infiltration or thrombosis, numerous high-pressure, thin-walled venous collaterals develop around the pancreatic head and neck in order to decompress the mesenteric venous system. Pancreatic resection and concurrent venous reconstruction in these cases is considerably high risk as they are often complicated by significant venous hemorrhage. Furthermore, the ligation of such collaterals during the course of the operation further contributes to mesenteric hypertension and bowel congestion. In an effort to minimize intraoperative bleeding and simultaneously allow adequate hepatopetal outflow, the use of a temporary mesocaval shunt (MCS) can be utilized. This procedure is performed early on in the operation before the resectional procedure and portal dissection to avoid injury to these high-pressure, high-flow collaterals. Our preference is to use autologous internal jugular vein as the interposition graft as it is pliable enough and of adequate length to initially bring towards to the anterior surface of the inferior vena cava for temporary intraoperative mesenteric outflow shunting during the resection portion of the case. Once the specimen is removed it is a straightforward procedure to then subsequently transpose this graft to the proximal portal vein for completion of the portomesenteric reconstruction following resection. Temporary PTFE grafts can also be utilized in this setting if additional length is needed for shunting and after resection can be removed with either primary end-to-end venous anastomosis or with interposition grafting. The need for construction of a concomitant DSRS during mesocaval shunting is best anticipated before splenic vein ligation, when venous pressure is lowest, in order to dissect an adequate length of splenic vein from the undersurface of the remnant pancreas to reach the left renal vein.

Arterial Resection

Arterial resection for pancreatic cancer has historically been considered contraindicated due to its associated operative morbidity, high margin positive resection rate, and dubious survival advantage [29]. Although complex arterial resections have been performed in selected patients, it is still regarded as an extraordinary approach as arterial infiltration is typically a surrogate of a biologically aggressive tumor with high likelihood of occult disseminated disease rather than just a function of tumor location. Although anatomically borderline resectable criteria include isolated common hepatic artery involvement and partial SMA abutment, an initial resection, even if it can be technically performed, is currently not recommended in the absence of preoperative treatment and appropriate patient selection. Even greater caution is advised in proceeding with arterial resection in those tumors classified as anatomically locally advanced/unresectable.

However, this dogma has now been challenged with the introduction of effective modern therapeutics: the current anatomic arterial classification of locally advanced tumors does not categorically imply unresectable disease per se. As surgical resection remains the only hope for cure, more aggressive surgical approaches may be advocated to increase resection rates and institutions have released data on their experience with pancreatectomy and simultaneous arterial resections. Data from several small series of arterial en bloc resections suggest that such aggressive operations can result in relatively comparable overall survival to standard resections and thus can be justified in highly selected patients [47, 48]. The best available data comes from a recent meta-analysis of 26 studies of 366 and 2243 patients who underwent pancreatectomy with and without arterial resection. The cumulative data reveal that arterial resections are associated with longer operative times, increased intraoperative blood loss, prolonged length of stay, increased morbidity (median 53.6 %) (with a significant proportion of patients [17 %] suffering from bleeding, thrombotic, or ischemic complications), and increased perioperative mortality (median 11.8 %) when compared to those patients without arterial resections. Overall survival rates were similarly worse among patients who underwent arterial resection. However, these data did suggest improved long-term survival compared to patients with locally advanced disease who did not undergo resection [49].

With the use of improved systemic and locoregional therapies, aggressive operations with arterial resection may offer substantial benefit after extensive preoperative treatment, albeit with significant perioperative risk. Our own large experience with arterial resections in patients with a locally dominant phenotype has confirmed this conclusion. The administration preoperative therapy prior to consideration of arterial resection has been widely accepted [33]. All patients with any degree of arterial involvement should be considered for neoadjuvant therapy which in our opinion should invariably include: induction systemic chemotherapy—treatment of occult metastases, potential downstaging of primary tumor; and locoregional irradiation—treatment of primary tumor and surrounding at risk structures for local tumor control and to maximize possibility of a potential margin negative resection. Only after such standardized treatment should consideration of surgical resection be entertained as results of nonoperative therapy using this sequencing suggests nearly equivalent outcomes compared to surgery alone for such advanced cases [7]. As a disclaimer the arterial procedures that will be described are currently not recommended and should only be considered in highly selected patients at experienced and specialized centers ideally under protocol-based or clinical trials settings.

The arterial structures that are at risk for locoregional tumor involvement include the celiac, hepatic, and superior mesenteric arteries. In addition variant hepatic arterial anatomy places such vessels at risk, most commonly a replaced right hepatic artery [33]. Celiac stenosis caused by atherosclerotic disease or median arcuate ligament compression is another potential indication for arterial procedures. Types of arterial procedures include primary repair or angioplasty, resection and/or ligation alone without reconstruction, resection with primary anastomosis, and resection with interposition grafting, and complex revascularization. Simply stated, the more extensive the arterial involvement the more technically complex the required procedures are in order to render a negative margin resection and the more ensuing attendant morbidity and mortality. Therefore, patient selection for such procedures is of paramount importance and just as critical as technical expertise taking into consideration patient age and expected life-expectancy, grade of comorbidities, performance status, and anticipated quality of life. In our experience, the ideal patients for such aggressive operations are relatively young, fit, sophisticated to understand the risks and potential for limited oncologic benefit, and have undergone extensive preoperative therapy with some objective measure of efficacy. Such exceptional procedures are definitively not widely recommended but may have a role in highly experienced and specialized centers.

Critical in cases requiring arterial resection is the establishment and maintenance of adequate hepatic, gastric, and visceral perfusion. The potential anatomic limits of arterial resection extend distally from the right and left hepatic artery bifurcation of the proper hepatic artery to the celiac axis, its branches, and the proximal SMA. Tumor infiltration into the porta hepatis beyond 1–2 cm above the proximal sectoral hepatic artery bifurcation implies unresectability as these vessels are often small in caliber and resulting anastomotic failure will have significant hepatic and biliary consequences. As the biliary system relies on this arterial inflow, failure to accomplish this either technically or due to postoperative occlusion/thrombosis can lead to anastomotic breakdown and leak, stricture, or intrahepatic abscesses that can be extremely difficult to manage.

Tumors in the pancreatic head may extend medially along the common hepatic artery towards the celiac. Hepatic artery resection up to the proximal common hepatic artery root is possible with graft conduits. Simultaneous resections of celiac axis and hepatic arteries with complex revascularization have been performed with oncologic success. However, such cases also may also require total pancreatectomy and gastrectomy. The extent of arterial involvement that needs to be resected determines the extent of pancreatic resection and other organs required to accomplish this. Such multivisceral resections are required due to ischemic consequences of these procedures and may further increase the resultant risks [50, 51].

En bloc celiac artery resections are almost exclusively performed as part of distal pancreatic resections for anatomically locally advanced body tumors and have been shown to be feasible while allowing a reasonably acceptable margin negative resection rate and the potential to achieve significant local tumor control in selected patients [52, 53]. Due to the extensive arterial collateral circulation via pancreaticoduodenal arcades from the SMA through the GDA, hepatic and gastric perfusion can be maintained in most cases as long the tumor spares the proper hepatic artery distal to the GDA (Fig. 13.5). These cases

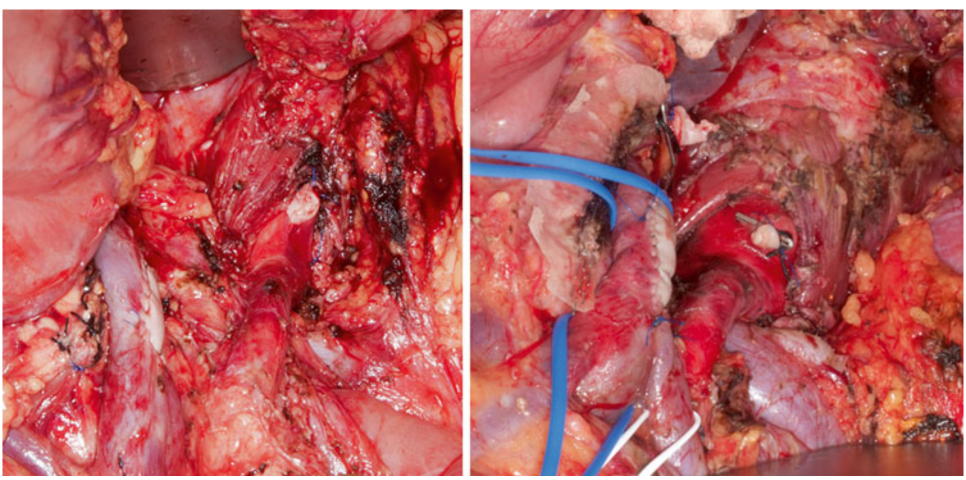

Fig. 13.5 R0 extended distal pancreatectomies with en bloc resections of tumor involved celiac arteries without arterial revascularization and concomitant bovine pericardial patch venoplasties. Patients underwent extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection

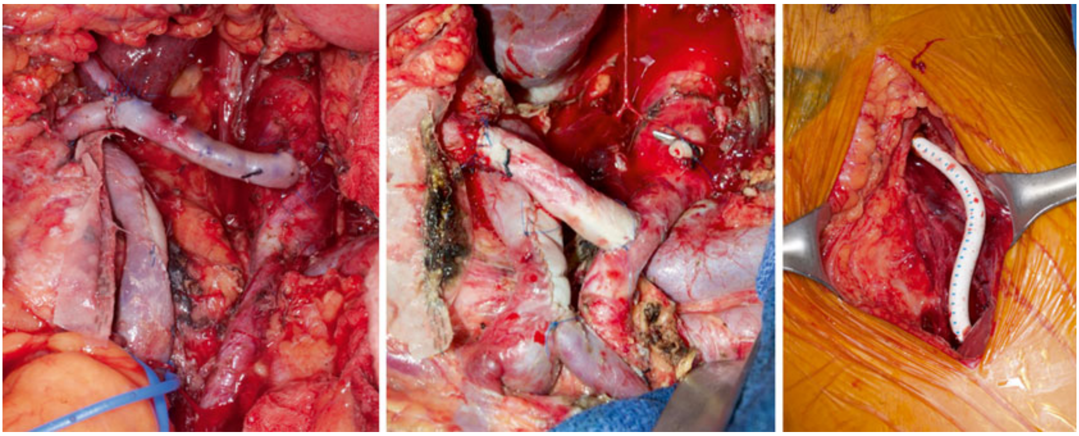

Fig. 13.6 R0 extended distal pancreatectomies with en bloc resections of tumor involved celiac arteries with arterial revascularization via SFA jump grafts from celiac stump or lateral SMA and concomitant bovine pericardial patch venoplasties. SFA harvest site is reconstructed with PTFE graft in lower extremity. Patients received extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection

commonly require some form of venous resection due to venous infiltration.

If hepatic or gastric perfusion is determined to be insufficient following temporary occlusion of the common hepatic artery or if the GDA and proper hepatic artery need to be resected for more extensive tumors, then conduit bypass grafting needs to be performed to avoid ischemic complications. This can be performed with a variety of conduits. We prefer the superficial femoral artery (SFA), which is of adequate length and diameter and is also thick enough to resist complications from postoperative pancreatic fistula. SFA is harvested from the lower extremity and replaced with a PTFE graft. SFA jump grafts to the distal hepatic artery can be anastomosed to the stump of the celiac artery, the supraceliac aorta, or the lateral SMA (Fig. 13.6). Intraoperative perfusion of the stomach should be carefully inspected as the left gastric and short gastric vessels via the splenic artery are resected en bloc with such resections. More complex advanced resections include extended distal pancreatectomy with en bloc celiac and SMA resections and revascularization for body tumors (Fig. 13.7). The higher incidence of POPF in patients undergoing distal pancreatic resection can severely comprise celiac procedures; thus all methods to decrease the incidence and severity of fistula should be employed.

For those cases where there is potential for SMA involvement, approaches to delineating resectability prior to resectional commitment include various artery-first strategies including left and right-sided dissections and infra- and supracolic approaches. After significant preoperative therapy including radiation, the residual soft tissue involving the SMA has been found in several cases to contain only fibros is and treated nonviable tumor on final pathologic processing; thus an argument for a planned R1 resection may exist in certain cases. The problem with this approach is that such a dissection is significantly difficult and may result in formal arterial injury thus not recommended unless performed with experienced hands capable of performing a repair if necessary. In some cases, there may exist extension of tumor infiltration deep into the mesenteric root involving multiple jejunal inflow vessels (Fig. 13.8). Furthermore it is exceedingly rare to not simultaneously require extensive venous confluence resection that often is the limiting anatomical factor to resection. Despite our group's highly aggressive approach to tumors with extensive vascular involvement, simultaneous segmental PV/SMV and SMA resection carries with it prohibitive risk as complications with either vessel reconstruction can lead to fatal consequences and is not currently pursued.

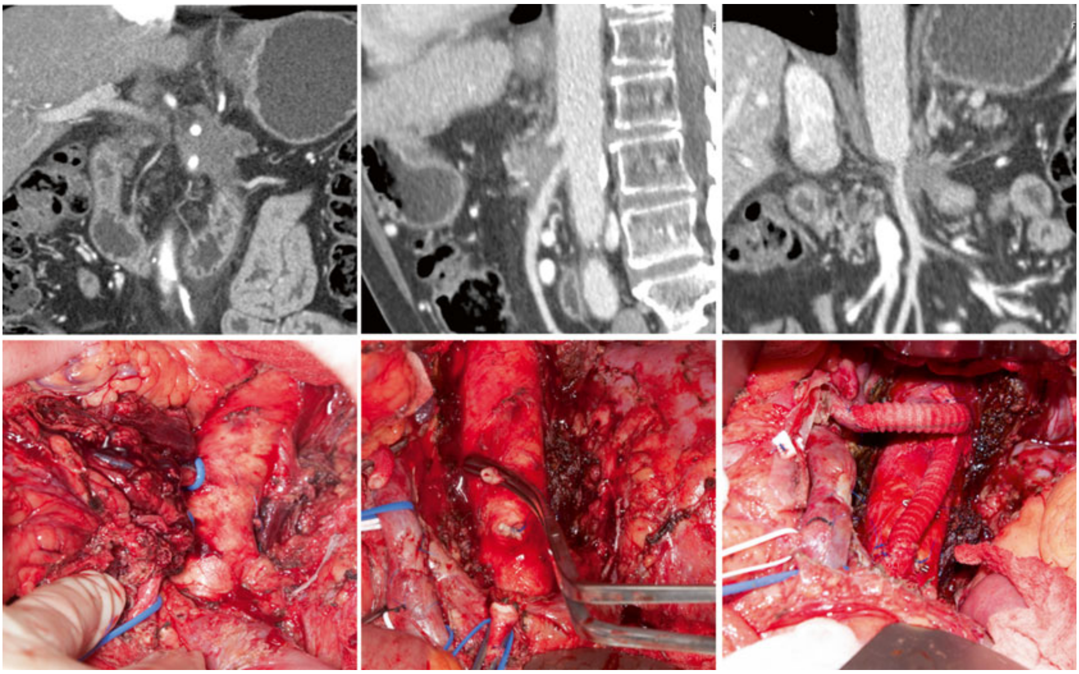

Fig. 13.7 R0 extended distal pancreatectomy with en bloc resection of tumor involved celiac and SMA with arterial revascularization via bifurcated rifampin-soaked Dacron graft from supraceliac aorta to distal HA and SMA and concomitant bovine pericardial patch venoplasty. Patient underwent extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection without radiographic response; however, no viable tumor in resected specimen. Currently NED 29 months from diagnosis

Fig. 13.8 Radiographic example of truly unresectable SMA/SMV tumor infiltration into mesenteric root

Our current recent practice for head tumors requiring simultaneous portovenous and hepatic arterial resection is to perform total pancreatectomy with en bloc vascular resection. This allows the use of the splenic artery as a conduit arterial graft that can either be harvested from the uninvolved pancreas as a jump graft or kept in situ and rotated to the right as a transposed neohepatic artery (Figs. 13.9, 13.10, 13.11, and 13.12). This approach although does result in permanent pancreatic insufficiency and diabetes but completely eliminates the risk of pancreatic fistula that in our experience is the single factor responsible for major morbidity and mortality in arterial resection cases. Bleeding and thrombotic complications after such dual vessel complex procedures can be life-threatening and are no longer amenable to traditional interventional procedures as the anatomy has been surgically altered.

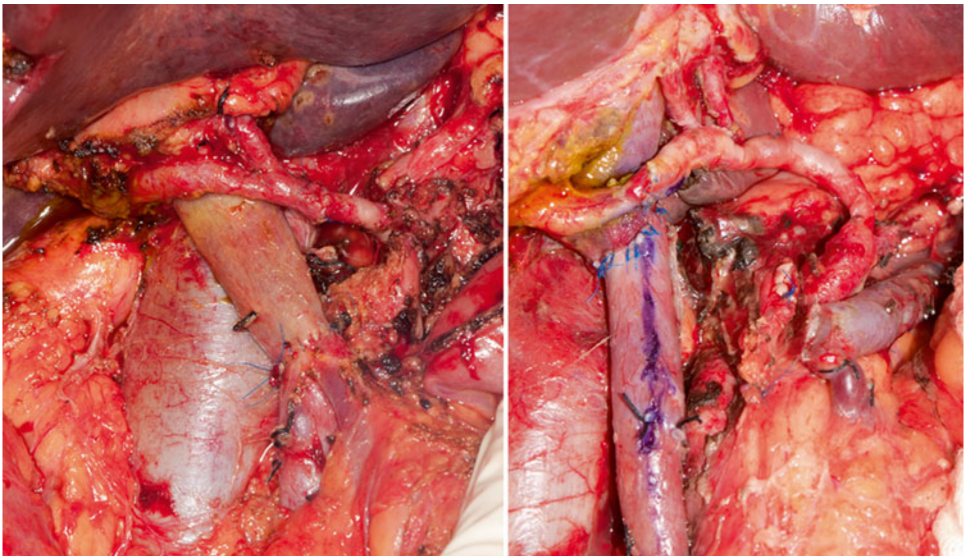

Fig. 13.9 R0 total pancreatectomies with en bloc resection of tumor involved hepatic arteries with revascularizations via splenic artery transpositions to create "neohepatic" arteries and concomitant segmental PV/SMV resection with primary venous anastomoses. Patients underwent extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection

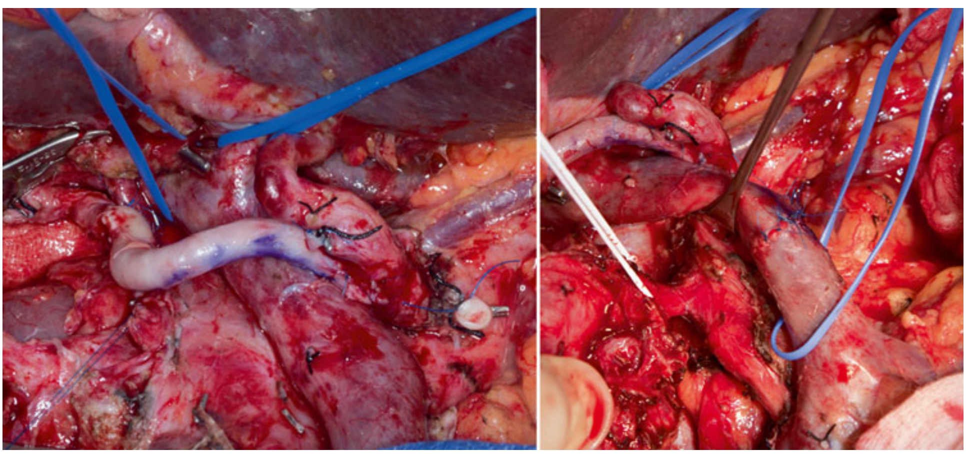

Fig. 13.10 R0 total pancreatectomy with en bloc resection of tumor involved replaced right hepatic artery with revascularization via splenic artery jump graft from ligated GDA proximal to distal right hepatic artery and concomitant segmental PV/SMV resection with primary venous anastomosis. Patient underwent extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection

Head tumors that involve a replaced right hepatic artery arising from the lateral proximal SMA can also be resected and reconstructed. Although some have suggested simple ligation, biliary consequences of arterial ischemia will lead to significant complications. Primary anastomoses can sometimes be performed if the involvement is focal. Otherwise, jump grafts from the proper or common hepatic artery or even the ligated GDA stump to the uninvolved proximal right hepatic artery may allow establishment of hepatic arterial inflow (Figs. 13.10

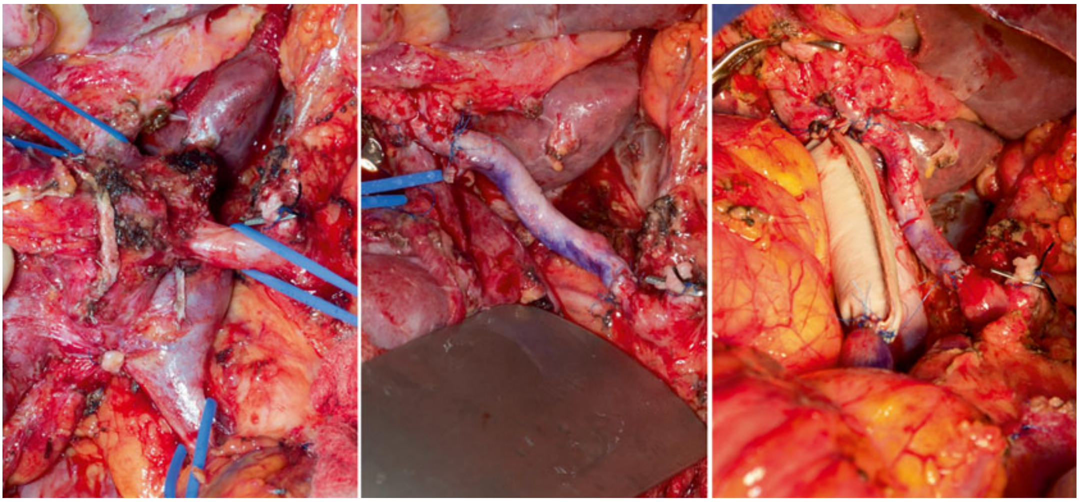

Fig. 13.11 R0 total pancreatectomy with en bloc resection of tumor involved proper and common hepatic artery with revascularization via splenic artery jump graft from CHA stump to right and left hepatic artery bifurcation and concomitant segmental PV/SMV resection with custom-fashioned bovine pericardial tube graft. This patient was previously explored elsewhere and deemed unresectable intraoperatively. Patient underwent extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection

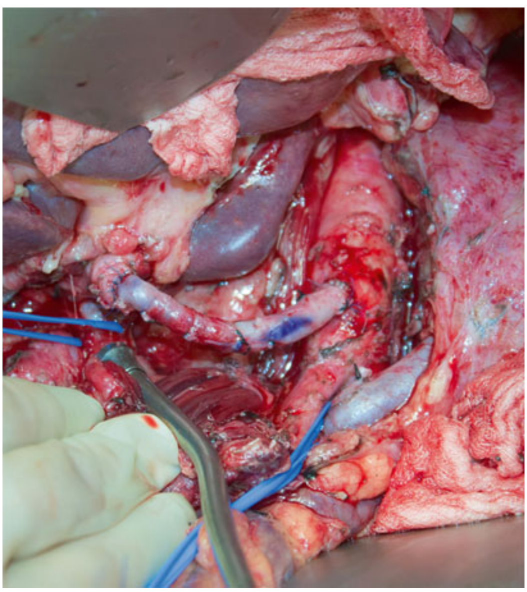

Fig. 13.12 R0 total pancreatectomy with en bloc resection of tumor involved proper hepatic, common hepatic artery, and celiac axis with revascularization via splenic artery jump graft from celiac stump to distal proper hepatic artery. Multivisceral resection requiring total gastrectomy. Patient underwent extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection

and 13.13). The proximal extent of the replaced hepatic artery as it arises from the lateral SMA should be carefully ligated at the time of en bloc specimen removal to prevent subsequent pseudoaneurysm formation.

All patients who undergo arterial resection should receive systemic heparin anticoagulation and the reconstruction should be performed early in the case, prior to specimen resection and/or concurrent venous resection/reconstruction. With simultaneous en bloc celiac and/or hepatic artery and portovenous reconstruction, hepatic ischemia time should be minimized. Postoperative liver function tests should be followed until the trend has normalized and any persistent elevations or increases should be thoroughly investigated to assess for graft problems. Our practice is to start ASA at the end of the operation and this is continued along with prophylactic heparin administration postoperatively. We obtain intraoperative formal duplex imaging and postoperative CT angiography if renal function is preserved to confirm technical success as this policy has identified several cases that required early intervention to prevent graft failure. As surgery-related major

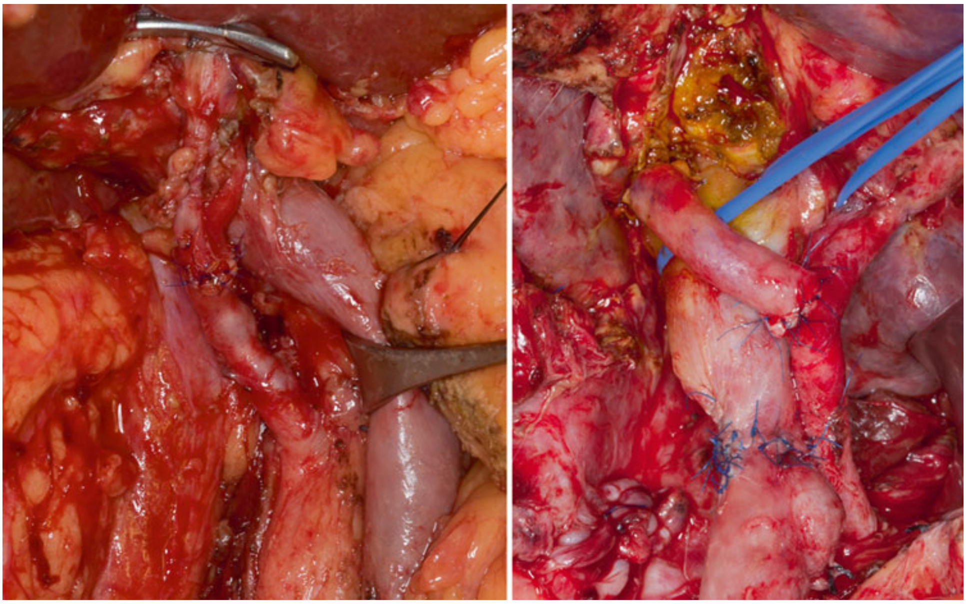

Fig. 13.13 R0 pancreaticoduodenectomies with en bloc resections of tumor involved replaced right hepatic arteries with revascularizations via primary anastomosis and saphenous vein jump graft from left hepatic artery to distal right hepatic artery and concomitant segmental PV/SMV resection with primary venous anastomosis in one case. Patients underwent extensive preoperative induction systemic chemotherapy and consolidative chemoradiation prior to resection

morbidity diminishes the oncologic efficacy of a margin negative pancreatectomy, patients undergoing such advanced procedures should be cautiously observed with a sense of urgency for any potential complication [54].

Preoperative Therapy

Approximately one-third of initially anatomically staged unresectable tumors are expected to convert to resectable tumors following neoadjuvant therapy with favorable outcomes thus should be included in neoadjuvant protocols and subsequently reevaluated for resection [55]. High-quality cross-sectional imaging can highly predict vascular involvement and need for vascular resection and various grading systems have been established with utilization of standardized imaging reporting templates; however, there is no consensus on grading response to therapy in pancreatic cancer [3, 56–60]. In contrast to other centers we do not rely solely on such radiologic downstaging after preoperative therapy to consider patients for arterial resection. Imaging poorly correlates with subsequent pathologic response after neoadjuvant therapy so in the absence of metastatic disease, resection should be considered if technically feasible [61, 62]. The author's significant personal experience of over 150 resections of borderline/locally advanced cancers after protocol-based neoadjuvant therapy supports the failure of traditional radiographic measures of response in these cases and other methods such as diffusion-weighted MR sequences and newer functional imaging (PET/CT/MR) scanners. Our current criteria for proceeding with operative intervention is foremost the absence of metastatic disease and other surrogates of response such as nutritional stabilization, cessation of preoperative pain symptoms, improved physical performance, and a biochemical tumor marker (CA19-9) response. Furthermore the planned resectional procedure should include resection of all potential residual disease with planned complex vascular and gastrointestinal resection and reconstruction as indicated. Often the persistent low-density residual tumor infiltration along critical vessels is found to have significant treatment effect and little viable tumor thus the potential for a true and oncologically beneficial negative margin can be achieved with advanced techniques in properly treated and selected patients [63, 64].

The author's standard protocol for all patients with borderline/locally advanced tumors is initial patient-risk stratification assessing anatomic, biological, and conditional characteristics. Patients with any borderline features or anatomically locally advanced tumors are considered for neoadjuvant therapy and this has invariably begun with extended induction systemic chemotherapy followed by chemoradiation with drug choices dependent on patient-specific factors [65, 66]. Caution should be considered with extended cycles of modern chemotherapeutics as this increases treatment-related toxicity as well as increase the risk of chemo-associated liver disease. We have found that patients that complete this admittedly difficult preoperative regimen, regardless of initial locoregional tumor extent, can expect significant oncologic benefit. Furthermore in those patients who are initially deemed unresectable at previous exploration, salvage pancreatectomy after such a multimodal strategy is feasible and can lead to with favorable long-term outcomes in the majority of cases [67].

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