

Imaging in pancreatic transplants

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Abstract

Pancreatic transplantation, performed alone or in conjunction with kidney transplantation, is an effective treatment for advanced type I diabetes mellitus and select patients with type II diabetes mellitus. Following advancements in surgical technique, postoperative management, and immunosuppression, pancreatic transplantation has significantly improved the length and quality of life for patients suffering from pancreatic dysfunction. While computed tomography (CT) and magnetic resonance imaging (MRI) have more limited utility, ultrasound is the preferred initial imaging modality to evaluate the transplanted pancreas; gray-scale assesses the parenchyma and fluid collections, while Doppler interrogation assesses vascular flow and viability. Ultrasound is also useful to guide percutaneous interventions for the transplanted pancreas. With knowledge of the surgical anatomy and common complications, the abdominal radiologist plays a central role in the perioperative and postoperative evaluation of the transplanted pancreas.

Key words: Diabetes; pancreas transplant; transplantation; ultrasound

Introduction

Pancreatic transplantation is effective for achieving normoglycemia in patients with insulin-dependent diabetes mellitus (type I) and in select patients with type II diabetes mellitus.^[1-3] Additionally, pancreatic transplantation counteracts the complications of diabetes mellitus, including diabetic neuropathy and retinopathy.^[4,5] The increasing success of the procedure is largely due to refinements of surgical technique, postoperative management, and immunosuppression.^[6-8] Pancreatic transplantation typically utilizes a cadaveric allograft and is most commonly performed in conjunction with a kidney transplant;^[4] this combined transplantation procedure has been shown to increase the survival of the patients and the transplanted organs.^[9,10] While ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI) can all be effectively used to image the pancreatic transplant, US is the preferred initial imaging modality.^[11]

Indications and work-up for pancreatic transplant

Pancreatic transplantation is limited by the number of available organs. The large majority of available pancreata go to patients with advanced type I diabetes mellitus who have, or are at risk of developing secondary complications of the disease, such as retinopathy, neuropathies, and nephropathy.^[12] Preoperative evaluation typically considers the potential recipient's age and ability to survive the operation. Key components of the assessment include determining the presence of renal, cardiac, peripheral vascular, cerebrovascular, and psychiatric diseases. The pre-transplant work-up consists of extensive laboratory, infectious, and physiologic testing.^[13] Of note, the only imaging examination that is typically required by most centers is chest radiography.

It has been shown that the simultaneous pancreas and kidney transplant is associated with 50% lower mortality and decreased morbidity compared to kidney transplant alone for patients with advanced type I diabetes with co-existing end-stage renal disease.^[10] Therefore, simultaneous transplant is the treatment of choice in this setting; patients experience decreased morbidity since insulin and dialysis are no longer required after successful pancreas transplant.^[7,14] For patients with labile serum glucose who are not yet uremic, pancreas transplant alone (PTA) may be considered.

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Types of pancreatic transplants

There are four general types of pancreatic transplants that depend on the presence and timing of a co-existing kidney transplant: PTA, pancreas after kidney (PAK), simultaneous pancreas-kidney transplant (SPK) from a cadaveric donor, and simultaneous cadaveric donor pancreas and live donor kidney (SPLK) transplant. According to data from the International Pancreas Transplant Registry, the recent unadjusted 5-year patient survival rates following pancreatic transplant are 87% for SPK, 83% for PAK, and 89% for PTA.^[1,15] The organs used for SPK transplant are harvested from a single cadaveric donor and transplanted during the same operation. PAK transplant recipients receive a kidney from a cadaveric or living donor, followed by the subsequent pancreas transplant from an unrelated, cadaveric donor in a separate operation; the timing between the kidney and pancreas transplants is variable and based upon the patient's symptoms and clinical course. During the SPLK procedure, the transplant recipient receives the kidney from a live donor and the pancreas from a cadaveric donor within the same operation. SPK has traditionally been the most commonly performed procedure of the four types, accounting for approximately 70-80% of all pancreas transplants over the past 15 years.^[9,15,16] Conversely, PTA has historically been the least common method, accounting for approximately 12%.^[9] The PAK procedure is performed less commonly than SPK transplants due to lower long-term pancreatic graft survival in PAK transplants.^[6] However, there is still a role for the PAK procedure; its advantages include significantly reduced transplant waiting times for uremic patients, the opportunity for a potential living kidney donor, and increased kidney graft survival compared to kidney transplant alone.^[17,18] The SPKL transplant is also associated with shorter waiting times and has been proven to have a lower rate of delayed graft dysfunction compared to SPK transplants.^[19]

Regardless, the presence or absence of a kidney transplant does not significantly influence the pancreatic surgical anatomy. The cadaveric pancreas is harvested with a short segment of duodenum that contains the ampulla of Vater. The splenic and proximal superior mesenteric arteries are also harvested. In addition, a segment of the donor's common iliac artery through its bifurcation into the internal/external iliac arteries is removed and fashioned into a Y-graft that is connected to the donor's splenic and mesenteric arteries to craft a single arterial conduit [Figure 1]; the end of this conduit is connected to the recipient's common or external iliac artery in a single end-to-side arterial anastomosis. The venous drainage of the pancreatic transplant is most commonly fashioned after distal ligation of the donor's splenic and superior mesenteric veins and anastomosis between a segment of the donor's portal vein and the recipient's common or external iliac vein in an end-to-side manner [Figure 2].^[16,20] Alternatively, some surgeons may choose to create the anastomosis between the donor's portal

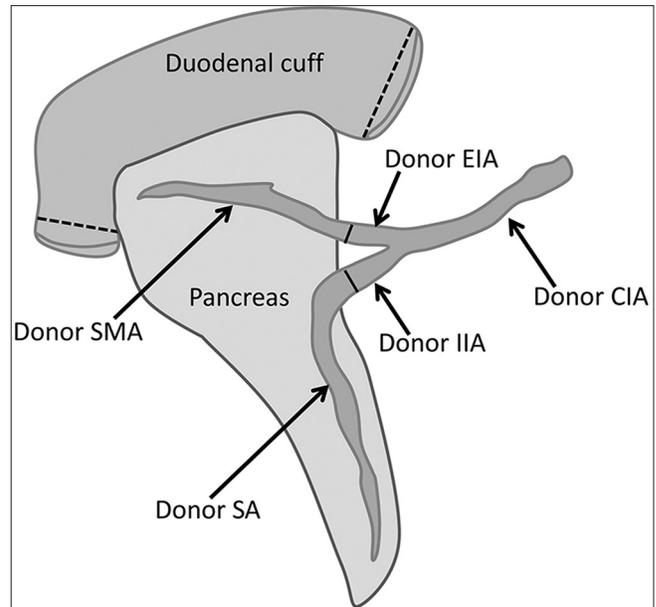


Figure 1: Diagram of Y-graft used for arterial anastomosis between pancreatic vessels and the recipient's CIA (CIA: Common iliac artery, IIA: Internal iliac artery, EIA: External iliac artery, SMA: Superior mesenteric artery, SA: Splenic artery)

or superior mesenteric vein and the recipient's superior mesenteric vein, thereby ultimately creating a portal venous route of drainage in the recipient that is thought to slow the development of insulin resistance and atherosclerosis.^[21,22] However, no significant difference of glycemic control has been shown to exist based on whether the transplant's venous drainage is into the recipient's iliac vein or superior mesenteric vein.

For many years, the duodenal cuff was anastomosed to the urinary bladder intraperitoneally in the right iliac fossa. The constant drainage of pancreatic exocrine secretions into the bladder often resulted in numerous urinary complications for transplant recipients, such as cystitis, urethritis, recurrent infections, dehydration, calculi, hematuria, and reflux into the pancreatic transplant that resulted in episodes of pancreatitis. Therefore, an enteric anastomosis between the oversewn duodenal cuff and the recipient's jejunum has become the preferred route for drainage of exocrine secretions [Figure 3].^[16,23] The success of the enteric anastomosis is based on the physiologic delivery of bicarbonate and enzymes into the bowel and was corroborated by studies that showed no difference in perioperative morbidity or long-term graft failure compared to pancreatic transplant patients who had bladder anastomoses.^[24,25]

Normal post-transplant evaluation

US is the most commonly used imaging modality in the postoperative setting and includes both gray-scale and Doppler interrogation. Performance of a proper Doppler interrogation is of paramount importance in the early

postoperative setting to confirm vessel patency and adequate perfusion of the allograft; application of color or power Doppler should reveal flow throughout the allograft while spectral Doppler analysis should elucidate arterial and venous waveforms in the intrapancreatic vessels [Table 1]. A thorough gray-scale investigation is needed to check for the development of fluid collections. Unlike kidney transplants that are positioned in the extraperitoneal space of the iliac fossa, pancreatic transplants are located in the intraperitoneal space and may be more readily obscured by overlying bowel gas. Re-positioning of the patient (in the oblique or lateral decubitus position) or application of gentle pressure with the US transducer can be performed in an attempt to displace overlying bowel and allow visualization of the pancreatic transplant. Although the lack of an organ capsule generally results in an ill-defined appearance, the pancreatic transplant can be identified by its relatively cylindrical shape and its normally homogeneous echotexture that lies immediately anterior to the transplanted splenic vein.^[26,27] Compared to the surrounding mesenteric fat, the pancreatic transplant is hypoechoic [Figure 4].^[11] The pancreatic transplant can be differentiated from the adjacent fluid-filled bowel due to its lack of peristalsis during real-time imaging and its slightly higher echogenicity. With respect to the native pancreas, the transplanted pancreas is typically less echogenic due to parenchymal edema in the postoperative setting.^[26] If the pancreatic transplant is not apparent upon initial gray-scale evaluation, it can

usually be found by applying color Doppler analysis and scanning the length of the patient's iliac vessels [Figure 5]. After the anastomosed vessels are identified, they should

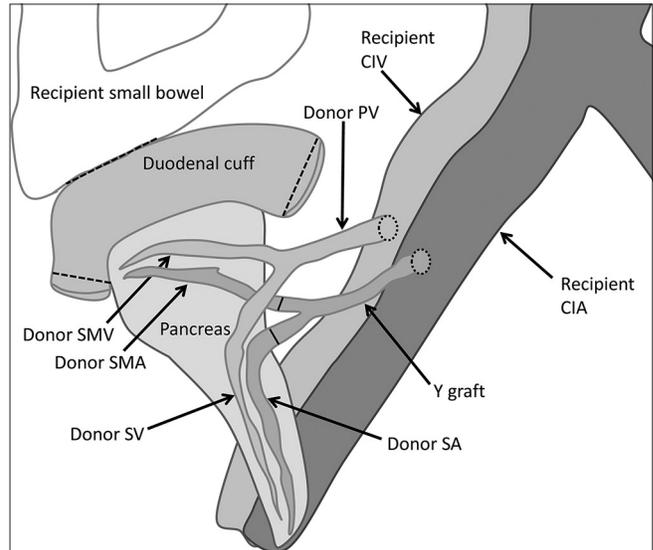


Figure 2: Diagram shows anastomoses for pancreatic transplant (CIA: Common iliac artery, CIV: Common iliac vein, PV: Portal vein, SMV: Superior mesenteric vein, SV: Splenic vein, SA: Splenic artery, SMA: Superior mesenteric artery)

Table 1: Reporting checklist

Grayscale

- Review operative note to determine nature of vascular anastomoses and to determine if pancreas is drained via the bladder or small bowel. Is there an abnormality of the bladder (wall thickening) or bowel (wall thickening, luminal dilatation)
- Is there fluid or a fluid collection present? If so, comment on its size, location, appearance and likelihood of successful percutaneous drainage
- Evaluate the pancreatic parenchymal texture (Is it homogeneous or heterogeneous?)
- Does the pancreatic duct have normal caliber?

Color Doppler

- Is color flow present within pancreatic parenchyma? Is the perfusion uniform?
- Are the arterial and venous anastomoses identified?
- Is flow identified in the splenic artery and vein?
- Is color flow apparent in the ipsilateral iliac vessels?
- Are there any areas of abnormal flow that would indicate arteriovenous fistula or pseudoaneurysm?

Spectral Doppler

- Are there normal arterial and venous waveforms?
- What is the peak systolic velocity in the splenic artery near the anastomosis and in the iliac artery?
- What is the ratio of the peak systolic velocity at the anastomosis compared to the iliac artery?
- Is there evidence of arterial stenosis?
- What is the peak velocity in the splenic vein near the anastomosis and in the iliac vein?
- What is the ratio of the velocity of the splenic vein at the anastomosis to the iliac vein?
- Is there evidence of venous stenosis?
- Apply spectral Doppler to any areas of abnormal color flow - is there spectral evidence of arteriovenous fistula or pseudoaneurysm?

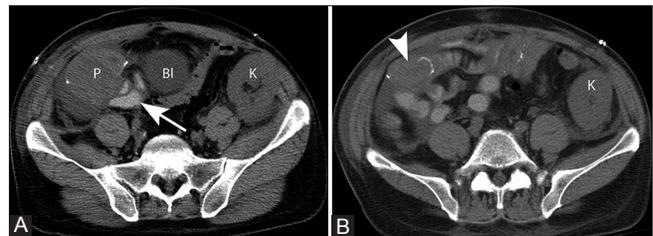


Figure 3 (A and B): Duodenal cuff. (A) Non-contrast axial CT shows contrast material in the small bowel (arrow) near enteric anastomosis (B) More superiorly, a suture identifies the edge of the underdistended, oversewn duodenal cuff (arrowhead) (P: Pancreas, K: Kidney transplant, Bl: Bladder)

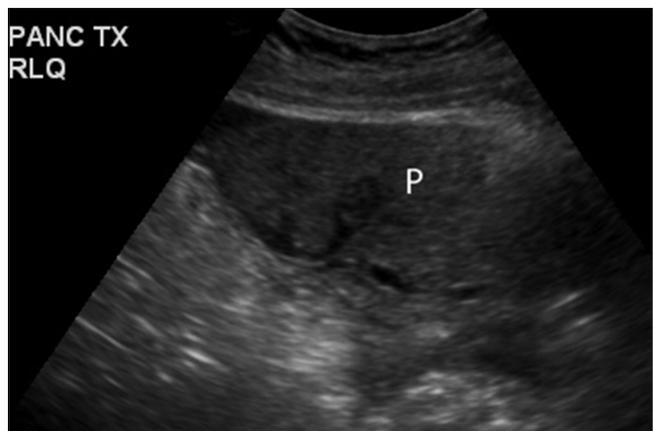


Figure 4: Normal pancreas transplant. Longitudinal gray-scale US demonstrates that the normal pancreas (P) transplant is homogeneous and hypoechoic relative to the adjacent fat

be interrogated with spectral Doppler to evaluate the velocities and waveforms [Figure 6]. The arterial velocities can be quite variable, but should be normalized to the ipsilateral iliac artery by determining the velocity ratio of the vessels. However, arterial anastomotic velocities can be much higher in the immediate postoperative setting, presumably due to transient postoperative edema or vessel kinking. An intrapancreatic artery waveform with a brisk systolic upstroke should be identified [Figure 7]; the normal venous waveform will be mildly undulating and will show continuous flow [Figure 8].

On non-contrast CT, the pancreatic transplant appears as an elongated, homogeneous structure in the iliac fossa [Figure 9], but may be difficult to distinguish from

the adjacent bowel.^[26,28,29] On MRI, the normal pancreatic transplant is isointense to renal cortex on T1W images and has intermediate signal on T2W images. The normal pancreatic transplant should enhance homogeneously after infusion of intravenous contrast material on CT or MRI [Figure 10]; however, it should be noted that iodinated intravenous contrast material may place the transplanted kidney at risk for contrast-induced nephropathy, while gadolinium-based contrast agents may pose the risk of nephrogenic systemic fibrosis in select patients with advanced renal dysfunction.^[26,27] However, with MRI, non-contrast time-of-flight images can be used to assess the vasculature. With both CT and MRI, post-contrast images should clearly depict the exocrine drainage anastomosis (duodenocystostomy or duodenojejunosomy), vascular anastomoses, and vascular structures of the

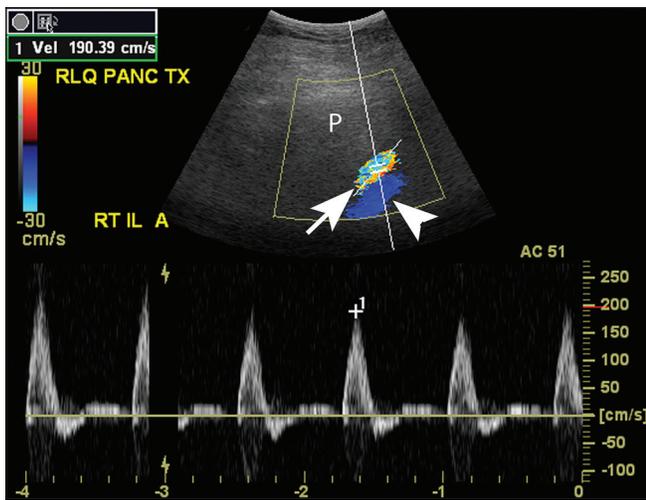


Figure 5: Iliac vessels as landmarks. The pancreatic transplant was difficult to find at gray-scale US. Transverse color and spectral Doppler US were used to scan along the iliac artery (arrow) and vein (arrowhead) which allowed identification of the transplant (P)

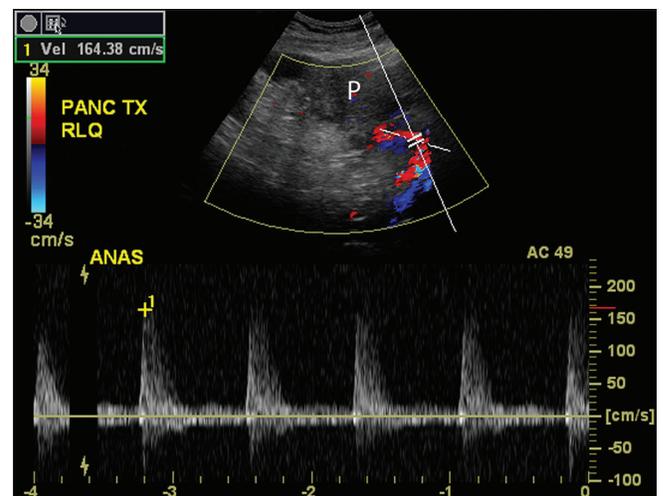


Figure 6: Normal arterial anastomosis. Transverse color and spectral Doppler US show a normal-appearing arterial anastomosis and waveform located just medial to the pancreatic transplant (P)

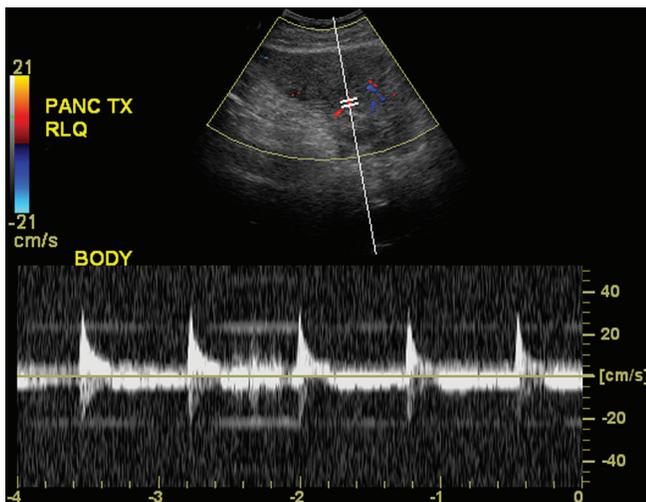


Figure 7: Normal intrapancreatic arterial flow. Transverse spectral US illustrates a normal arterial waveform within the body of the pancreatic transplant. Note the brisk systolic upstroke and the continuous diastolic flow

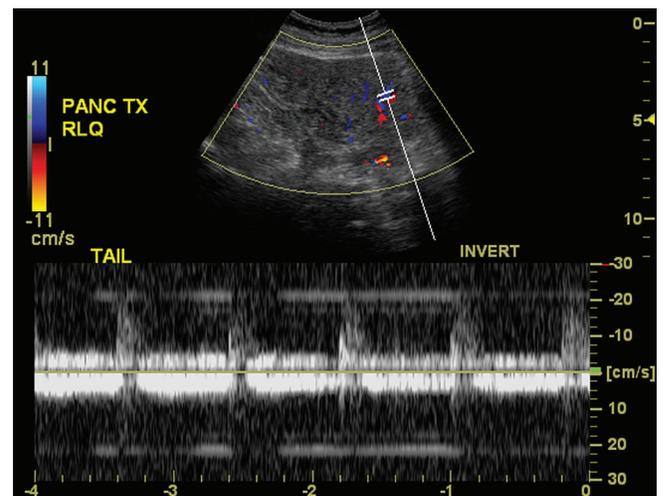


Figure 8: Normal intrapancreatic venous flow. Transverse spectral Doppler reveals a normal venous waveform within the tail of the pancreas transplant. Note that there is continuous flow with mild undulation of the venous waveform

allograft. The normal pancreatic duct is generally not visible with US or CT, but may be observed as a thin (≤ 3 mm) smooth line on T2W MRI.

Imaging of complications of pancreatic transplants

Complications of pancreatic transplants can generally be divided into vascular and non-vascular categories. The non-vascular category can be further subdivided into complications that affect the parenchyma and bowel. The most common complications leading to early transplant failure are acute rejection and vascular thrombosis.^[30] Although the imaging findings and clinical signs and symptoms of transplant dysfunction are often nonspecific when considered alone, their integration often permits diagnosis and facilitates treatment.

Vascular complications

Vascular complications of pancreatic transplants consist of venous and arterial thrombosis, pseudoaneurysms, arteriovenous fistulas, and anastomotic strictures. The most feared complication is complete vascular thrombosis since it can quickly lead to infarction of the allograft.^[31] Complete arterial thrombosis is shown as absence of arterial Doppler signal within the graft despite parameter optimization [Figure 11]. The parenchyma becomes

heterogeneous at gray scale US, CT, or MRI; angiographic images can reveal the site of vascular occlusion within the donor artery.^[32] Venous thrombosis is more common than arterial thrombosis and can result in enlargement of the pancreatic transplant and parenchymal edema due to the venous outlet obstruction.^[31] Gray-scale US findings include increased hypoechogenicity or heterogeneity of the pancreatic parenchyma and perigraft fluid; occasionally, echogenic clot can be identified within the splenic vein. Spectral Doppler findings include the absence of a venous waveform and reversal of diastolic flow on the arterial waveform [Figure 12]. In rare cases, extrinsic compression or kinking of the veins can masquerade as venous thrombosis at Doppler interrogation.^[33] Venous thrombosis generally affects pancreatic allografts within the first few weeks after surgery and complicates approximately 5% of allografts.^[34] Treatment options include anticoagulation, mechanical thrombectomy, or pancreatectomy.



Figure 9: Normal pancreatic transplant. Non-contrast axial CT demonstrates the pancreatic transplant (arrowheads) with head oriented anterosuperiorly adjacent to the enteric anastomosis (arrow) (K: Kidney transplant, Bl: Bladder)

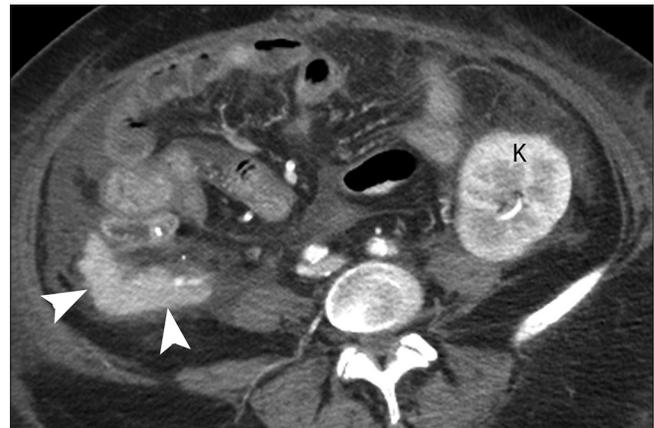


Figure 10: Normal pancreatic transplant enhancement. Post-contrast axial CT demonstrates homogeneous enhancement throughout the pancreatic transplant (arrowheads) (K: Kidney transplant)

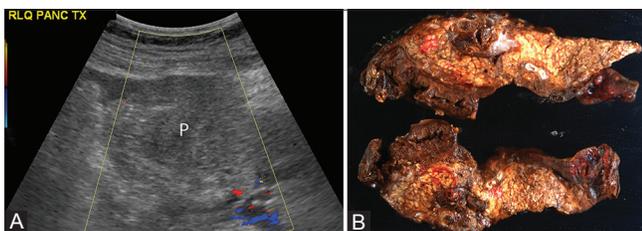


Figure 11 (A and B): Transplant thrombosis and infarction. (A) Transverse US image using color Doppler shows complete lack of flow within the enlarged pancreatic transplant (P) (B) Surgical specimen following pancreatectomy revealed infarction

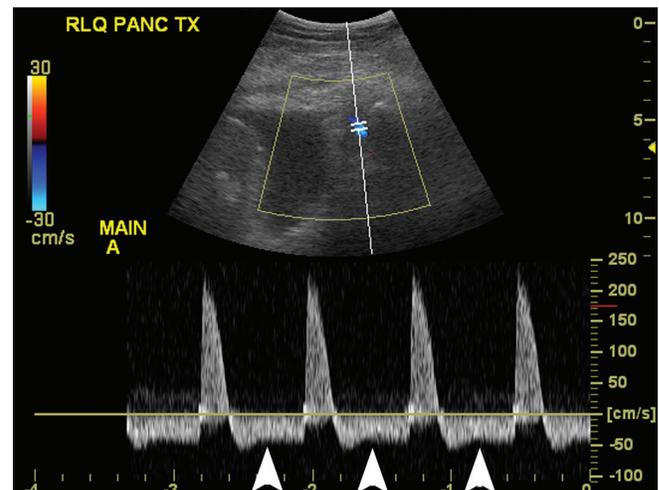


Figure 12: Venous thrombosis. Spectral US of the pancreatic transplant reveals reversal of diastolic flow (arrowheads) in an intrapancreatic artery. No venous waveforms could be identified throughout the transplant

Pseudoaneurysms associated with pancreatic transplants result from damage to the arterial wall and should be considered in the differential diagnosis for any perigraft fluid collection.^[27,35] While most pseudoaneurysms occur at, or near, the arterial anastomosis, they can occur elsewhere secondary to biopsy sites, pancreatitis, and infections.^[27,35] At gray-scale US, pseudoaneurysms appear as anechoic, round, or ovoid structures of variable size. Application of color Doppler reveals internal flow with a typical swirling or “yin-yang” appearance.^[11] When the neck of the pseudoaneurysm is interrogated with spectral Doppler US, the waveform consists of a classic “to-and-fro” pattern characterized by biphasic flow.^[11,36] Post-contrast CT and MRI show a round or ovoid focus of enhancement adjacent to the transplant. Treatment options include percutaneous stent placement or surgical repair.

An additional uncommon vascular complication is formation of an arteriovenous fistula. The fistula typically has an iatrogenic etiology, resulting from previous biopsy or during surgery. There are generally no gray-scale imaging findings, but color Doppler can show a focus of color aliasing at the abnormal connection between an artery and the adjacent vein; the associated waveform is notable for a high-velocity, low-resistance pattern with increased diastolic flow in the artery and pulsatile flow in the draining vein [Figure 13]. Post-contrast CT and MRI may reveal early opacification of the draining vein during arterial phase images.^[32] The majority of small arteriovenous fistulas will spontaneously resolve, while large, hemodynamically significant fistulas may require surgical repair.

The arterial and venous anastomoses should ideally be identified each time the pancreatic transplant is evaluated with US. The most reliable landmark that can be used

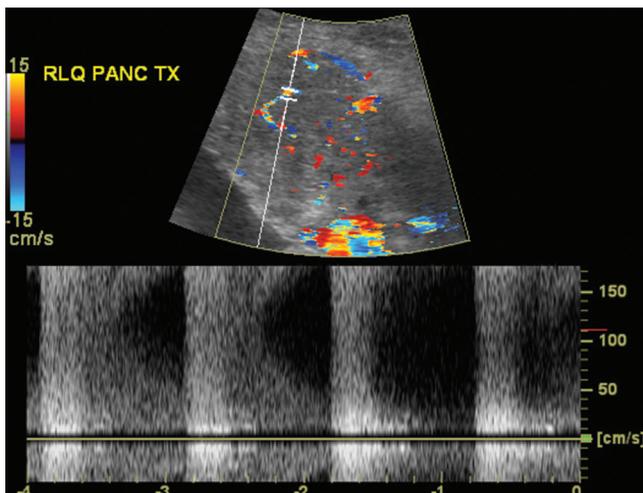


Figure 13: Arteriovenous fistula. Transverse US using color Doppler revealed focal, turbulent flow within pancreatic transplant. Spectral Doppler analysis showed a low-resistance arterial waveform with increased diastolic flow due to a small arteriovenous fistula at a site of prior biopsy

to identify the anastomosis is the patient’s iliac vessels. The anastomoses can then be found as branch points that project laterally. The anastomotic region should be interrogated with color and spectral Doppler analysis. Color interrogation is important initially to show turbulent flow that is identified as a focus of aliasing [Figure 14]. If focal color aliasing is identified, the spectral Doppler box should be placed on that site so that the velocity and waveforms can be studied; elevated velocities and turbulent flow are findings that suggest stricture, but can be transient in the immediate postoperative setting.^[37] The velocities at the anastomoses should be compared to the velocities in the ipsilateral iliac vessels. For an arterial anastomotic stricture to be considered hemodynamically significant, the ratio of the velocities recorded at the anastomosis to iliac artery should be greater than ≥ 2.5 ;^[38] for the venous anastomoses, the ratio should be ≥ 3.5 . While it is not uncommon for arterial anastomotic velocities to be elevated (300-400 cm/s or greater) in the immediate postoperative period, these velocities should normalize over the next 5-7 days as the perianastomotic edema resolves. Persistent velocity gradients after this time are suggestive of stenosis [Figure 15]. Persistently elevated anastomotic velocities should be further investigated by CT angiography or MR angiography to confirm the presence of anastomotic stricture prior to a catheter-based angiogram.

Fluid collections

Postoperative fluid collections are the most common complication affecting pancreatic transplants. Clinically significant fluid collections can be identified by US, CT, or MRI. The development of intra-abdominal fluid collections can be variable, occurring anywhere from the immediate to late postoperative periods. The presence of postoperative fluid collections may herald intra-abdominal infection; however, not all fluid collections are abscesses. One of the most common postoperative fluid collections is a hematoma.

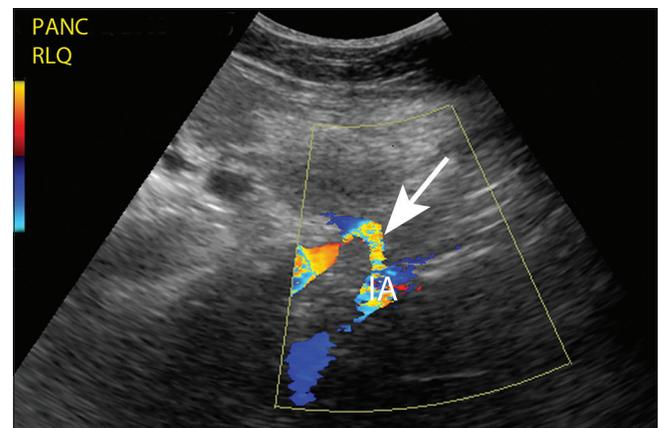


Figure 14: Turbulent flow due to anastomotic edema. Transverse color Doppler US shows aliasing at the arterial anastomosis (arrow). This finding resolved at follow-up US done 2 days later and was attributed to perianastomotic edema (IA: iliac artery)

If imaged within the first few days after surgery, hematomas appear typically well-margined and are shown to be echogenic and devoid of color Doppler flow on US; CT shows the hematoma as a non-enhancing, hyperattenuating collection. In the subacute and chronic phases, hematomas evolve and may develop internal complexity consisting of heterogeneous contents, septations, and fluid hematocrit levels. Eventually hematomas liquefy, becoming more homogeneously hypoechoic and hypoattenuating with US and CT evaluations, respectively. The MRI signal of hematomas varies with the age of the hematoma; when a larger concentration of extracellular methemoglobin is present, there is high intensity signal on both T1- and T2-W images.^[37] The complex internal contents of hematomas can make differentiation from abscess difficult, although the presence of clinical findings of infection facilitates the diagnosis.

Abscesses can occur within any portion of the surgical field due to contamination during surgery or can be associated with anastomotic dehiscence and leakage of enteric contents.^[27,39] Compared to most other types of fluid collections, abscesses are generally more complex: They typically contain internal debris, have thicker, more irregular walls, and are associated with adjacent inflammation or infiltration of the surrounding tissue planes [Figure 16]. Relative hyperemia within the abscess wall manifests as increased color flow on Doppler US and as rim enhancement on contrast-enhanced CT. Gas within a fluid collection is typically readily apparent at CT and appears as echogenic foci with reverberation artifact, also known as “dirty shadowing” on US; the presence of gas within a fluid collection near the pancreatic transplant is suggestive of abscess.^[26]

Abscesses can also arise from infected pseudocysts. However, majority of the pseudocysts are not infected and have a relatively simple imaging characteristic; they appear as well-circumscribed collections with relatively thin walls. In most cases, the pseudocysts are anechoic and show strong through transmission, but occasionally, a small amount of layering debris can be observed as internal low-level echoes. CT or MRI can show a mild degree of adjacent inflammation. Pseudocysts are associated with prior bouts of allograft pancreatitis and may form within the pancreatic transplant or in the perigraft tissues.^[28]

Although a pseudocyst may be suggested based on the clinical context, several other types of postoperative fluid collections are often indistinguishable from them. Pseudocysts, seromas, lymphoceles, and urinomas can all appear as well-margined, anechoic fluid collections [Figure 17]. Due to the lack of specificity of imaging characteristics, percutaneous sampling is needed if definitive diagnosis is required.

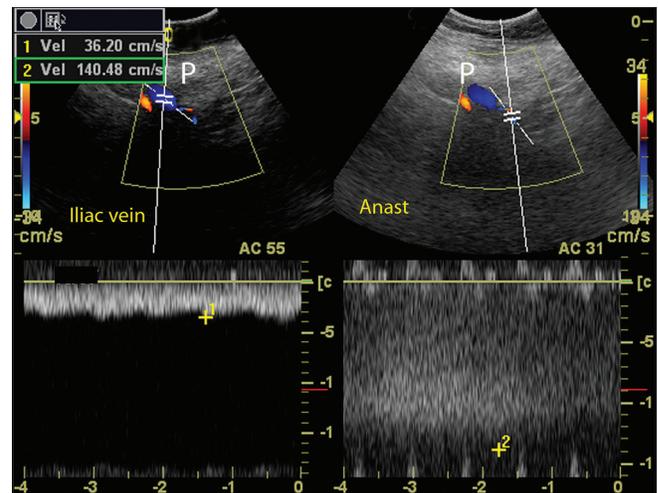


Figure 15: Venous stenosis. Transverse spectral US reveals an approximately four fold velocity gradient between the venous anastomosis and the adjacent iliac vein due to venous stenosis which was treated with angioplasty (not shown)

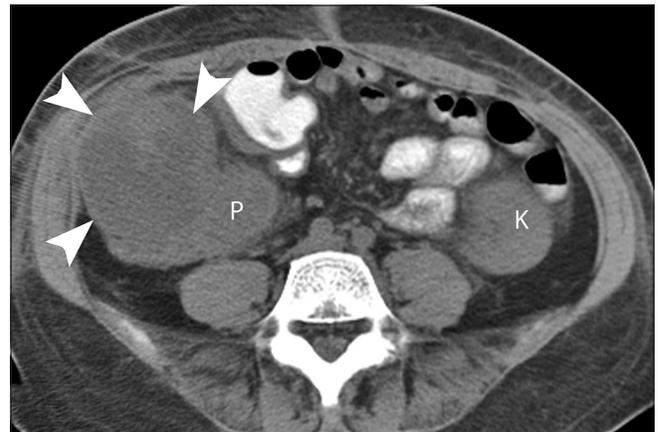


Figure 16: Abscess. Axial CT performed with oral contrast material demonstrates an irregular, thick-walled fluid collection (arrowheads) along the ventral margin of the pancreatic transplant (P). Aspiration and drainage contents were consistent with abscess (K: Kidney transplant)

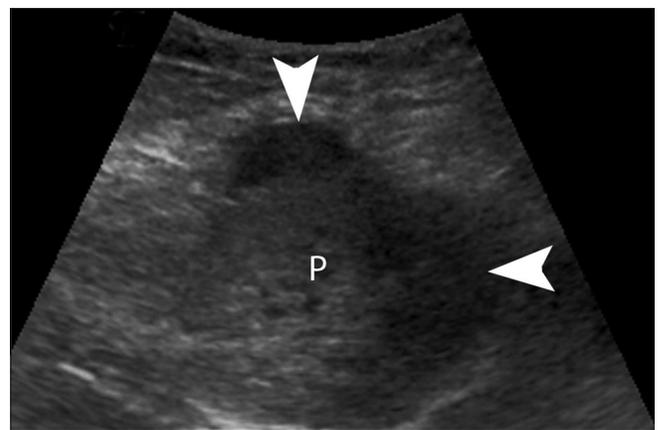


Figure 17: Seroma. Transverse gray-scale US shows an anechoic fluid collection (arrowheads) partially surrounding the pancreatic transplant (P). Aspiration was consistent with seroma

Bowel-related complications

Although most cases of allograft dysfunction are readily assessed by US, bowel complications are better evaluated by CT. As with any bowel surgery, there are risks of anastomotic leak and obstruction. Anastomotic leak is relatively easy to diagnose when ingested oral contrast extravasates from the anastomotic site into the peritoneum [Figure 18]. If oral contrast has not been ingested, CT findings that suggest leak include the presence of new or persistent extraluminal gas or fluid near the anastomosis. In most cases, bowel leaks must be repaired surgically. Common causes of small bowel obstruction include internal hernias and adhesions, which have been reported to occur in 3% and 5% of patients, respectively.^[27]

Allograft dysfunction

Severe pancreatitis affects only approximately 10% of pancreatic transplants and can be confirmed by elevation of the serum amylase level.^[27,40] In mild pancreatitis, the US findings are often normal. With more severe disease, the pancreatic transplant becomes heterogeneous and more hypoechoic due to parenchymal edema [Figure 19]. As edema and inflammation progress, the transplant can develop a more globular appearance with associated loss of the normal mild surface undulation as the acini become blunted; this gray-scale appearance can be indistinguishable from acute rejection. Variable amounts of perigraft fluid may develop. Application of color Doppler reveals a varying degree of parenchymal hyperemia in cases of more advanced pancreatitis. On CT and MRI, perigraft fluid, infiltration of the adjacent fat, and heterogeneous parenchymal enhancement can all be observed [Figure 20]. Management of allograft pancreatitis consists of conservative medical management unless parenchymal necrosis is present. On US, the hallmark of necrosis is lack of arterial and venous flow within segments of the parenchyma or throughout the entire gland; on CT or MRI, there is regional or diffuse lack of parenchymal enhancement. Regions of necrosis may liquefy and lead to intraparenchymal fluid collections. Additionally, necrosis may be complicated by superinfection with development of intraparenchymal gas which manifests as echogenic foci with associated incomplete or "dirty" shadowing. If necessary, follow-up evaluation with non-contrast CT can confirm the presence of intraparenchymal gas.

Rejection of the pancreatic transplant can be acute, subacute, or chronic depending on the timing of onset relative to the transplant operation. Rejection is a common reason for patient morbidity and failure of the allograft; it has been shown that acute and chronic rejection affect approximately 15% and 25% of pancreatic transplants, respectively.^[41] Despite the frequency at which pancreatic allografts are affected, renal transplants are more commonly subjected to bouts of acute rejection. Unfortunately, there are no specific imaging findings of acute rejection in a pancreatic

transplant. The possibility of rejection can be suggested based on changes in the size of the allograft [Figure 21];

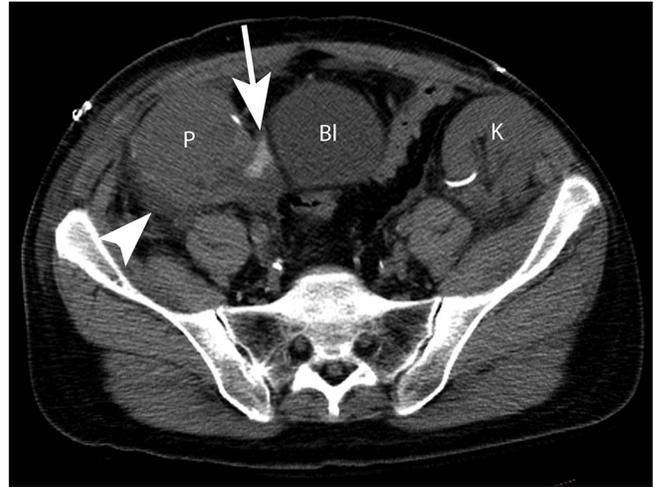


Figure 18: Duodenal cuff leak. Axial CT demonstrates extravasation of ingested oral contrast material (arrow) due to a leak in the duodenal cuff (P: Pancreatic transplant, Bl: Bladder, K: Kidney transplant)

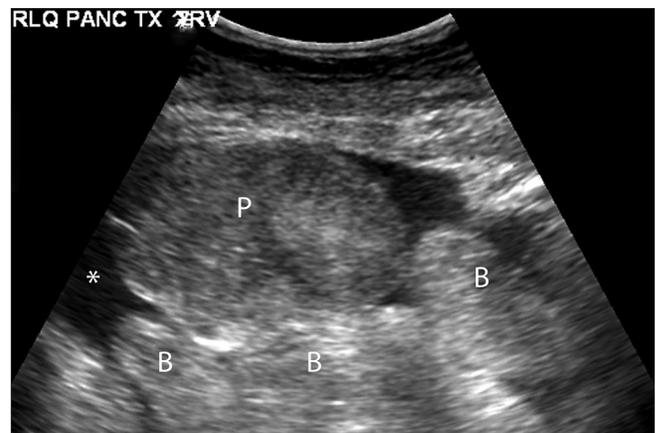


Figure 19: Pancreatitis. Transverse gray-scale US shows an enlarged, edematous pancreatic transplant (P) and adjacent fluid due to pancreatitis. Note that the pancreatic transplant is slightly hypoechoic compared to adjacent fluid filled bowel (B)

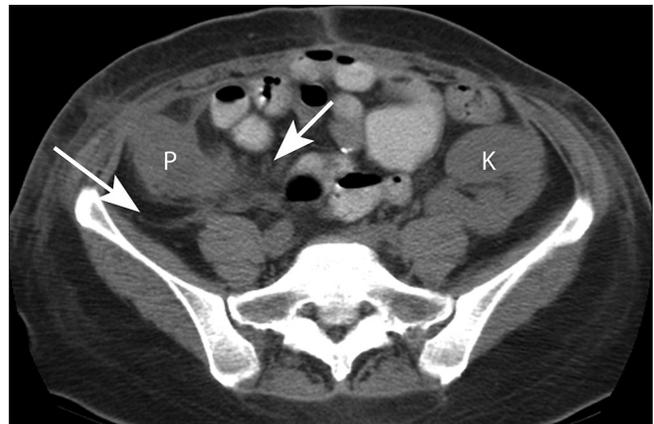


Figure 20: Pancreatitis. Axial CT performed with oral contrast shows inflammation (arrow) in the fat adjacent to the pancreatic transplant (P) due to pancreatitis (K: Kidney transplant)

acute rejection generally results in enlargement due to parenchymal edema while chronic rejection eventually leads to volume loss and atrophy. Although some studies have previously suggested that elevated arterial resistive indices coincided with episodes of acute rejection, others have failed to show a correlation.^[11,29,42] One previous study showed that the resistive index was typically elevated in chronic rejection, but neither the absolute value nor an increase of the resistive index correlated with episodes of acute rejection [Figure 22].^[43] On CT and MRI evaluation, abnormal size, degree of enhancement, and increased T2 signal of the allograft have been associated with rejection, but are also nonspecific.^[26,44] Due to the inaccuracy of imaging and serum biochemical markers, acute rejection is usually suspected by clinical signs and symptoms and confirmed by US-guided biopsy of the pancreatic transplant.^[11,45]

Post-transplant lymphoproliferative disorder (PTLD) is an uncommon complication that has been reported to affect approximately 3-12% of pancreatic transplant patients.^[10,26,46] The onset of PTLD is typically several months to even years after pancreatic transplantation; while the precise etiology has not been fully elucidated, the development is likely related to the interaction of the Epstein-Barr virus and chronic immunosuppression. PTLD can range from a relatively benign polyclonal lymphoid hyperplasia to overt lymphoma.^[47] Imaging findings include lymphadenopathy, potential hepatic masses, and diffuse enlargement of the allograft, a nonspecific finding which can also be found in pancreatitis and acute rejection.^[28,48]

Complications of the lower urinary tract

Complications of the lower urinary tract are rare and generally limited to patients who have an anastomosis between the pancreatic transplant and the urinary bladder. When the lower urinary tract is bathed in pancreatic

exocrine secretions, the urothelial mucosa is repeatedly exposed to chemical irritation and subjected to injury. The chronic irritation can lead to cystitis, urethritis, or balanitis; cystitis results in bladder wall thickening and inflammation during imaging examinations. In males, the urethral mucosa is also subject to chronic inflammation and injury. In severe cases, urethral perforation can occur; perforation most commonly affects the bulbous segment of the anterior segment or the bulbomembranous junction. Urethral perforation is often associated with recent instrumentation and predisposes the patient for future strictures.^[49] The pertinent imaging finding is extravasation of injected contrast material during retrograde urethrography.

Percutaneous interventions for pancreatic transplants

Percutaneous biopsy of the pancreatic transplant can be facilitated by US guidance and has been shown to be a safe and effective means of further evaluating the pancreatic parenchyma when allograft dysfunction is detected clinically.^[45,50] The biopsy procedure is typically performed with an 18-gauge core biopsy needle after Power Doppler analysis has been applied to exclude the intervening vessels [Figure 23]. Power Doppler is also applied after the biopsy to evaluate for complications such as hemorrhage and pseudoaneurysm formation. US-guided percutaneous biopsy yields diagnostic tissue in most cases, having been reported to be as high as 100% in one study.^[51] In addition to its use during biopsy, imaging guidance is often used to allow percutaneous drainage of postoperative fluid collections. Drainage of fluid collections can be performed as either needle aspiration or placement of an indwelling catheter via Seldinger or direct trocar technique. US permits continuous visualization of the needle or catheter as it enters the fluid collection, allowing for optimal positioning and more efficient drainage.

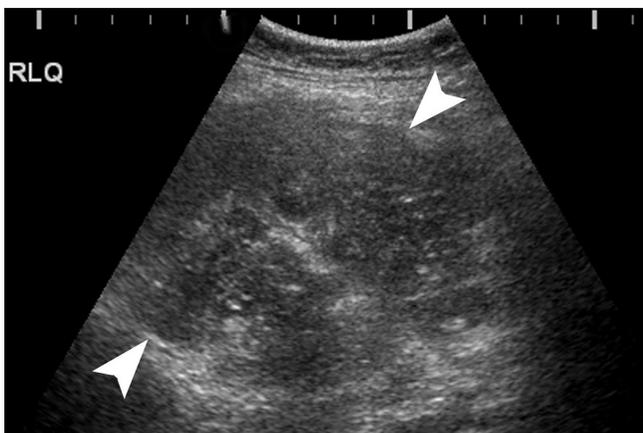


Figure 21: Acute rejection. Transverse gray-scale US shows an enlarged, edematous pancreas (arrowheads) due to an episode of acute rejection

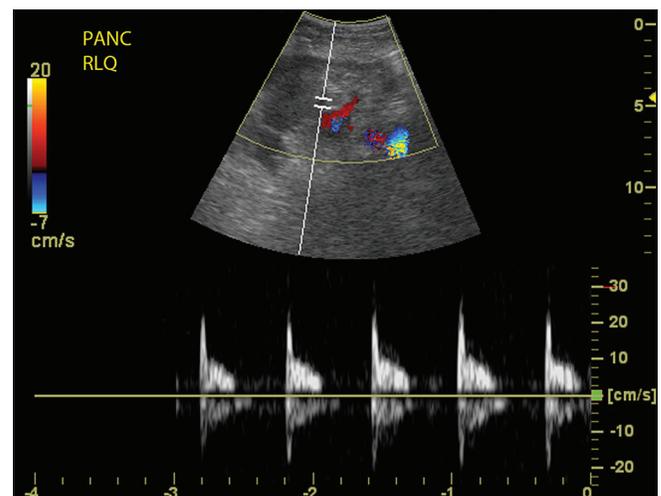


Figure 22: Elevated resistive index. Transverse spectral Doppler US demonstrates a high-resistance arterial waveform where the resistive index is 1 due to lack of diastolic flow. However, the biopsy of the pancreatic transplant showed no findings of rejection or inflammation

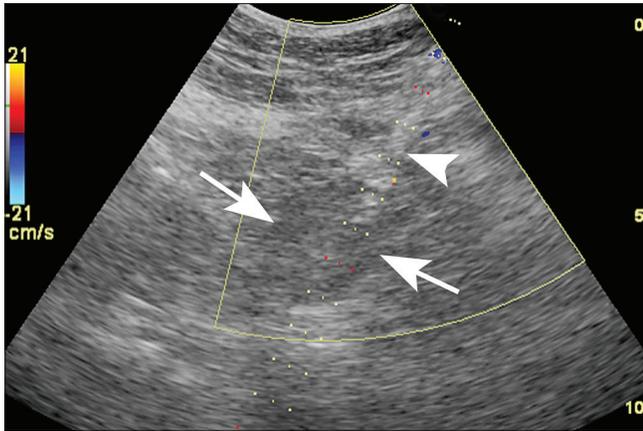


Figure 23: US-guided biopsy. Transverse gray-scale US with color Doppler shows that the percutaneous 18-gauge needle (arrowheads) penetrates the pancreatic transplant (arrow) while avoiding any significant overlying vessels

When extensive bowel gas obscures US identification of the pancreatic transplant, CT can often be used to facilitate the percutaneous intervention. Placing the patient in supine or slightly oblique position generally allows the maximum access to the allograft. If differentiation of the pancreatic transplant from adjacent bowel is still problematic, it is suggested that the patient ingest oral contrast material and return to the CT suite after the contrast has traversed the adjacent bowel.

Conclusion

Pancreatic transplantation is an effective treatment for patients with advanced type I diabetes. Pancreatic transplantation can be performed alone or combined with renal transplantation. In order to provide clinically relevant interpretation of imaging examinations involving the transplanted pancreas, the radiologist should have knowledge of the types of pancreatic transplantation, the typical surgical anatomy of the transplanted pancreas, and the appearance of various associated complications. US is the preferred initial imaging modality to evaluate the pancreatic transplant. US provides an effective, non-invasive method for determining the presence of various complications that can affect the parenchyma, vascular supply, and adjacent tissues. CT is the preferred imaging modality to evaluate potential bowel complications associated with pancreatic transplants. Image guidance also plays a central role in facilitating percutaneous therapeutic intervention.

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