Published in final edited form as:
CA Cancer J Clin. 2013 September ; 63(5): 318–348. doi:10.3322/caac.21190.

Recent Progress in Pancreatic Cancer

Christopher L. Wolfgang[1,2,3,*], **Joseph M. Herman**[4,*], **Daniel A. Laheru**[2,*], **Alison P. Klein**[2,3,5], **Michael A. Erdek**[6], **Elliot K. Fishman**[7], and **Ralph H. Hruban**[2,3]

[1]Department of Surgery, The Sol Goldman Pancreatic Cancer Research Center, The Johns Hopkins University School of Medicine

[2]Department of Oncology, The Sol Goldman Pancreatic Cancer Research Center, The Johns Hopkins University School of Medicine

[3]Department of Pathology, The Sol Goldman Pancreatic Cancer Research Center, The Johns Hopkins University School of Medicine

[4]Department of Radiation Oncology & Molecular Radiation Sciences, The Sol Goldman Pancreatic Cancer Research Center, The Johns Hopkins University School of Medicine

[5]Department of Epidemiology, the Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA

[6]Department of Anesthesiology and Critical Care Medicine, The Sol Goldman Pancreatic Cancer Research Center, The Johns Hopkins University School of Medicine

[7]Department of Radiology, The Sol Goldman Pancreatic Cancer Research Center, The Johns Hopkins University School of Medicine

Abstract

Pancreatic cancer is currently one of the deadliest of the solid malignancies. However, surgery to resect neoplasms of the pancreas is safer and less invasive than ever, novel drug combinations have been shown to improve survival, advances in radiation therapy have resulted in less toxicity, and enormous strides have been made in our understanding of the fundamental genetics of pancreatic cancer. These advances provide hope but they also increase the complexity of caring for patients. It is clear that multidisciplinary care that provides comprehensive and coordinated evaluation and treatment is the most effective way to manage patients with pancreatic cancer.

Keywords

pancreatic neoplasms; molecular biology; radiology; radiation oncology; medical oncology

Introduction

The American Cancer Society estimates that 45,220 Americans will be diagnosed with ductal adenocarcinoma of the pancreas (referred to in this review as “pancreatic cancer”) in 2013, and that 38,460 will die from the disease.[1] Despite decades of effort, the five-year survival rate remains at only ~5%. There are no early detection tests and most patients with

Corresponding author: Ralph H. Hruban, M.D., Department of Pathology and Oncology, The Sol Goldman Pancreatic Cancer Research Center, The Johns Hopkins University School of Medicine, Weinberg Room 2242, 401 North Broadway, Baltimore, MD 21231, rhruban@jhmi.edu, (410) 955-9132, Fax: (410) 955-0115.
*contributed equally to this work

Conflict of interest: Dr. Hruban receives royalty payments from Myriad Genetics for the PALB2 invention

localized disease have no recognizable symptoms or signs; as a result, most patients are not diagnosed until late in their disease, after their cancer has metastasized to other organs.

Despite these grim statistics, we believe that there is real hope on the horizon. In this article we will review recent progress in pancreatic cancer, with emphasis on genetic advances and the multidisciplinary team approach to patient care.

Risk Factors (Table 1)

Population and family-based studies have helped to establish that both environmental and inherited factors contribute to the development of pancreatic adenocarcinoma. The most common risk factor for pancreatic adenocarcinoma is cigarette smoking. Analyses of data from 12 case-control studies showed that current smokers have a 2.2-fold (95% Confidence Interval (CI) 1.71–2.83) increased risk of pancreatic cancer compared with never smokers.[2] Approximately 25% of pancreatic cancers are attributable to cigarette smoking.[3] The “finger print” of tobacco smoking can be seen in pancreatic cancers, as genetic analyses have shown that pancreatic cancers resected from smokers have more mutations than do pancreatic cancers from never-smokers.[4] Importantly, smoking cessation reduces this risk.[2] Risk estimates of 1.64 (Odds Ratio (OR), 95% CI 1.36–1.97) have been reported for recent quitters (1–10 years) and of 1.12 (95% CI 0.86–1.44) for individuals who quit smoking 15–20 years ago.[2]

Longstanding type 2 diabetes mellitus is also associated with an increased risk of pancreatic cancer, with patients with type 2 diabetes of >10 years duration having a 1.51-fold (95% CI=1.16–1.96) increased risk of pancreatic cancer compared with non-diabetics.[5] In addition, new onset diabetes can be the first sign of pancreatic cancer.[6] Up to 1% of new-onset adult diabetics are diagnosed with pancreatic cancer within 3 years of their diagnosis of diabetes, suggesting that new onset diabetes could be a clue to the early diagnosis of pancreatic cancer in some people.[6] Thus long-standing diabetes is a risk factor for pancreatic cancer, and new onset diabetes can be an early sign of the disease.

In the past several years, a number of studies have demonstrated that increased body mass index (BMI) is also associated with an increased risk of developing pancreatic cancer.[7] This risk is independent of the risk of pancreatic cancer due to diabetes. An analysis of data from 12 cohort studies and one case-control study estimated that the risk of pancreatic cancer is 1.55-fold (95% CI=1.16 – 2.07) greater for individuals with a BMI >35 compared to individuals with a BMI of 18.9 to 24.9.[7] Although it has not been established, one would hope that significant weight loss in patients with an elevated BMI would help reduce some of this risk.

Other risk factors for pancreatic cancer include alcohol consumption and pancreatitis. Heavy alcohol consumption (>=6 drinks per day) has been associated with an increased risk of pancreatic cancer with an OR of 1.46 (95% CI=1.16–1.83) compared with light consumption (less than one drink per day).[8] Low to moderate alcohol consumption does not appear to increase risk. Chronic pancreatitis also elevates risk of pancreatic cancer. An analysis of data from 10 case-control studies demonstrated that individuals with a history of chronic pancreatitis have a 2.71-fold (95% CI 1.96–3.74) increased risk of pancreatic cancer.[9] As was true for diabetes, pancreatitis can also be caused by pancreatic cancer and new onset pancreatitis can therefore also be a sign of a pancreatic neoplasm.

Inherited Risk Factors (Table 2)

In addition to environmental risk factors, inherited genetic changes can be important risk factors for ductal adenocarcinoma of the pancreas. Case-control and cohort studies have all

demonstrated that individuals with a family history of pancreatic cancer are at an increased risk of developing pancreatic cancer themselves. Estimates from these studies range from a 1.9 to a 13-fold increased risk.[10–14] Family registries, in addition to population based studies, have helped to demonstrate the clustering of ductal adenocarcinoma of the pancreas in families and these registries have been used to quantify the risk of pancreatic cancer due to familial factors. One such registry is the National Familial Pancreas Tumor Registry (NFPTR) at Johns Hopkins (www.nfptr.org). Familial pancreatic cancer is defined as at least a pair of first-degree relatives diagnosed with pancreatic cancer in a family, and prospective studies of families enrolled in the NFPTR demonstrated a 6.8-fold (95% CI 4.54 to 9.75) increased risk of pancreatic cancer in the first-degree relatives of familial pancreatic cancer patients compared the general United States population.[15] The standardized incidence ratio reached 17 (95% CI 7.34 to 33.5) among individuals with 3 or more close relatives with pancreatic cancer.[15] Data from the NFPTR also indicated that having a relative who developed pancreatic cancer at a young age is also associated with an increased risk of pancreatic cancer in familial pancreatic cancer families, however risk did not vary with age in families with just a single pancreatic cancer.[15] As if having an increased risk of pancreatic cancer wasn't bad enough, families in which there is a clustering of pancreatic cancer also have an increased risk of extra-pancreatic cancers.[16] Relatives of familial pancreatic cancer patients have an increased risk of dying from breast (1.66-fold, 95% CI 1.15–2.34), ovarian (2.05-fold, 95% CI 1.10–3.49), and bile duct cancers (2.89-fold, 95% CI 1.04–6.39).[16]

Several germline genetic syndromes have been identified that are associated with an increased risk of ductal adenocarcinoma of the pancreas, these range from high-penetrance genes which are associated with high lifetime risk of pancreatic cancer, to low penetrance genes associated with only a slightly increased (<1.5 fold) risk of pancreatic cancer (Table 2).[17] There are three important points to remember about these genetic syndromes. First, the risk of pancreatic cancer can be quantified if one knows the gene responsible for the aggregation of pancreatic cancer in a family. Quantifying risk is important for the design of clinical trials to screen at-risk patients for early curable precancerous lesions.[18, 19] Second, all of these genes, with the exception of those associated with familial pancreatitis, not only increase the risk of pancreatic cancer, but they also increase the risk of extra-pancreatic malignancies.[20] This suggests that lives can be saved by screening for these extra-pancreatic malignancies. Third, some of these syndromes have implications for therapy. For example, germline *BRCA2* gene mutations increase the risk of pancreatic cancer, and cancers in which the *BRCA2* gene has been inactivated appear to be sensitive to DNA cross-linking agents.[21]

BRCA2

Inherited mutations in the *BRCA2* gene are associated with a significantly elevated lifetime risk of breast, ovarian, prostate and pancreatic cancer.[22] The prevalence of germline *BRCA2* gene mutations in pancreatic cancer patients varies among different populations and is particularly high in individuals of Ashkenazi Jewish decent.[22, 23] Four to ten percent of Ashkenazi Jews with pancreatic cancer carry a germline *BRCA2* mutation.[23, 24] The prevalence of *BRCA2* gene mutations among pancreatic cancer patients also increases as the number of relatives they have with pancreatic cancer increases; 6–12% of pancreatic cancer patients from families in which two or more relatives have pancreatic cancer carry deleterious *BRCA2* mutations, and 16% of patients from families in which three or more relatives have pancreatic cancer carry germline *BRCA2* mutations.[25, 26] While many of the pancreatic cancer families that are found to have deleterious *BRCA2* mutations also report a family history of breast and/or ovarian cancer, a sizeable proportion of pancreatic cancer patients with germline *BRCA2* mutations report no breast or ovarian cancers in their

family.[22] Clearly, the penetrance of these genetic changes is not complete. Several clinical trials are evaluating approaches to specifically target *BRCA2*-deficient pancreatic cancers.[27]

PALB2

Germline mutations in the *PALB2* (partner and localizer of *BRCA2*) gene have been reported in 1–3% of familial pancreatic cancer kindreds.[28, 29] The first observation of *PALB2* in familial pancreatic cancer kindreds was made by Jones et al using a whole-exome sequencing approach.[30] Subsequent studies have replicated this finding.[28, 29] As is true for its binding partner *BRCA2*, mutations in the *PALB2* gene are also associated with an increased risk of breast cancer, yet, not all pancreatic cancer patients found to have germline *PALB2* mutations report a personal or family history of breast cancer. Just as pancreatic cancers harboring *BRCA2* mutations appear to be sensitive to DNA cross-linking agents, so are pancreatic cancers harboring *PALB2* mutations. [19, 31]

BRCA1

Unlike germline mutations in *BRCA2* and *PALB2* which have been consistently associated with an increased risk of pancreatic cancer, it is less clear if carriers of germline *BRCA1* mutation are also at higher risk of pancreatic cancer. While several studies have reported an increased risk of pancreatic cancer in *BRCA1* carriers, including a large-scale study conducted by the Breast Cancer Linkage Consortium which found a 2.26-fold (95% CI 1.26 to 4.06) increased risk of pancreatic cancer in *BRCA1* mutation carriers, other studies have not reported an increased prevalence of *BRCA1* gene mutations in pancreatic cancer patients.[24,32 33]

The associations of germline *BRCA2*, *PALB2* and possibly *BRCA1* gene mutations with pancreatic cancer make it clear that a good family history, one that specifically asks about a family history of breast cancer, is important in the evaluation of patients with pancreatic cancer.

p16/CDKN2A

Germline mutations in the *p16/CDKN2A* gene are associated with a high lifetime risk of melanoma and the “familial atypical multiple mole melanoma syndrome (Figure 1),” as well as an increased risk of pancreatic cancer.[20, 34, 35] Individuals born with a mutation in the *p16/CDKN2A* gene have a 38-fold increased risk of developing pancreatic cancer.[20, 34, 35] Studies of kindreds with a 19 base pair deletion in exon 2 of the *p16/CDKN2A* gene (the Leiden mutation) have estimated that these carriers have a 17% lifetime (by age 75) risk of developing pancreatic cancer.[36] The association of germline mutations in the *p16/CDKN2A* gene with pancreatic cancer suggests that a careful skin examination for nevi and melanomas should be a part of the clinical evaluation of patients with pancreatic cancer. Importantly, lives can be saved by screening *p16/CDKN2A* gene mutation carriers and their relatives for early melanocytic lesions.[37]

Lynch Syndrome

Lynch Syndrome is an autosomal dominant hereditary disease characterized by early onset colon cancer due to germline mutations in one of the DNA mismatch repair genes (*hMSH2*, *hMLH1*, *hPMS1*, *hPMS2* or *hMSH6*/*GTBP*).[38] Patients with Lynch Syndrome also have an increased risk of endometrial, gastric, small intestinal, ureteral and pancreatic cancer.[38] A recent study of 147 families containing a mutation in a mismatch gene reported an 8.6-fold (95% CI, 4.7–15.7) increased risk of pancreatic cancer compared with the general population.[39] This corresponds to a 3.68% (95% CI, 1.45–5.88%) lifetime (by age 70) risk of pancreatic cancer.[39] The pancreatic cancers that occur in these kindreds frequently have

microsatellite instability (MSI^+) and a distinct poorly differentiated medullary histopathology as is seen in MSI+ colorectal cancers.[40, 41] Of note, despite their poor differentiation, medullary cancers of the pancreas are associated with a good prognosis.[41, 42]

Hereditary Pancreatitis

Hereditary pancreatitis is a rare inherited form of pancreatitis in which the patients suffer repeated episodes of acute pancreatitis beginning in childhood, and which typically results in pancreatic insufficiency by early adulthood.[43] Mutations in the cationic trypsinogen gene (*PRSS1)* cause an autosomal dominant form of hereditary pancreatitis, whereas mutations in the serine protease inhibitor gene (*SPINK1*) cause an autosomal recessive form of hereditary pancreatitis.[44, 45,46] Patients with hereditary pancreatitis have a remarkable 58-fold (95% confidence interval [CI] = 23–105) increased risk of developing pancreatic cancer and a lifetime risk (by age 70) of pancreatic cancer of 30–40%.[47,48] Cigarette smoking has been shown to further increase this risk.[48] Because the risk of pancreatic cancer is high, and the risk of cancer in patients with hereditary pancreatitis is confined to the pancreas, some of these patients choose prophylactic pancreatectomy. The risks and morbidity associated with total pancreatectomy are high, and such procedures should not be undertaken lightly.

Peutz-Jeghers Syndrome

Individuals with the Peutz-Jeghers syndrome, an autosomal dominant disorder characterized by hamartomatous polyps in the gastrointestinal tract and pigmented macules of the lips, buccal mucosa, and digits, have been shown have an 11–32% lifetime risk of pancreatic cancer.[49, 50] Mutations in the *STK11* gene explain more than 80% of Peutz-Jeghers cases. This risk of pancreatic cancer is so high in patients with Peutz-Jeghers that they would be a natural population to benefit from screening tests for early pancreatic neoplasia as such tests become available.[19, 51, 52]

Susceptibility Variants

In addition to the above genetic mutations, which have been associated with a high lifetime risk of pancreatic cancer, several additional variants have been identified that are associated with a weak to modest increased risk of pancreatic cancer. For example, a single nucleotide variant in the ABO blood group gene, rs505922, has been associated with a per-allele odds ratio of 1.20-for pancreatic cancer (95% CI 1.12–1.28).[53]

Pathology (Table 3)

A number of clinically and pathologically distinct neoplasms arise in the pancreas. These neoplasms can be broadly divided pathologically into those that are typically solid and those that are usually cystic. This categorization parallels the primary radiologic appearances of these neoplasms, and it helps narrow the clinical differential diagnosis. Specific pathologic diagnoses within each of these two broad categories have important implications for patient management and prognosis (Table 3). The treatment recommendations in the Treatment section of this review are specific for invasive ductal adenocarcinoma (“pancreatic cancer”), and may not apply completely to some of the other tumor types that can arise in the pancreas.

Solid Tumors

The most common solid tumor is the **invasive ductal adenocarcinoma**, more commonly called “pancreatic cancer.” By definition, the neoplastic cells of invasive ductal adenocarcinoma, as the name suggests, form glands and infiltrate into tissues (Figure 2A).[54] Grossly, these cancers are usually solid and firm, and send tongues of neoplastic cells far

beyond the main tumor. Microscopically, almost all invasive ductal adenocarcinoma invade nerves and spread along perineural spaces. These cancers also have a proclivity to invade lymphatic spaces and small veins, and in so doing to spread to regional lymph nodes and to metastasize to the liver. As a result, by the time most invasive ductal adenocarcinomas are diagnosed they have spread beyond the gland and are not amenable to surgical resection.

Another important histologic feature of invasive ductal adenocarcinomas of the pancreas is that these cancers elicit an intense desmoplastic reaction.[54–56] This desmoplastic reaction is composed of fibroblasts, inflammatory cells, endothelial cells and a complex extracellular matrix, and is associated with significantly increased interstitial fluid pressure within the tumor. This elevated interstitial fluid pressure has been hypothesized to be an impediment to perfusion of the tumor, explaining the low attenuation seen on contrast enhanced imaging, and the elevated pressure may serve as an obstacle to the diffusion of therapeutic agents.[55] The desmoplastic reaction associated with pancreatic cancer has to be taken into account when designing therapeutic regimens, as even the best agents will not be effective if they do not reach the neoplastic cells.[57] Some have also suggested that the desmoplastic reaction can be exploited therapeutically. For example, the albumin in nab-paclitaxel (albumin-bound paclitaxel) may bind to SPARC, a protein expressed at high levels in the desmoplastic stroma, increasing the delivery of paclitaxel to the neoplastic cells.[58, 59] Cell-matrix interactions could also be targeted therapeutically, and some investigators are testing novel approaches to remodeling the tumor microenvironment, such as enzymatic digestion of stromal hyaluronan.[55]

Several clinically important variants of ductal adenocarcinoma of the pancreas have been described. **Adenosquamous carcinoma** has, in addition to neoplastic cells with ductal differentiation, a significant component with squamous differentiation.[54, 60] Adenosquamous carcinomas are particularly aggressive cancers with an extremely poor prognosis, however, patients with an adenosquamous carcinoma may still benefit from surgical resection.[60, 61]

Colloid carcinoma is a mucin-producing epithelial neoplasm composed of neoplastic cells “floating” in pools of mucin embedded in the stroma.[54] These invasive carcinomas almost always arise in association with intraductal papillary mucinous neoplasms (IPMNs), and colloid carcinomas are associated with a better prognosis than invasive ductal adenocarcinomas.[62] Some of the improved prognosis associated with colloid carcinomas may be related to their tendency to present clinically at a lower stage than invasive ductal adenocarcinomas that did not arise in association with an IPMN.[63]

Medullary carcinoma is composed of poorly-differentiated cells with a syncytial growth pattern, and characterized by pushing boarders, extensive necrosis, and an associated lymphocytic inflammatory cell infiltrate.[41] As described earlier, some medullary cancers arise in patients with the Lynch syndrome, and not surprisingly, some medullary carcinomas are microsatellite unstable, and patients with these cancers are more likely to have a family history of cancer. [41] Patients with medullary cancers have a better prognosis than do patients with invasive ductal adenocarcinomas, despite the poor differentiation of the neoplastic cells in medullary carcinomas.[41]

Signet ring carcinoma is composed of individual neoplastic cells each with a prominent mucin globule, imparting a “signet ring” appearance to the cells.[54] Although signet ring cell carcinomas can arise in the pancreas, clinicians should be aware that cancers with this morphology more commonly arise in the stomach or breast, and these latter two cancers can metastasize to the pancreas and mimic a pancreatic primary.

Undifferentiated carcinomas and **undifferentiated carcinomas with osteoclast-like giant cells** are extremely aggressive carcinomas associated with a very poor prognosis.[54]

Perhaps because the prognosis for invasive ductal adenocarcinoma is so poor, significant emphasis has been placed on understanding the potentially curable noninvasive precursor lesions that give rise to these cancers. Extensive histologic and genetic studies have helped establish that a small microscopic lesion, called pancreatic intraepithelial neoplasia (PanIN), can be a precursor to invasive pancreatic cancer.[64–66] While most PanINs are too small to be detected using currently available imaging technologies, abnormal DNA shed from PanINs can be detected in the duodenal fluid and even in the stool, raising the possibility of a gene-based early detection test for PanINs the future.[67, 68] In addition, the pancreatic parenchyma immediately surrounding PanIN lesions is often fibrotic and atrophic, a finding called "lobulocentric atrophy."[69] When PanINs are multifocal, as can be seen in individuals with a strong family history of pancreatic cancer, the associated multiple foci of lobulocentric atrophy can produce histologic changes of chronic pancreatitis, and these changes can be detected by endoscopic ultrasonography, suggesting another possible approach to the early detection of curable PanIN lesions.[70]

Pancreatic neuroendocrine tumors (PanNETs) are the second most common type of solid neoplasm of the pancreas. PanNETs are less aggressive than invasive ductal adenocarcinomas, but they are fully malignant with a ten-year survival rate of only 45%.[54] Although not as common as ductal adenocarcinomas, these neoplasms are clinically important for two reasons. First, some arise in the setting of a genetic predisposition syndrome such as the multiple endocrine neoplasia 1 (MEN-1) and von Hippel Lindau (VHL) syndromes. PanNETs arising in these settings cannot be managed in isolation, instead the entire patient has to be considered as other neoplasms may dominate the patient's course. Second, some PanNETs produce endocrine hormones that are released into the blood stream producing a clinical syndrome (such as insulinomas, glucagonomas, etc.). These are designated functional PanNETs, and the prognosis and management of functional PanNETs is usually determined by the specific clinical syndrome produced.[54]

Grossly, PanNETs are usually well-demarcated, soft and solid neoplasms. Microscopically, the neoplastic cells form nests or trabeculae, and the neoplasms are characteristically richly vascular. This rich vascularity explains the proclivity of PanNETs to enhance with contrast. Tumor grade and stage are the most important prognosticators, with grade determined by the proliferation rate of the neoplastic cells, and stage by the size and extent of the tumor.[71, 72]

Surgery is the treatment of choice for patients with a localized PanNET, and there are a variety of treatment options for patients with metastatic or progressive disease. For example, the tyrosine kinase inhibitor sunitinib and the mammalian target of rapamycin (mTOR) pathway inhibitor everolimus have both been reported to significantly improve progression-free survival in patients with advanced PanNETs.[72, 73]

Acinar carcinoma and **pancreatoblastoma** are rare usually solid tumors, and both are composed of neoplastic cells with differentiation along the lines of exocrine enzyme production.[54] Pancreatoblastomas also have a component of squamoid nests. Unfortunately, both acinar cell carcinoma and pancreatoblastoma are associated with a poor prognosis.

Cystic Neoplasms

With recent improvements in and the increasing use of cross sectional imaging such as computed tomography (CT) scanning, more and more people are being diagnosed with cystic lesions in their pancreas. For example, in one series, pancreatic cysts were identified in 2.6% of over 2,800 CT scans performed on patients without pancreas-related

symptoms.[74] Many of these cysts are neoplastic cysts, and some will progress to invasive carcinoma if left untreated. Cystic neoplasms of the pancreas therefore represent a unique opportunity to treat pancreatic neoplasia before an invasive cancer develops. Unfortunately, since cystic tumors of the pancreas are so common and many are entirely benign, pancreatic cysts also present a significant risk for over treating patients.

There are four main cystic neoplasms of the pancreas.[54] **Intraductal papillary mucinous neoplasms** (IPMNs) and **mucinous cystic neoplasms** (MCNs) are noninvasive mucin-producing neoplasms. IPMNs, by definition, involve the larger pancreatic ducts (Figure 2B), while MCNs usually arise in the tail of the gland and the cysts of MCNs do not communicate with the pancreatic duct system. Some IPMNs and MCNs progress over years from lesions with low-grade dysplasia and few genetic abnormalities, to lesions with high-grade dysplasia, to invasive carcinomas with complex genetic changes. The clinical goal in managing these patients is to resect high-risk lesions such as IPMNs and MCNs with high-grade dysplasia, and to observe, and not over treat, those with low-grade dysplasia. Patients who have had an IPMN resected are at risk for developing an invasive cancer in the remnant of their pancreas and should be followed carefully.[75]

Solid-pseudopapillary neoplasms (SPNs) are low-grade malignant neoplasms composed of poorly cohesive cells. SPNs almost always arise in younger women, and are best treated surgically.[76] **Serous cystic neoplasms** (SCNs) are almost always benign, and are composed of uniform glycogen-rich cuboidal cells which form small cysts filled with straw-colored fluid. Most SCNs can be safely followed clinically and need not be resected unless they are large or cause symptoms.[77]

Molecular Biology (Table 4)

Cancer is fundamentally caused by inherited (germline) and acquired (somatic) mutations in cancer-causing genes. The germline changes associated with ductal adenocarcinoma of the pancreas were discussed earlier. The exomes of ductal adenocarcinoma and of all of the most common types of tumors of the pancreas have been completely sequenced, providing unprecedented insight into the somatic mutations in these neoplasms (Table 4).[78–81] This insight, in turn, will almost certainly change the way these neoplasms are clinically managed, and form the basis for new approaches to the early detection and treatment of pancreatic neoplasia.

The sequencing of infiltrating ductal adenocarcinomas of the pancreas revealed that four genes, *KRAS*, *p16/CDKN2A*, *TP53* and *SMAD4*, are each somatically altered in >50% of the cancers.[79] *KRAS*, an oncogene on chromosome 12, is activated by point mutation in 95% of invasive ductal adenocarcinomas.[79, 82] The protein coded for by the *KRAS* gene is a small GTPase that plays an important role in cell signaling through the mitogen-activated protein kinase (MAPK) and other pathways. The point mutations in *KRAS* occur early in pancreatic neoplasia, and almost exclusively target three codons (codons 12, 13 and 61), making them relatively easy to identify and, suggesting that *KRAS* mutations could form the basis for gene-based tests to detect early curable pancreatic neoplasia.[83]

The *p16/CDKN2A* gene, a tumor suppressor gene on chromosome 9p, is inactivated in ~95% of pancreatic cancers.[79] The protein product of the *p16/CDKN2A* gene, p16, plays an important role in the regulation of the cell cycle and loss of p16 function in pancreatic cancer is believed to promote unrestricted cell growth.

The *TP53* tumor suppressor gene on chromosome 17p is inactivated in 75% of pancreatic cancers.[79] *TP53* codes for the p53 protein, and p53 plays an important role in cellular stress responses, particularly by activating DNA repair, inducing growth arrest and triggering cell

death (apoptosis). Loss of p53 function, through mutation of the *TP53* gene, therefore promotes pancreatic neoplasia through the loss of a number of critical cell functions.

The fourth major gene that is somatically targeted in pancreatic cancer is the *SMAD4* (previously designated *DPC4*) tumor suppressor gene on chromosome 18q.[84] The protein product of the *SMAD4* gene, Smad4, functions in the transforming growth factor beta (TGFβ) cell signaling pathway. *SMAD4* gene mutations in pancreatic cancer are associated with poor prognosis and with more widely metastatic disease.[85, 86]

In addition to these four major genes, several genes are somatically mutated in pancreatic cancer at lower frequencies. They include *MLL3*, *TGFBR2*, *FBXW7*, *ARID1A, AIRID2*, and *ATM.*[79, 87] *ATM* is particularly interesting because it is a possible therapeutic target as cancers which have genetically inactivated *ATM* may be particularly sensitive to radiation damage and to poly ADP ribose polymerase (PARP) inhibitors.[88]

In addition to changes in the DNA sequence, the expression of a number of genes in pancreatic cancer is altered by epigenetic mechanisms such as aberrant methylation.[89] The expression of these aberrantly methylated genes is often downregulated, as can be seen with *p16/CDKN2A*. Other genes are hypomethylated and over-expressed in pancreatic cancer. DNA methylation in a cell can be chemically altered, and it has been suggested that the aberrant methylation in pancreatic cancer could be targeted therapeutically or used as a marker for early detection.[90, 91]

In addition to studies of DNA changes, a number of investigators have studied changes in gene expression in pancreatic cancer. The list of genes abnormally over-expressed in pancreatic cancer is large, and includes proteins such as mesothelin, trefoil factor 1, prostate stem cell antigen, claudin 4, and several of the S100-related proteins.[92] These over-expressed genes are potentially clinically important for two reasons. First, some, such as mesothelin, are potentially targetable therapeutically.[93, 94] Second, some, such as those that are secreted, could form the basis for a clinical test for the detection of pancreatic cancer.[92] Of interest, Wang et al have suggested that one could integrate our understanding of the genes that are genetically altered with those that are expressed in pancreatic cancer to develop a test that detects mutant proteins shed by the cancers.[95]

MicroRNAs are small non-coding RNA molecules that regulate gene expression. As such, microRNAs can serve as master switches in cells, turning on and off the expression of a number of genes in concert. Several microRNAs are aberrantly expressed in pancreatic cancer, and, because microRNAs tend to be long-lived, these abnormally expressed microRNAs could serve as markers for pancreatic cancer.[96–98]

The molecular alterations that characterize invasive ductal adenocarcinoma can be used as tools to study other lesions in the pancreas. For example, as discussed earlier, PanINs are thought to be precursor lesions to infiltrating ductal adenocarcinomas. The genetic changes in PanINs have been extensively studied and, as one would expect in a bona fide precursor, PanINs harbor many of the same changes as have been identified in invasive cancers.[65] *KRAS* and *p16/CDKN2A* mutations appear to occur early, in PanINs with low-grade dysplasia, while *TP53* and *SMAD4* mutations appear to be late events, occurring in PanINs with high-grade dysplasia and in invasive cancer. These findings not only help establish PanINs as noninvasive precursors to invasive pancreatic cancer, but they are also useful in designing early detection tests. For example, since *KRAS* mutations occur early and are present in most PanINs, they could be used as markers for the presence of a PanIN, but they would not provide information on histologic grade. By contrast, the presence of *TP53* or *SMAD4* gene mutations would suggest that a high-grade precursor or an invasive carcinoma is present.

The exomes (all known coding genes) of the four most common cystic neoplasms of the pancreas, IPMN, MCN, SPN and SCN, have also recently been sequenced, and each tumor type appears to have its' own specific mutational profile (Table 4).[80, 81] *KRAS*, *TP53* and *RNF43* mutations are found in the mucin-producing tumors (IPMN and MCN); *GNAS* mutations are relatively specific for IPMNs; *VHL* mutations are specific for SCN; and *CTNNB1* (beta-catenin) alterations are specific for SPNs. The identification of cyst-type specific mutations is very exciting because it suggests that the genetic analysis of cyst fluid collected at the time of endoscopic ultrasound (EUS) could be used to classify cyst type.[99] The challenge will be to identify markers of the degree of dysplasia.

The exomes of pancreatic neuroendocrine tumors (PanNETs) have also been sequenced and the results are dramatic.[78, 100] In addition to *MEN1*, a known tumor suppressor gene which is inactivated in 45% of PanNETs, *DAXX* or *ATRX* are altered in 45%, and mTOR pathway genes are targeted in at least 15% of PanNETs. *DAXX* and *ATRX* mutations have been associated with "alternative lengthening of telomeres (ALT+)," establishing a new cancer pathway in PanNETs.[100] The mTOR pathway gene mutations are particularly interesting because the drug everolimus targets the mTOR pathway and everolimus has been shown to be effective in some patients with PanNETs.[101, 102] Although it still needs to be validated in clinical trials, it is reasonable to hypothesize that PanNETs with genetic mutations in an mTOR pathway gene may be particularly sensitive to everolimus, while patients with PanNETs that lack an mTOR pathway activation could be spared the side effects of a drug that may be less effective for them. This is an exciting potential opening of the door to individualized therapy in which the optimal therapy for a patient with a PanNET is based on the genetic changes in their tumor.

Thus, analyses of molecular alterations at the DNA, RNA and protein levels have identified alterations specific for the various tumors of the pancreas (Table 4). Some of these alterations are candidate early detection markers, and others have the potential to form the basis for the rational selection of patient specific therapies.

Signs and Symptoms

Unfortunately, most pancreatic cancers present non-specifically and are not diagnosed until late in the course of the disease, after the cancer has already spread to other organs. Common symptoms include pain, particularly epigastric pain that radiates to the back, unexplained weight loss, jaundice, clay-colored stools, nausea, and in ~10% migratory thrombophlebitis (Trousseau's syndrome).[54]

As noted earlier in the section on risk factors, patients with pancreatic cancer sometimes present with new onset diabetes mellitus or with signs and symptoms of chronic pancreatitis. Of interest, depression is common in patients with pancreatic cancer, and in some instances the diagnosis of depression is established before the patient is found to have the cancer.[103] This observation suggests that the cancers are producing a factor that induces the depression.

The radiologic diagnosis of pancreatic cancer has improved significantly with enhancements in the sensitivity of imaging technologies. Multi-detector computed tomography (MDCT) (Figures 3, 4A and 4B), magnetic resonance imaging (MRI), and endoscopic ultrasound (EUS) can all be used to visualize the tumors. CT and MRI have comparable sensitivities and specificities, and both have the advantage that they can also be used to stage the neoplasm, and as described below, three-dimensional reconstructions can provide detailed information on the relationship of the tumor to nearby vessels. The gold standard for establishing a diagnosis is pathology, and tissues can be sampled at the time of EUS. Positron emission tomography (PET) imaging also has a role in selected instances.[104]

Clinical Staging

Once a diagnosis of pancreatic cancer has been established, the next step is careful staging, as stage will determine treatment. The American Joint Committee on Cancer (AJCC) staging system, which includes the TNM classification, is the most widely used system to stage pancreatic cancer.[105, 106] This system has undergone recent revisions to emphasize the importance of resectability of the cancer and it has been optimized to stratify survival by stage. Resectable stages include AJCC Stages I and II, and the subset of Stage III that is defined as borderline resectable. The unresectable categories include the subset of Stage III that is defined as locally advanced (unresectable), and Stage IV (metastatic). The staging workup focuses on defining the relationship of the tumor to large vessels and on identifying extra-regional metastatic disease and, when done properly, predicts the ability to perform a margin-negative resection.

The presence of clinically apparent extra-regional metastasis is classified as Stage IV and is a contraindication to an attempt at a curative resection. Frequent sites of extra-regional disease are the liver, peritoneum and lung, and these sites are not accurately assessed by physical exam. Palpable supraclavicular, periumbilical or pelvic nodes do occur, but are uncommon. Thus, the identification of extra-regional metastases relies heavily on imaging studies and the selective use of staging laparoscopy.

In the absence of metastatic disease, the relationship of the tumor to the adjacent major vascular structures defines resectability.[107] These vessels include the superior mesenteric artery (SMA), the celiac axis, and the superior mesenteric and portal veins (SMV-PV). Patients who do not have vessel involvement or who have only focal involvement of the SMV-PV confluence are considered to be resectable, while patients whose cancers involve arteries or have more extensive involvement of the SMV-PV confluence are classified as clinical Stage III. As detailed below, the extent of involvement determines the further subclassification of Stage III into borderline resectable or locally advanced.[107]

Abutment (defined as less than 180-degree involvement), of the celiac axis (celiac, common hepatic, replaced hepatic or proper hepatic arteries) or SMA is considered Stage III borderline resectable (Figures 4A and 5).[106, 107] Although resection of Stage III borderline tumors is likely to be technically feasible, the probability of a positive margin is high and neoadjuvant therapy is recommended for this group of patients with the intent of sterilizing the margin of viable cancer cells. Greater than 180-degree involvement of any of these arteries is defined as encasement and is considered Stage III locally advanced or unresectable (Figure 4B and 6). Resection of these cancers is either not possible or would result in a R2 (where some visible tumor could not be removed) resection. Rarely, exceptions are made in which short-segment encasement of the common hepatic artery is resected *en bloc* and reconstructed or, as will be discussed in greater detail later, in which focal involvement of the celiac artery and proximal common hepatic artery is resected with an Appleby's procedure. In these rare cases, patients are typically treated with neoadjuvant chemotherapy and radiation prior to resection.

In contrast to the arterial side, resectability on the venous side depends on the prospect of resecting and reconstructing the vessel.[108] Tumors that focally involve the SMV-PV confluence can be reconstructed since the PV and SMV can be reanastomosed. As a result these tumors are considered to be resectable. In contrast, tumors that involve a large segment of the portal vein high in the porta hepatis or inferior on the superior mesenteric vein in the area of confluence of multiple tributaries are not technically reconstructable and are considered to be Stage III locally advanced (Figure 7).

A contrast enhanced thin slice CT scan of the chest, abdomen and pelvis is the primary modality for the clinical staging of patients with pancreatic cancer and can accurately identify metastatic disease and local tumor relationships.[109, 110] Using this technology, the ability to predict a margin-negative resection (R0) is on the order of 73%. [110] Three important features should be noted on CT. The absence of vessel involvement is defined by the presence of a fat-plane separating the tumor from the vessels (Figure 3). Abutment of a vessel is defined by loss of the fat-plane with less than 180 degrees of involvement (Figures 4A and 5), while encasement is defined as greater than 180 degrees (Figures 4B and 6).

Patients who undergo R2 resection have a median survival less than 12 months which is no better than patients with locally advanced disease who do not have their tumors resected.[111, 112] Patients with vascular encasement by CT should therefore not undergo surgical exploration unless they respond to neoadjuvant therapy.

Treatment

Pancreatic cancer is a complex disease, and patients with pancreatic cancer are best treated by a multi-disciplinary team (see, for example, http://pathology.jhu.edu/pc).[113] As outlined in Figure 8 the optimal treatment first and foremost depends on careful accurate staging. Patients with Stage I/II disease should undergo surgical resection followed by adjuvant therapy. Neoadjuvant therapy should be considered in this patient population but is controversial, while patients with Stage III borderline resectable cancers should undergo neoadjuvant therapy prior to resection.[114] Patients with stage III locally advanced disease should be treated with chemotherapy and/or chemoradiotherapy. A vast majority of these patients eventually develops metastatic disease, however select patients can still be considered for surgical resection. Patients with Stage IV and good performance status may receive systemic therapy and those with poor overall health should be given supportive therapy.[115]

Localized Disease: Stage I/II and Stage III Borderline Resectable

Although the best chance of long-term survival for patients with localized pancreatic cancer is through complete resection of the primary lesion, the systemic nature of pancreatic cancer at diagnosis, the impact of pancreatectomy on quality of life and the relatively low chance of long-term survival must all be taken into account when selecting patients who will most benefit from surgery. Since most patients have locally invasive and micrometastatic disease at the time of surgery, the risk of both local and systemic recurrence following a potentially curative operation is high. The operations necessary to resect pancreatic cancer are associated with significant morbidity in 40–60% of patients and mortality in the 2–3% range.[111, 116] Moreover, complete recovery to a normal quality of life can take 2–3 months even in the absence of complications. In addition, long-term survival is uncommon. The median survival reported for resected pancreatic cancer ranges from 17–27 months and the 5-year survival is approximately 20%.[116] Taken together, these points underscore the importance of the multidisciplinary approach in the care of patients with pancreatic cancer regardless of stage.[113] The purpose of this section is to provide a surgical perspective on the management of pancreatic cancer with an emphasis on patient selection and recent advances in pancreas surgery.

Patient Selection for surgery—Several factors, in addition to stage, need to be considered in the selection of patients who will benefit from pancreatectomy.[117] These include the patient's overall health, their tumor biology and the use of neoadjuvant therapy. Often these three factors impact upon each other and should be considered collectively in formulating a management plan. It cannot be emphasized enough that this is best achieved through patient evaluation by a multidisciplinary team.[113]

Significant comorbidities can influence the ability of a patient to tolerate a major pancreatectomy.[117] Typical comorbidities in patients presenting with pancreatic cancer include cardiac disease, chronic obstructive pulmonary disease (COPD) and dementia. Moreover, cachexia and malnutrition that result from the cancer itself are common and can be further debilitating. Patients with poor overall health as a result of comorbid conditions and advanced age (>75 years) are not likely to benefit from pancreatectomy and may be harmed by the further debilitation and immunosuppression brought on with these operations.[117] A classification system proposed by Katz takes this into account and classifies patients with poor overall health as "medically borderline" regardless of tumor-vessel relationships.[118]

Another consideration in selecting patients for resection is "tumor biology." This is a term used to describe the relative propensity of a patient's tumor toward metastatic spread or locally aggressive behavior. Since no validated biomarkers are currently available to predict clinical behavior, the assessment of tumor biology is subjective. Indicators of aggressive biology include extensive metastatic disease at diagnosis, locally infiltrative tumors and rapid progression over time. Unvalidated markers include serum CA19-9 levels and tumor *SMAD4* gene status.[85, 86, 119] Patients with significantly elevated CA19-9 levels often do worse than those with low levels, and patients with tumors that have a wild-type *SMAD4* gene have been reported to have a lower propensity for wide-spread metastases than do those with loss of *SMAD4*.[85] In general, patients with aggressive tumor biology are unlikely to benefit from local therapy such as surgical resection even if they have an early stage tumor. Patients with localized but suspected biologically aggressive tumors may benefit from neoadjuvant therapy to control micrometastatic disease or at the very least allow assessment of biological behavior over time.

Neoadjuvant Therapy for Localized Disease—Neoadjuvant therapy remains controversial in the treatment of pancreatic cancer. It does have the advantage of down-staging some locally advanced patients and sterilizing the margin of borderline resectable patients allowing them to undergo a surgery with a higher likelihood of an R0 resection.[114, 120] In fact, 15–40% of patients with initially borderline or unresectable tumors can eventually undergo surgery. Neoadjuvant therapy also has the advantage that it will spare the 15–35% of patients who develop metastatic disease the risks and stress of a major operation; as metastases develop they would no longer be considered for surgery.[118, 121, 122] Neoadjuvant therapy also guarantees that almost all patients will receive some form of chemotherapy or radiation because they do not have any post-operative complications and recovery to overcome prior to starting therapy. Studies show that 73–100% of patients are able to complete the majority of their neoadjuvant regimens.[114, 120, 123–126] If radiation is given as part of the neoadjuvant regimen, it can be delivered to a smaller volume (tumor plus 1–2 cm) thus allowing for escalation of radiation dose to the tumor and resulting in less toxicity by decreasing the radiation exposure of adjacent normal organs.

Although neoadjuvant therapy is attractive for the reasons described above, surgery is required for a cure and neoadjuvant therapy delays patients' potentially curative surgery. Simply put, there are no randomized trials favoring neoadjuvant over adjuvant therapy. Therefore, at this time resectable patients are usually taken to surgery immediately and subsequently given adjuvant therapy, and neoadjuvant therapy is usually reserved for borderline resectable patients. The decision of whether to use neoadjuvant therapy followed by surgery, or surgery first followed by adjuvant therapy should be made in a multidisciplinary manner to achieve the timeliest and most coordinated treatments.[113]

There are no clear protocols established for neoadjuvant therapy, however most centers use similar regimens as for locally advanced/unresectable disease. The combination of 5-

flurouracil (5-FU), leucovorin, irinotecan and oxaliplatin (a regimen referred to as FOLFIRINOX), the combination of gemcitabine, docetaxel and capecitabine (a regimen referred to as GTX), and gemcitabine alone are possible chemotherapy regimens that are typically followed by continuous infusion 5-FU, capecitabine, or gemcitabine-based chemoradiation to 45–54 Gy in 1.8–2.5 Gy fractions or 36 Gy in 2.4 Gy fractions.[115, 120, 121, 126–128] Surgery should be performed within 6–8 weeks following completion of neoadjuvant therapy. Further delays lead to increased radiation-induced fibrosis, more challenging operations, longer operating times, and sometimes increased length of stay. An additional 2–3 cycles of adjuvant chemotherapy should be considered based on multidisciplinary evaluation of the tumor pathology.[129, 130]

Surgery for Localized disease—The required operation for a given patient depends on the location of their tumor. Cancers arising in the head of the pancreas require a pancreaticoduodenectomy (Whipple operation), while those in the tail require a distal pancreatectomy with an *en bloc* splenectomy.[131] Lesions located in the neck and body may require a pancreaticoduodenectomy, distal pancreatectomy or, rarely, a total pancreatectomy.[111, 132] Other partial resections, such as central pancreatectomy or enucleations do not result in an adequate lymphadenectomy and are not considered to be a potentially curative resection for pancreatic cancer. With the emergence of nonoperative biliary decompression, endoscopically directed therapies, such as duodenal wall stents and nonoperative celiac plexus blocks, the need for elective surgical palliation has dramatically decreased.

Pancreaticoduodenectomy

The pancreaticoduodectomy has three broad phases: 1) exploration to assess for occult extra-regional spread not identified on preoperative imaging; 2) resection of the tumor (Figure 9), and 3) reconstruction of the pancreaticobiliary and intestinal tracts (Figures 10A and 10B).

The operation begins with a careful inspection of the peritoneal surface for occult cancer implants. The liver is inspected both visually for surface lesions and by palpation for deeper lesions. Intraoperative ultrasonography may be used to assess the liver parenchyma. Patients at high risk for peritoneal dissemination based on CT findings or significantly elevated serum CA19-9 should undergo these initial steps laparoscopically.[133–135] The second phase is the resection of the head of the pancreas, duodenum, distal common bile duct and gallbladder (Figure 9). In a standard pancreaticoduodenectomy the stomach is divided proximal to the antrum, and in a pylorus preserving pancreaticoduodenectomy the first portion the duodenum is transected distal to the pylorus (Figure 9). In tumors that involve the SMV-PV, the SMV-PV can be divided and resected *en bloc* with the specimen. The PV and SMV are then reconstructed (Figure 11).

Optimal patient selection by a multidisciplinary team has made even more extensive resections possible in appropriate patients. For example, if the cancer involves the common hepatic artery in the region of the gastroduodenal artery (GDA), the cancer can be resected by removing the involved segment of artery *en bloc* with the specimen and performing an end-to-end reconnection of common and proper hepatic arteries (Figure 12).

In the third phase of the pancreaticoduodectomy, the enteric, biliary and pancreatic continuity are re-established with three anastomoses; pancreaticojejunostomy, hepaticojejunostomy and gastrojejunostomy for a standard pancreaticoduodenectomy (Figure 10A) or pancreaticojejunostomy, hepaticojejunostomy and duodenojejunostomy for the pylorus preserving version (Figure 10B).

Distal Pancreatectomy

In a distal pancreatectomy the distal pancreas and spleen are removed *en bloc*. Cancer of the body of the pancreas can be the most difficult lesion to manage surgically and is usually resected through a distal pancreatectomy. By virtue of this location, extension of the tumor superiorly beyond the pancreas often results in involvement of the celiac trunk, common hepatic artery and base of the splenic artery at its take-off from the celiac trunk (Figure 13A). Growth slightly to the right and posteriorly will involve the medial wall of the PV or SMV and may also infiltrate the junction of the splenic vein with the PV-SMV confluence. In these patients, considerable complexity is added to a distal pancreatectomy. The determination of resectability in these patients is based on the extent of involvement of the celiac axis.

In a variation of the standard distal pancreatectomy, cancers involving the celiac artery and proximal common hepatic artery can be resected using an Appleby procedure (Figure 13).[136] Patients have to be carefully selected for this operation which involves the *en bloc* resection the body and tail of pancreas along with the celiac artery, proximal common hepatic artery and splenic artery. Hepatic arterial blood supply is dependent on retrograde flow from the GDA to the proper hepatic artery. This operation also requires a total gastrectomy since the blood supply to the stomach is compromised.

Minimally Invasive Surgery

Minimally invasive surgery is used extensively in general surgery for a variety of procedures including anti-reflux procedures, bariatric surgery, hernia repairs, colectomies and cholecystectomy. The benefits of minimally invasive approaches in these instances include less scarring, less post-operative pain, less wound complications and an earlier return to normal activity.

As a result of the complexity of most pancreatectomies, minimally invasive approaches to pancreas surgery have lagged behind other areas of general surgery in terms of wide-spread acceptance, however, in recent years minimally invasive approaches have been applied to pancreatic resections and most pancreatic cancer operations can now been performed laparoscopically or robotically.[137–141] Access to the abdomen is gained through small ports placed through the abdominal wall, and early published series have shown that minimally invasive pancreatic operations can be performed safely and with similar outcomes to the standard approach.[139, 140] Important oncological parameters such as margin status and lymph node counts are also comparable to standard pancreatectomy.[138, 140] The benefits of minimally invasive pancreatectomy are, however, less clear than they are for other general surgical procedures. Wound complications such as surgical site infections do appear to favor minimally invasive pancreatectomy, but length of stay has not been reduced significantly.[140] Moreover, in contrast to minimally invasive colectomy for colon cancer, no high quality studies exist that compare long-term disease specific outcomes between minimally invasive and open pancreatectomy. In theory, the reduction of wound complications and reduced impact on immune function seen with minimally invasive surgery does have the potential to improve disease specific survival. In particular, fewer wound complications may increase the number of patients who are able to undergo adjuvant therapy. With the ever increasing use of minimally invasive pancreatectomy the importance of this approach in the management of patients with pancreatic cancer will become clear.

Surgical Complications

Through the 1970s, the mortality rate associated with a pancreaticoduodenectomy was as high as 30%. This has been reduced to less than 2% over the subsequent three decades.[116] Results have been shown to be significantly better at high-volume centers.[142] However, the

morbidity rate associated with the pancreaticoduodenectomy has remained between 30% and 45%, even at high volume centers.[142] The most common post-operative morbid complication is delayed gastric emptying, occurring in 15% of patients, followed by wound infection (8%), pancreatic fistula (5%), cardiac morbidity (4%), abdominal abscess (4%), cholangitis (2%), sepsis (2%), bile leak (2%) and several other complications occurring in less than 2% of patients.[116]

Outcomes of Surgery

In one of the largest series reported of pancreaticoduodenectomies for pancreatic adenocarcinoma, the median survival was 18 months and the 5-year survival was 18%.[116] Factors that negatively affected survival included tumor size of greater than 3 cm (hazard ratio [HR] 1.6; $p < .001$), positive resection margin (HR 1.6; $p < .001$), histological grade (HR 1.6; $p < .001$), and regional lymph node metastases (HR 1.3;$p = .05$).

Adjuvant Therapy—While surgery offers the only chance of cure, the majority of patients who undergo resection will still recur locally near the superior mesenteric artery margin or distantly (liver, lung, peritoneum). Adjuvant therapy is therefore indicated to decrease the risk of loco-regional and metastatic recurrence (Table 5). Adjuvant therapy is typically started 1–2 months after surgery to allow the patient to recover from the side effects or complications associated with surgery. Although no regimen has been proven substantially more effective than others, six months of adjuvant therapy with a 5-FU-based or gemcitabine-based chemotherapy is an appropriate standard option. The integration of approximately 6 weeks of 5-FU or gemcitabine based chemoradiation (CRT) (45Gy directed to the tumor bed, surgical anastomoses (pancreaticojejunostomy), and peri-pancreatic nodes with an additional 5–15 Gy boost to the tumor bed) during this six months period is an option and may be more favored for R1 (microscopically positive) resections and when the risk of loco-regional recurrence is higher (the debate surrounding radiation therapy for pancreatic cancer will be discussed in detail later in this review).[143] The appropriate sequencing of chemoradiation therapy in the adjuvant setting is unclear. As over 70% of patients will recur with distant disease, systemic chemotherapy is usually given first to be followed by CRT if there are no radiographic or clinical concerns for metastatic recurrence after chemotherapy is completed.

The benefit of adjuvant systemic chemotherapy was evaluated in the Charité Onkologie (CONKO)-001 trial in which 354 patients were randomized to either observation or adjuvant gemcitabine given intravenously (IV) for a total of 6 cycles.[144] Disease free survival (DFS) and OS were 6.9 months and 20.5 months for the observation arm, and 13.4 months and 24.2 months for the treatment arm, respectively. Similarly, the European Study Group for Pancreatic Cancer (ESPAC)-3 phase III trial randomized 1088 patients to bolus 5-FU daily with folinic acid for 5 days every 4 weeks or gemcitabine weekly for 3 weeks every 4 weeks for 6 cycles total.[145] Overall survival (OS) was 23.0 months in the 5-FU group and 23.6 months in the gemcitabine group, with higher rates of stomatitis and diarrhea in the 5-FU group and higher rates of hematologic toxicity in the gemcitabine group, but without any difference in quality of life. Taken together, the CONKO and ESPAC trials establish both 5-FU and gemcitabine as effective options for adjuvant chemotherapy. Unfortunately, the median overall survival for patients with resected pancreatic cancer is still approximately 20–22 months.

The Controversy over Radiation Therapy—The role of adding radiation therapy in the adjuvant setting is controversial. The Gastrointestinal Tumor Study Group (GITSG) trial in the 1980s was the first trial to show a survival benefit for adjuvant chemoradiation.[146] In this trial, patients with resected pancreatic cancer were randomized to either observation or

to chemoradiation. Chemoradiation included a 40-gray (Gy) split course of radiation with a 2-week break after 20 Gy, given with concurrent bolus 5-fluorouracil (5-FU) (500 mg/m2 on days 1–3 of each 20-Gy course of RT), followed by additional weekly 5-FU for 2 years or until progression.[146] The median overall survival (OS) was 20 months in the treatment arm compared to 11 months in the observation arm.[146] The European Organization for Research and Treatment of Cancer (EORTC) trial randomized patients to observation or to chemoradiation with 40-Gy split course given identically to the GITSG trial, with continuous infusion 5-FU (25 mg/kg/d) during the first course of radiation therapy, and for 0, 3, or 5 days of the second course (depending on toxicities).[147] Although the OS was 12.6 months in the observation arm compared to 17.1 months in the treatment arm, this difference was not statistically significant, however unlike the GITSG trial patients did not receive maintenance chemotherapy. A third trial, ESPAC-1, put the use of chemoradiation into question when it compared adjuvant chemoradiation, chemotherapy, both, or neither.[148] Patients were randomized to either 20 Gy total of radiation with bolus 5-FU over 2 weeks, bolus 5-FU daily for 5 days that was repeated every 4 weeks for a total of 6 cycles, chemoradiation followed by chemotherapy, or observation. With approximately 71 patients in each arm, median overall survivals were 13.9 months, 21.6 months, 19.9 months and 16.9 months, respectively. Patients who received radiation had a median OS of 15.9 months compared to 17.9 months for those who didn't receive radiation, suggesting that radiation was detrimental.[148] However, there was a great deal of non-adherence within this trial. Only 70% of patients randomized to receive chemoradiation received the prescribed dose of radiation (50% of the violations due to patient decision not to receive assigned treatment), and only 50% of patients randomized to receive chemotherapy received the full course of chemotherapy (33% of violations due to patient decision not receive assigned treatment).[149] As with trials previous to this trial, a split-course radiation regimen was utilized, and the quality assurance for the radiation therapy was lacking with no centralized review of the radiation fields. Finally, it is worth nothing that patients in the chemoradiation arm received only 2 cycles of 5-FU during radiation, while patients in the chemotherapy and chemoradiation followed by chemotherapy arms received ≥6 cycles of 5-FU. Not surprisingly, the results of this study have been criticized highly based on the perceived weaknesses in trial design and the quality of radiation delivery.[150]

Improvements in the delivery of radiation therapy now offer hope. The increased use of more three-dimensional (3D) conformal planning has led to more focused radiation fields (Figure 14), and it has now become feasible to deliver higher doses of continuous chemoradiation without increasing toxicities. Using these more modern approaches, two high volume surgical centers, Johns Hopkins University and the Mayo Clinic, reported on a large series of patients who had undergone surgical resection for pancreatic cancer and received post-operative CRT with a median dose of 50.4 Gy.[143, 151] Independently, both studies found that chemoradiation was associated with improved survival and increased local-regional control compared to surgery alone. These two studies were combined (n=1,092) and propensity scores were created and a matched pair analysis was performed to control for patient and treatment related variables.[152] Again, adjuvant chemoradiation was found to provide a statistically significant survival benefit (median survival 21.1 months) compared to surgery alone (15.5 months, p=<0.001). In the match pair analyses, the benefit of chemoradiation was seen in margin-positive or margin-negative patients and node-positive disease.

In an effort to improve on chemoradiation therapy, several studies have examined the use of agents other than 5-FU. The benefit of adding gemcitabine to 5-FU based chemoradiation was examined in RTOG 9704, a multicenter, randomized controlled phase III study.[153] The final analysis included 451 patients (388 pancreatic head tumors) and incorporated 5-FU or gemcitabine before and after 5-FU based chemoradiation. Of note, this trial utilized a

continuous course of chemoradiation and prospective central quality review was instituted for the first time. A 5-year update of the trial demonstrated a trend toward improved survival (p=0.08) for those patients (pancreatic head tumors only) who received gemcitabine.[153] Reported local failure rates were 25% for the gemcitabine arm and 30% for the 5-FU arm, much improved from the earlier studies which used a lower radiation dose, suggesting that an increased radiation dose is more effective in preventing local recurrence. The primary mode of failure remained distant metastasis, occurring in >70% of patients, which highlights the need for better systemic therapies.

Novel adjuvant therapy approaches—Smaller trials have also looked at other systemic therapies in the adjuvant setting (Table 5). The combination of interferon-alpha, cisplatin and 5-FU with chemoradiation had a median OS of 32 months compared to 28.5 months in the standard arm of 5-FU alone.[154–156] Erlotinib is being studied in the adjuvant setting and can be safely combined with gemcitabine as well with concurrent capecitabine and chemoradiation.[157] Immunotherapy is also being elavuated in the adjuvant setting. In a phase II trial of 5-FU based chemoradiation combined with a pancreatic cancer vaccine of irradiated granulocyte-macrophage colony stimulating factor (GM-CSF) transfected allogeneic whole cell tumor lines, the median OS was 24.8 months and patients who demonstrated a CD8+ T cell response to mesothelin had a higher likelihood of remaining disease free.[158] K-Ras mutant vaccines and MUC1 peptide-loaded dendritic cell vaccines also have shown early promising results.[159, 160]

In summary, a growing body of evidence-based medicine has established a role for systemic chemotherapy in the adjuvant setting. The role of chemoradiation is less clear, but newer technologies such as intensity modulated radiation therapy (IMRT) or stereotactic body radiation therapy (SBRT) use multiple, modulated beams of radiation that are likely to be safer and more effective than older radiation techniques. IMRT and SBRT can limit the dose to normal structures (bowel, kidneys, and liver) and deliver higher doses of radiation to the tumor bed (Figure 14) than traditional methods.[161] The incorporation of both modern radiation therapy and combination chemotherapies such as FOLFIRINOX (oxaliplatin, leucovorin, irinotecan, and 5-FU), which has shown promising results in the metastatic setting, is currently being tested in the adjuvant setting.[162]

Locally Advanced Pancreatic Adenocarcinoma

For patients with locally advanced pancreatic adenocarcinoma the median survival in most historical studies ranges from 8 to 12 months.[127, 163–171] Standard therapy includes external beam radiation therapy (EBRT) (total doses of 50–54 Gy in 1.8 to 2.0 Gy fractions) with concurrent chemotherapy (often 5-FU or gemcitabine), but some radiation therapy regimens can be delivered over shorter intervals.[127, 163, 172–174]

More contemporary studies using aggressive induction systemic therapy and/or dose escalated radiation therapy using 3-dimensional conformal, IMRT, or SBRT have reported improvements in treatment related toxicity and survival.[127, 175] Nevertheless, a majority of patients with locally advanced or metastatic pancreatic cancer are not curable, and multidisciplinary treatment that optimizes patient selection while balancing disease control, toxicity, and quality of life (QOL) is paramount.

The order in which chemo- and radiation therapy are given to patients with locally advanced disease can be important. Many patients (~20%) who receive upfront chemoradiation will be found to have metastases soon after their therapy is completed.[115] Furthermore, patients who receive upfront chemoradiation are likely to experience more toxicities than patients who receive chemotherapy alone, and these toxicities may interfere with subsequent chemotherapy needed to prevent and/or delay metastatic disease. An attractive alternative

approach is therefore to start with several cycles of chemotherapy (1–4 months) and then to restage the patient. Patients who have no evidence of metastatic disease on restaging, and who have a good performance status, would then be consolidated with chemoradiation. This strategy selects those patients who are more likely to benefit from chemoradiation, and has been shown to prevent or delay loco-regional progression which could result in pain (celiac plexus involvement) or duodenal obstruction. Studies have also shown that CRT-based control of local progression can prevent the development of metastatic disease and improve survival when compared to chemotherapy alone.[171,176]

Several modern single phase II studies have reported impressive increases in median survival by incorporating more aggressive chemotherapy (multiple agents), radiosensitizers and/or targeted agents during the induction phase of treatment and/or in conjunction with radiation therapy.[169, 177–181,182] For example, S-1 is a combination of tegafur (a prodrug converted to fluorouracil), gimeracil (an inhibitor of an enzyme which degrades fluorouracil), and oteracil (an inhibitor of fluorouracil phosphorylation in the gastrointestinal tract that acts to decrease toxicities).[164] In a study by Sudo et al, S-1 (oral, twice daily) was given concurrently with radiation (50.4 Gy) and followed with S-1 maintenance in patients with locally advanced pancreatic adenocarcinoma (N=−34).[164] Toxicity rates were acceptable (Grade 3–4), and outcomes were promising, with a median overall survival of 16.8 months and a 1-year survival rate of 70.6%. Although the results are encouraging, S-1 is currently not available in the United States. These single arm treatment studies, however, have all been small, and future study is needed.

Agents directed against the human epidermal growth factor receptor (EGFR) are among the best studied targeted agents in pancreatic cancer.[157] A phase I study examined the role of erlotinib (small molecule inhibitor of EGFR) with concurrent chemoradiation, and the results were promising, with partial responses seen in 35% of patients.[170] Crane et al. reported a multicenter phase II study in which patients with locally advanced pancreatic adenocarcinoma were treated with two months of induction cetuximab (antibody targeting EGFR), gemcitabine, and oxaliplatin, followed by concurrent capecitabine and cetuximab with RT (50.4 Gy) and maintenance gemcitabine and cetuximab therapy.[127] Median overall survival time was 19.2 months (95% CI, 14.2 to 24.2 months), and 1-year, 2-year, and 4-year actuarial overall survival rates were 66.0%, 25.02%, and 11.3%, respectively. Gastrointestinal toxicity was 32% and 10% for grades 2 and 3, respectively. In this study, Smad4 (Dpc4) expression was determined from pretreatment fine needle aspirations and was found to correlate with patterns of recurrence. Cancers with Smad4 inactivation were more likely to recur distantly whereas Smad4 intact cancers tended to recur locally ($P = .016$).

Selection of the optimal area to radiate is critical (Figure 14). The standard of care is to deliver a radiation field encompassing only the tumor plus a small margin to account for microscopic disease (clinical tumor volume=CTV) and tumor movement secondary to breathing, bowel distension, and set up error (planning treatment volume=PTV). By not treating elective nodal regions, the smaller margin around the tumor can: 1) allow for the escalation of radiation dose to the tumor above 54 Gy, 2) limit the dose delivered to the bowel and stomach in the field thus decreasing toxicity, and 3) allow for a shorter course of radiation such as can be achieved with stereotactic body radiation therapy (Figure 14).[183–186] Overall, results of recent studies indicate that the use of intensity modulated radiation therapy and stereotactic body radiation therapy provide a promising means of intensifying treatment without adding excessive toxicity.[104, 187, 188]

Treating metastatic disease (Table 6)

In the last few decades of the 20th century, 5-FU was the standard of care for the treatment of advanced pancreatic cancer. A meta-analysis of trials performed between 1970 and 2003

demonstrated that 5-FU was superior to best supportive care.[189] In 1997 a randomized phase III trial demonstrated a survival benefit for gemcitabine (dose at 1000 mg/m^2 weekly for 7 weeks with a 1 week break followed by cycles of 3 weeks on/1 week off) over bolus 5-FU with a median survival of 5.65 months as compared to 4.41 months, and 1-year survivals of 18% versus 2%.[190] Gemcitabine also had a superior clinical benefit response described as improvement in pain, performance status or weight in 24% of the patients versus 5% in the 5-FU group.[190] Both gemcitabine and 5-FU were well tolerated with similar toxicities. Based on this trial, gemcitabine was approved by the Food and Drug Administration for pancreatic cancer and gemcitabine became the standard of care. Fixed dose gemcitabine, given at a fixed rate of 10mg/m^2/min, is an alternative to the standard regimen described above as the prolonged exposure with the fixed rate dosing leads to an increased intracellular gemcitabine triphosphate concentration, however it did not lead to a statistical improvement in overall survival as compared to gemcitabine standard dose and infusion.[191, 192]

Numerous gemcitabine-based combinations have been tested and these combinations can be considered in patients with good performance status (ECOG 0–1).[193, 194] Gemcitabine combined with capecitabine in a phase III trial did not result in a statistically significant improvement in overall survival compared to gemcitabine alone.[195] Capecitabine has also been studied alone and it does provide clinical benefit response, although capecitabine could be considered as an alternative to single-agent gemcitabine in patients with moderate performance status.

The combination of gemcitabine and platinums (DNA-binding alkylating agents) has not shown improved efficacy in general. Gemcitabine plus oxaliplatin or gemcitabine in combination with cisplatin showed no statistically significant improvement in survival in phase III trials, although the results may have trended in that direction.[165, 196, 197] Selected subgroups of patients may, however, benefit. For example, retrospective analyses have suggested that patients with inherited *BRCA1* or *BRCA2* gene mutations and/or a family history of pancreatic, breast, or ovarian cancer may respond to gemcitabine-platinum combinations with longer median survivals compared to patients who were not given a platinum.[198] This sensitivity to platinum is thought to be a result of the fact that the BRCA1/2 protein complex is needed to repair DNA cross-linking damage, the very type of damage that platinum containing agents can induce.[27, 31]

The addition of docetaxel and capecitabine to gemcitabine (in a regimen referred to as GTX) has demonstrated good activity. Phase II trials and a retrospective review have demonstrated disease control rates of 63–80% with median survival for locally advanced patients of 25 months and for metastatic patients of 11 months.[128] The most common toxicities were neutropenia, diarrhea and hand/foot syndrome. Although these are smaller trials, GTX is a commonly used first-line therapy for patients with good performance status who want another option for combination therapy.

A phase I/II trial published in 2011 demonstrated exciting results when gemcitabine was combined with *nab*-paclitaxel (albumin-bound paclitaxel) as first-line therapy for metastatic pancreatic cancer patients. As discussed earlier, this combination makes sense as it has been suggested that nab-paclitaxel binds SPARC in the stroma of pancreatic cancer helping to deliver the paclitaxel.[58, 59] Gemcitabine was given at the standard dose of 1000 mg/m^2 and nab-paclitaxel (maximum tolerated dose was 125 mg/m^2) weekly for 3 weeks on, repeated every 4 weeks. Median overall survival was 12.2 months with tolerable toxicity and a negative PET-CT at 3 months was a predictor for good response.[59] A much anticipated phase III study of gemcitabine with or without nab-paclitaxel demonstrated only a less than two month improvement in survival from the addition of nab-paclitaxel (8.5 months vs.

6.7months) with more side effects in the nab-paclitaxel group.[199] Clinicians will need to weigh the small benefit from nab-paclitaxel with its toxicity and cost.

Gemcitabine has also been tested in combination with several different targeted therapies, and the combination with erlotinib improved overall survival, albeit minimally. A phase III randomized trial demonstrated a statistically significant improvement in overall survival from 5.91 months with single-agent gemcitabine to 6.24 months with gemcitabine plus erlotinib.[200] Erlotinib was approved by the Food and Drug Administration (FDA) after this trial and can be considered as first-line therapy in patients with good performance status, although again, one needs to weigh the small benefit of this agent versus the toxicity and cost. The addition of cetuximab to gemcitabine, and of bevacizumab (vascular endothelial growth factor [VEGF] inhibitor) to gemcitabine both demonstrated no survival benefit and an increase in toxicities in phase II and III trials.[166, 201]

The newest combination regimen for patients with metastatic pancreatic cancer is FOLFIRINOX.[162] FOLFIRINOX was initially described in France as oxaliplatin 85 mg/m^2, leucovorin 400 mg/m^2, irinotecan 180 mg/m^2, 5-FU bolus 400 mg/m^2 on day 1 followed by a 46 hour continuous infusion of 5-FU (2400 mg/m^2) repeated every 2 weeks. When 342 patients were randomized, disease control rate and median overall survival were 70% and 11.1 months in the FOLFIRINOX arm compared to 51% and 6.8 months in the gemcitabine arm.[162] Although there were more grade 3 and 4 toxicities in the FOLFIRINOX arm, quality of life was not different. FOLFIRINOX has therefore been recommended as an option for first-line therapy in patients with a good performance status (ECOG 0–1), however the doses are usually reduced and adjusted when given in the United States because of the greater toxicity seen here.

Second-line treatment is not very well established, partially because many of the patients are not strong enough to undergo further treatment. Patients with an adequate performance status who progressed on a gemcitabine-based regimen should be treated with a 5-FU based regimen, and vice versa. Single agent capecitabine is well tolerated and can be considered in patients with moderate performance status. Capecitabine and oxaliplatin (referred to as CAPOX or XELOX), provided 28% of patients with disease control with median overall survival of 23 weeks in a second-line phase II trial.[202, 203] Capecitabine plus erlotinib was reasonably tolerated and partial responses were seen in 10%.[204] Modified 5-FU and oxaliplatin (FOLFOX) and 5-FU and irinotecan (FOLFIRI) regimens can also be considered as second-line options with the former demonstrating a two month survival advantage over best supportive care.

If patients recur after resection and adjuvant therapy, biopsy can be considered. If the disease relapse is locoregional only, chemoradiation can be performed if no prior radiation was given. In regards to chemotherapy, if relapse occurs > 6 months after completion of adjuvant therapy, the same regimen can be considered. If relapse occurs earlier, a different regimen should be chosen. Metastatectomy can be considered in very fit patients who have isolated metastases. Although resection of liver metastases have shown mixed results in terms of improving survival as compared to a palliative procedure only, pulmonary and brain metastatectomy have improved survival in a carefully selected group of patients.[205]

Future therapies

The future for the development of new treatments is promising as there has been significant progress in the understanding of the genetics and molecular biology of pancreatic cancer.[69,199] Several attempts have been made to target the genetic changes specific to pancreatic cancer. The most appealing one to target is the *KRAS* gene since it is mutated in the vast majority of pancreatic cancers, however, inhibitors targeting the Kras protein itself

have been largely unsuccessful. More recent strategies have focused on targeting downstream pathways such as MEK, ERK and AKT.[206, 207] Very promising are therapies targeting the rarer genetic alterations in pancreatic cancer. As discussed earlier, cancers in which either *BRCA2* or *PALB2* is biallelically inactivated appear to be uniquely sensitive to DNA cross-linking agents such as mitomycin C, and to poly ADP ribose polymerase (PARP) inhibitors.[21, 31] Similarly, although the evidence in pancreatic cancer is lacking, one would predict that pancreatic cancers with inactivating *ATM* mutations may be particularly sensitive to radiation damage and to PARP inhibitors.[88]

We can easily imagine a scenario in the not too distant future in which all patients with pancreatic cancer will have their tumor DNA sequenced and information gleaned from the genetic changes in their cancer will be used to individualize their care.

In addition, much has been learned about the supportive tumor-stromal cell environment that is thought to not only influence the development of pancreatic cancer progression but which also supports mechanisms for resistance to effective treatment given its inherent protective properties.[208, 209] This includes the complex relationship between inflammation and the immune suppressive tumor microenvironment in pancreatic cancer. Targeting this environment is an exciting area only slowly being explored. Already there are new treatment opportunities targeting small molecules that can reverse immune suppression, as well as immunotherapy approaches that activate the immune system.[158, 210]

Another exciting new area is the targeting of cancer-specific cell metabolism including pathways associated with glucose/glutamine metabolism as well as mechanisms associated with the altered metabolic pathways or amino acid supply.[211–216]

Pain Assessment and Treatment

Patients with pancreatic cancer frequently present with pain as the initial symptom of their disease, with nearly 75% of patients suffering from pain at the time of diagnosis.[217] It is important for the practitioner to manage a patient's pain appropriately while other therapies such as chemotherapy, radiation therapy, or surgery are being carried out. Consultation with a physician with specific expertise in pain medicine is often helpful both in the outpatient clinic and multidisciplinary clinic settings. The initial assessment of pain includes evaluating the intensity, frequency, duration, exacerbating and/or alleviating factors, and a comprehensive history of current and previous pain medications along with documentation of any side effects encountered on these medications. Once obtained, this pain history and concomitant physical examination allows the health care team to make appropriately guided decisions regarding the potential implementation of pharmacologic, procedural, or surgical pain therapy.

Opioids are the mainstay of pharmacologic therapy for pancreatic cancer pain. Initial therapy may consist of a short-acting agent such as morphine or oxycodone. A sustained-release opioid, along with a short-acting opioid for breakthrough pain, may work better for those patients with constant pain or those who encounter difficulties with sleep secondary to pain. Common side effects of opioids include sedation, constipation, pruritis, nausea, and testosterone suppression in those on long-term therapy. Constipation is commonly addressed with stool softeners or bowel motility-promoting agents.

The most common and effective procedural intervention for pancreatic cancer pain is celiac plexus block[218]. The celiac plexus is formed by the coalescence of the greater, lesser, and least splanchnic nerves in the vicinity of the celiac trunk and provides visceral innervation from the pancreas and its surrounding structures (Figure 15). Patients who may benefit most from a celiac plexus block are those who have pain refractory to escalating doses of opioids

or those who suffer debilitating opioid-mediated side effects. Patients whose pain is relieved by diagnostic celiac plexus block may undergo subsequent celiac plexus neurolysis, with careful patient selection maximizing therapeutic outcomes.[219] Although initial celiac plexus neurolysis yields >3 months relief in most patients, disease progression often mitigates the efficacy of repeat procedure, and may indicate the need for more invasive therapy.[220]

Intrathecal delivery of analgesic agents is helpful in patients whose pain is poorly controlled by less invasive means (Figure 16).[221] Typically, a temporary percutaneous catheter is placed and the effectiveness of treatment is assessed and the dose optimized over several days. Subsequently, a pump and catheter system is surgically implanted to deliver opioid and/or adjuvant analgesic agents directly into the cerebrospinal fluid. Randomized, controlled studies have delineated the benefit of this therapeutic modality, not only for pain control, but particularly in minimizing the toxicities of systemically administered opioids.[222]

Ongoing consultation with a pain specialist is advised to optimize an integrated approach to pharmacologic, procedural, and surgical pain care for the patient with pancreatic cancer. Reassurance given to the patient that his or her pain care is paramount during their care, regardless of the stage and severity of their disease, are essential in a process where the emphasis is often more focused on palliation rather than cure.

Depression

Ten to 20% of patients with pancreatic cancer suffer from depression, and patients who are depressed are less likely to have their cancers managed optimally than are patients who are not depressed.[223, 224] Of note, while it is often assumed that this depression is caused by the psychological burden of the diagnosis of a life-threatening cancer, in fact, depression can precede the diagnosis of pancreatic cancer. This latter observation raises the possibility that pancreatic cancers provide a factor or factors that contribute to depression.[103] Regardless of its etiology, the immense suffering depression causes and its prevalence and make it clear that patients should be screened for depression, and if they have it adequately treated.[103]

End of Life

While it is natural for health care providers to focus on prolonging life, helping a patient and their family through the difficult transitions that come all too often with pancreatic cancer are equally as important. While a detailed discussion of palliative care is beyond the scope of this review, practitioners are encouraged to include a palliative care expert as a part of their multidisciplinary team.[115]

The Importance of Multidisciplinary care

It should be clear from this review that pancreatic cancer is a complex disease and that this complexity is best managed clinically by a multidisciplinary team of health care providers working in concert to deliver the best individualized care for their patients.[113] Indeed, a recent analysis of the Multidisciplinary Pancreatic Cancer Clinic at Johns Hopkins (http://pathology.jhu.edu/pc) showed that 25% of the patients referred to the clinic had a significant change in their diagnosis or treatment.[113] In addition, a large number of patients who went through the clinic elected to participate in research studies including clinical trials and the National Familial Pancreas Tumor Registry. The advantages of multidisciplinary care go beyond this, as these clinics build cohesion and communication within the team, helping to ensure the highest quality care even after the patient leaves the clinic to pursue specific treatments.

Summary and Conclusions

Pancreatic cancer is a complex and highly lethal disease that is best treated in the multidisciplinary setting. Although the survival statics are currently bleak, there are a number of bright spots on the horizon including individualized therapies and the prevention of an invasive pancreatic cancer by improvements in the management of cystic lesions of the pancreas.

Acknowledgments

Grant support: P30 CA006973 and P50 CA62924

References

1. Siegel R, Naishadham D, Jemal A. Cancer statistics, 2013. CA: a cancer journal for clinicians. 2013; 63:11–30. [PubMed: 23335087]
2. Bosetti C, Lucenteforte E, Silverman DT, et al. Cigarette smoking and pancreatic cancer: an analysis from the International Pancreatic Cancer Case-Control Consortium (Panc4). Ann Oncol. 2012; 23:1880–1888. [PubMed: 22104574]
3. Maisonneuve P, Lowenfels AB. Epidemiology of pancreatic cancer: an update. Dig Dis. 2010; 28:645–656. [PubMed: 21088417]
4. Blackford A, Parmigiani G, Kensler TW, et al. Genetic mutations associated with cigarette smoking in pancreatic cancer. Cancer Res. 2009; 69:3681–3688. [PubMed: 19351817]
5. Huxley R, Ansary-Moghaddam A, Berrington de Gonzalez A, Barzi F, Woodward M. Type-II diabetes and pancreatic cancer: a meta-analysis of 36 studies. British journal of cancer. 2005; 92:2076–2083. [PubMed: 15886696]
6. Chari ST, Leibson CL, Rabe KG, Ransom J, de AM, Petersen GM. Probability of pancreatic cancer following diabetes: a population-based study. Gastroenterology. 2005; 129:504–511. [PubMed: 16083707]
7. Arslan AA, Helzlsouer KJ, Kooperberg C, et al. Anthropometric measures, body mass index, and pancreatic cancer: a pooled analysis from the Pancreatic Cancer Cohort Consortium (PanScan). Arch Intern Med. 170:791–802. [PubMed: 20458087]
8. Lucenteforte E, La Vecchia C, Silverman D, et al. Alcohol consumption and pancreatic cancer: a pooled analysis in the International Pancreatic Cancer Case-Control Consortium (PanC4). Annals of oncology : official journal of the European Society for Medical Oncology / ESMO.
9. Duell EJ, Lucenteforte E, Olson SH, et al. Pancreatitis and pancreatic cancer risk: a pooled analysis in the International Pancreatic Cancer Case-Control Consortium (PanC4). Annals of oncology : official journal of the European Society for Medical Oncology / ESMO. 2012; 23:2964–2970. [PubMed: 22767586]
10. Jacobs EJ, Chanock SJ, Fuchs CS, et al. Family history of cancer and risk of pancreatic cancer: a pooled analysis from the Pancreatic Cancer Cohort Consortium (PanScan). Int J Cancer. 127:1421–1428. [PubMed: 20049842]
11. Ghadirian P, Boyle P, Simard A, Baillargeon J, Maisonneuve P, Perret C. Reported family aggregation of pancreatic cancer within a population-based case-control study in the Francophone community in Montreal, Canada. IntJPancreatol. 1991; 10:183–196.
12. Falk RT, Pickle LW, Fontham ET, Correa P, Fraumeni JF. Life-Style Risk Factors for Pancreatic Cancer in Louisiana: A Case-Control Study. American Journal of Epidemiology. 1988; 128:324–336. [PubMed: 3394699]
13. Price TF, Payne RL, Oberleitner MG. Familial pancreatic cancer in south Louisiana. Cancer Nurs. 1996; 19:275–282. [PubMed: 8768685]
14. Schenk M, Schwartz AG, O'Neal E, et al. Familial Risk of Pancreatic Cancer. JNatlCancer Inst. 2001; 93:640–644.
15. Brune KA, Lau B, Palmisano E, et al. Importance of age of onset in pancreatic cancer kindreds. J NatlCancer Inst. 2010; 102:119–126.

16. Wang L, Brune KA, Visvanathan K, et al. Elevated cancer mortality in the relatives of patients with pancreatic cancer. Cancer Epidemiol Biomarkers Prev. 2009; 18:2829–2834. [PubMed: 19843679]

17. Shi C, Hruban RH, Klein AP. Familial pancreatic cancer. ArchPatholLab Med. 2009; 133:365–374.

18. Canto MI, Hruban RH, Fishman EK, et al. Frequent Detection of Pancreatic Lesions in Asymptomatic High-Risk Individuals. Gastroenterology. 2012

19. Canto MI, Harinck F, Hruban RH, et al. International Cancer of the Pancreas Screening (CAPS) Consortium summit on the management of patients with increased risk for familial pancreatic cancer. Gut. 2012

20. McWilliams RR, Wieben ED, Rabe KG, et al. Prevalence of CDKN2A mutations in pancreatic cancer patients: implications for genetic counseling. European journal of human genetics : EJHG. 2011; 19:472–478. [PubMed: 21150883]

21. van der Heijden MS, Brody JR, Dezentje DA, et al. In vivo Therapeutic Responses Contingent on Fanconi Anemia/BRCA2 Status of the Tumor. Clin Cancer Res. 2005; 11:7508–7515. [PubMed: 16243825]

22. Goggins M, Schutte M, Lu J, et al. Germline BRCA2 gene mutations in patients with apparently sporadic pancreatic carcinomas. Cancer Res. 1996; 56:5360–5364. [PubMed: 8968085]

23. Ozcelik H, Schmocker B, DiNicola N, et al. Germline BRCA2 6174delT mutations in Ashkenazi Jewish pancreatic cancer patients. Nature Genet. 1997; 16:17–18. [PubMed: 9140390]

24. Ferrone CR, Levine DA, Tang LH, et al. BRCA germline mutations in Jewish patients with pancreatic adenocarcinoma. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2009; 27:433–438. [PubMed: 19064968]

25. Couch FJ, Johnson MR, Rabe KG, et al. The Prevalence of BRCA2 Mutations in Familial Pancreatic Cancer. Cancer EpidemiolBiomarkers Prev. 2007; 16:342–346.

26. Murphy KM, Brune KA, Griffin CA, et al. Evaluation of candidate genes MAP2K4, MADH4, ACVR1B, and BRCA2 in familial pancreatic cancer: deleterious BRCA2 mutations in 17%. Cancer Research. 2002; 62:3789–3793. [PubMed: 12097290]

27. Lowery MA, Kelsen DP, Stadler ZK, et al. An emerging entity: pancreatic adenocarcinoma associated with a known BRCA mutation: clinical descriptors, treatment implications, and future directions. The oncologist. 2011; 16:1397–1402. [PubMed: 21934105]

28. Tischkowitz MD, Sabbaghian N, Hamel N, et al. Analysis of the gene coding for the BRCA2-interacting protein PALB2 in familial and sporadic pancreatic cancer. Gastroenterology. 2009; 137:1183–1186. [PubMed: 19635604]

29. Slater EP, Langer P, Niemczyk E, et al. PALB2 mutations in European familial pancreatic cancer families. Clin Genet. 78:490–494. [PubMed: 20412113]

30. Jones S, Hruban RH, Kamiyama M, et al. Exomic sequencing identifies PALB2 as a pancreatic cancer susceptibility gene. Science. 2009; 324:217. [PubMed: 19264984]

31. Villarroel MC, Rajeshkumar NV, Garrido-Laguna I, et al. Personalizing cancer treatment in the age of global genomic analyses: PALB2 gene mutations and the response to DNA damaging agents in pancreatic cancer. MolCancer Ther. 2011; 10:3–8.

32. Thompson D, Easton DF. Cancer Incidence in BRCA1 mutation carriers. JNatlCancer Inst. 2002; 94:1358–1365.

33. Axilbund JE, Argani P, Kamiyama M, et al. Absence of germline BRCA1 mutations in familial pancreatic cancer patients. Cancer Biol Ther. 2009; 8:1–5.

34. Moskaluk CA, Hruban RH, Lietman AS, et al. Novel germline p16 (INK4) allele (Asp145Cys) in a family with multiple pancreatic carcinomas. Mutations in brief no. 148. Online. Hum Mutat. 1998; 12:70–73. [PubMed: 10627132]

35. Rutter JL, Bromley CM, Goldstein AM, et al. Heterogeneity of risk for melanoma and pancreatic and digestive malignancies: a melanoma case-control study. Cancer. 2004; 101:2809–2816. [PubMed: 15529312]

36. Vasen HF, Gruis NA, Frants RR, van dV, Hille ET, Bergman W. Risk of developing pancreatic cancer in families with familial atypical multiple mole melanoma associated with a specific 19 deletion of p16 (p16-Leiden). Int J Cancer. 2000; 87:809–811. [PubMed: 10956390]

37. Santillan AA, Cherpelis BS, Glass LF, Sondak VK. Management of familial melanoma and nonmelanoma skin cancer syndromes. Surg Oncol Clin N Am. 2009; 18:73–98. viii. [PubMed: 19056043]
38. Rustgi AK. The genetics of hereditary colon cancer. Genes Dev. 2007; 21:2525–2538. [PubMed: 17938238]
39. Kastrinos F, Mukherjee B, Tayob N, et al. Risk of pancreatic cancer in families with Lynch syndrome. JAMA. 2009; 302:1790–1795. [PubMed: 19861671]
40. Alexander J, Watanabe T, Wu TT, Rashid A, Li S, Hamilton SR. Histopathological identification of colon cancer with microsatellite instability. Am J Pathol. 2001; 158:527–535. [PubMed: 11159189]
41. Wilentz RE, Goggins M, Redston M, et al. Genetic, immunohistochemical, and clinical features of medullary carcinoma of the pancreas: a newly described and characterized entity. American Journal of Pathology. 2000; 156:1641–1651. [PubMed: 10793075]
42. Nakata B, Wang YQ, Yashiro M, et al. Prognostic value of microsatellite instability in resectable pancreatic cancer. Clin Cancer Res. 2002; 8:2536–2540. [PubMed: 12171881]
43. Le Bodic L, Bignon JD, Raguenes O, et al. The hereditary pancreatitis gene maps to long arm of chromosome 7. Hum Mol Genet. 1996; 5:549–554. [PubMed: 8845851]
44. Whitcomb DC, Preston RA, Aston CE, et al. A gene for hereditary pancreatitis maps to chromosome 7q35. Gastroenterology. 1996; 110:1975–1980. [PubMed: 8964426]
45. Whitcomb DC, Gorry MC, Preston RA, et al. Hereditary pancreatitis is caused by a mutation in the cationic trypsinogen gene [see comments]. NatGenet. 1996; 14:141–145.
46. Witt H, Luck W, Hennies HC, et al. Mutations in the gene encoding the serine protease inhibitor, Kazal type 1 are associated with chronic pancreatitis. Nat Genet. 2000; 25:213–216. [PubMed: 10835640]
47. Lowenfels AB, Maisonneuve P, DiMagno EP, et al. Hereditary pancreatitis and the risk of pancreatic cancer. International Hereditary Pancreatitis Study Group. J Natl Cancer Inst. 1997; 89:442–446. [PubMed: 9091646]
48. Lowenfels AB, Maisonneuve P, Whitcomb DC, Lerch MM, DiMagno EP. Cigarette smoking as a risk factor for pancreatic cancer in patients with hereditary pancreatitis. JAMA. 2001; 286:169–170. [PubMed: 11448279]
49. Korsse SE, Harinck F, van Lier MG, et al. Pancreatic cancer risk in Peutz-Jeghers syndrome patients: a large cohort study and implications for surveillance. J Med Genet. 2013; 50:59–64. [PubMed: 23240097]
50. Giardiello FM, Brensinger JD, Tersmette AC, et al. Very high risk of cancer in familial Peutz-Jeghers Syndrome. Gastroenterology. 2000; 119:1447–1453. [PubMed: 11113065]
51. Canto MI, Goggins M, Hruban RH, et al. Screening for early pancreatic neoplasia in high-risk individuals: a prospective controlled study. Clinical gastroenterology and hepatology : the official clinical practice journal of the American Gastroenterological Association. 2006; 4:766–781. quiz 665. [PubMed: 16682259]
52. Sato N, Rosty C, Jansen M, et al. STK11/LKB1 Peutz-Jeghers gene inactivation in intraductal papillary-mucinous neoplasms of the pancreas. The American journal of pathology. 2001; 159:2017–2022. [PubMed: 11733352]
53. Wolpin BM, Chan AT, Hartge P, et al. ABO blood group and the risk of pancreatic cancer. J Natl Cancer Inst. 2009; 101:424–431. [PubMed: 19276450]
54. Hruban, RH.; Pitman, MB.; Klimstra, DS. Atlas of tumor pathology. Vol Fourth Series, Fascicle 6. Washington, DC: American Registry of Pathology and Armed Forces Institute of Pathology; 2007. Tumors of the pancreas.
55. Provenzano PP, Cuevas C, Chang AE, Goel VK, Von Hoff DD, Hingorani SR. Enzymatic targeting of the stroma ablates physical barriers to treatment of pancreatic ductal adenocarcinoma. Cancer Cell. 2012; 21:418–429. [PubMed: 22439937]
56. Jacobetz MA, Chan DS, Neesse A, et al. Hyaluronan impairs vascular function and drug delivery in a mouse model of pancreatic cancer. Gut. 2012

57. Olive KP, Jacobetz MA, Davidson CJ, et al. Inhibition of Hedgehog signaling enhances delivery of chemotherapy in a mouse model of pancreatic cancer. Science. 2009; 324:1457–1461. [PubMed: 19460966]
58. Infante JR, Matsubayashi H, Sato N, et al. Peritumoral fibroblast SPARC expression and patient outcome with resectable pancreatic adenocarcinoma. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2007; 25:319–325. [PubMed: 17235047]
59. Von Hoff DD, Ramanathan RK, Borad MJ, et al. Gemcitabine plus nab-paclitaxel is an active regimen in patients with advanced pancreatic cancer: a phase I/II trial. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2011; 29:4548–4554. [PubMed: 21969517]
60. Voong KR, Davison J, Pawlik TM, et al. Resected pancreatic adenosquamous carcinoma: clinicopathologic review and evaluation of adjuvant chemotherapy and radiation in 38 patients. Hum Pathol. 2010; 41:113–122. [PubMed: 19801164]
61. Boyd CA, Benarroch-Gampel J, Sheffield KM, Cooksley CD, Riall TS. 415 patients with adenosquamous carcinoma of the pancreas: a population-based analysis of prognosis and survival. J Surg Res. 2012; 174:12–19. [PubMed: 21816433]
62. Seidel G, Zahurak M, Iacobuzio-Donahue C, et al. Almost all infiltrating colloid carcinomas of the pancreas and periampullary region arise from in situ papillary neoplasms: a study of 39 cases. Am J Surg Pathol. 2002; 26:56–63. [PubMed: 11756769]
63. Poultsides GA, Reddy S, Cameron JL, et al. Histopathologic basis for the favorable survival after resection of intraductal papillary mucinous neoplasm-associated invasive adenocarcinoma of the pancreas. Ann Surg. 2010; 251:470–476. [PubMed: 20142731]
64. Hruban RH, Takaori K, Canto M, et al. Clinical importance of precursor lesions in the pancreas. J Hepatobiliary Pancreat Surg. 2007; 14:255–263. [PubMed: 17520200]
65. Maitra A, Fukushima N, Takaori K, Hruban RH. Precursors to invasive pancreatic cancer. Adv Anat Pathol. 2005; 12:81–91. [PubMed: 15731576]
66. Sipos B, Frank S, Gress T, Hahn S, Klöppel G. Pancreatic intraepithelial neoplasia revisited and updated. Pancreatology. 2009; 9:45–54. [PubMed: 19077454]
67. Kanda M, Sadakari Y, Borges M, et al. Mutant TP53 in Duodenal Samples of Pancreatic Juice from Patients with Pancreatic Cancer or High-Grade Dysplasia. Clinical gastroenterology and hepatology : the official clinical practice journal of the American Gastroenterological Association. 2012
68. Kanda M, Knight S, Topazian M, et al. Mutant GNAS detected in duodenal collections of secretin-stimulated pancreatic juice indicates the presence or emergence of pancreatic cysts. Gut. 2012
69. Detlefsen S, Sipos B, Feyerabend B, Klöppel G. Pancreatic fibrosis associated with age and ductal papillary hyperplasia. Virchows Arch. 2005; 447:800–805. [PubMed: 16021508]
70. Brune KA, Abe T, Canto MI, et al. Multifocal neoplastic precusor lesions associated with lobular atrophy of the pancreas in patients having a strong family history of pancreatic cancer. American Journal of Surgical Pathology. 2006; 30:1067–1076. [PubMed: 16931950]
71. WHO Classification of Tumours of the Digestive System. 4th ed. Lyon: IARC; 2010.
72. Raymond E, Hobday T, Castellano D, Reidy-Lagunes D, Garcia-Carbonero R, Carrato A. Therapy innovations: tyrosine kinase inhibitors for the treatment of pancreatic neuroendocrine tumors. Cancer Metastasis Rev. 2011; 30(Suppl 1):19–26. [PubMed: 21308478]
73. Yao JC, Shah MH, Ito T, et al. Everolimus for Advanced Pancreatic Neuroendocrine Tumors. NEnglJ Med. 2011; 364:514–523.
74. Laffan TA, Horton KM, Klein AP, Fishman EK, Johnson PT, Hruban RH. Prevelance of unsuspected pancreatic cysts on MDCT. AJRAmerican Journal of Roentgenology. 2008; 191:802–807.
75. He J, Cameron JL, Ahuja N, et al. Is It Necessary to Follow Patients after Resection of a Benign Pancreatic Intraductal Papillary Mucinous Neoplasm? J Am Coll Surg. 2013
76. Reddy S, Cameron JL, Scudiere J, et al. Surgical management of solid-pseudopapillary neoplasms of the pancreas (Franz or Hamoudi tumors): a large single-institutional series. J Am Coll Surg. 2009; 208:950–957. discussion 957-959. [PubMed: 19476869]

77. Wargo JA, Fernandez-del-Castillo C, Warshaw AL. Management of pancreatic serous cystadenomas. Adv Surg. 2009; 43:23–34. [PubMed: 19845167]

78. Jiao Y, Shi C, Edil BH, et al. DAXX/ATRX, MEN1, and mTOR pathway genes are frequently altered in pancreatic neuroendocrine tumors. Science. 2011; 331:1199–1203. [PubMed: 21252315]

79. Jones S, Zhang X, Parsons DW, et al. Core signaling pathways in human pancreatic cancers revealed by global genomic analyses. Science. 2008; 321:1801–1806. [PubMed: 18772397]

80. Wu J, Jiao Y, Dal Molin M, et al. Whole-exome sequencing of neoplastic cysts of the pancreas reveals recurrent mutations in components of ubiquitin-dependent pathways. Proc Natl Acad Sci U S A. 2011; 108:21188–21193. [PubMed: 22158988]

81. Wu J, Matthaei H, Maitra A, et al. Recurrent GNAS mutations define an unexpected pathway for pancreatic cyst development. Science translational medicine. 2011; 3:92ra66.

82. Hruban RH, van Mansfeld ADM, Offerhaus GJ, et al. K-ras oncogene activation in adenocarcinoma of the human pancreas. A study of 82 carcinomas using a combination of mutant-enriched polymerase chain reaction analysis and allele-specific oligonucleotide hybridization. American Journal of Pathology. 1993; 143:545–554. [PubMed: 8342602]

83. Shi C, Fukushima N, Abe T, et al. Sensitive and quantitative detection of KRAS2 gene mutations in pancreatic duct juice differentiates patients with pancreatic cancer from chronic pancreatitis, potential for early detection. Cancer Biol Ther. 2008; 7:353–360. [PubMed: 18075308]

84. Hahn SA, Schutte M, Hoque AT, et al. DPC4, a candidate tumor suppressor gene at human chromosome 18q21.1. Science. 1996; 271:350–353. [PubMed: 8553070]

85. Iacobuzio-Donahue CA, Fu B, Yachida S, et al. DPC4 gene status of the primary carcinoma correlates with patterns of failure in patients with pancreatic cancer. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2009; 27:1806–1813. [PubMed: 19273710]

86. Blackford A, Serrano OK, Wolfgang CL, et al. SMAD4 gene mutations are associated with poor prognosis in pancreatic cancer. Clin Cancer Res. 2009; 15:4674–4679. [PubMed: 19584151]

87. Roberts NJ, Jiao Y, Yu J, et al. ATM Mutations in Patients with Hereditary Pancreatic Cancer. Cancer Discovery. 2012; 2:41–46. [PubMed: 22585167]

88. Williamson CT, Kubota E, Hamill JD, et al. Enhanced cytotoxicity of PARP inhibition in mantle cell lymphoma harbouring mutations in both ATM and p53. EMBO molecular medicine. 2012; 4:515–527. [PubMed: 22416035]

89. Omura N, Li CP, Li A, et al. Genome-wide profiling of methylated promoters in pancreatic adenocarcinoma. Cancer Biol Ther. 2008; 7:1146–1156. [PubMed: 18535405]

90. Missiaglia E, Donadelli M, Palmieri M, Crnogorac-Jurcevic T, Scarpa A, Lemoine NR. Growth delay of human pancreatic cancer cells by methylase inhibitor 5-aza-2'-deoxycytidine treatment is associated with activation of the interferon signalling pathway. Oncogene. 2005; 24:199–211. [PubMed: 15637593]

91. Fukushima N, Walter KM, Uek T, et al. Diagnosing pancreatic cancer using methylation specific PCR analysis of pancreatic juice. Cancer BiolTher. 2003; 2:78–83.

92. Harsha HC, Kandasamy K, Ranganathan P, et al. A compendium of potential biomarkers of pancreatic cancer. PLoS Med. 2009; 6:e1000046. [PubMed: 19360088]

93. Argani P, Iacobuzio-Donahue C, Ryu B, et al. Mesothelin is overexpressed in the vast majority of ductal adenocarcinomas of the pancreas: identification of a new pancreatic cancer marker by serial analysis of gene expression (SAGE). Clin Cancer Res. 2001; 7:3862–3868. [PubMed: 11751476]

94. Hassan R, Bera T, Pastan I. Mesothelin: a new target for immunotherapy. ClinCancer Res. 2004; 10:3937–3942.

95. Wang Q, Chaerkady R, Wu J, et al. Mutant proteins as cancer-specific biomarkers. Proc Natl Acad Sci U S A. 2011; 108:2444–2449. [PubMed: 21248225]

96. Habbe N, Koorstra JB, Mendell JT, et al. MicroRNA miR-155 is a biomarker of early pancreatic neoplasia. Cancer Biol Ther. 2009; 8

97. Matthaei H, Wylie D, Lloyd MB, et al. miRNA Biomarkers in Cyst Fluid Augment the Diagnosis and Management of Pancreatic Cysts. Clin Cancer Res. 2012; 18:4713–4724. [PubMed: 22723372]

98. Wan C, Shen Y, Yang T, Wang T, Chen L, Wen F. Diagnostic value of microRNA for pancreatic cancer: a meta-analysis. Archives of medical science : AMS. 2012; 8:749–755. [PubMed: 23185182]

99. Siddiqui AA, Kowalski TE, Kedika R, et al. EUS-guided pancreatic fluid aspiration for DNA analysis of KRAS and GNAS mutations for the evaluation of pancreatic cystic neoplasia: a pilot study. Gastrointest Endosc. 2013; 77:669–670. [PubMed: 23498145]

100. Heaphy CM, de Wilde RF, Jiao Y, et al. Altered telomeres in tumors with ATRX and DAXX mutations. Science. 2011; 333:425. [PubMed: 21719641]

101. Krueger DA, Care MM, Holland K, et al. Everolimus for subependymal giant-cell astrocytomas in tuberous sclerosis. NEnglJ Med. 2010; 363:1801–1811.

102. Yao JC, Shah MH, Ito T, et al. A randomized, double-blind, placebo-controlled, multicenter Phase III trial of Everolimus in patients with advanced pancreatic neuroendorcrine tumors (PNET) (RADIANT-3). Annals of Oncology. 2010; 21

103. Mayr M, Schmid RM. Pancreatic cancer and depression: myth and truth. BMC cancer. 2010; 10:569. [PubMed: 20961421]

104. Schellenberg D, Quon A, Minn AY, et al. 18Fluorodeoxyglucose PET is prognostic of progression-free and overall survival in locally advanced pancreas cancer treated with stereotactic radiotherapy. Int J Radiat Oncol Biol Phys. 2010; 77:1420–1425. [PubMed: 20056345]

105. American Joint Committee on C. AJCC cancer staging handbook. Vol. Vol 7th. New York: Springer-Verlag; 2010.

106. Tamm EP, Balachandran A, Bhosale PR, et al. Imaging of pancreatic adenocarcinoma: update on staging/resectability. Radiol Clin North Am. 2012; 50:407–428. [PubMed: 22560689]

107. Vauthey JN, Dixon E. AHPBA/SSO/SSAT Consensus Conference on Resectable and Borderline Resectable Pancreatic Cancer: rationale and overview of the conference. Ann Surg Oncol. 2009; 16:1725–1726. [PubMed: 19396495]

108. Tseng JF, Raut CP, Lee JE, et al. Pancreaticoduodenectomy with vascular resection: margin status and survival duration. J Gastrointest Surg. 2004; 8:935–949. discussion 949–950. [PubMed: 15585381]

109. Qiu H, Wild AT, Wang H, et al. Comparison of conventional and 3-dimensional computed tomography against histopathologic examination in determining pancreatic adenocarcinoma tumor size: Implications for radiation therapy planning. Radiother Oncol. 2012; 104:167–172. [PubMed: 22883106]

110. House MG, Yeo CJ, Cameron JL, et al. Predicting resectability of periampullary cancer with three-dimensional computed tomography. J Gastrointest Surg. 2004; 8:280–288. [PubMed: 15019924]

111. Sohn TA, Yeo CJ, Cameron JL, et al. Resected adenocarcinoma of the pancreas-616 patients: results, outcomes, and prognostic indicators. J Gastrointest Surg. 2000; 4:567–579. [PubMed: 11307091]

112. Willett CG, Lewandrowski KB, Warshaw AL, Efird J, Corris PA. Resection margins in carcinoma of the head of the pancreas. Implications for radiation therapy. Annals of Surgery. 1993; 217:144–148. [PubMed: 8094952]

113. Pawlik TM, Laheru D, Hruban RH, et al. Evaluating the impact of a single-day multidisciplinary clinic on the management of pancreatic cancer. Ann Surg Oncol. 2008; 15:2081–2088. [PubMed: 18461404]

114. Evans DB, Varadhachary GR, Crane CH, et al. Preoperative gemcitabine-based chemoradiation for patients with resectable adenocarcinoma of the pancreatic head. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2008; 26:3496–3502. [PubMed: 18640930]

115. Tempero MA, Arnoletti JP, Behrman SW, et al. Pancreatic Adenocarcinoma, version 2.2012: featured updates to the NCCN Guidelines. Journal of the National Comprehensive Cancer Network : JNCCN. 2012; 10:703–713. [PubMed: 22679115]

116. Winter JM, Cameron JL, Campbell KA, et al. 1423 pancreaticoduodenectomies for pancreatic cancer: a single institution experience. JGastrointestSurg. 2006; 10:1199–1211.

117. Hsu CC, Wolfgang CL, Laheru DA, et al. Early mortality risk score: identification of poor outcomes following upfront surgery for resectable pancreatic cancer. J Gastrointest Surg. 2012; 16:753–761. [PubMed: 22311282]
118. Katz MH, Pisters PW, Evans DB, et al. Borderline resectable pancreatic cancer: the importance of this emerging stage of disease. J Am Coll Surg. 2008; 206:833–846. discussion 846-838. [PubMed: 18471707]
119. van den Bosch RP, van Eijck CH, Mulder PG, Jeekel J. Serum CA19-9 determination in the management of pancreatic cancer. Hepatogastroenterology. 1996; 43:710–713. [PubMed: 8799418]
120. Gillen S, Schuster T, Meyer Zum Buschenfelde C, Friess H, Kleeff J. Preoperative/neoadjuvant therapy in pancreatic cancer: a systematic review and meta-analysis of response and resection percentages. PLoS Med. 2010; 7:e1000267. [PubMed: 20422030]
121. Laurence JM, Tran PD, Morarji K, Eslick GD, Lam VW, Sandroussi C. A systematic review and meta-analysis of survival and surgical outcomes following neoadjuvant chemoradiotherapy for pancreatic cancer. J Gastrointest Surg. 2011; 15:2059–2069. [PubMed: 21913045]
122. White RR, Paulson EK, Freed KS, et al. Staging of pancreatic cancer before and after neoadjuvant chemoradiation. J Gastrointest Surg. 2001; 5:626–633. [PubMed: 12086901]
123. Varadhachary GR, Wolff RA, Crane CH, et al. Preoperative gemcitabine and cisplatin followed by gemcitabine-based chemoradiation for resectable adenocarcinoma of the pancreatic head. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2008; 26:3487–3495. [PubMed: 18640929]
124. Heinrich S, Pestalozzi BC, Schafer M, et al. Prospective phase II trial of neoadjuvant chemotherapy with gemcitabine and cisplatin for resectable adenocarcinoma of the pancreatic head. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2008; 26:2526–2531. [PubMed: 18487569]
125. Palmer DH, Stocken DD, Hewitt H, et al. A randomized phase 2 trial of neoadjuvant chemotherapy in resectable pancreatic cancer: gemcitabine alone versus gemcitabine combined with cisplatin. Ann Surg Oncol. 2007; 14:2088–2096. [PubMed: 17453298]
126. Le Scodan R, Mornex F, Girard N, et al. Preoperative chemoradiation in potentially resectable pancreatic adenocarcinoma: feasibility, treatment effect evaluation and prognostic factors, analysis of the SFRO-FFCD 9704 trial and literature review. Ann Oncol. 2009; 20:1387–1396. [PubMed: 19502533]
127. Crane CH, Varadhachary GR, Yordy JS, et al. Phase II trial of cetuximab, gemcitabine, and oxaliplatin followed by chemoradiation with cetuximab for locally advanced (T4) pancreatic adenocarcinoma: correlation of Smad4(Dpc4) immunostaining with pattern of disease progression. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2011; 29:3037–3043. [PubMed: 21709185]
128. De Jesus-Acosta A, Oliver GR, Blackford A, et al. A multicenter analysis of GTX chemotherapy in patients with locally advanced and metastatic pancreatic adenocarcinoma. Cancer chemotherapy and pharmacology. 2012; 69:415–424. [PubMed: 21800112]
129. Chatterjee D, Katz MH, Rashid A, et al. Perineural and intraneural invasion in posttherapy pancreaticoduodenectomy specimens predicts poor prognosis in patients with pancreatic ductal adenocarcinoma. Am J Surg Pathol. 2012; 36:409–417. [PubMed: 22301497]
130. Chatterjee D, Rashid A, Wang H, et al. Tumor invasion of muscular vessels predicts poor prognosis in patients with pancreatic ductal adenocarcinoma who have received neoadjuvant therapy and pancreaticoduodenectomy. Am J Surg Pathol. 2012; 36:552–559. [PubMed: 22301496]
131. Winter JM, Cameron JL, Campbell KA, et al. 1423 pancreaticoduodenectomies for pancreatic cancer: A single-institution experience. J Gastrointest Surg. 2006; 10:1199–1210. discussion 1210-1191. [PubMed: 17114007]
132. Nathan H, Wolfgang CL, Edil BH, et al. Peri-operative mortality and long-term survival after total pancreatectomy for pancreatic adenocarcinoma: a population-based perspective. J Surg Oncol. 2009; 99:87–92. [PubMed: 19021191]

133. Karachristos A, Scarmeas N, Hoffman JP. CA 19-9 levels predict results of staging laparoscopy in pancreatic cancer. J Gastrointest Surg. 2005; 9:1286–1292. [PubMed: 16332484]

134. Jimenez RE, Warshaw AL, Rattner DW, Willett CG, McGrath D, Fernandez-del Castillo C. Impact of laparoscopic staging in the treatment of pancreatic cancer. Arch Surg. 2000; 135:409–414. discussion 414-405. [PubMed: 10768705]

135. Conlon KC, Brennan MF. Laparoscopy for staging abdominal malignancies. Adv Surg. 2000; 34:331–350. [PubMed: 10997227]

136. Gagandeep S, Artinyan A, Jabbour N, et al. Extended pancreatectomy with resection of the celiac axis: the modified Appleby operation. Am J Surg. 2006; 192:330–335. [PubMed: 16920427]

137. Huebner M, Kendrick M, Reid-Lombardo KM, et al. Number of lymph nodes evaluated: prognostic value in pancreatic adenocarcinoma. J Gastrointest Surg. 2012; 16:920–926. [PubMed: 22421988]

138. Kamath AS, Sarr MG, Nagorney DM, et al. Gastrointestinal stromal tumour of the duodenum: single institution experience. HPB : the official journal of the International Hepato Pancreato Biliary Association. 2012; 14:772–776. [PubMed: 23043666]

139. Kendrick ML, Sclabas GM. Major venous resection during total laparoscopic pancreaticoduodenectomy. HPB : the official journal of the International Hepato Pancreato Biliary Association. 2011; 13:454–458. [PubMed: 21689228]

140. Venkat R, Edil BH, Schulick RD, Lidor AO, Makary MA, Wolfgang CL. Laparoscopic distal pancreatectomy is associated with significantly less overall morbidity compared to the open technique: a systematic review and meta-analysis. Ann Surg. 2012; 255:1048–1059. [PubMed: 22511003]

141. Kendrick ML, Cusati D. Total laparoscopic pancreaticoduodenectomy: feasibility and outcome in an early experience. Arch Surg. 2010; 145:19–23. [PubMed: 20083750]

142. Birkmeyer JD, Siewers AE, Finlayson EV, et al. Hospital volume and surgical mortality in the United States. New England Journal of Medicine. 2002; 346:1128–1137. [PubMed: 11948273]

143. Herman JM, Swartz MJ, Hsu CC, et al. Analysis of fluorouracil-based adjuvant chemotherapy and radiation after pancreaticoduodenectomy for ductal adenocarcinoma of the pancreas: results of a large, prospectively collected database at the Johns Hopkins Hospital. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2008; 26:3503–3510. [PubMed: 18640931]

144. Oettle H, Post S, Neuhaus P, et al. Adjuvant chemotherapy with gemcitabine vs observation in patients undergoing curative-intent resection of pancreatic cancer: a randomized controlled trial. JAMA : the journal of the American Medical Association. 2007; 297:267–277. [PubMed: 17227978]

145. Neoptolemos JP, Stocken DD, Bassi C, et al. Adjuvant chemotherapy with fluorouracil plus folinic acid vs gemcitabine following pancreatic cancer resection: a randomized controlled trial. JAMA : the journal of the American Medical Association. 2010; 304:1073–1081. [PubMed: 20823433]

146. Gastrointestinal Tumor Study G. Further evidence of effective adjuvant combined radiation and chemotherapy following curative resection of pancreatic cancer. Cancer. 1987; 59:2006–2010. [PubMed: 3567862]

147. Klinkenbijl JH, Jeekel J, Sahmoud T, et al. Adjuvant radiotherapy and 5-fluorouracil after curative resection of cancer of the pancreas and periampullary region: phase III trial of the EORTC gastrointestinal tract cancer cooperative group. Annals of Surgery. 1999; 230:776–782. [PubMed: 10615932]

148. Neoptolemos JP, Stocken DD, Friess H, et al. A randomized trial of chemoradiotherapy and chemotherapy after resection of pancreatic cancer. New England Journal of Medicine. 2004; 350:1200–1210. [PubMed: 15028824]

149. Abrams RA, Winter KA, Regine WF, et al. Failure to adhere to protocol specified radiation therapy guidelines was associated with decreased survival in RTOG 9704--a phase III trial of adjuvant chemotherapy and chemoradiotherapy for patients with resected adenocarcinoma of the pancreas. Int J Radiat Oncol Biol Phys. 2012; 82:809–816. [PubMed: 21277694]

150. Shah AP, Strauss JB, Abrams RA. Review and commentary on the role of radiation therapy in the adjuvant management of pancreatic cancer. Am J Clin Oncol. 2010; 33:101–106. [PubMed: 19636239]

151. Corsini MM, Miller RC, Haddock MG, et al. Adjuvant radiotherapy and chemotherapy for pancreatic carcinoma: the Mayo Clinic experience (1975–2005). Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2008; 26:3511–3516. [PubMed: 18640932]

152. Hsu CC, Herman JM, Corsini MM, et al. Adjuvant chemoradiation for pancreatic adenocarcinoma: the Johns Hopkins Hospital-Mayo Clinic collaborative study. Ann Surg Oncol. 2010; 17:981–990. [PubMed: 20087786]

153. Regine WF, Winter KA, Abrams R, et al. Fluorouracil-based chemoradiation with either gemcitabine or fluorouracil chemotherapy after resection of pancreatic adenocarcinoma: 5-year analysis of the U.S. Intergroup/RTOG 9704 phase III trial. Ann Surg Oncol. 2011; 18:1319–1326. [PubMed: 21499862]

154. Picozzi VJ, Abrams RA, Decker PA, et al. Multicenter phase II trial of adjuvant therapy for resected pancreatic cancer using cisplatin, 5-fluorouracil, and interferon-alfa-2b-based chemoradiation: ACOSOG Trial Z05031. Ann Oncol. 2011; 22:348–354. [PubMed: 20670978]

155. Picozzi VJ, Kozarek RA, Traverso LW. Interferon-based adjuvant chemoradiation therapy after pancreaticoduodenectomy for pancreatic adenocarcinoma. Am J Surgery. 2003; 185:476–480.

156. Schmidt J, Abel U, Debus J, et al. Open-label, multicenter, randomized phase III trial of adjuvant chemoradiation plus interferon Alfa-2b versus fluorouracil and folinic acid for patients with resected pancreatic adenocarcinoma. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2012; 30:4077–4083. [PubMed: 23008325]

157. Ma WW, Herman JM, Jimeno A, et al. A tolerability and pharmacokinetic study of adjuvant erlotinib and capecitabine with concurrent radiation in resected pancreatic cancer. Translational oncology. 2010; 3:373–379. [PubMed: 21151476]

158. Lutz E, Yeo CJ, Lillemoe KD, et al. A lethally irradiated allogeneic granulocyte-macrophage colony stimulating factor-secreting tumor vaccine for pancreatic adenocarcinoma. A Phase II trial of safety, efficacy, and immune activation. Ann Surg. 2011; 253:328–335. [PubMed: 21217520]

159. Weden S, Klemp M, Gladhaug IP, et al. Long-term follow-up of patients with resected pancreatic cancer following vaccination against mutant K-ras. International journal of cancer Journal international du cancer. 2011; 128:1120–1128. [PubMed: 20473937]

160. Lepisto AJ, Moser AJ, Zeh H, et al. A phase I/II study of a MUC1 peptide pulsed autologous dendritic cell vaccine as adjuvant therapy in patients with resected pancreatic and biliary tumors. Cancer therapy. 2008; 6:955–964. [PubMed: 19129927]

161. Minn AY, Koong AC, Chang DT. Stereotactic body radiation therapy for gastrointestinal malignancies. Frontiers of radiation therapy and oncology. 2011; 43:412–427. [PubMed: 21625166]

162. Conroy T, Desseigne F, Ychou M, et al. FOLFIRINOX versus gemcitabine for metastatic pancreatic cancer. The New England journal of medicine. 2011; 364:1817–1825. [PubMed: 21561347]

163. Loehrer PJ Sr, Feng Y, Cardenes H, et al. Gemcitabine alone versus gemcitabine plus radiotherapy in patients with locally advanced pancreatic cancer: an Eastern Cooperative Oncology Group trial. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2011; 29:4105–4112. [PubMed: 21969502]

164. Sudo K, Yamaguchi T, Ishihara T, et al. Phase II study of oral S-1 and concurrent radiotherapy in patients with unresectable locally advanced pancreatic cancer. Int J Radiat Oncol Biol Phys. 2011; 80:119–125. [PubMed: 20605363]

165. Colucci G, Labianca R, Di Costanzo F, et al. Randomized phase III trial of gemcitabine plus cisplatin compared with single-agent gemcitabine as first-line treatment of patients with advanced pancreatic cancer: the GIP-1 study. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2010; 28:1645–1651. [PubMed: 20194854]

166. Philip PA, Benedetti J, Corless CL, et al. Phase III study comparing gemcitabine plus cetuximab versus gemcitabine in patients with advanced pancreatic adenocarcinoma: Southwest Oncology

Group-directed intergroup trial S0205. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2010; 28:3605–3610. [PubMed: 20606093]

167. Sawaki A, Hoki N, Ito S, et al. Clinical impact of radiotherapy for locally advanced pancreatic cancer. J Gastroenterol. 2009; 44:1209–1214. [PubMed: 19705054]
168. Crane CH, Winter K, Regine WF, et al. Phase II study of bevacizumab with concurrent capecitabine and radiation followed by maintenance gemcitabine and bevacizumab for locally advanced pancreatic cancer: Radiation Therapy Oncology Group RTOG 0411. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2009; 27:4096–4102. [PubMed: 19636002]
169. Moureau-Zabotto L, Phelip JM, Afchain P, et al. Concomitant administration of weekly oxaliplatin, fluorouracil continuous infusion, and radiotherapy after 2 months of gemcitabine and oxaliplatin induction in patients with locally advanced pancreatic cancer: a Groupe Coordinateur Multidisciplinaire en Oncologie phase II study. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2008; 26:1080–1085. [PubMed: 18309942]
170. Duffy A, Kortmansky J, Schwartz GK, et al. A phase I study of erlotinib in combination with gemcitabine and radiation in locally advanced, non-operable pancreatic adenocarcinoma. Ann Oncol. 2008; 19:86–91. [PubMed: 17878176]
171. Huguet F, Andre T, Hammel P, et al. Impact of chemoradiotherapy after disease control with chemotherapy in locally advanced pancreatic adenocarcinoma in GERCOR phase II and III studies. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2007; 25:326–331. [PubMed: 17235048]
172. Small W Jr, Mulcahy MF, Rademaker A, et al. Phase II trial of full-dose gemcitabine and bevacizumab in combination with attenuated three-dimensional conformal radiotherapy in patients with localized pancreatic cancer. Int J Radiat Oncol Biol Phys. 2011; 80:476–482. [PubMed: 20598452]
173. Small W Jr, Berlin J, Freedman GM, et al. Full-dose gemcitabine with concurrent radiation therapy in patients with nonmetastatic pancreatic cancer: a multicenter phase II trial. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2008; 26:942–947. [PubMed: 18281668]
174. Schneider BJ, Ben-Josef E, McGinn CJ, et al. Capecitabine and radiation therapy preceded and followed by combination chemotherapy in advanced pancreatic cancer. Int J Radiat Oncol Biol Phys. 2005; 63:1325–1330. [PubMed: 15993549]
175. Katz MH, Wang H, Balachandran A, et al. Effect of neoadjuvant chemoradiation and surgical technique on recurrence of localized pancreatic cancer. J Gastrointest Surg. 2012; 16:68–78. discussion 78-69. [PubMed: 22065318]
176. Krishnan S, Rana V, Janjan NA, et al. Induction chemotherapy selects patients with locally advanced, unresectable pancreatic cancer for optimal benefit from consolidative chemoradiation therapy. Cancer. 2007; 110:47–55. [PubMed: 17538975]
177. Mishra G, Butler J, Ho C, et al. Phase II trial of induction gemcitabine/CPT-11 followed by a twice-weekly infusion of gemcitabine and concurrent external beam radiation for the treatment of locally advanced pancreatic cancer. Am J Clin Oncol. 2005; 28:345–350. [PubMed: 16062075]
178. Ko AH, Quivey JM, Venook AP, et al. A phase II study of fixed-dose rate gemcitabine plus low-dose cisplatin followed by consolidative chemoradiation for locally advanced pancreatic cancer. Int J Radiat Oncol Biol Phys. 2007; 68:809–816. [PubMed: 17363191]
179. Wahl RL, Herman JM, Ford E. The promise and pitfalls of positron emission tomography and single-photon emission computed tomography molecular imaging-guided radiation therapy. Seminars in radiation oncology. 2011; 21:88–100. [PubMed: 21356477]
180. Spalding AC, Jee KW, Vineberg K, et al. Potential for dose-escalation and reduction of risk in pancreatic cancer using IMRT optimization with lexicographic ordering and gEUD-based cost functions. Medical physics. 2007; 34:521–529. [PubMed: 17388169]
181. Yovino S, Maidment BW 3rd, Herman JM, et al. Analysis of local control in patients receiving IMRT for resected pancreatic cancers. Int J Radiat Oncol Biol Phys. 2012; 83:916–920. [PubMed: 22284684]

182. Rich TA, Winter K, Safran H, et al. Weekly paclitaxel, gemcitabine, and external irradiation followed by randomized farnesyl transferase inhibitor R115777 for locally advanced pancreatic cancer. OncoTargets and therapy. 2012; 5:161–170. [PubMed: 22977306]

183. Dawson LA, Eccles C, Bissonnette JP, Brock KK. Accuracy of daily image guidance for hypofractionated liver radiotherapy with active breathing control. Int J Radiat Oncol Biol Phys. 2005; 62:1247–1252. [PubMed: 15990028]

184. Goldstein SD, Ford EC, Duhon M, McNutt T, Wong J, Herman JM. Use of respiratory-correlated four-dimensional computed tomography to determine acceptable treatment margins for locally advanced pancreatic adenocarcinoma. Int J Radiat Oncol Biol Phys. 2010; 76:597–602. [PubMed: 19836156]

185. Khashab MA, Kim KJ, Tryggestad EJ, et al. Comparative analysis of traditional and coiled fiducials implanted during EUS for pancreatic cancer patients receiving stereotactic body radiation therapy. Gastrointest Endosc. 2012; 76:962–971. [PubMed: 23078921]

186. Poulsen PR, Cho B, Keall PJ. A method to estimate mean position, motion magnitude, motion correlation, and trajectory of a tumor from cone-beam CT projections for image-guided radiotherapy. Int J Radiat Oncol Biol Phys. 2008; 72:1587–1596. [PubMed: 19028282]

187. Ben-Josef E, Schipper M, Francis IR, et al. A phase I/II trial of intensity modulated radiation (IMRT) dose escalation with concurrent fixed-dose rate gemcitabine (FDR-G) in patients with unresectable pancreatic cancer. Int J Radiat Oncol Biol Phys. 2012; 84:1166–1171. [PubMed: 22543215]

188. Murphy JD, Christman-Skieller C, Kim J, Dieterich S, Chang DT, Koong AC. A dosimetric model of duodenal toxicity after stereotactic body radiotherapy for pancreatic cancer. Int J Radiat Oncol Biol Phys. 2010; 78:1420–1426. [PubMed: 20399033]

189. Fung MC, Takayama S, Ishiguro H, Sakata T, Adachi S, Morizane T. Chemotherapy for advanced or metastatic pancreatic cancer: analysis of 43 randomized trials in 3 decades (1974–2002). Gan To Kagaku Ryoho. 2003; 30:1101–1111. [PubMed: 12938264]

190. Burris HA III, Moore MJ, Andersen J, et al. Improvements in survival and clinical benefit with gemcitabine as first-line therapy for patients with advanced pancreas cancer: a randomized trial. J Clin Oncol. 1997; 15:2403–2413. [PubMed: 9196156]

191. Tempero M, Plunkett W, Ruiz VHV, et al. Randomized phase II comparison of dose-intense gemcitabine: thirty-minute infusion and fixed dose rate infusion in patients with pancreatic adenocarcinoma. J Clin Oncol. 2003; 21:3402–3408. [PubMed: 12885837]

192. Poplin E, Feng Y, Berlin J, et al. Phase III, randomized study of gemcitabine and oxaliplatin versus gemcitabine (fixed-dose rate infusion) compared with gemcitabine (30-minute infusion) in patients with pancreatic carcinoma E6201: a trial of the Eastern Cooperative Oncology Group. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2009; 27:3778–3785. [PubMed: 19581537]

193. Heinemann V, Boeck S, Hinke A, Labianca R, Louvet C. Meta-analysis of randomized trials: evaluation of benefit from gemcitabine-based combination chemotherapy applied in advanced pancreatic cancer. BMC cancer. 2008; 8:82. [PubMed: 18373843]

194. Sultana A, Smith CT, Cunningham D, Starling N, Neoptolemos JP, Ghaneh P. Meta-analyses of chemotherapy for locally advanced and metastatic pancreatic cancer. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2007; 25:2607–2615. [PubMed: 17577041]

195. Cunningham D, Chau I, Stocken DD, et al. Phase III randomized comparison of gemcitabine versus gemcitabine plus capecitabine in patients with advanced pancreatic cancer. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2009; 27:5513–5518. [PubMed: 19858379]

196. Louvet C, Labianca R, Hammel P, et al. Gemcitabine in combination with oxaliplatin compared with gemcitabine alone in locally advanced or metastatic pancreatic cancer: results of a GERCOR and GISCAD phase III trial. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2005; 23:3509–3516. [PubMed: 15908661]

197. Heinemann V, Quietzsch D, Gieseler F, et al. Randomized phase III trial of gemcitabine plus cisplatin compared with gemcitabine alone in advanced pancreatic cancer. Journal of clinical

oncology : official journal of the American Society of Clinical Oncology. 2006; 24:3946–3952. [PubMed: 16921047]

198. Cui Y, Brosnan JA, Blackford AL, et al. Genetically defined subsets of human pancreatic cancer demonstrate unique in vitro chemosensitivity. Clin Cancer Res. 2012
199. Von Hoff D, E TJ, A FP. Randomized Phase III study of weekly nab-paclitacel plus gemcitabine versus gemcitabine along in patients with metastatic adenocarcinoma of the pancreas (MPACT). Journal of Clinical Oncology. 2013; 30:148.
200. Moore MJ, Goldstein D, Hamm J, et al. Erlotinib plus gemcitabine compared with gemcitabine alone in patients with advanced pancreatic cancer: a phase III trial of the National Cancer Institute of Canada Clinical Trials Group. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2007; 25:1960–1966. [PubMed: 17452677]
201. Kindler HL, Niedzwiecki D, Hollis D, et al. Gemcitabine plus bevacizumab compared with gemcitabine plus placebo in patients with advanced pancreatic cancer: phase III trial of the Cancer and Leukemia Group B (CALGB 80303). Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2010; 28:3617–3622. [PubMed: 20606091]
202. Xiong HQ, Varadhachary GR, Blais JC, Hess KR, Abbruzzese JL, Wolff RA. Phase 2 trial of oxaliplatin plus capecitabine (XELOX) as second-line therapy for patients with advanced pancreatic cancer. Cancer. 2008; 113:2046–2052. [PubMed: 18756532]
203. Pelzer U, Schwaner I, Stieler J, et al. Best supportive care (BSC) versus oxaliplatin, folinic acid and 5-fluorouracil (OFF) plus BSC in patients for second-line advanced pancreatic cancer: a phase III-study from the German CONKO-study group. Eur J Cancer. 2011; 47:1676–1681. [PubMed: 21565490]
204. Kulke MH, Blaszkowsky LS, Ryan DP, et al. Capecitabine plus erlotinib in gemcitabine-refractory advanced pancreatic cancer. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2007; 25:4787–4792. [PubMed: 17947726]
205. Arnaoutakis GJ, Rangachari D, Laheru DA, et al. Pulmonary resection for isolated pancreatic adenocarcinoma metastasis: an analysis of outcomes and survival. J Gastrointest Surg. 2011; 15:1611–1617. [PubMed: 21725701]
206. Yap JL, Worlikar S, MacKerell AD Jr, Shapiro P, Fletcher S. Small-molecule inhibitors of the ERK signaling pathway: Towards novel anticancer therapeutics. ChemMedChem. 2011; 6:38–48. [PubMed: 21110380]
207. Collisson EA, Trejo CL, Silva JM, et al. A central role for RAF-->MEK-->ERK signaling in the genesis of pancreatic ductal adenocarcinoma. Cancer Discov. 2012; 2:685–693. [PubMed: 22628411]
208. Hwang RF, Moore T, Arumugam T, et al. Cancer-associated stromal fibroblasts promote pancreatic tumor progression. Cancer Res. 2008; 68:918–926. [PubMed: 18245495]
209. Erkan M, Reiser-Erkan C, Michalski CW, Kleeff J. Tumor microenvironment and progression of pancreatic cancer. Experimental oncology. 2010; 32:128–131. [PubMed: 21403605]
210. Beatty GL, Chiorean EG, Fishman MP, et al. CD40 agonists alter tumor stroma and show efficacy against pancreatic carcinoma in mice and humans. Science. 2011; 331:1612–1616. [PubMed: 21436454]
211. Yang S, Kimmelman AC. A critical role for autophagy in pancreatic cancer. Autophagy. 2011; 7:912–913. [PubMed: 21494085]
212. Yang S, Wang X, Contino G, et al. Pancreatic cancers require autophagy for tumor growth. Genes Dev. 2011; 25:717–729. [PubMed: 21406549]
213. Lim JP, Gleeson PA. Macropinocytosis: an endocytic pathway for internalising large gulps. Immunology and cell biology. 2011; 89:836–843. [PubMed: 21423264]
214. Wise DR, Thompson CB. Glutamine addiction: a new therapeutic target in cancer. Trends in biochemical sciences. 2010; 35:427–433. [PubMed: 20570523]
215. Kaelin WG Jr, Thompson CB. Q&A: Cancer: clues from cell metabolism. Nature. 2010; 465:562–564. [PubMed: 20520704]
216. Le A, V RN, A M, Dang CV. Conceptual framework for cutting the pancreatic cancer fuel supply. Clinical Cancer Research. 2012; 18 xx-xx.

217. Yan BM, Myers RP. Neurolytic celiac plexus block for pain control in unresectable pancreatic cancer. The American journal of gastroenterology. 2007; 102:430–438. [PubMed: 17100960]

218. Wong GY, Schroeder DR, Carns PE, et al. Effect of neurolytic celiac plexus block on pain relief, quality of life, and survival in patients with unresectable pancreatic cancer: a randomized controlled trial. JAMA : the journal of the American Medical Association. 2004; 291:1092–1099. [PubMed: 14996778]

219. Erdek MA, Halpert DE, Gonzalez Fernandez M, Cohen SP. Assessment of celiac plexus block and neurolysis outcomes and technique in the management of refractory visceral cancer pain. Pain Med. 2010; 11:92–100. [PubMed: 20002595]

220. McGreevy K, Hurley RW, Erdek MA, Aner MM, Li S, Cohen SP. The Effectiveness of Repeat Celiac Plexus Neurolysis for Pancreatic Cancer: A Pilot Study. Pain practice : the official journal of World Institute of Pain. 2012

221. Deer TR, Prager J, Levy R, et al. Polyanalgesic Consensus Conference 2012: recommendations for the management of pain by intrathecal (intraspinal) drug delivery: report of an interdisciplinary expert panel. Neuromodulation : journal of the International Neuromodulation Society. 2012; 15:436–464. discussion 464-436. [PubMed: 22748024]

222. Smith TJ, Staats PS, Deer T, et al. Randomized clinical trial of an implantable drug delivery system compared with comprehensive medical management for refractory cancer pain: impact on pain, drug-related toxicity, and survival. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2002; 20:4040–4049. [PubMed: 12351602]

223. Boyd AD, Brown D, Henrickson C, et al. Screening for depression, sleep-related disturbances, and anxiety in patients with adenocarcinoma of the pancreas: a preliminary study. TheScientificWorldJournal. 2012; 2012:650707.

224. Boyd CA, Benarroch-Gampel J, Sheffield KM, Han Y, Kuo YF, Riall TS. The effect of depression on stage at diagnosis, treatment, and survival in pancreatic adenocarcinoma. Surgery. 2012; 152:403–413. [PubMed: 22938900]

225. Howlader, N.; Noone, A.; Krapcho, M., et al. SEER Cancer Statistics Review. Bethesda, MD: National Cancer Institute; 1975–2008.

226. Cancer risks in BRCA2 mutation carriers.The Breast Cancer Linkage Consortium. JNatlCancer Inst. 1999; 91:1310–1316.

227. Giardiello FM, Brensinger JD, Tersmette AC, et al. Very high risk of cancer in familial Peutz-Jeghers syndrome. Gastroenterology. 2000; 119:1447–1453. [PubMed: 11113065]

228. van Lier MG, Wagner A, Mathus-Vliegen EM, Kuipers EJ, Steyerberg EW, van Leerdam ME. High cancer risk in Peutz-Jeghers syndrome: a systematic review and surveillance recommendations. The American journal of gastroenterology. 105:1258–1264. author reply 1265. [PubMed: 20051941]

229. Giardiello FM, Welsh SB, Hamilton SR, et al. Increased risk of cancer in the Peutz-Jeghers syndrome. NEnglJMed. 1987; 316:1511–1514.

230. Goldstein AM, Struewing JP, Fraser MC, Smith MW, Tucker MA. Prospective risk of cancer in CDKN2A germline mutation carriers. Journal of medical genetics. 2004; 41:421–424. [PubMed: 15173226]

231. Petersen GM, Amundadottir L, Fuchs CS, et al. A genome-wide association study identifies pancreatic cancer susceptibility loci on chromosomes 13q22.1, 1q32.1 and 5p15.33. Nat Genet. 2010; 42:224–228. [PubMed: 20101243]

232. Kalser MH, Ellenberg SS. Pancreatic cancer. Adjuvant combined radiation and chemotherapy following curative resection. Arch Surg. 1985; 120:899–903. [PubMed: 4015380]

233. Riall TS, Cameron JL, Lillemoe KD, et al. Resected periampullary adenocarcinoma: 5-year survivors and their 6- to 10-year follow-up. Surgery. 2006; 140:764–772. [PubMed: 17084719]

234. Regine WF, Winter KA, Abrams RA, et al. Fluorouracil vs gemcitabine chemotherapy before and after fluorouracil-based chemoradiation following resection of pancreatic adenocarcinoma: a randomized controlled trial. JAMA : the journal of the American Medical Association. 2008; 299:1019–1026. [PubMed: 18319412]

235. Rocha Lima CM, Green MR, Rotche R, et al. Irinotecan plus gemcitabine results in no survival advantage compared with gemcitabine monotherapy in patients with locally advanced or

metastatic pancreatic cancer despite increased tumor response rate. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2004; 22:3776–3783. [PubMed: 15365074]

236. Heinemann V, Quietzsch D, Gieseler M, et al. A phase III trial comparing gemcitabine plus cisplatin vs. gemcitabine alone in advanced pancreatic carcinoma. Proc Am Soc Clin Oncol. 2003; 22:250.

237. Abou-Alfa GK, Letourneau R, Harker G, et al. Randomized phase III study of exatecan and gemcitabine compared with gemcitabine alone in untreated advanced pancreatic cancer. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2006; 24:4441–4447. [PubMed: 16983112]

238. Oettle H, Richards D, Ramanathan RK, et al. A phase III trial of pemetrexed plus gemcitabine versus gemcitabine in patients with unresectable or metastatic pancreatic cancer. Ann Oncol. 2005; 16:1639–1645. [PubMed: 16087696]

239. Kulke MH, Tempero MA, Niedzwiecki D, et al. Randomized phase II study of gemcitabine administered at a fixed dose rate or in combination with cisplatin, docetaxel, or irinotecan in patients with metastatic pancreatic cancer: CALGB 89904. Journal of clinical oncology : official journal of the American Society of Clinical Oncology. 2009; 27:5506–5512. [PubMed: 19858396]

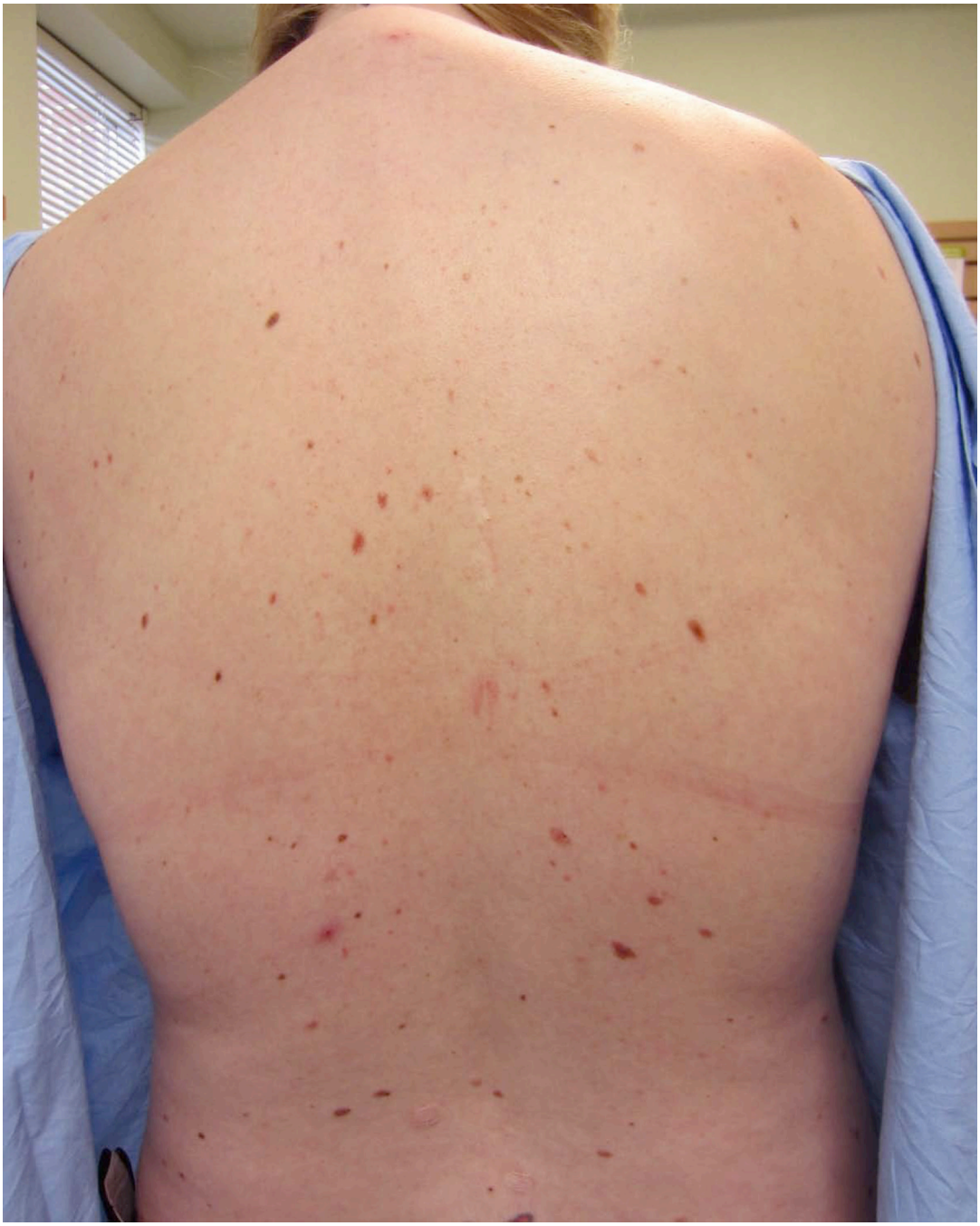
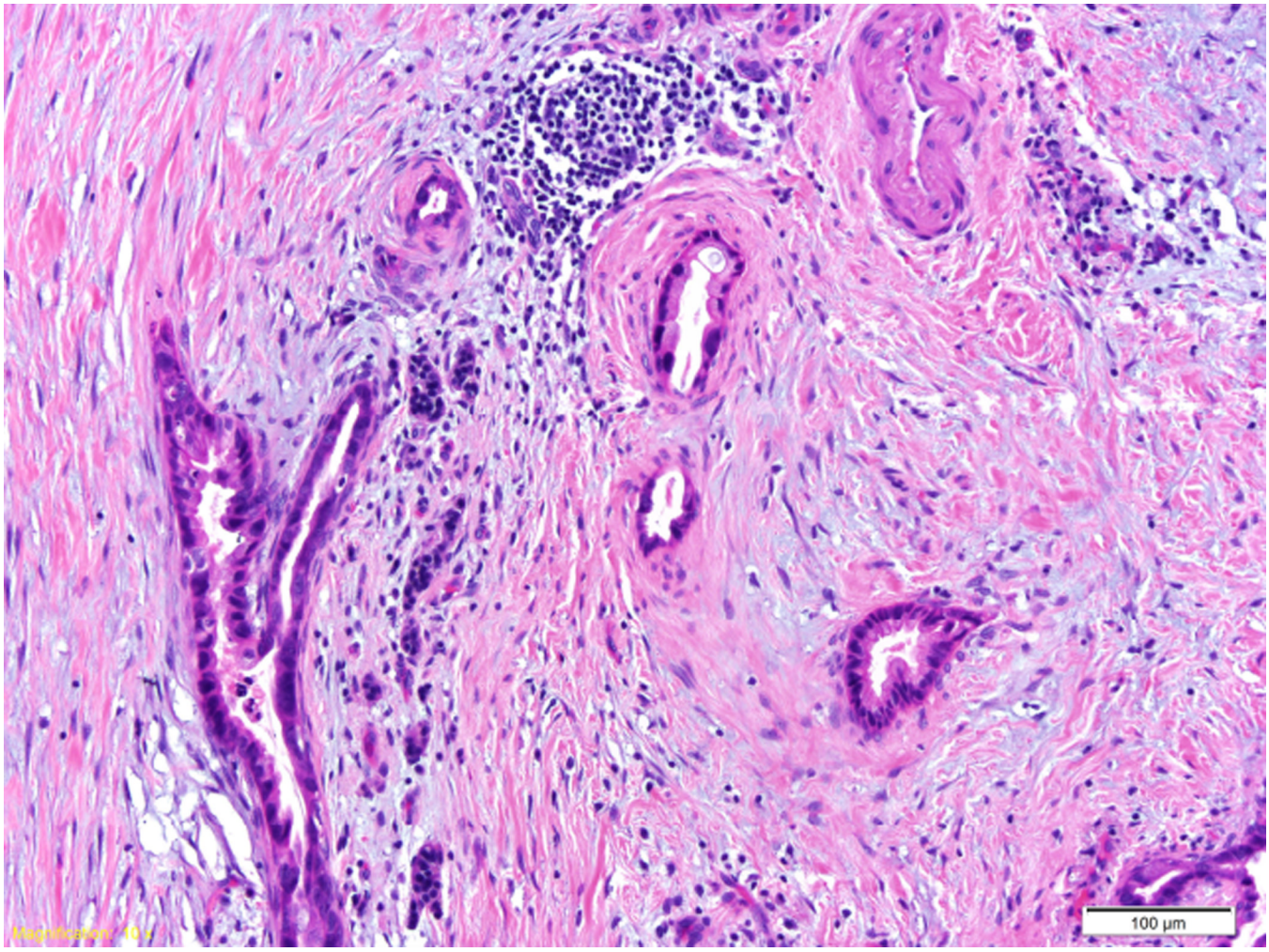


Figure 1.
Patients, such as the one shown here, with Familial Atypical Multiple Mole Melanoma syndrome have increased numbers of melanocytic nevi and an increased risk of melanoma and pancreatic cancer.



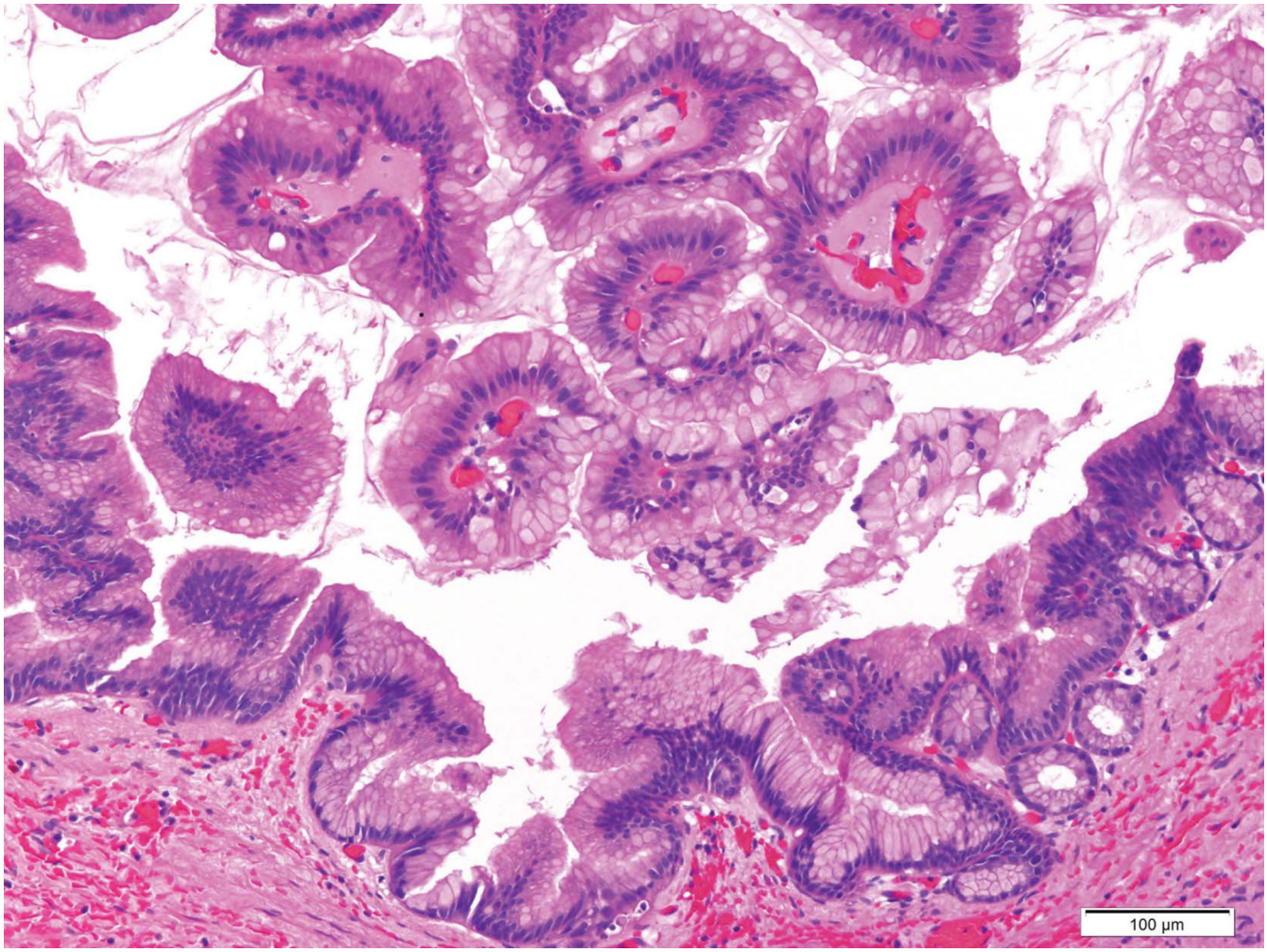


Figure 2.
A) Histopathology of a ductal adenocarcinoma of the pancreas. Note the atypical glands embedded in the desmoplastic stroma. B) Intraductal papillary mucinous neoplasms (IPMNs) are characterized by an intraductal growth of neoplastic mucin-producing cells that typically form papillae (both hematoxylin and eosin stain).

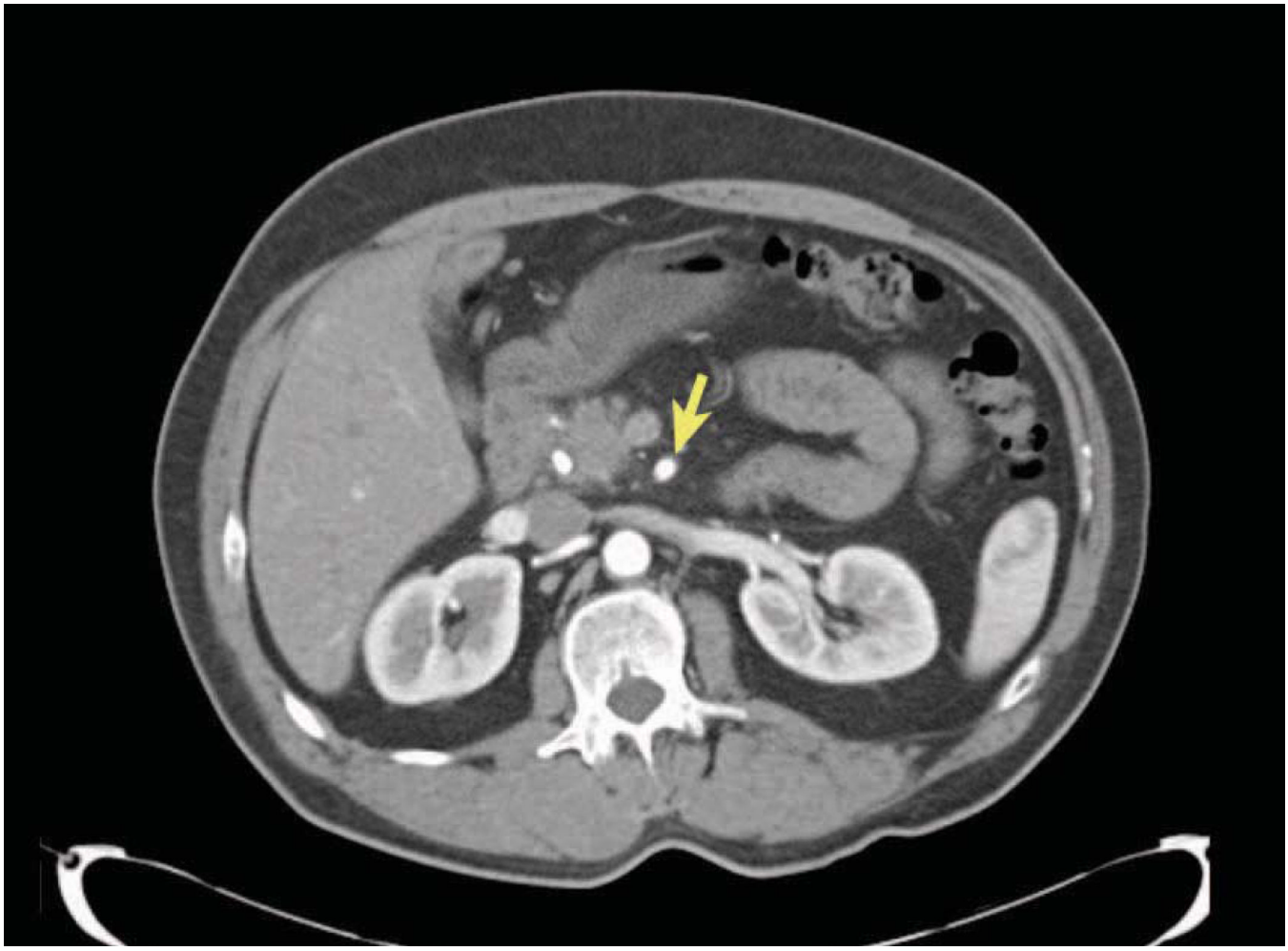
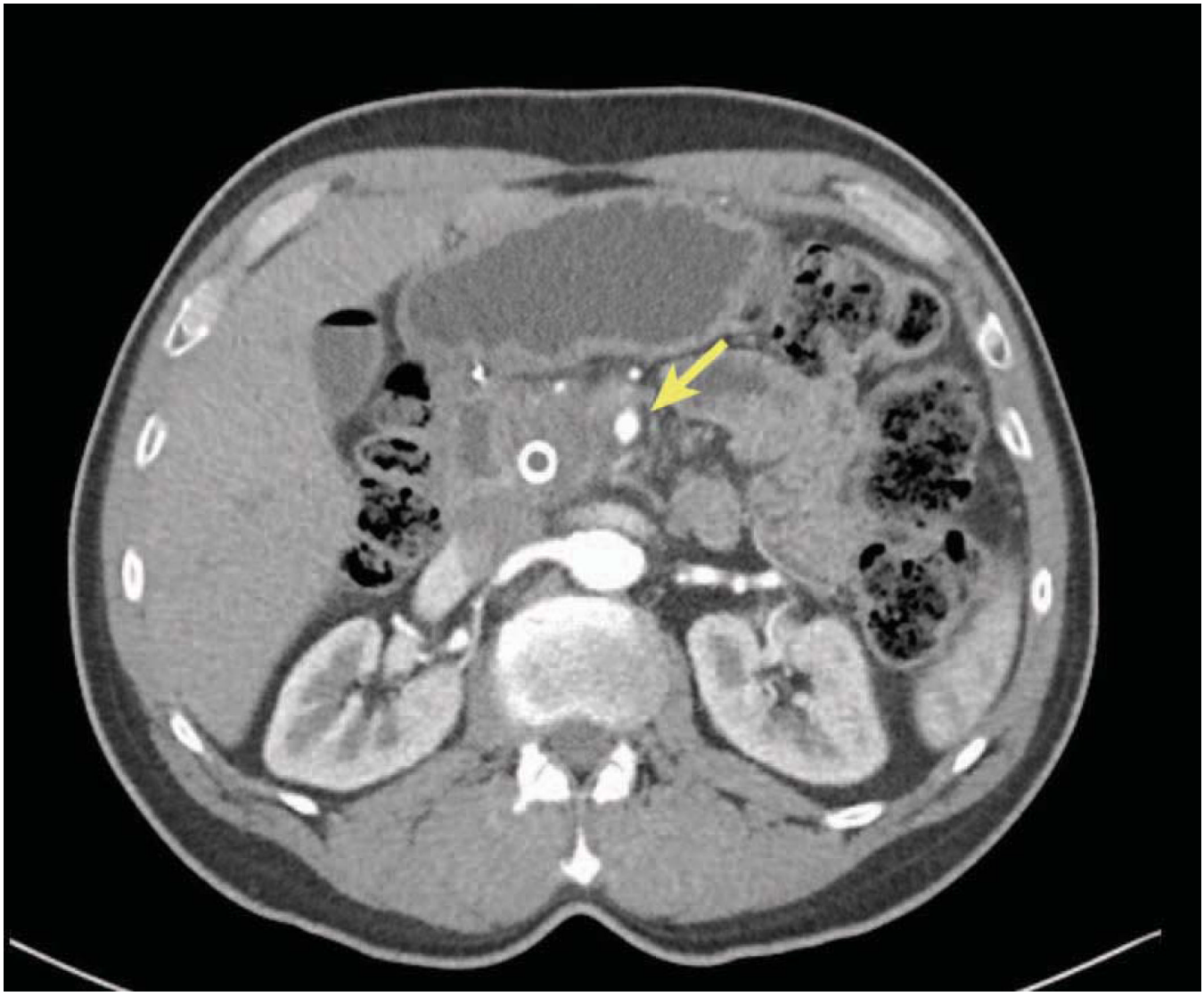


Figure 3.
CT of pancreatic cancer. A resectable pancreatic cancer with a well-defined fat plane around the artery (arrow).



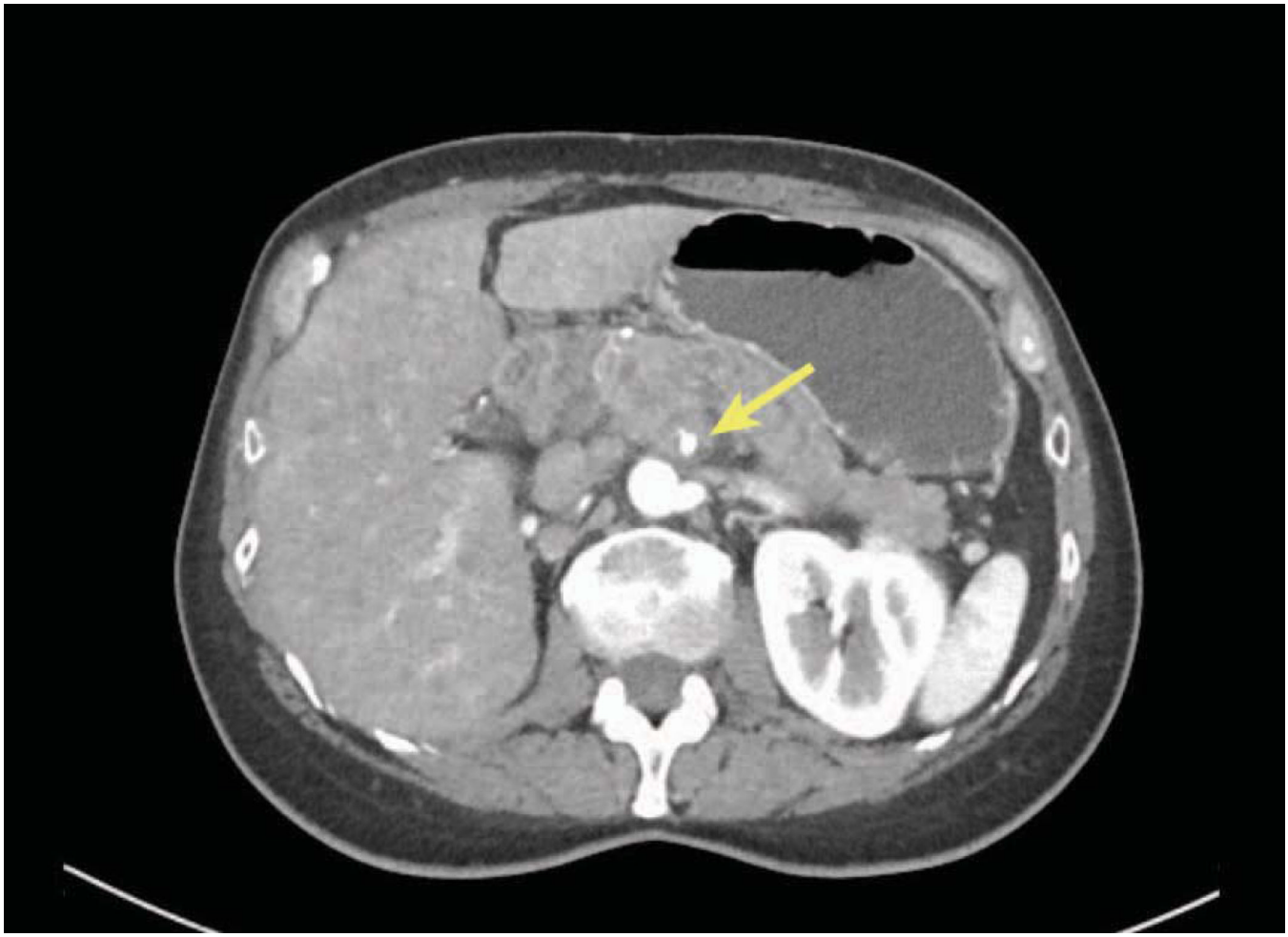


Figure 4.
CT of pancreatic cancer. A) Abutment, defined as less than 180-degree involvement of the celiac axis (arrow), is considered Stage III borderline resectable. B) Greater than 180-degree involvement of the arteries (arrow) is defined as encasement and is considered Stage III locally advanced or unresectable.

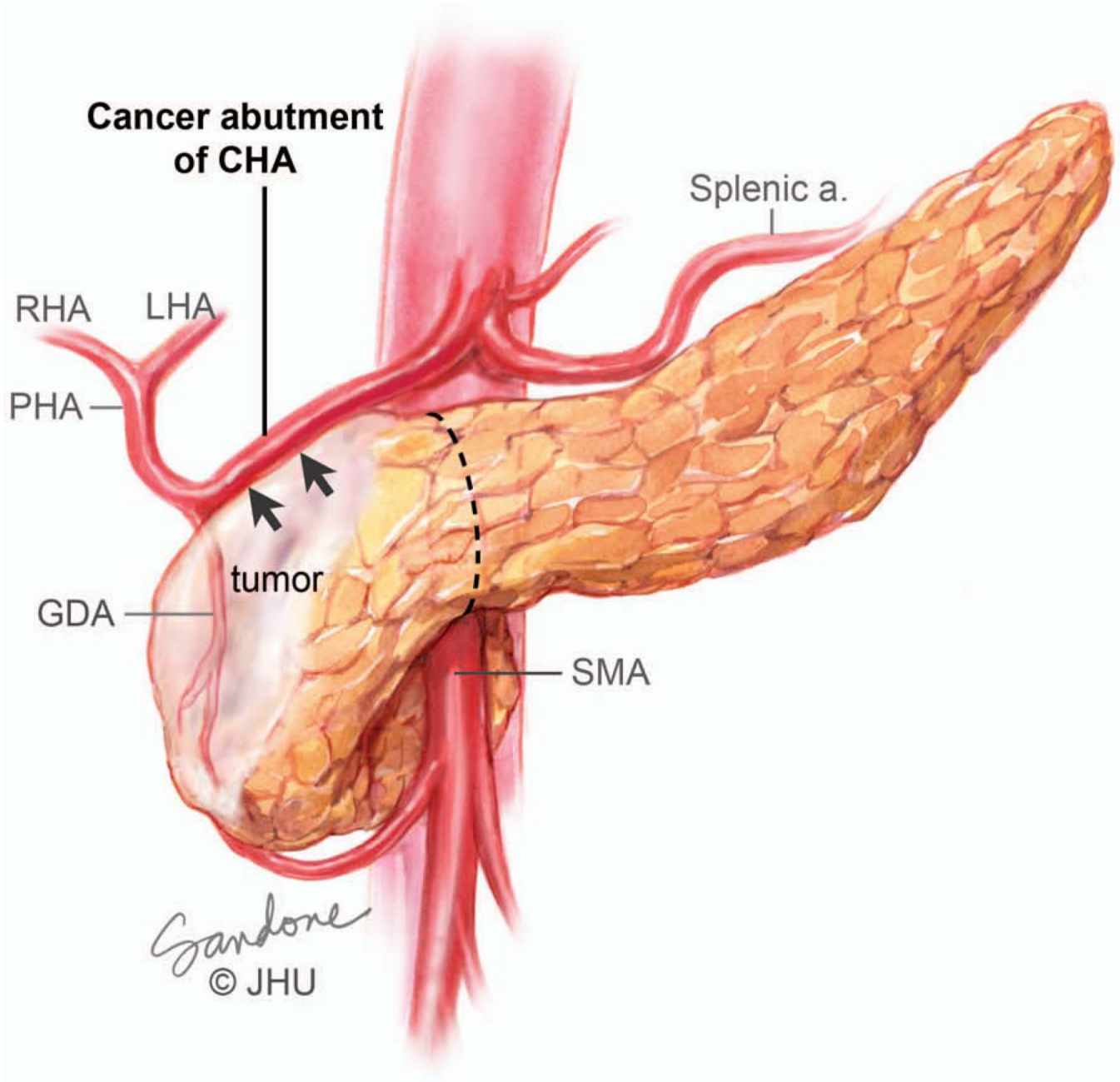


Figure 5.

Abutment of an artery, in this case the common hepatic artery, by tumor. Note that the tumor extends to the border of the artery but does not invade or narrow the vessel. On CT scan imaging this is seen as less than 180 degree involvement of the vessel and is considered to be borderline resectable. At operation this degree of involvement would allow the artery to be separated from the tumor, although it would likely leave microscopic cancer cells at the margin. Borderline resectable patients should undergo neoadjuvant therapy. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

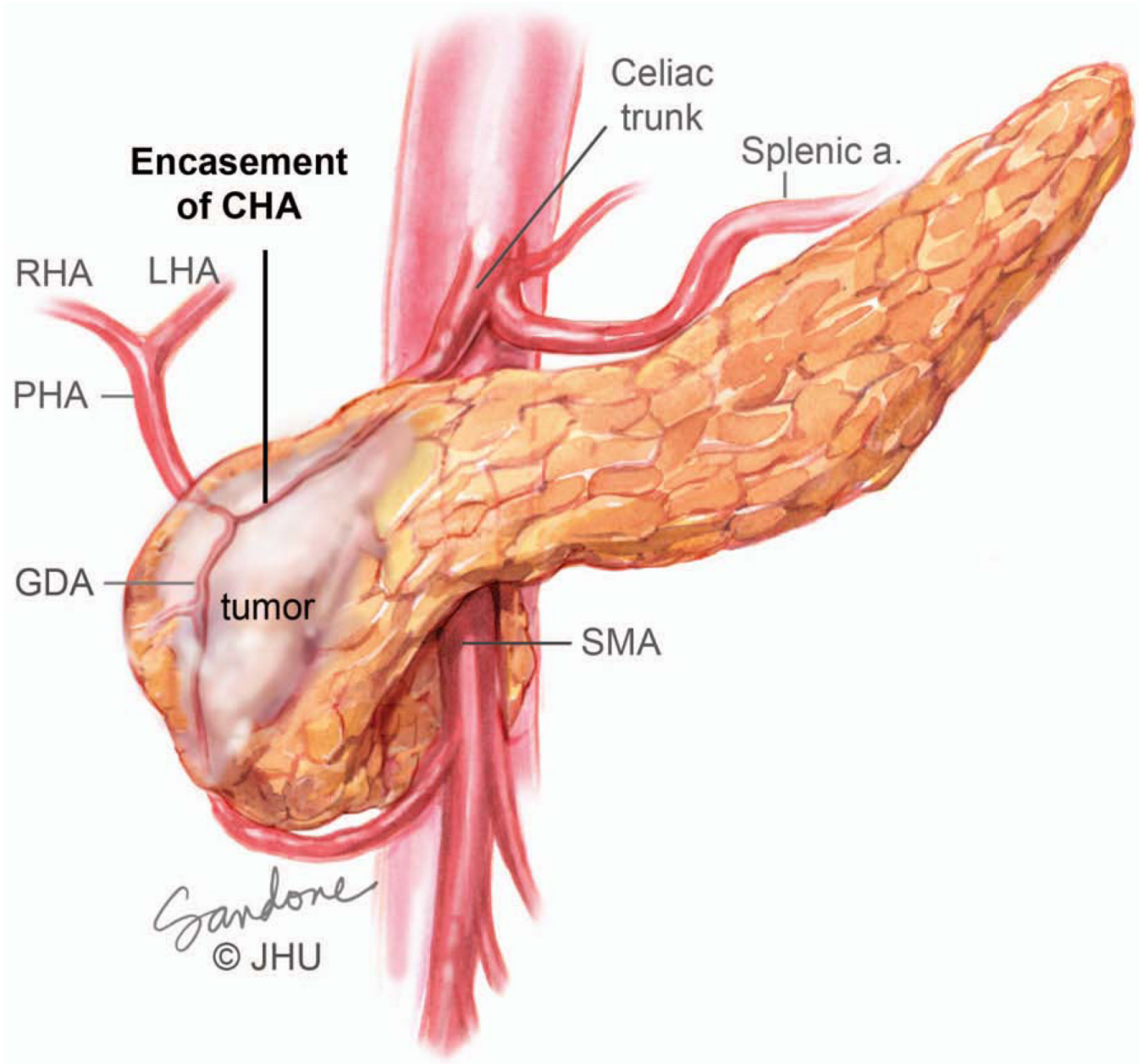


Figure 6.

Encasement of an artery, in this case the common hepatic artery, by tumor. Note that the tumor surrounds and narrows the artery. On CT scan imaging this is seen as greater than 180 degree involvement of the vessel and is considered to be locally advanced unresectable. At operation this degree of involvement would not allow separation of the tumor from the artery and would likely result in an R2 resection. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

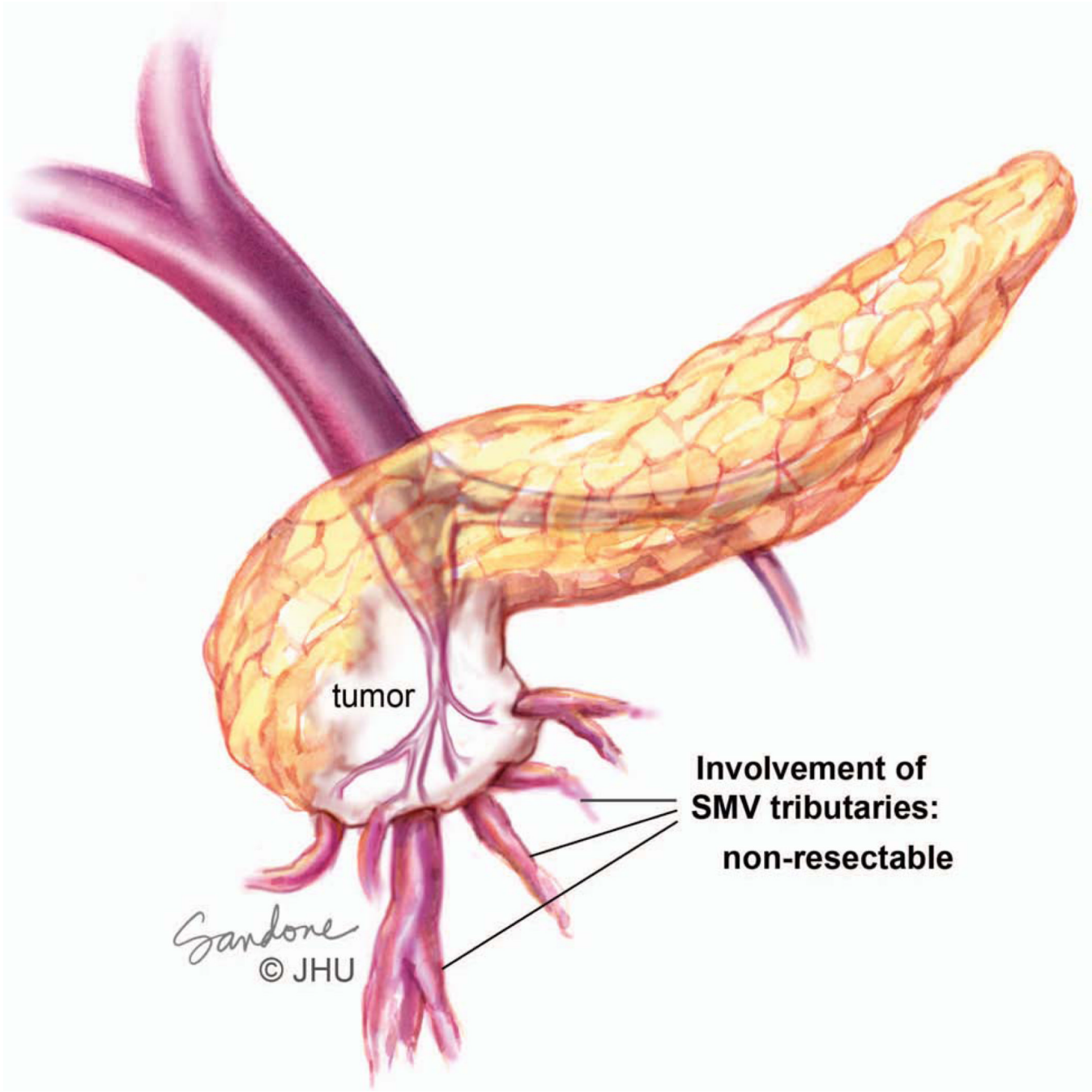


Figure 7.
Tumor involving the superior mesenteric vein (SMV), including numerous small tributaries of the vein. Since there is no single target vessel below the necessary region of resection this is considered unresectable. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

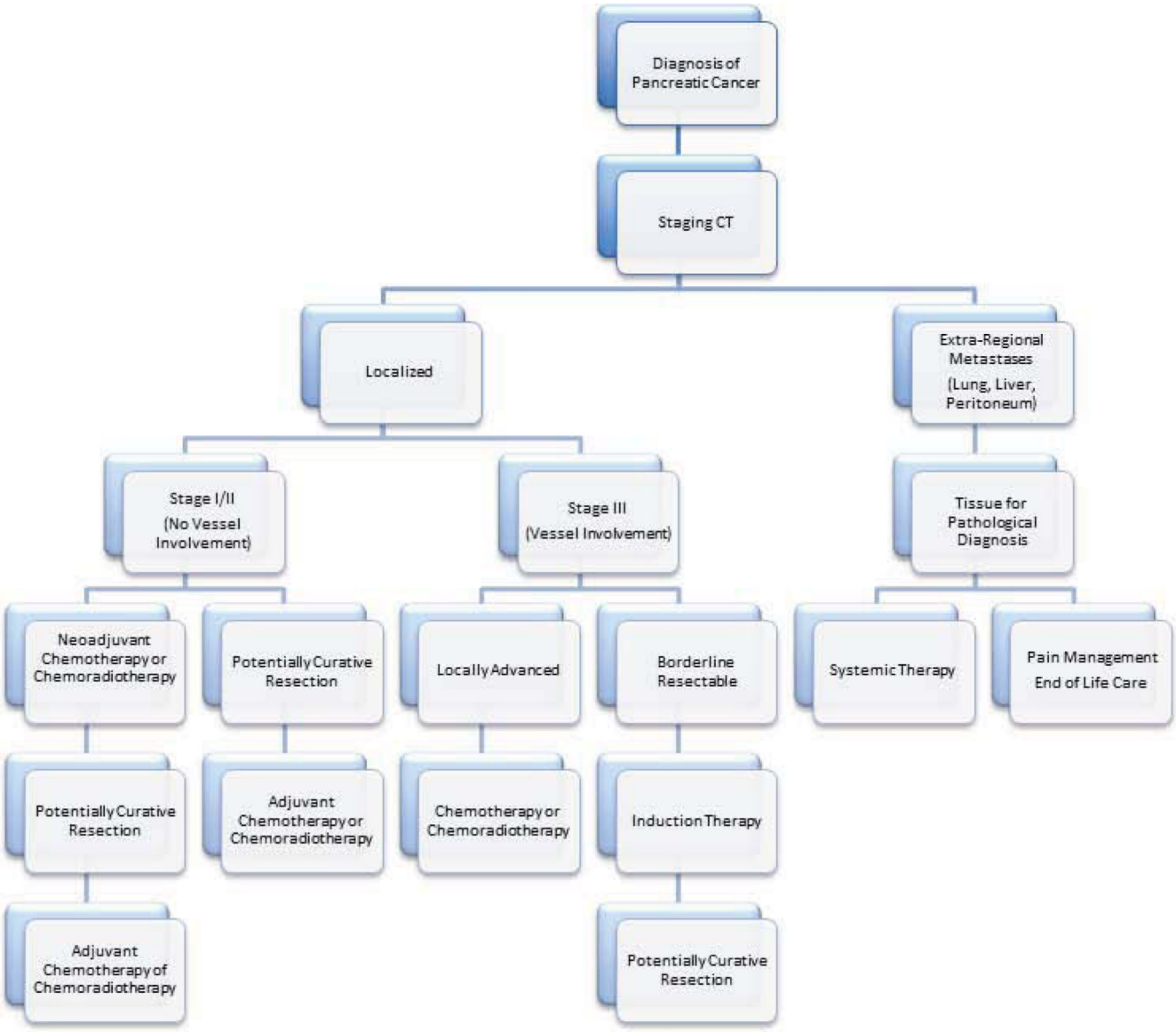


Figure 8.
Flow chart diagraming a general approach to the treatment of pancreatic cancer. © Johns Hopkins University; used with permission.

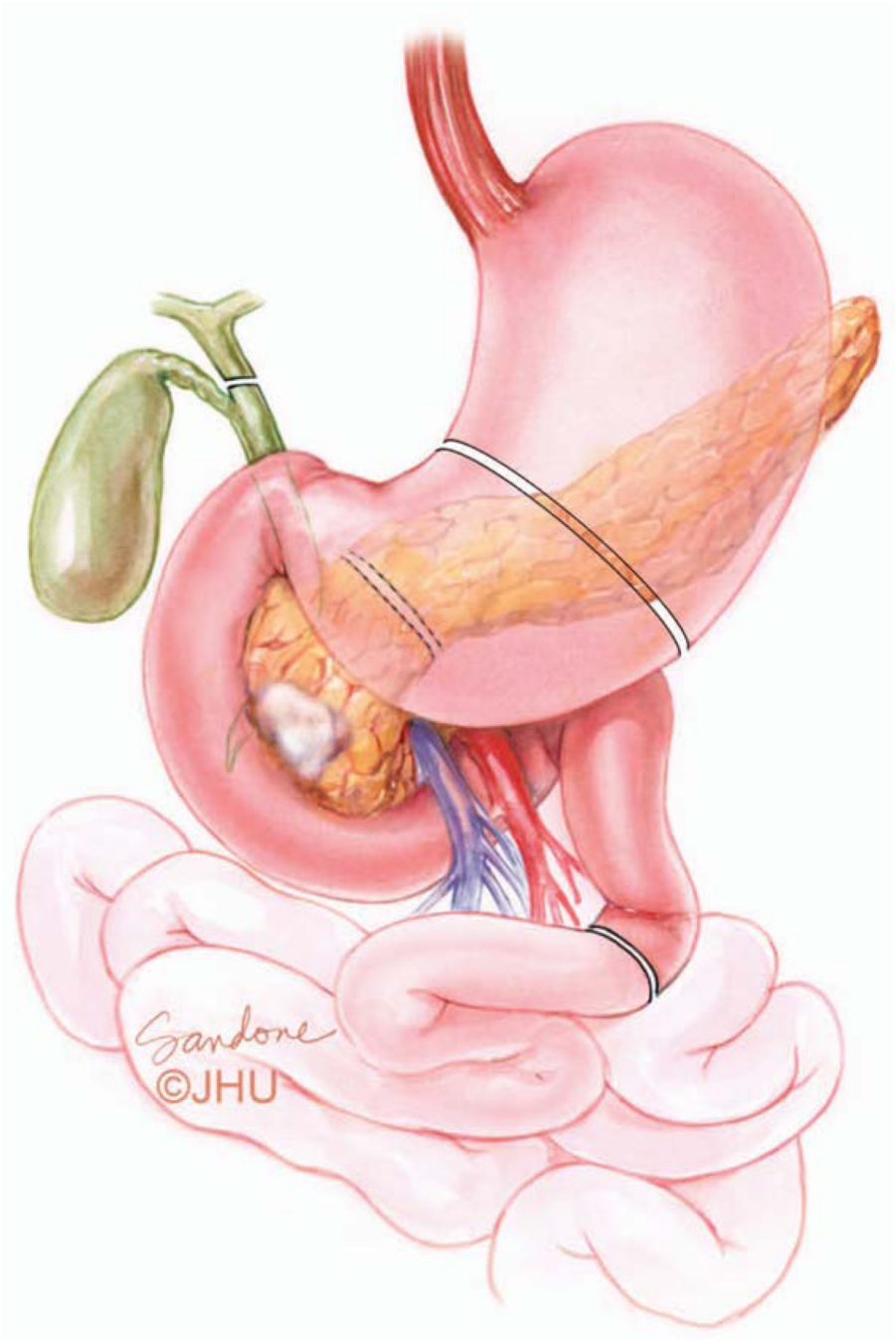


Figure 9.

The organs resected in a pancreatoduodenectomy (PD) include a portion of the stomach, the entire duodenum, the proximal 20–30 cm of jejunum, the common bile duct, gall bladder, the head and uncinate of the pancreas along with the associated regional lymph nodes. In the pylorus preserving version of the PD the duodenum is divided just beyond the first portion and the stomach and pylorus are preserved. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

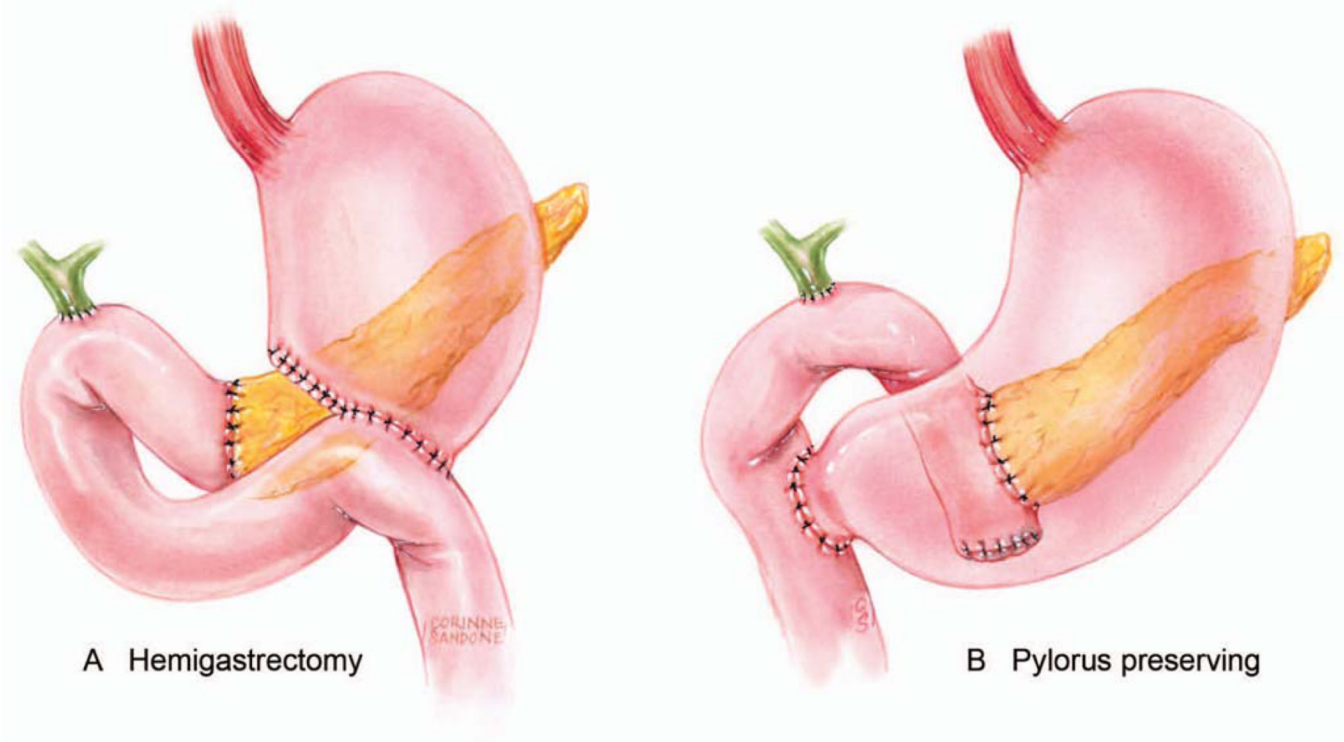


Figure 10.
Illustrations of standard (A) and pylorus-preserving (B) pancreatoduodenectomies (PD). Three anastomoses are necessary to reestablish gastrointestinal function. In the typical reconstruction shown here the end of the pancreas and end of the common hepatic duct are connected to the same limb of jejunum. Downstream from this the stomach is connected to the jejunum in a standard PD (A) or for a pylorus preserving version the duodenum is connected to the jejunum (B). Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

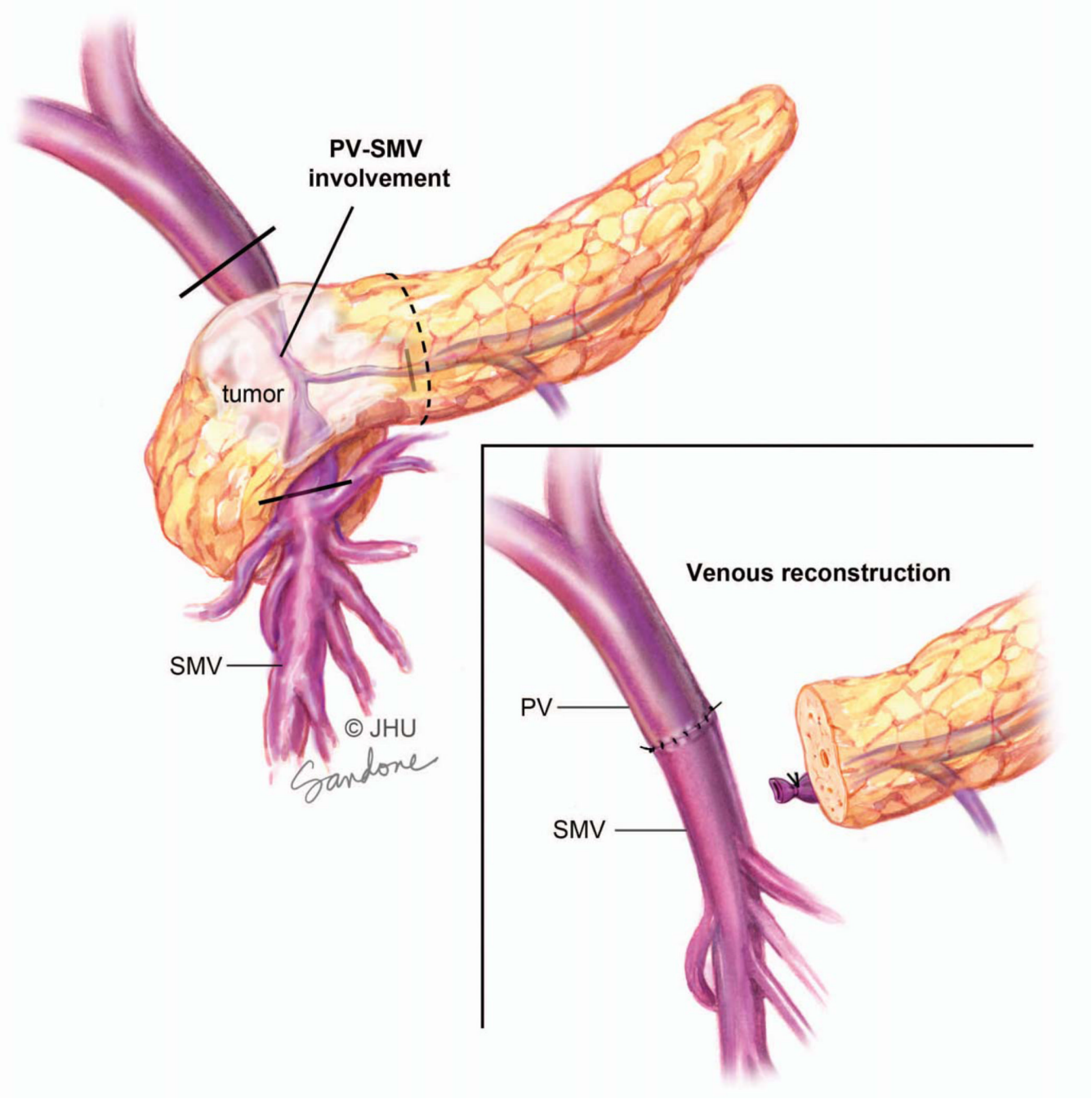


Figure 11.

Focal tumor involvement of the portal vein-superior mesenteric vein confluence. Note that the tumor invades the vessel in a location that does not involve numerous small tributaries of the superior mesenteric vein (SMV) nor does it extend high on the portal vein. Since there is a single target vessel (dark lines) above and below the necessary region of resection this is considered to be resectable. The inset shows a primary anastomosis of the portal vein (PV) and SMV after *en bloc* resection of the vessel with the splenic vein tied off. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

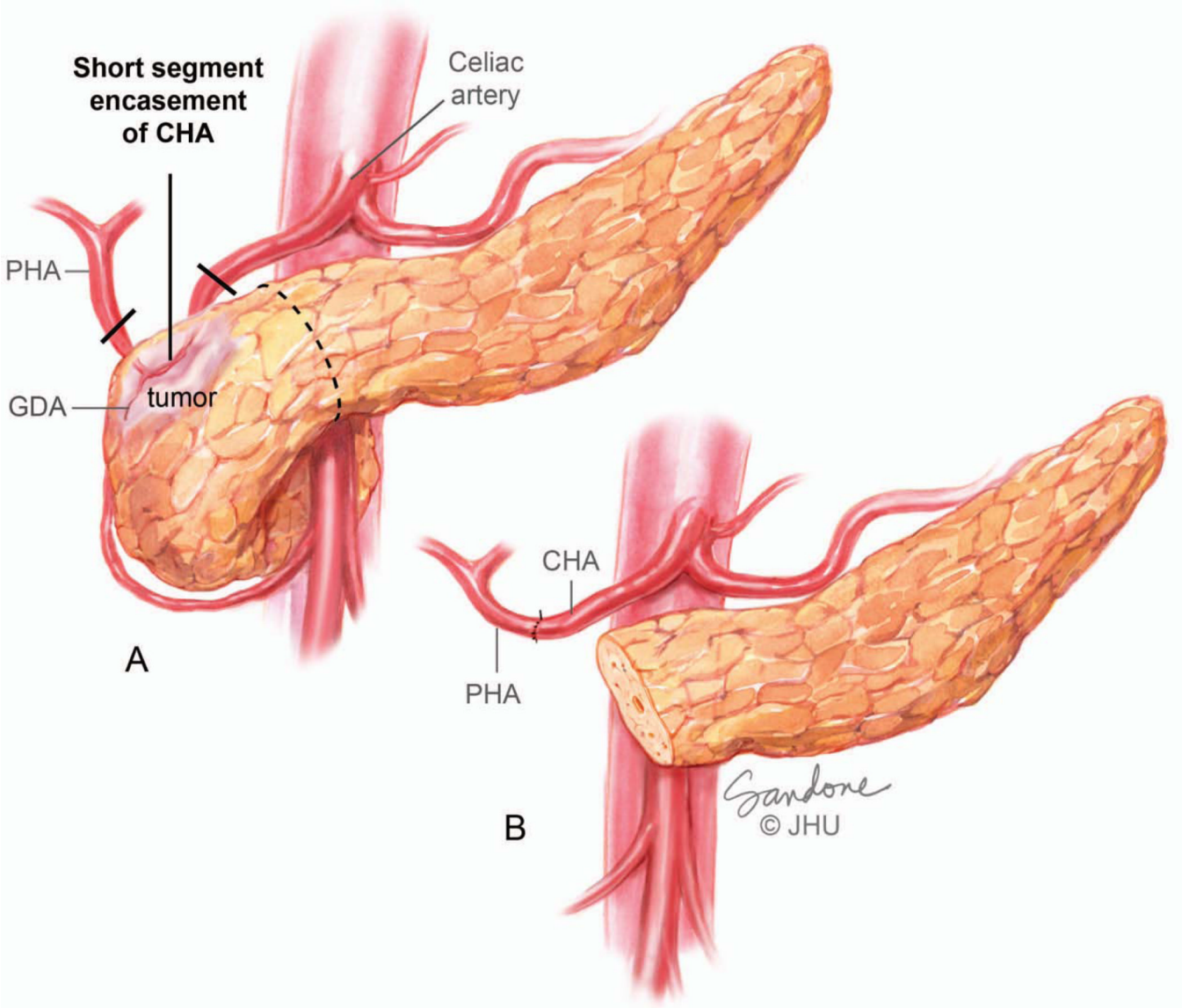


Figure 12.
(A) Short-Segment encasement of the common hepatic artery. (B) Although arterial encasement is most often considered to be locally advanced, short segment encasement of the common hepatic artery is amenable to resection and primary anastomosis. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

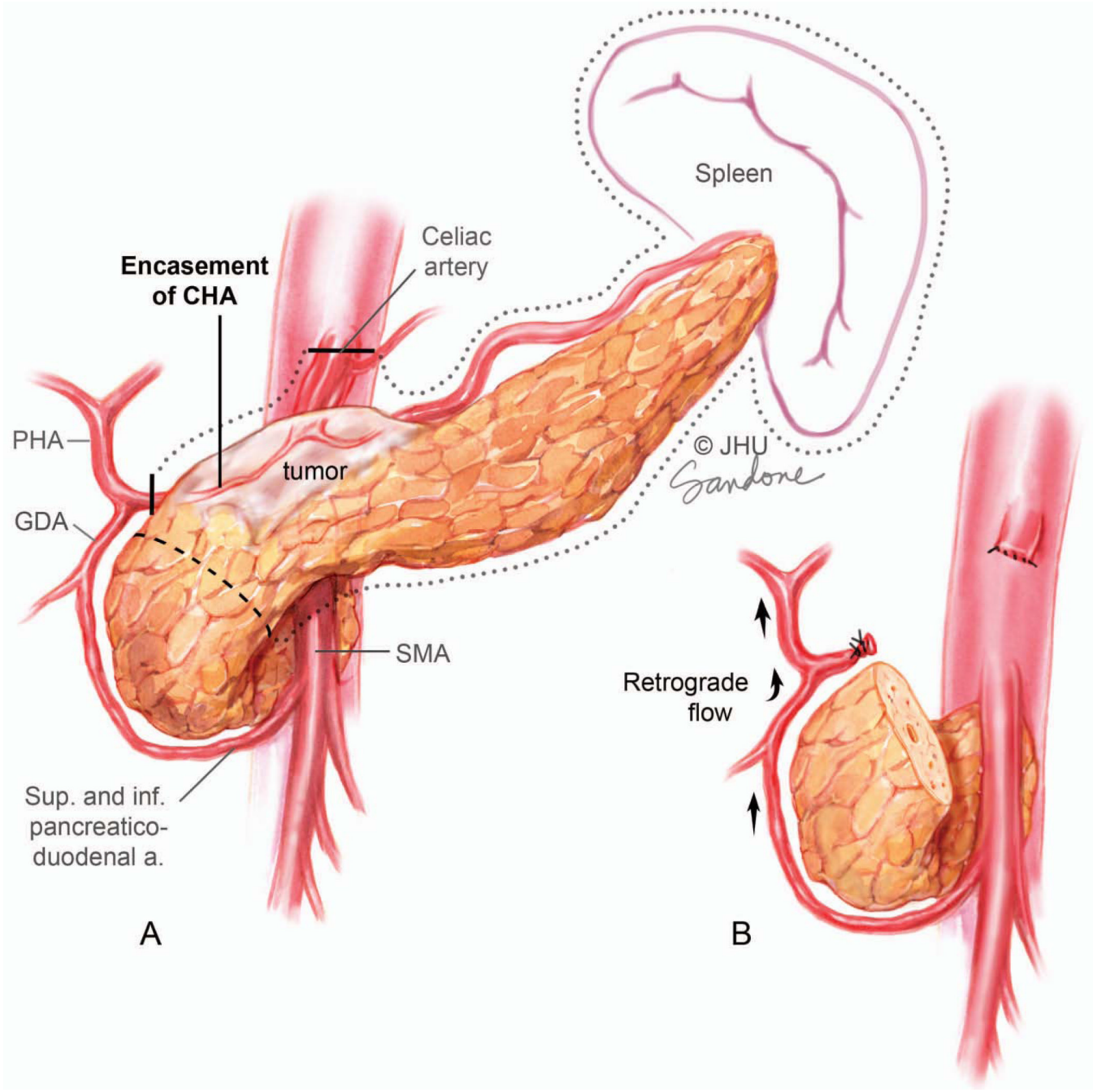


Figure 13.

Tumor encasing the celiac artery, proximal hepatic artery and splenic artery. Although arterial encasement is most often considered to be locally advanced unresectable this configuration of vessel involvement allows en bloc resection of the proximal hepatic, celiac and splenic arteries (dark line marks transection margin of artery) in combination with a distal pancreatectomy. This is called the Appleby procedure. (B) The gastroduodenal artery (GDA) must be preserved since perfusion of the liver is by retrograde flow through this vessel to the common hepatic artery. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

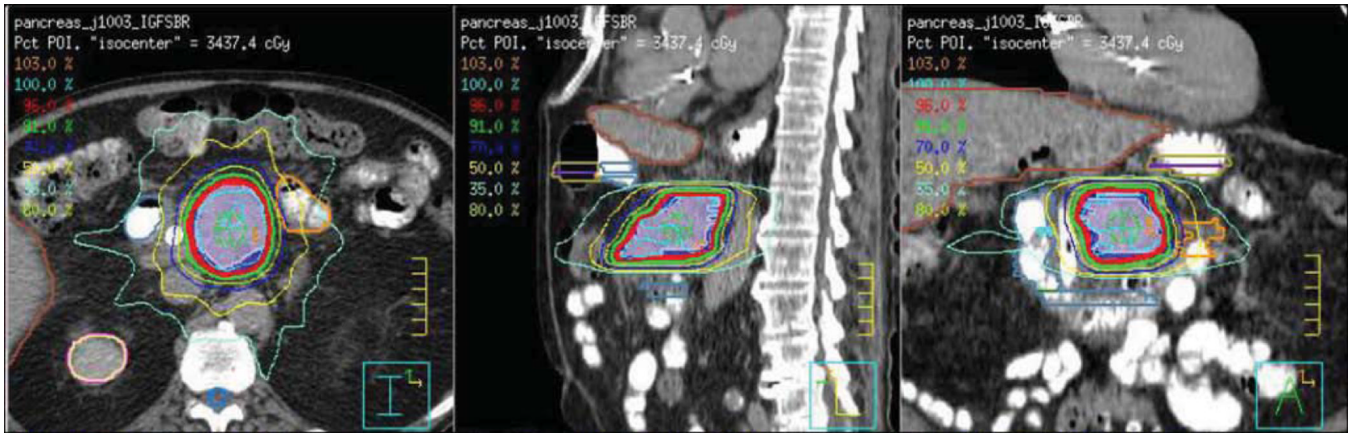


Figure 14.

Stereotactic body radiation therapy plan delivering 33 Gy to the pancreatic tumor over 5 treatments. Breath hold during treatment and pancreatic tumor markers (fiducials) allows for small margins (3 mm) and accurate targeting of the tumor. Notice the low dose of radiation (colored lines) to the bowel and adjacent normal structures.

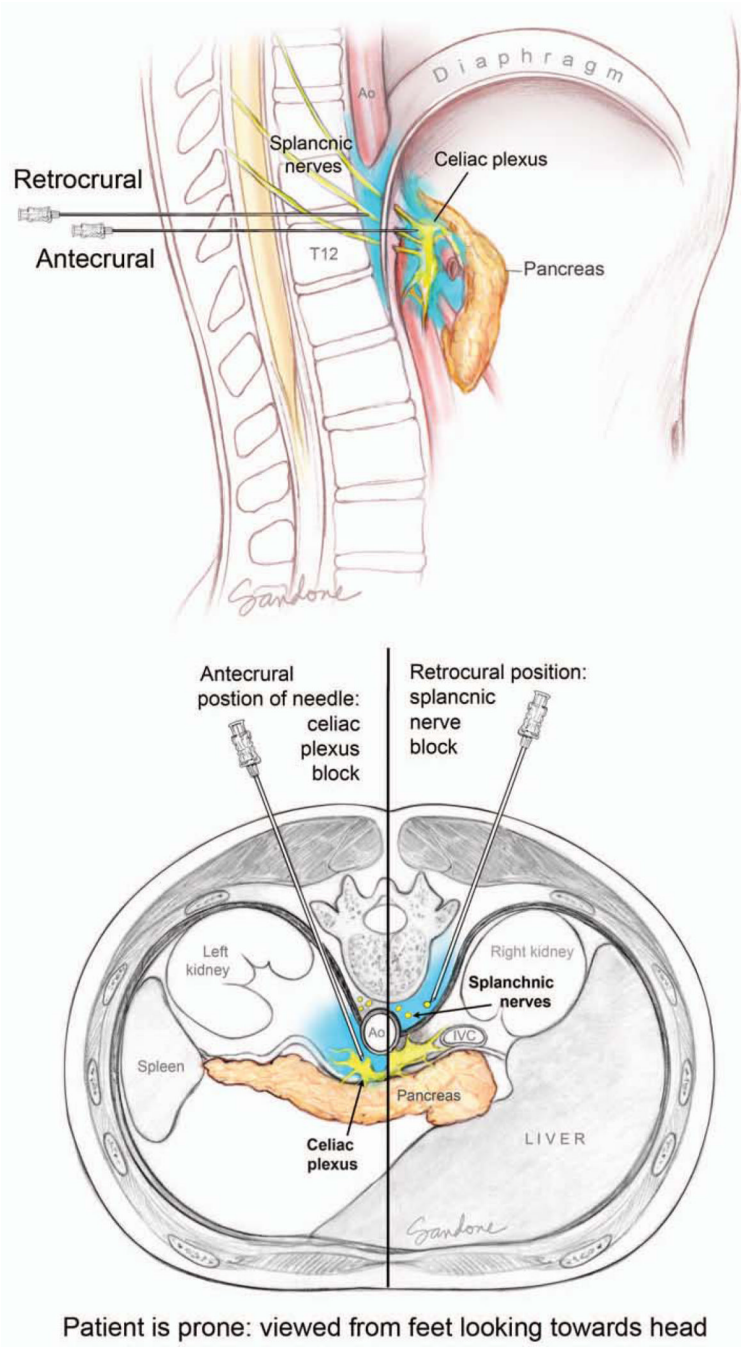


Figure 15.

Retrocrural and antecrural nerve blocks are effective approaches to alleviating pain caused by pancreatic cancer. Top illustrates a mid-sagittal view and the bottom an axial view with the patient prone. Note the position of the needle tip in the antecrural versus retrocrural positions. Blue represents the injected anesthetic. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

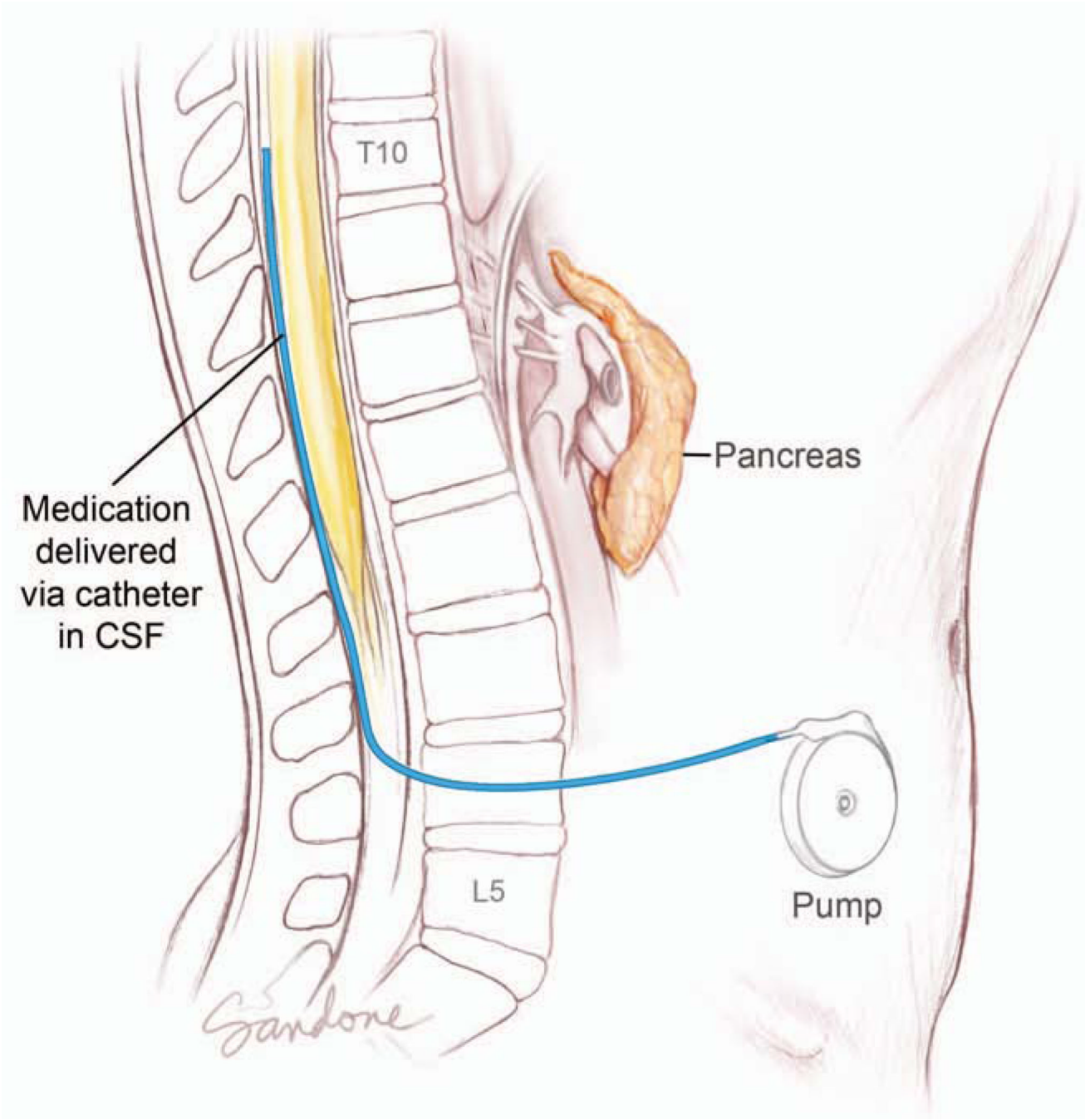


Figure 16.
Pain medication can also be delivered intrathecally into the cerebrospinal fluid (CSF) using a catheter attached to a surgically implanted pump. Blue represents the injected anesthetic. Illustration by Corinne Sandone. Illustration by Corinne Sandone. © Johns Hopkins University; used with permission.

Table 1

Pancreatic Cancer Risk Factors

Risk Factor	Risk Estimate (95% CI)
Current Cigarette Smoking	OR= 2.20 (1.71–2.83)
Past Cigarette Smoking 1–10 years since quitting 15–20 years since quitting	OR=1.64 (1.36–1.97) OR=1.12 (0.86–1.44)
Diabetes Mellitus <3 years >10 years duration	RR=7.94 (95% CI, 4.70–12.55) OR 1.51 (95% CI=1.16–1.96)
BMI (>35 vs 18.9–24.9)	OR =1.55 (95%CI=1.16 – 2.07)
Heavy Alcohol (> 6 drinks/day)	OR 1.46 (95%CI=1.16–1.83)
Pancreatitits (>2 years)	2.71 fold (95% CI 1.96–3.74)

BMI= Body mass index; OR=odds ratio; RR=relative risk

Table 2

Pancreatic Cancer Susceptibility Genes

Gene/Risk Group	Risk Estimate (95% CI)	Estimated Lifetime Pancreatic Cancer Risk
General Population	1	0.96(by age 80)[225]
Familial Pancreatic Cancer Overall 3 or more first-degree relatives with pancreatic cancer	RR= 6.79 (4.54 to 9.75) RR= 17.02 (7.34 to 33.5)	Varies with youngest age of onset
High Penetrance		
BRCA2	RR = 3.51(1. 87–6.58)[226]	3.36% (age 80) *
PALB2	Elevated	Elevated
BRCA1	OR=2.26 (1.26 to 4.06)[32]	2.16% (age 80) *
Mis-Match Repair (HNPCC)	RR=8.6 (4.7–15.7) [39]	3.68%(1.45%-5.88%)(age 70)[39]
Hereditary Pancreatitis (*PRSS1*)	RR=58 (23–105)[47]	30–40%(age 70) [4748]
Peutz-Jeghers (*STK11*)	RR=132 (44, 261)[227]	11%-32%[228, 229]
Familial Melanoma(*CDKN2A*)	RR=38 (10–97)[230]	17% (age 75)
ATM	Unknown	Unknown
Low-Penetrance		
ABO blood group	OR=1.20 (1.12–1.28)[231]	1.15% (age 80)
1q32.1(rs3790844T/C)	OR=0.77 (0.71–0.84)[231]	0.73% (age 80)
13q22.1(rs9543325 T/C)	OR=1.26 (1.18–1.35)[231]	1.2% (age 80) *
5p15.33(rs401681C/T)	OR=1.19 (1.11–1.27)[231]	1.10% (age 80) *

* Estimated based by multiplying general population risk by risk estimate. HNPCC=hereditary non-polyposis colorectal cancer syndrome; OR=odds ratio; RR=relative risk

Table 3

Pathology of the Major Neoplasms of the Pancreas

Tumor type	Gross	Microscopy	Clinical Importance
Acinar cell carcinoma	Large soft fleshy solid masses	Pyramidal cells neoplastic cells form small lumina. Expression of digestive enzymes can be demonstrated by immunolabeling.	Rare fully malignant neoplasm. 15% associated with metastatic fat necrosis caused by the release of digestive enzymes into the blood stream.
Invasive ductal adenocarcinoma	Poorlydefined firm solid infiltrative masses	The neoplastic cells form glands and infiltrate tissues. Vascular and perineural invasion are common. Associated with a dense desmoplasticstroma.	Most common type of pancreatic cancer. Very poor prognosis.
Intraductal papillary mucinous neoplasm (IPMN)	Cystic tumors that arise in the larger pancreatic ducts. Finger-like papillae of neoplastic cells project into mucin-filled ducts	Papillae lined by mucin-producing neoplastic cells with varying degrees of dysplasia.	IPMNs are detectable and curable non-invasive precursors to invasive pancreatic cancer. The challenge is not to over treat low-grade IPMNs.
Mucinous cystic neoplasm (MCN)	Cystic neoplasm that almost always arises in the tail of the pancreas. Cysts filled with mucin.	Mucin-producing neoplastic epithelium resting on ovarian-type stroma.	Can progress to invasive cancer if untreated.
Pancreatic intraepithelial neoplasia (PanIN)	Microscopic lesions	Noninvasive epithelial proliferations in the smaller pancreatic ducts. Associated with lobulocentric atrophy.	PanINs are a curable noninvasive precursor to invasive pancreatic cancer, but most are too small to detect.
Pancreatoblastoma	Large soft solid masses	Similar to acinar carcinoma but also have squamoid nests.	More common in children than adults.
Pancreatic neuroendocrine tumor (PanNET)	Well-demarcated and soft solid masses	Nests and trabecullae of relatively uniform cells with “salt and pepper” chromatin. Expression of neuroendocrine markers and hormones can be demonstrated by immunolabeling.	Some arise in the setting of a familial genetic syndrome. Aberrant hormone production can cause clinical syndromes. Fully malignant, with a 45% 10-year survival rate
Serous cystadenoma	Cystic neoplasms with thin septa, and straw-colored fluid. Often have a central scar.	Clear cuboidal cells without atypia line cysts.	Virtually always benign.
Solid-pseudopapillary neoplasm	Solid masses that undergo cystic change caused by hemorrhage and necrosis	Poorly cohesive cells surround delicate blood vessels.	Most arise in young women. Low-grade malignant neoplasms.
Variants of ductal carcinoma (adenosquamous, colloid, medullary, undifferentiated, etc.)	Most are solid	Varies based on tumor type.	Can be clinically important to recognize.

IPMN=intraductal papillary mucinous neoplasm; MCN=mucinous cystic neoplasm; PanIN=pancreatic intraepithelial neoplasia; PanNET=pancreatic neuroendocrine tumor; SCN=serous cystic neoplasm; SPN=solid-pseudopapillary neoplasm

Table 4

Genetic Alterations in Common Neoplasms of the Pancreas

Tumor type	Gene(s)	Prevalence of the Alteration	Comment
Acinar cell carcinoma	*APC*	15%	
	CTNNB1 (beta-catenin)	5%	
Invasive ductal adenocarcinoma	*KRAS*	95%	
	p16/CDKN2A	95%	
	TP53	75%	
	SMAD4	55%	*SMAD4* loss associated with poor prognosis and widespread disease
	MLL3, *TGFBR2*, *FBXW7*, *ARID1A*,*AIRID2*, and *ATM*	<5%	Some of these, such as *ATM*, may be targetable therapeutically
IPMN	*KRAS*	80%	
	RNF43	75%	*RNF43* is a marker of mucin-producing tumors as it is present in both IPMNs and MCNs
	GNAS	60%	*GNAS* is a marker of IPMNs. *GNAS* and/or *KRAS* mutations are present in >95% of all IPMNs
	p16/CDKN2A	Varies dependent on histologic grade	
	TP53	Varies dependent on histologic grade	Associated with higher grade lesions
	SMAD4	Varies dependent on histologic grade	Associated with higher grade lesions
	PIK3CA	10%	
MCN	*KRAS*	75%	
	RNF43	40%	*RNF43* is a marker of mucin-producing tumors--IPMNs and MCNs
	p16/CDKN2A	Varies dependent on histologic grade	
	TP53	Varies dependent on histologic grade	Associated with higher grade lesions
	SMAD4	Varies dependent on histologic grade	Associated with higher grade lesions
Pancreatoblastoma	Imprinted region on chromosome 11	85%	Same region is targeted in hepatoblastoma and Wilms tumors
	CTNNB1 (beta-catenin)	55%	
	APC	10%	
PanNET	*MEN1*	45%	
	DAXX or ATRX	45%	
	TSC2, PTEN, DDIT4, and *PIK3CA* (mTOR Pathway genes)	15%	Potentially targetable therapeutically with everolimus
SCN	*VHL*	50%	Among the cystic tumors of the pancreas, *VHL* loss is specific for SCN
SPN	*CTNNB1* (beta-catenin)	95%	Immunolabeling for beta-catenin is useful diagnostically

IPMN=intraductal papillary mucinous neoplasm; MCN=mucinous cystic neoplasm; PanNET=pancreatic neuroendocrine tumor; SCN=serous cystic neoplasm; SPN=solid-pseudopapillary neoplasm

Table 5

Selected Key Adjuvant Studies

Study	Treatment	1 year survival (%)	2 year survival (%)	5 year survival (%)	DFS (mo)	Median Survival (mo)
GITSG (1985)[232] N=43	Observe v. chemorad	49 v. 63	15 v. 42	14 v. 4	< 9 v. 16	11 v. 20 (p=.01)
EORTC 40891 (1999) N=218[147]	Observe v. Chemorad	53 v. 65	23 v. 37	22 v. 25	NR	12.6 v. 17.1 (pancreas only, p=.099)
JHH retrospective N=452[233]	Observe v. Chemorad	NR	32 v 44	15.4 v. 20.4	NR	14.4 v. 21.2 P<.001
ESPAC-1 (2004) N=289[148]	2 X 2 design Observe v. Chemo	? v. 67	? v 38	11.v. 29	chemoXRT-10.7 no chemoXRT 15.2 chemo 15.3 no chemo-9.4	16.9 v. 21.6
CONKO-1 (2007) N=354[144]	Observe v. Chemo	72 v 72	42 v. 47	11 v. 22	6.9 v. 13.4 (P<.001)	20 v. 22 (p=.06)
RTOG-9704 (2008) N=538[153, 234]	Gem-5FU/XRT v. 5FU, 5FU/XRT	69 v. 65	35 v. 39	20 v. 20	NR	20.6 v. 16.9 (P=.03)
ESPAC-3 (2009) N=1030[145]	Gem v 5FU	70 v. 70	40 v. 40	NR	14.3 v. 14.1	23.6 v. 23
JHH and Mayo Clinic Retrospective (2010) N=1272[152]	Observation v. chemorads	58. v 80	34.6 v. 44.7	16.1 v. 22.3		15.5 v. 21.1 (P<.001)
ACOSOG (2011) N=89[154]	5FU CI, IFN/cisplatin +XRT	80	60	NR	14.1	25.4
CapRI (2012) N=110[156]	5-FU/cis/XRT + IFN followed by 5FU v. 5FU	85 v. 80	60 v. 55	25 v. 25	15.2 v. 11.5 (p=.61)	32. 1 v. 28.5 (P=.49)

ACOSOG=American College of Surgeons Oncology Group; CaPRI=Combined Chemoradioimmunotherapy for Pancreatic Adenocarcinoma; CI=continuous infusion; CONKO=CharitéOnkologie; DFS= disease free survival; EORTC=European Organization for Research and Treatment of Cancer; ESPAC=European Study group for Pancreatic Cancer; 5-FU=5-fluorouracil; GITSG=Gastrointestinal Tumor Study Group; IFN= interferon; JHH=Johns Hopkins Hospital; RTOG=Radiation Therapy Oncology Group; XRT=external beam radiation therapy.

Table 6

Key metastatic pancreatic cancer studies

Study	Chemo	RR	MS (months)	1-year survival %
Burris (1997) N= 126[190]	5-FU v. Gem	NR	4.4 v. 5.6 (P=.0025)	2 v. 18
Rocha Lima (2003) N=342[235]	Gem ± Irinotecan	4.4 v. 16	6.6 v. 6.3	22 v. 21
Heinemann (2003) N=195[236]	Gem ± Cisplatin	8 v. 10.2	6 v. 7.6 (p=.12)	22 v. 26
Tempero (2003) N=92[191]	Gem ± Gem (Fixed rate)	9.1 v. 5.9	5 v. 8 (p=.013)	9 v. 29
O'Reilly (2006) N=340[237]	Gem ± exatecan	6.3 v. 8.2	6.2 v. 6.7 (p=.52)	21 v. 23
Richards (2004) N=565[238]	Gem ± Pemetrexed	9.1 v 18.3	6.3 v. 6.2 (p=.85)	21 v. 20 (p=.72)
Louvet (2005) N=313[196]	Gem v. Gem (FDR+ + Oxali	17.3 v. 26.8 (p=.04)	7.1 v. 9 P=.13)	28 v. 35
Cunningham (2009) N=533[195]	Gem ± Capecitabine	14 v. 7 (p=.008)	7.4 v. 6 (p<.05)	26 v. 19
CALGB (2009) N=259[239]	Gem/cis Gem (FDR) Gem/taxotere Gem/Irinotecan	11 14 12 12	6.7 6.4 6.4 7.1	
Conroy (2011) N=343[162]	Gem. V. FOLFIRINOX		6.8 v. 11.1 (P<.0001)	17 v. 36
Moore (2005) N=569[200]	Gem ± erlotinib	8.7 v. 7.9 (P=.8)	6.4 v. 5.9 (P=.025)	26 v. 20
Kindler (2007) N=602[201]	Gem ± bevacizumab	13.1 v. 11.3	6 v. 5.7	NR
Philip (2007) N=735[166]	Gem ±cetuximab	14 v. 12	6 v. 6.5 (p=.14)	NR
Von Hoff (2013) N=861[199]	Gem ±nab-paclixatel	8.5 v. 6.7		

Cis= cisplatin; 5-FU= 5-flurouracil; FDR=; Gem=gemcitabine; MS=median survival; NR=not reached