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REVIEW

Small bowel transplant: state-of-the-art vascular and nonvascular imaging

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Abstract

Background Small bowel transplant (SBT) is a surgical procedure that may be used in patients with pathology resulting in severe intestinal failure resistant to conventional forms of surgical and nonsurgical treatment. Intestinal failure is defined as the failure of enterocytes to absorb sufficient macronutrients, water, and/or electrolytes to sustain homeostasis and/or promote growth. With the advancement of surgical techniques and advancements in perioperative transplant management, SBT has become an increasingly common treatment for intestinal failure, with survival rates for SBT comparable to those for other solid organ transplants.

Materials and methods This review provides background on SBT, its variations, and the associated preoperative and postoperative imaging studies with regard to surgical planning and anticipated complications.

Results and conclusions With the increasing use of SBT, radiologists will be expected to be familiar with the diagnostic studies and available endovascular interventions associated with this procedure.

Keywords Small bowel transplant · Intestinal failure · Perioperative imaging

Introduction

Small bowel transplant (SBT) is considered as a treatment option for patients with intestinal failure that can no longer be treated with intravenous supplementation via parenteral nutrition (PN) [1]. Intestinal failure can range from acute to chronic and is defined as the failure of enterocytes to absorb sufficient macronutrients, water, and/or electrolytes to sustain homeostasis and/or promote growth [2–4]. A variety of conditions can cause intestinal failure in children and adults. In the pediatric population, intestinal failure is most commonly the result of short bowel syndrome secondary to congenital etiologies such as gastroschisis or atresia or acquired conditions such as necrotizing enterocolitis, volvulus, or trauma [3, 5, 6]. Less common causes of intestinal failure in the pediatric population include motility disorders, malabsorption, and neoplastic processes [6]. In the adult population, intestinal failure is also most commonly a result of short bowel syndrome secondary to etiologies such as ischemia, infectious/inflammatory processes such as Crohn's disease and radiation-induced enteritis, trauma, or volvulus, but can also be the result of motility disorders or neoplastic disease such as desmoid tumor [3, 5–7]. More recently, bariatric surgery–associated intestinal failure has been recognized as another rare cause of intestinal failure [8].

Regardless of the cause of intestinal failure, PN is almost always the first-line treatment, but PN does come with its own complications such as intestinal failure–associated liver disease (IFALD), central line infections/sepsis, and central vein thrombosis [1, 2, 9]. IFALD is a less well-known, but important entity with a multifactorial pathogenesis. Liver disease in IFALD stems from alterations to the gut-liver axis secondary to total abstinence from oral intake; total parenteral nutrition; and systemic alterations in bile acid circulation, the gut microbiome, intestinal permeability, and

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hormonal alterations [10]. Development of these complications or failure of PN to adequately treat intestinal failure should prompt referral of the patient to a transplant center for consideration of SBT.

Early referral to a transplant center is of utmost importance to optimize outcomes [11]; SBT should be considered as a treatment option once the patient develops clinical signs and symptoms of refractory intestinal failure [4, 12–14]. Patients with intestinal failure should be assessed for SBT candidacy in the settings of PN failure, including patients with impending or progressive liver failure, frequent episodes of severe dehydration, failure to thrive, high-risk of death from underlying disease (eg, invasive intra-abdominal desmoid tumor, congenital mucosal disorder, ultra short bowel syndrome), and high-risk coexistent morbidities [1, 15]. Indications to proceed with SBT include (1) IFALD-related liver failure, (2) loss of two or more central venous access points, and (3) locally aggressive intra-abdominal desmoid tumor necessitating exenteration [1]. Contraindications for intestinal transplant include incurable malignancy, significant cardiopulmonary insufficiency, persistent life-threatening intraabdominal or systemic infection, and severe immune deficiency syndrome without capacity for successful pretransplant stem cell transplant [7]. Relative contraindications include a history of prior gut malignancy, advanced age, and lack of social support [7]. In these cases, consideration for SBT should be made on a case-by-case basis [7].

Once a patient is considered a transplant candidate, they are listed for transplant via the United Network of Organ Sharing (UNOS) transplant lists [16]. If only an intestinal transplant is needed, the patient is placed on the intestinal transplant list with the most recent median wait time from 2016 to 2017 being 4.7 months in the adult population [17]. However, in instances where the liver is also needed, the patient is placed on both the intestinal and liver transplant lists with a median wait time of 5.2 months [16, 17]. This increased wait time is attributable to liver allocation as patients who are allocated a liver will also be allocated an intestinal transplant according to their liver transplant status, but will not be allocated a liver based on their intestinal transplant status [16]. This is reflected in pretransplant waitlist mortality. From the most recent data evaluated from 2016 to 2017, waitlist mortality was 7.9/100 waitlist-years for all-comers listed for intestinal transplant (including those listed for liver and intestinal transplant) versus 1.9/100 waitlist-years for patients listed for intestinal transplant only [17]. The match process is similar to that for liver and other visceral organ transplants. Potential donors are screened by ABO blood type and size. Additionally, donors are screened for cytomegalovirus (CMV) positivity with an effort to avoid matching CMV positive donors to CMV negative recipients given the risk of CMV enteritis posttransplant [16]. Survival rates for SBT are now comparable to those for other solid organ transplant surgeries. Most recent data show one and five year graft survival rates of 72.0% and 43.5%, respectively for all adults receiving intestinal transplant with or without a liver and 74.5% and 46.5%, respectively, for all adults receiving an intestine-only transplant [17]. Intestinal transplant is thus becoming an increasingly established treatment option for intestinal failure with which the radiologic community should be familiar.

Preoperative imaging

Once a patient is determined to be a candidate for SBT, thorough preoperative assessment and workup are necessary to determine the extent of intestinal failure and the type of SBT needed and to identify possible contraindications, such as occult malignancy [7, 18]. Much of this workup involves biochemical, endoscopic, and histologic testing, as well as extensive imaging assessment. Different combinations of imaging modalities may be selected based on patient history, underlying diagnoses, and institutional preferences.

Assessment of anatomy and function

Preoperative imaging can aid in the initial assessment of native anatomy for surgical planning [6, 18]. The most essential imaging modality in this preoperative assessment is multiphase CT with administration of contrast if possible. CT studies of the chest, abdomen, and pelvis (including non-contrast, arterial phase, and portal venous phase) are standard in all cases of preoperative assessment for detection of occult malignancy or metastatic disease that may preclude transplant as well as for broad assessment of visceral and vascular anatomy, which aids in directing additional targeted imaging studies [18, 19]. Inclusion of multiple phases is most valuable in assessing the liver and pancreas for occult lesions, which can be more thoroughly characterized on multiphase contrast-enhanced CT with inclusion of a noncontrast study as a helpful comparison when inherently high-attenuating components are present. Depending on the etiology of intestinal failure, patients may have undergone previous surgical procedures resulting in limited remaining native intra-abdominal organs that should be characterized preoperatively, as this condition may determine the type of SBT pursued as well as the reconstructive surgical approach (Fig. 1) [7]. For example, assessing the volume and texture of the liver can aid in identifying findings consistent with cirrhosis, steatosis, or portal hypertension, which may affect the type of transplant selected. In cases of questionable liver cirrhosis or fibrosis, transjugular liver biopsy can be performed to assess for portal hypertension via the indirect portosystemic gradient (difference between free and wedge hepatic pressures) and to assess for severity of cirrhosis via histopathology [6]. The anatomy and functionality of the hindgut are also of particular importance in surgical planning to assess for potential future

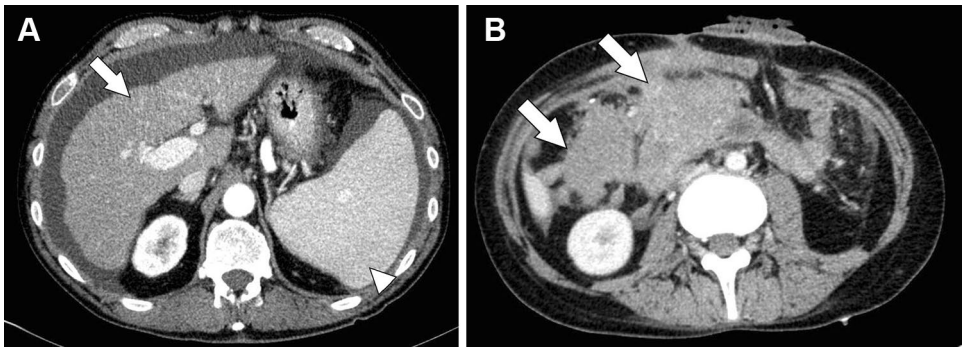

Fig. 1 Value of preoperative CT. Image from axial contrast-enhanced CT through the upper abdomen in a patient with Crohn's disease resulting in short bowel syndrome demonstrates nodular hepatic surface contour (arrow) and splenomegaly (arrowhead; craniocaudal dimension measuring 15 cm), indicative of cirrhosis and portal hypertension (**a**). Given these findings, the patient was triaged to liver-intestinal transplant (LIT) rather than isolated intestinal transplant (IIT). Image from axial contrast-enhanced CT through the mid abdomen in a patient with Gardner's syndrome and short bowel syndrome demonstrates several bulky intra-abdominal desmoid tumors (arrows) (**b**). This preoperative localization helps to facilitate optimal debulking in order to better accommodate placement of the intestinal graft

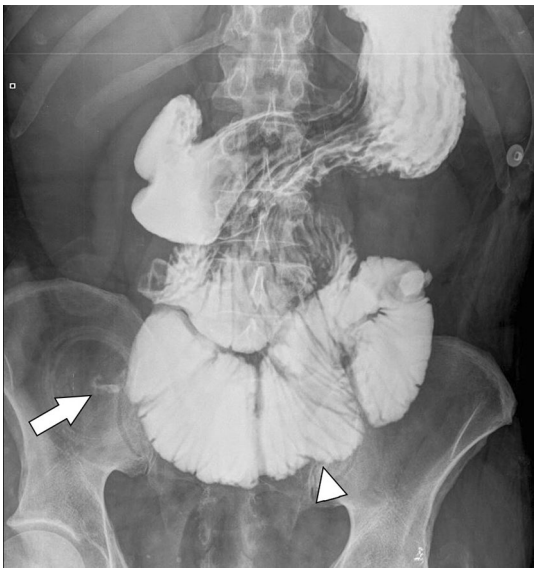

Fig. 2 Frontal radiograph from small bowel follow-through demonstrates ultrashort small bowel length after multiple bowel resections for Crohn's disease. Only a short segment of proximal jejunum remains in place (arrowhead), approximately 20–30 cm in length. Note the jejunostomy in the right abdomen (arrow)

reconstruction options and reversal of ileostomy, which may dictate which sections of bowel are included and which types of visceral anastomoses are made [7].

Fluoroscopy is another essential imaging modality in the preoperative assessment of anatomy and function. Upper gastrointestinal studies with or without small bowel follow-through and contrast enemas can aid in assessing motility and structure [6]. For cases in which the recipient has remnant native small bowel, both the length and, to a degree, the functional state can be evaluated via fluoroscopy (Fig. 2) [6]. Scintigraphic gastric emptying studies are of particular use in planned multivisceral intestinal transplants, as delayed emptying can be an indication for inclusion of the stomach in the transplant [20]. Enteric and enterocutaneous fistulization may also be identified using fluoroscopy, and follow-up imaging with fistulography can be performed to further characterize the fistulous connections [20]. Given the typical severity of gastrointestinal dysfunction and dysmotility in this patient population, water-soluble contrast agents are preferred [6].

Assessment of vasculature

Describing the course and condition of native vasculature is essential for preoperative planning and delineation of potential future vascular access points and anastomotic sites [6, 18]. For example, in any patient with a history of central vein thrombosis, preoperative central venous angiography is mandatory to determine a reliable intraoperative access plan [7]. Venous phase imaging is helpful to determine the patency of the bilateral jugular and femoral veins as well as the central venous system (Fig. 3). Additionally, in patients with known or suspected portomesenteric venous thrombosis, CT angiography or conventional catheter angiography of the mesenteric vasculature and inferior vena cava (IVC) is indicated to determine the extent of thrombosis (and thereby determine the type of SBT necessary) and to identify vascular reconstruction approaches [6, 7]. For cases in which liver transplant is being considered, angiography of the hepatic venous system can be used to identify drainage patterns preoperatively [6]. Lastly, MR angiography and venography can be used to map the native arterial and venous anatomy in each individual SBT candidate [20].

Surgical candidacy or intraoperative approach may be affected when severe atherosclerotic disease or certain

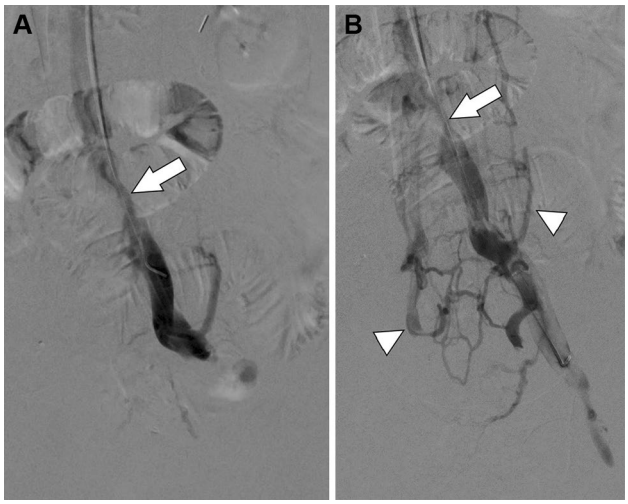

Fig. 3 Preoperative planning venogram performed in a patient undergoing workup for IIT demonstrates left common iliac vein stenosis (arrows in **a, b**) with numerous collateral vessels in left pelvis (arrowheads in **b**)

anatomic variants are present. Diffuse atherosclerosis may limit options for vascular anastomoses and may influence operative planning [19], and severe atherosclerosis or calcification of the aorta may preclude intraoperative aortic cross-clamping or may preclude the surgery entirely [20]. Anatomic anomalies may also contraindicate surgery (eg, in cases of aortic valve stenosis) or may affect intraoperative vascular reconstruction (eg, in cases of a replaced right hepatic artery arising from the superior mesenteric artery [SMA]) [6].

In all cases, the contrast agent used in imaging studies must be chosen wisely. This patient population in general has advanced disease and other comorbidities including possible chronic kidney disease, which may limit the amount or type of iodinated contrast used. In such cases, ultrasound imaging with Doppler may be sufficient or supplemental in assessing the vasculature, particularly the venous access sites [6]. Contrast-enhanced ultrasound is a newer technique that uses microbubbles as a contrast agent. These microbubbles are not nephrotoxic [21] and are secreted via the respiratory tract [22]. This technique has been used to assess the arterial and venous vasculature [23]. Contrast-enhanced MRI is also a valuable technique for patients who cannot receive iodinated contrast material for CT, such as those with a significant allergy history. In addition, the American College of Radiology now advocates for the use of novel gadolinium contrast agents (class II agents) in patients with renal disease, such as those with acute kidney injury or chronic kidney disease, including patients with severe and end-stage chronic kidney disease [24]. Although older gadolinium chelates have been associated with the development of nephrogenic systemic fibrosis in patients with underlying renal disease, these newer group II agents have few (if any) documented cases of nephrogenic systemic fibrosis associated with their use. As such, group II agents are now clearly preferred in patients with potential renal dysfunction, with many centers now moving away from screening for renal dysfunction altogether in patients receiving group II agents. As such, contrast-enhanced MRI may be an excellent alternative technique for evaluating both visceral and vascular structures in potential transplant patients. Finally, if neither of these techniques is sufficient, conventional catheter venography using carbon dioxide can be considered. Although this modality provides lower resolution, it carries no significant risk of nephrotoxicity [6].

Assessment of abdominal wall and cavity

It is essential to assess the volume of the abdominal cavity and the condition of the abdominal wall to determine whether the transplant can be accommodated. Many patients with intestinal failure develop scaphoid abdomen secondary to intra-abdominal fat losses from malnutrition; patients may also have undergone multiple abdominal surgeries resulting in adhesions, fibrosis, and overall decreased compliance of the abdominal wall that may prevent adequate surgical closure [19]. If there is extension of desmoid tumors into the abdominal wall, these should be excised before transplant. For cases in which transplant is nonurgent, attempts to re-expand the abdominal cavity via tissue expanders and plastic surgery interventions can be considered [19]. If closure is not possible at the time of surgery, temporizing measures such as synthetic coverings and/or staged closure can be employed, or abdominal wall transplant can be performed [25–27].

Surgical anatomy

Overview

Three main variations of SBT exist, including isolated intestinal transplant (IIT), liver-intestinal transplant (LIT), and multivisceral intestinal transplant (MIT) (Fig. 4). The surgical approach in each case is somewhat similar, in that the majority of the native small bowel and colon are removed and replaced with donor viscera connected, via anastomoses, to the remaining native viscera. There are few variations in visceral anastomoses, but depending on the particular donor and native anatomy encountered, side-to-side, side-to-end, or end-to-end anastomoses may be used (Fig. 5a–c) [7]. Proximal anastomosis generally connects two small bowel segments, whereas distal anastomosis typically connects donor ileum to residual native colon or rectum depending on the preoperative imaging results and planning [7]. In all variations, the surgical

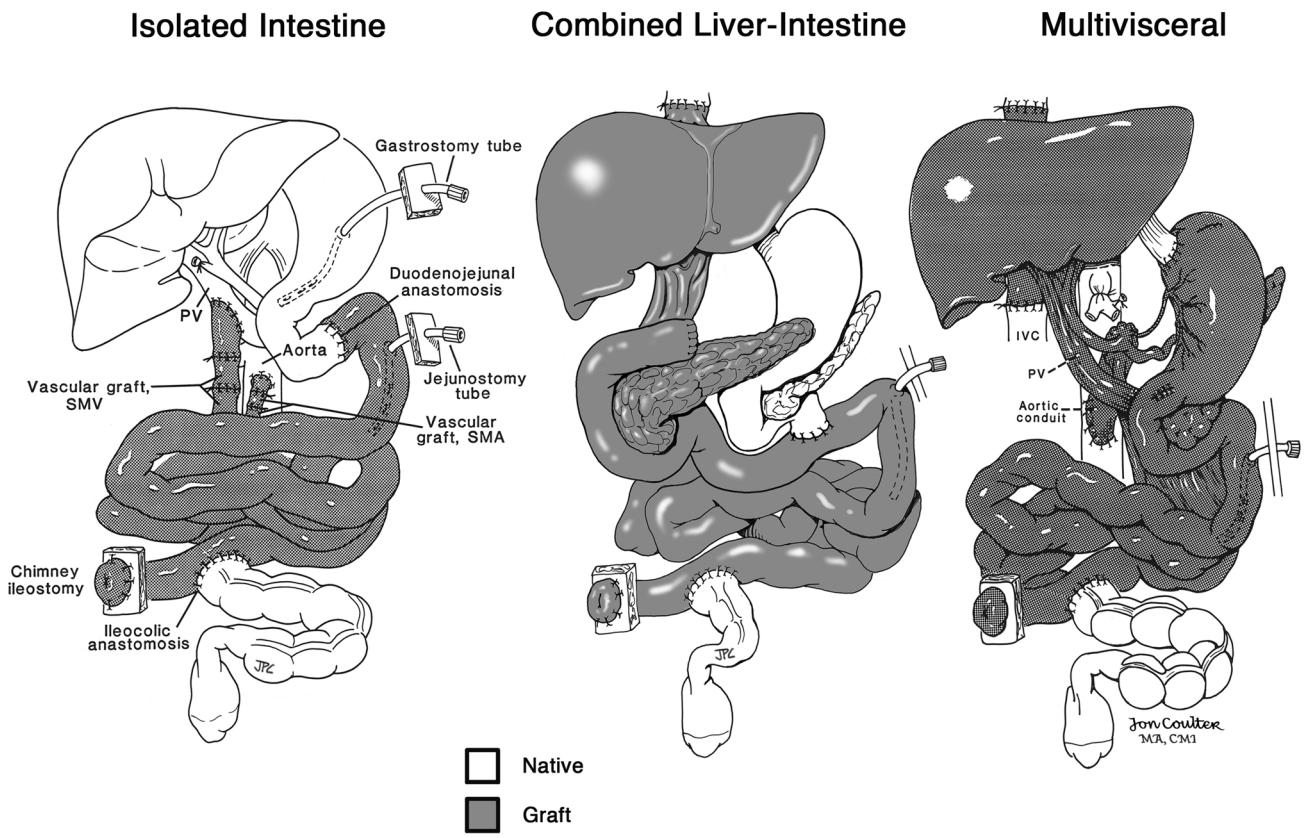

Fig. 4 Surgical anatomy of intestinal transplant types including IIT, LIT, and MIT

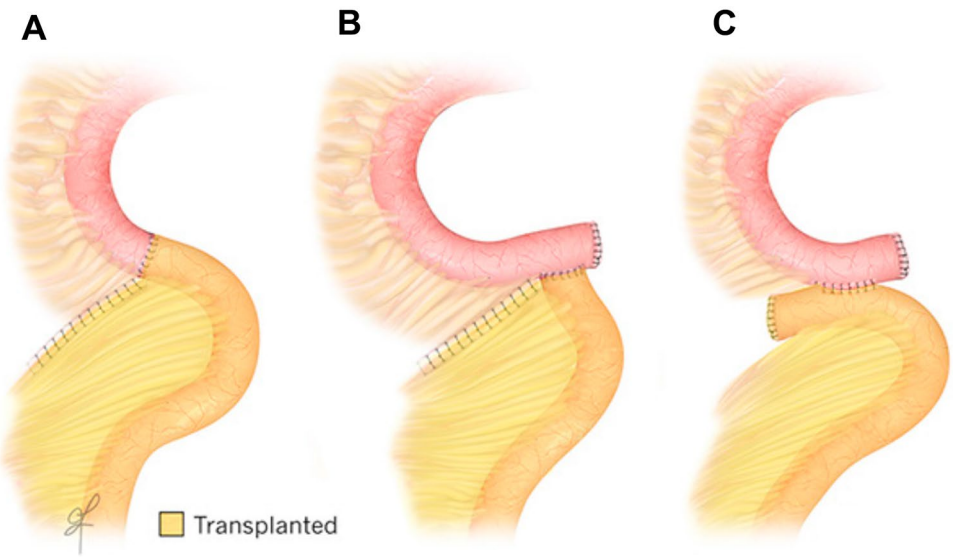

Fig. 5 Intestinal reconstruction of proximal allograft small bowel and retained native small bowel in end-to-end (**a**) end-to-side (**b**), and side-to-side (**c**)

anatomy will include a distal loop or chimney ileostomy of the donor ileum that provides endoscopic access for mucosal biopsies for rejection surveillance, as well as a percutaneous enteric tube that serves to decompress the bowel and aid in gut rehabilitation [7, 19]. Additionally, an interposition graft created from native colon may be used proximally to reduce the number of required donor organs (eg, if donor duodenum is not available or not viable), or donor colon may be transplanted en-bloc for future reversal of end-ileostomy (Fig. 6) [7].

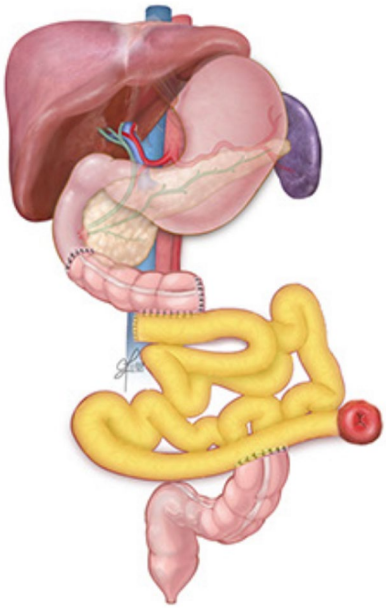

Fig. 6 Reconstruction with an interposition graft of native colon with a chimney ileostomy

On the other hand, there is a much larger range of vascular anastomoses that can be used to reconstruct arterial supply and venous return [7, 28], the most common of which are described below.

Isolated intestinal transplant

Organs included in IIT are donor jejunum and ileum with or without a segment of donor colon and/or pancreas [6]. IIT is the preferred technique in cases of intestinal failure in the absence of moderate to severe liver disease. This type of SBT is performed in approximately 50% of all cases of SBT, making it the most common variation [12]. IIT is more frequently performed in adults than in children, as IFALD is more common in the pediatric population, requiring transplant of the liver, as well [19, 29].

In IIT, the donor viscera are placed orthotopically. Proximally, a side-to-side anastomosis is made between the native duodenum and donor jejunum; distally, a side-to-end anastomosis is made between the donor ileum and native colon [6, 19, 28]. The distal donor ileum is brought through the abdominal wall to create either an end or loop ileostomy [7, 19].

There is considerable variation in vascular anastomoses used in IIT. Arterial inflow is often achieved via anastomosis of the native infrarenal abdominal aorta to the donor SMA with or without an interposition graft (Fig. 7a) [6, 28]. Alternatively, a native iliac artery, native SMA, or other section of native abdominal aorta may be anastomosed to the donor SMA to achieve arterial inflow [19, 28]. Venous drainage is typically achieved via an anastomosis between the donor superior mesenteric vein (SMV) and native portal vein; however, the donor SMV may also be anastomosed to the native IVC, left renal vein, SMV, splenic vein, or portal vein [6, 19, 28]. In cases of preserved liver function, portomesenteric anastomosis is preferred, whereas in cases of

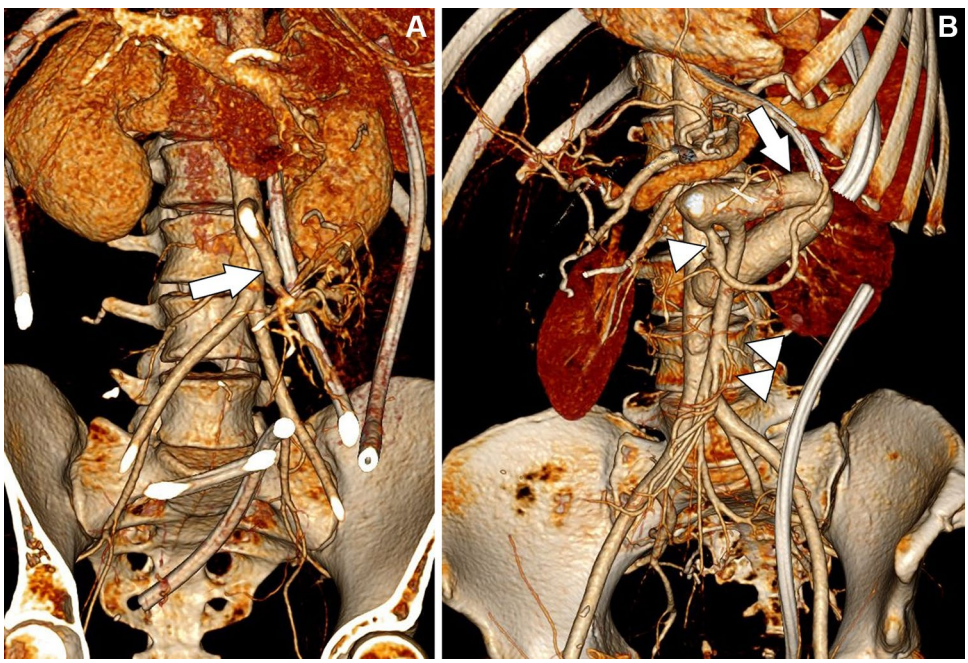

Fig. 7 Volume-rendered image from CTA in a patient who underwent IIT demonstrates a short segment arterial interposition graft originating from the infrarenal abdominal aorta (arrow) with downstream anastomosis to donor SMV (**a**). Volume-rendered image from CTA in a patient who underwent MIT demonstrates a large arterial conduit originating from the infrarenal abdominal aorta with associated Carrel patch (**b**). This gives rise to discrete large donor arteries, including donor celiac axis (arrowhead) and donor SMA (double arrowheads)

mild liver disease, systemic anastomosis can be considered to decrease the portal pressure, although this carries a higher risk of postoperative encephalopathy [20].

Liver and intestinal transplant

Organs included in LIT are donor liver and small bowel with or without donor colon and/or kidney [6, 19]. Liver and intestinal transplant is the preferred procedure for patients with intestinal failure and moderate to severe liver disease. This variation of SBT is more common in the pediatric population, as children are more likely to develop IFALD secondary to prolonged treatment with PN [19, 29].

In early LIT procedures, donor liver and small bowel were transplanted separately. Reconstruction of the pancreaticobiliary system with the small bowel was achieved via a Roux-en-Y choledochojejunostomy between the donor biliary system and the donor jejunum after completion of the liver and small bowel transplants [6, 30]. This technique resulted in various complications stemming from the reconstructed biliary connections, so the surgical approach was modified to use an en-bloc transplant of the donor liver, common bile duct, duodenum, and partial pancreas without removal of the native duodenum or pancreas [20, 29]. However, with the inclusion of only the proximal portion of the donor pancreas, complications such as pancreatic leak and fistulization were common [31]. Further developments led to inclusion of the entire donor pancreas without removal of native pancreas or native duodenum [31]. Postoperative anatomy therefore includes redundant duodenum and pancreas.

The proximal visceral anastomosis is a side-to-side anastomosis of native duodenum and donor jejunum. Distally, a side-to-end anastomosis of donor ileum and native sigmoid colon is achieved, with the remaining end of the ileum used for construction of the end or loop ileostomy [3, 6, 19].

As with IIT, the vascular anastomoses in LIT vary depending on the encountered anatomy. Typically, using a segment of the donor aorta with the SMA and celiac branches (Carrel patch) is preferred for arterial anastomosis to the native infrarenal abdominal aorta. Alternatively, the donor celiac trunk and SMA can be separately anastomosed to the native infrarenal abdominal aorta or iliac artery with or without the use of interposition graft(s) [19, 28]. Venous outflow typically involves a piggyback anastomosis between the donor IVC with the confluence of hepatic veins and the native IVC [6, 19, 20]. Alternatively, a side-to-side cavocavostomy of the donor and native IVCs can be performed. Additionally, end-to-end anastomoses can be constructed between donor and native suprahepatic and infrahepatic IVC sections, with removal and replacement of the intervening segment [19].

Multivisceral intestinal transplant

The indication for MIT is small bowel failure in the presence of irreversible liver disease and/or vascular disease that precludes other transplant options (eg, extensive or diffuse portomesenteric thrombosis, massive polyposis) [19, 20, 32]. Additionally, MIT is used when desmoid tumor burden necessitates exenteration [19, 20]. In these cases, extensive desmoid tumor burden has been associated with an increased risk of mortality if intestinal transplant is not pursued. Multiple variations of MIT exist. By definition, MIT includes duodenum, pancreas, liver, and small bowel, but the transplant may also include stomach, spleen, colon, and/or kidney(s) (Fig. 8a, b) [7, 12, 28, 33]. Inclusion of the spleen should be mentioned, as previous research suggested an increased risk of graft-versus-host disease (GVHD) with this procedure; however, more recent studies have found no association between inclusion of the spleen and GVHD [33–35]. Further studies are needed to confirm this finding, as inclusion of the spleen is known to impart the benefit of decreased infection rate and decreased risk of post-transplant lymphoproliferative disease (PTLD) [33, 35]. The other organs are included on a case-by-case basis depending on the needs of the individual patient and the underlying pathology.

Regardless of the type of MIT performed, the pancreaticoduodenal complex is preserved, so visceral anastomoses include an end-to-end anastomosis of the native distal esophagus or proximal stomach to the donor stomach as well as an end-to-side anastomosis of the native colon to the donor ileum [6, 19]. The donor ileum is typically used to create an end or loop ileostomy [7].

In MIT that includes the liver, vascular anastomoses are generally similar to those made in LIT. Arterial inflow is again achieved via donor Carrel patch to native infrarenal abdominal aorta and venous outflow is achieved via donor IVC grafted to native IVC via a piggyback anastomotic approach (Fig. 7b) [19, 28]. The alternative vascular anastomoses are the same as those described for LIT. However, in MIT, the venous outflow from any remaining segments of the native stomach, duodenum, pancreas, and spleen must be ascertained to avoid organ ischemia. The typical approach is to anastomose the native portal vein remnant to the native IVC or to the donor portal venous system [28].

Modified MIT

Modified MIT involves transplant of the same organs as those transplanted in MIT with the exception of the liver (Figs. 8c, d). This is the preferred procedure for patients with small bowel failure and decreased gastric function but with preserved liver function [19]. Again, the donor spleen may or may not be included and this is determined on a case-by-case basis.

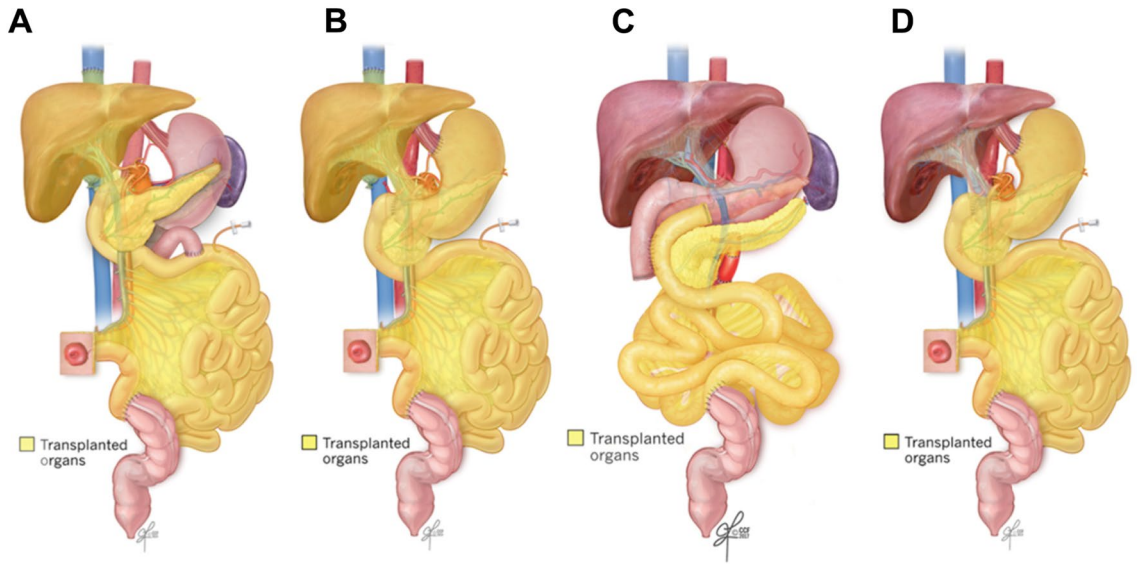

Fig. 8 MIT surgical anatomy without (**a**) and with (**b**) includion of the stomach. Modified MIT surgical anatomy without (**c**) and with (**d**) inclusion of the stomach

Visceral anastomoses are similar to those used in traditional MIT. Proximally, end-to-end anastomosis of the native distal esophagus or proximal stomach to the donor stomach is created. In addition, a side-to-side duodenoduodenostomy is formed to preserve pancreaticobiliary secretions from the native pancreas and liver, as the donor liver and biliary tree are not transplanted in modified MIT [19, 28]. Distally, donor ileum and native colon/rectum are anastomosed with creation of an end or loop ileostomy [7, 28].

Arterial reconstruction is again achieved via the use of a Carrel patch anastomosed to the native infrarenal abdominal aorta, and venous outflow is reconstructed via donor SMV to native portal vein [28]. As in IIT, the donor portomesenteric system is ideally connected to the native portomesenteric system, but when this is not achievable, anastomosis to the native systemic system via the IVC is an acceptable alternative [28].

Postoperative imaging

Modalities

CT and fluoroscopic studies are the most commonly used imaging modalities in the postoperative period [6, 20, 36]. Both modalities are essential for assessing transplant integrity, structure, and function. Contrast-enhanced CT of the abdomen and pelvis with arterial and venous phases provides a comprehensive assessment of the resulting anatomy, with particular attention to anastomotic integrity of both the viscera and the vasculature. CT is also valuable in cases of suspected intra-abdominal infection or fluid collections. Not only does CT provide diagnostic value, but it can also be used to guide aspiration and drainage procedures and/or biopsy [37]. Fluoroscopy can also be used to identify anastomotic leaks and to assess for return of gut motility in the allograft in the early postoperative period [6, 20]. In the later postoperative period, suspected ileus or obstruction can be screened for with abdominal radiography, but CT will usually be needed for further assessment [6].

MRI is another valuable modality to consider in patients with pancreaticobiliary derangements and in patients who cannot receive intravenous iodinated contrast agents [6]. For example, MR cholangiopancreatography (MRCP) is of particular utility in assessing the pancreaticobiliary system and is the preferred noninvasive imaging modality [38, 39]. Contrast-enhanced MRI can be performed in lieu of contrast-enhanced CT, including in patients with significant iodinated contrast allergy. If a patient cannot receive gadolinium contrast due to allergy, there remain several robust noncontrast MR angiography techniques that can be used to evaluate the major vessels and vascular anastomoses [6, 20].

Lastly, ultrasound imaging is particularly useful as a screening tool and is an excellent modality to assess for complications in the biliary tree, liver, and vasculature [38, 40]. However, when concerning findings are encountered on ultrasound examinations or when there is discordance between imaging finings and the patient's clinical condition, follow-up cross-sectional imaging is usually indicated.

Normal postoperative findings

Familiarity with normal postoperative imaging appearance is imperative to enable the radiologist to identify abnormal findings. Given the variability and immensity of anatomic reconstruction in SBT, the innervation, vascular supply, and lymph drainage of the allograft will inevitably be altered. This results in mild dilation of bowel caliber, mild bowel wall thickening, mild mesenteric lymph node enlargement, and small-volume mesenteric edema (Fig. 9a) [6, 36, 41]. Mild pneumatosis is also to be expected in the immediate postoperative period and should not raise concern unless the patient is symptomatic [6]. In cases of inclusion of the liver in the transplant, a mild degree of biliary ductal dilation can be seen; this is more commonly associated with biliary-enteric anastomoses [6]. Lastly, it is not uncommon to note small hematomas and seromas in the early preoperative period. These are generally self-limited and do not require intervention unless there is suspicion for superinfection.

Complications

The most commonly encountered complications of SBT include rejection (acute and chronic), infection (most commonly bacterial), and vascular compromise (hemorrhage, thrombosis, and pseudoaneurysm) [42]. Less commonly, gastrointestinal complications such as anastomotic leak, delayed gastric emptying, and pancreatitis or hematological complications such as PTLD, GVHD, and thrombotic microangiopathies can occur.

Rejection

Graft rejection is surveilled via routine endoscopy and biopsy of the donor small bowel through the donor ileostomy. Acute cellular rejection is the leading cause of rejection in the first 90 days postoperatively, as well as the leading cause of graft loss and patient mortality [14, 43]. In recent years, the prevalence of acute rejection has decreased with the advent of improved immunosuppressive regimens [3, 14, 43]. Typically, rejection is diagnosed via pathological examination of serial biopsies of the gastrointestinal mucosa, with imaging playing only a supportive role in diagnosis. Contrast-enhanced CT or MR findings of rejection are nonspecific and can include hyperenhancement and wall thickening of the small bowel as well as moderate ascites. Of note, similar findings may also be seen in cases of infectious enteritis. Hence, the clinical context should be considered.

Chronic rejection causes hyperplasia of the mucosa and subsequently results in narrowing of the intestinal lumen and chronic ischemic injury to the mucosa, which results in fibrotic changes and development of stenosis [6, 40, 42]. Such changes may not be easily detectible on cross-sectional imaging, again making histopathologic examination of a full-thickness tissue biopsy the gold standard for diagnosis in cases of chronic rejection [20].

Infection

Infection is a common complication in all SBT procedures, given the complexity of the surgery and the need for immunosuppression. Interestingly, both excessive immunosuppression and insufficient immunosuppression can cause infection [44]. Pathophysiologically, insufficient immunosuppression increases the risk of developing acute rejection, which leads to mucosal damage and subsequently increases the incidence of bacteremia and hematogenous spread of infection [44]. The most common infection sites associated with SBT are intra-abdominal, central venous catheter sites, the respiratory tract, the surgical wound, and the urinary

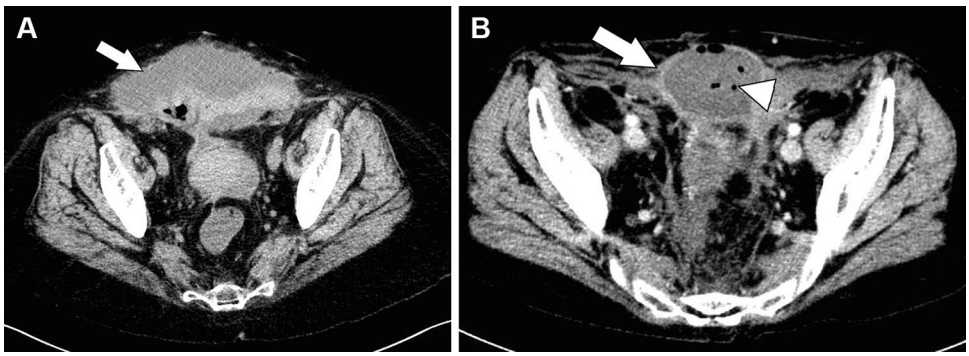

Fig. 9 Image from axial noncontrast CT through the pelvis in a patient who underwent IIT demonstrates expected bulging along the anterior abdominal wall due to skin-only closure (**a**). There is nonorganized fluid (arrow) along the transplant graft, which is a normal postoperative finding. Image from axial contrast-enhanced CT through the pelvis in a patient who underwent IIT demonstrates a loculated collection along the operative bed, with thick enhancing wall (arrow) and several foci of gas within the collection (arrowhead) (**b**). These findings are indicative of postoperative abscess, which was corroborated by the return of thick pus at the time of percutaneous drain placement. Note how these features differ significantly from the expected postoperative findings of nonorganized fluid seen in (**a**)

bladder [45, 46]. Some of these infections may happen in any postoperative case (eg, pneumonia, urinary tract infection) and do not carry unique challenges or findings in the context of SBT. However, intra-abdominal infections can be more complicated in the context of SBT.

Intra-abdominal abscess is a common infectious complication of SBT. On CT imaging, the abscess will appear as a thick, enhancing rim surrounding a focal, gas-containing fluid collection with surrounding inflammatory stranding (see Fig. 9b). Abscesses may also be seen intraparenchymally, with the liver being the most common site because of its highly vascular nature [6, 41]. CT is particularly useful in characterizing abscesses, as this modality can also provide guidance for aspiration or drainage if needed for definitive management [37]. Additionally, ultrasound imaging offers a radiation-sparing option for guidance if the abscess is relatively superficial and/or there is a sonographic window for access.

Other intra-abdominal infections aside from abscess are not diagnosable with imaging alone. For example, thickening and enhancement of the peritoneum on contrast-enhanced CT is suggestive of peritonitis, but only if the clinical symptomatology is consistent with the diagnosis as well. Infectious enteritis can also be seen on CT, but these findings are similar to those of acute rejection and thus must be interpreted in the context of clinical findings and histopathologic studies [20].

Vascular complications

Various vascular complications can arise after SBT. Anastomotic sites are the most common locations for complications such as hemorrhage, thrombosis, and pseudoaneurysm formation [47]. Contrast-enhanced CT or CT angiography is the modality of choice if vascular complications are suspected [40, 47]. Doppler ultrasound imaging is useful in detecting complications arising from the hepatic vasculature [6]. Arterial complications such as thrombosis and pseudoaneurysm are relatively uncommon but are critically important to recognize as they can lead to bowel ischemia and jeopardize the graft [14]. Conventional catheter-guided angiography and CT angiography are the preferred imaging modalities for the diagnosis of such complications. Thrombosis will appear as an intraluminal filling defect, whereas pseudoaneurysm will appear as relatively irregular vascular enlargement as there is disruption of the intimal and medial vascular walls. Conventional angiography additionally has the benefit of allowing for immediate intervention if such complications are detected. In instances of arterial pseudoaneurysm or frank dehiscence of an anastomotic site, conventional angiography is often preferred, as the sequelae could be catastrophic if not treated promptly [47].

Venous thrombosis typically presents in the postoperative period as abdominal congestion with findings of bowel wall edema with a variable level of enhancement on contrast-enhanced imaging [6]. The clot may be visualized directly on cross-sectional techniques such as ultrasound, CT, and MRI (Fig. 10). Venous thrombosis in the portal system presents with hepatic congestion, with perfusion deficits seen on liver imaging. Lastly, venous thrombosis of the hepatic system presents as Budd-Chiari syndrome with ascites, liver enlargement with hyperenhancement in the central and caudate lobes, filling defects in the hepatic veins, and, if recurrent, prominent abdominal wall collaterals [6, 41].

Anastomotic stenosis is another serious vascular complication that can lead to bowel ischemia. This complication appears on contrast-enhanced CT or MRI as a nonenhancing segment of bowel with or without pneumatosis and portal venous gas (Fig. 11) [6]. Keeping the normal postoperative surgical anatomy in mind will aid the radiologist in identifying a potential stenosis and/or occlusion based on the supply of the affected section of bowel.

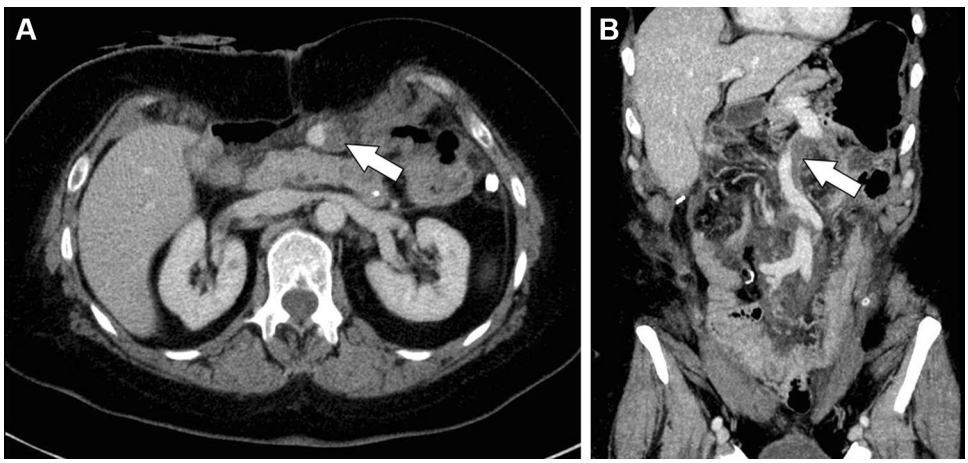

Fig. 10 Axial (**a**) and coronal reformatted (**b**) images from CT angiography in a patient who underwent IIT demonstrate thrombus along a venous conduit between the transplant SMV and the native portal system (arrows in **a, b**)

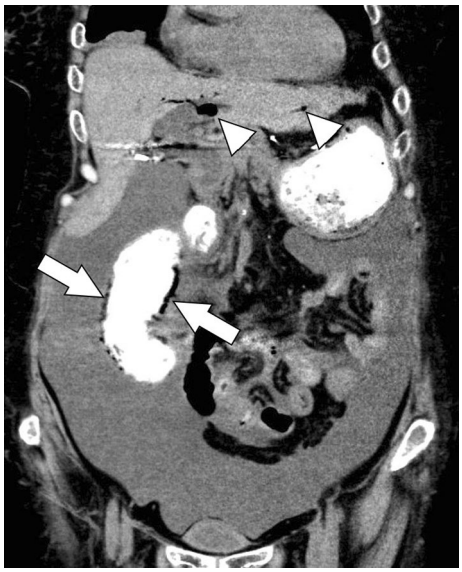

Fig. 11 Coronal reformatted image from abdominal CT in a patient who underwent IIT demonstrates segmental pneumatosis of the right abdominal small bowel (arrows) with associated portal venous gas (arrowheads) along the intrahepatic portal vein radicals. Surgical exploration revealed complete thrombosis of the arterial and venous conduits, requiring a graft explant

Gastrointestinal complications

Gastrointestinal complications such as anastomotic leak, anastomotic stricture, delayed gastric emptying, and small bowel dysmotility are not uncommon after SBT [6, 20]. The modality of choice to diagnose anastomotic leak is fluoroscopy with a water-soluble contrast medium [20], although this complication can also be detected on routine postoperative CT scans as described above. Delayed gastric emptying becomes an increasing concern in cases of full or partial stomach transplants in MIT and modified MIT procedures [20]. Gastric emptying scintigraphy is the imaging procedure of choice in these instances. Mechanical obstruction is a common postoperative complication that can be secondary to stricture, adhesions, hernia, and volvulus. In patients who have undergone SBT, particular attention should be paid to the visceral anastomoses as areas possibly developing strictures.

Small bowel dysmotility and obstruction are concerns in all types of SBT owing to the nature of the transplant anatomy and the substantial surgical time and recovery course. Although mild dysmotility can be considered normal within the first few months of recovery, prolonged or persistent dysmotility or hypomotility can lead to recurrent pseudo-obstruction and thus should be assessed with imaging [6, 36, 41]. CT is often the first-ordered imaging modality if small bowel dysmotility or obstruction is suspected, but fluoroscopy with a water-soluble contrast offers additional diagnostic utility, as this modality provides real-time imaging and is able to characterize functional motility in addition to anatomic structure [20].

Pancreaticobiliary complications

Biliary complications occur in patients who have undergone LIT or MIT. These complications can include biliary leak, biliary obstruction, cholangitis, pancreatitis, and pancreatic duct fistula [31]. Most of these complications can be managed with endoscopic retrograde cholangiopancreatography (ERCP) or percutaneous interventions, such as biliary catheter or stent placement [31, 32, 39].

Biliary leak can occur at any anastomotic or drainage site such as duct-to-duct anastomosis, choledochojejunostomy, or at the entry point of biliary drain(s) [6, 31]. Bilomas are the most common resulting pathology from a biliary leak and can be diagnosed at the time of ERCP, during hepatobiliary scintigraphy, or on MRI [32].

Biliary obstruction can be secondary to ampullary stenosis or bile duct stones or casts. Ampullary stenosis is more commonly seen at the donor ampulla, as the underlying pathophysiologic mechanism is denervation injury during graft harvesting [48]. Ampullary stenosis appears as proximal biliary ductal dilation on imaging studies and can be diagnosed with ultrasound imaging, MRCP, or ERCP in combination with an obstructive pattern on liver function tests. Choledocholithiasis and bile duct casts are thought to be secondary to bile duct injury or inflammation as well as biliary stasis and present similarly to ampullary stenosis, with proximal bile duct dilation and an obstructive pattern on liver function tests [31]. In these cases, MRCP can be advantageous in showing a finer level of detail, allowing clinicians to differentiate between casts and stones, which present with increased T1 signal intensity [38, 39, 49]. ERCP is the modality of choice for treatment via sphincterotomy in cases of ampullary stenosis and removal of stones or casts.

Cholangitis can result from reflux of enteric contents into the biliary system and is most commonly seen in cases of LIT or MIT after choledochojejunostomy. This is most pertinent to the radiologist in cases of enteric contrast-enhanced studies, where reflux of the contrast agent may be visualized [31]. More commonly associated findings of biliary duct dilation and wall thickening can also be seen in these cases [31].

Pancreatic complications include acute and chronic pancreatitis as well as pancreatic fistula. Acute pancreatitis is the most common pancreaticobiliary complication after multivisceral transplant and typically occurs in the donor pancreas rather than in the native pancreas [31, 32]. As with any case of pancreatitis, findings such as enlargement of the pancreas, peripancreatic inflammatory fat stranding, and peripancreatic fluid collections on CT in addition

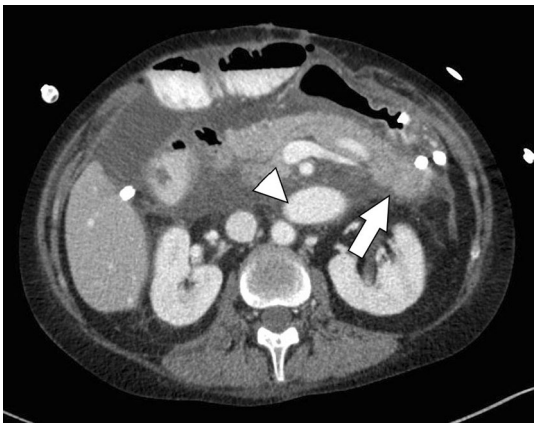

Fig. 12 Axial contrast-enhanced CT at the level of the mid abdomen in a patient who underwent MIT demonstrates enlargement of the transplant pancreas with edematous changes, particularly along the tail (arrow). Some associated inflammatory changes in the adjacent fat with fascial thickening can also be seen. Note the presence of a vascular conduit related to MIT (arrowhead)

to decreased T1 signal on MRI are all supportive of the diagnosis (Fig. 12) [32]. Chronic pancreatitis is less common than acute pancreatitis, but the chronic form affects the native pancreas more commonly than the acute form. Typical findings of chronic pancreatitis include parenchymal atrophy and calcifications and irregular ductal dilation on CT imaging as well as decreased T1 signal intensity on MRI [6, 32]. Fistulization can occur in the setting of necrotizing pancreatitis but may also develop postoperatively in cases that involve donor splenectomy or transection of the donor pancreas [31, 32]. Identification of a peripancreatic fluid collection has important clinical implications as this finding indicates that treatment is needed via percutaneous drainage, stent placement during ERCP, or surgical intervention depending on the exact anatomy and severity of the complication [31].

Chylous collections

Chylous collections occur most commonly after IIT and modified MIT as these procedures involve more extensive reconstruction of the small bowel mesentery [6]. As these collections often require drainage secondary to mass effect, it is important to differentiate them from other fluid collections. These collections are typically large, which can be an initial differentiating feature; more specifically, these collections will demonstrate internal fat attenuation [6]. Although uncommon, a nondependent fat-fluid level is also characteristic of these collections. Once accessed, the fluid should be sent for further analysis to confirm its chylous nature.

Immunologic and hematologic complications

Various hematologic complications such as GVHD and PTLD can occur after SBT. GVHD is a complication that can occur after any solid organ transplant but occurs most commonly after intestinal transplants because of the high lymphoid content of the small bowel [50]. In a recent review, GVHD was found to be associated with a mortality rate of 40–70% in patients undergoing some form of SBT [50]. GVHD has a variety of manifestations and most commonly involves the skin, gastrointestinal tract, and liver, with a maculopapular rash being the most common and earliest presentation [51]. Imaging findings are variable and generally nonspecific but may include bowel wall thickening, vasa recta engorgement, mesenteric fat stranding, and mucosal enhancement [14, 50, 52].

PTLD is the result of proliferation of the recipient's B cells, usually secondary to Epstein-Barr virus. The rate of PTLD occurrence has decreased since the introduction of more effective preoperative and postoperative immunotherapy strategies, earlier detection via polymerase chain reaction, and improved treatment options [3, 14]. PTLD can be seen on postoperative CT imaging, appearing as lymphadenopathy and/or lymph node conglomeration either within the graft or at remote sites (Fig. 13) [6, 20, 53]. When the graft itself is involved, infiltration can be seen along the mesenteric plexus, manifesting as aneurysmal-like bowel dilation and thickening of the bowel wall [6, 20, 53]. Extraintestinal PTLD typically involves the liver or other solid organs and manifests as hypoattenuating lymphoid tissue [6, 53]. PTLD is diagnosed via histopathologic examination of lymphoid tissue, which can be acquired via CT-guided lymph node biopsy.

Conclusion

SBT is an increasingly common procedure that is effective in treating patients with intestinal failure. With the advancement of surgical techniques and perioperative transplant management, SBT survival rates have become comparable to those of other solid organ transplant surgeries, and operative rates are expected to increase in the near future. It is therefore imperative that radiologists become familiar with the imaging studies used for SBT. This requires adequate background knowledge regarding the surgical variations of SBT, indicated preoperative imaging studies, and anticipated complications and their appearance on postoperative imaging studies.

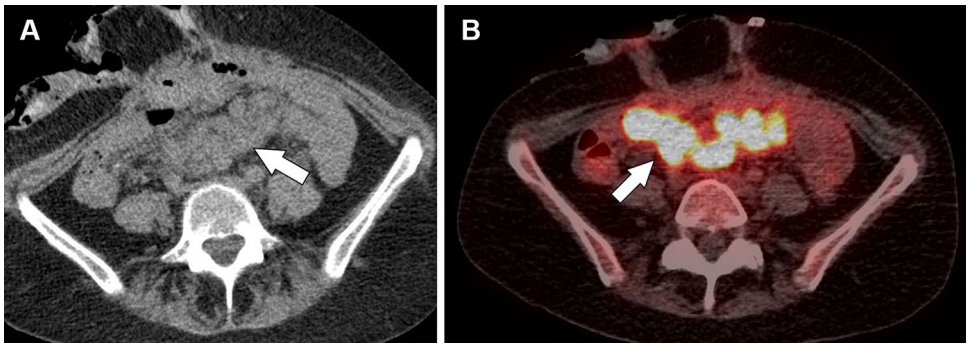

Fig. 13 Axial non-contrast CT at the level of mid abdomen (**a**) in a patient who underwent IIT approximately 4 months earlier, demonstrating bulky lymphadenopathy along the transplant mesentery (arrow, **a**). Axial image from fused PET-CT at level of mid abdomen (**b**) demonstrates intense metabolic activity in the bulky mesenteric adenopathy (arrow, **b**). A biopsy confirmed post-transplant lymphoproliferative disease (PTLD)

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