Interventional Radiology in Liver Transplantation

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Improvements in surgical technique, advances in the field of immunosuppression and the early diagnosis and treatment of complications related to liver transplantation have all led to prolonged survival after liver transplantation. In particular, advances in diagnostic and interventional radiology have allowed the Interventional Radiologist, as part of the transplant team, to intervene early in patients presenting with complications related to organ transplant with resultant increase in graft and patient survival. Such interventions are often achieved using minimally invasive percutaneous endovascular techniques. Herein we present an overview of some of these diagnostic and therapeutic approaches in the treatment and management of patients before and after liver transplantation. Liver Transpl 12:330–351, 2006. © 2006 AASLD.

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Since the first liver transplantation (LT) over 40 years ago, several advancements have occurred that have resulted in improved patient survival rates. The latest 1, 5, and 10-yr patient survival rates after primary LT have been reported at 86%, 79%, and 73%, respectively.1 Not only have there been significant improvements in surgical technique and immunosuppressive agents but major technological advancements have occurred in diagnostic imaging and the interventional radiologic treatment of complications in this patient population.

Furthermore, a close working relationship between the interventional radiologist (IR) and transplant team has always been and continues to remain an essential component of a successful LT program. Herein we describe our experience with some of the interventional procedures that have proved to be useful in managing patients before and after LT.

SUPPORTING THE TRANSPLANT CANDIDATE

Despite widespread education about the life-saving need for organ donation by several national and international organizations, there still continues to be a small donor pool and a large waiting list for LT. Currently there are close to 18,000 patients awaiting a LT in the United States.2 The IR can provide nonsurgical therapies to delay the need for LT. Such treatments include transjugular intrahepatic portosystemic shunt (TIPS) placement and the percutaneous treatment of liver tumors.

Transjugular Intrahepatic Portosystemic Shunt

Although described 4 decades ago, TIPS was not clinically feasible nor widely available until the development of intravascular stents in the early 1980s.3–5 Its clinical and surgical value lies in the ability to percutaneously create a portosystemic shunt, thereby decreasing portal hypertension without disturbing the extrahepatic vasculature. Over the last 2 decades, TIPS has established itself as the standard of care in selected patients who present with the end-stage complications of portal hypertension such as life threatening hemorrhage or refractory ascites not responsive to medical or primary endoscopic therapy.6–10 TIPS may also be used in pa...
tients with Budd Chiari Syndrome who are either not LT candidates or awaiting LT. Long-term patency issues with TIPS requiring secondary interventions to maintain flow has lead to the general opinion that patients who are in Child-Turcotte-Pugh class A should undergo shunt surgery while patients in Child-Turcotte-Pugh classes B and C are better suited for TIPS.

Absolute contraindications to TIPS include: elevated central venous pressures from right heart failure, severe hepatic failure, severe encephalopathy, active infection, and advanced polycystic liver disease. Relative contraindications that can make the procedure challenging but possible in experienced hands include portal vein thrombosis and hepatic neoplasms.

As experience with this procedure has grown, we have learned that TIPS is not a cure for portal hypertension but often serves well reported to range from 20 to 69%. Surveillance classes B and C are better suited for TIPS.

who are in Child-Turcotte-Pugh class A should undergo TIPS requiring secondary interventions to maintain flow through the TIPS or even occlude it if necessary (Fig. 1). TIPS thrombosis and may be avoided by the use of covered stents or based on institutional protocol.

The technique of TIPS placement has been well described and will not be described here. A baseline ultrasound (US) is obtained within 24 hours of TIPS placement. The baseline US should be delayed by at least 3 days if a covered stent is used, since it may take 2-3 days for the air in the graft material to be replaced with fluid and allow transmission of US. Serial US examinations can be performed initially at 3-month intervals or based on institutional protocol.

Pseudointimal hyperplasia, usually at the hepatic venous end, results in narrowing and eventually occlusion of the TIPS. Biliary leak from transaction of bile ducts during TIPS placement is a known cause of early TIPS thrombosis and may be avoided by the use of covered stents. Primary patency rates of TIPS are reported to range from 20 to 69%. Primary patency rates of TIPS are reported to range from 20 to 69%. Primary patency rates of TIPS are reported to range from 20 to 69%. Primary patency rates of TIPS are reported to range from 20 to 69%. Primary patency rates of TIPS are reported to range from 20 to 69%. Primary patency rates of TIPS are reported to range from 20 to 69%

in end-stage cirrhotic livers, newer generation multivessel CT scanners and the use of contrast agents have greatly improved detection rates of 3-dimenisional angiographic quality images. Abdominal CT has a much better detection rate for hepatic mass lesions, especially when a helical CT scan is performed with arterial and venous phase imaging. Powerful workstations, in conjunction with newer generation multidetector CT scanners, allows the rapid creation of 3-dimensional angiographic quality images in a short time period. This is particularly important in accurately evaluating vascular anatomy. In living donor transplantation, there is a tremendous demand in end-stage cirrhotic livers, newer generation CT scanners provide outstanding quality images. Abdominal CT has a much better detection rate for hepatic mass lesions, especially when a helical CT scan is performed with arterial and venous phase imaging. In living donor transplantation, there is a tremendous demand for minimizing invasive procedures in the donor without sacrificing preoperative accuracy. Sakai et al. found that, at contrast infusion rates of 4 mL/second, there was higher visualization of the smaller visceral branches and they successfully identified 23 of 24 aberrant vessels.

Even though previous studies have demonstrated US to be relatively insensitive in the detection of malignancy in end-stage cirrhotic livers, newer generation scanners and the use of contrast agents have greatly improved detection rates. US also can be performed relatively quickly at the bedside, making it more appealing in the often critically ill perioperative patient.
tency and flow directionality can be adequately demonstrated at the bedside. Newer techniques utilizing US contrast agents and microbubbles may yield better diagnostic rates. Advancements in MR imaging and MR angiography pulse sequences and the use of contrast agents have laid the foundation for this modality to be safely and effectively used in the LT population. In fact, the ability of a noninvasive study to provide multiplanar anatomic, vascular, and cholangiographic data is very appealing, especially in the living donor population. Three-dimensional gadolinium-enhanced MR angiography also plays a role in the evaluation of complications in the posttransplantation patient. Additionally, MR imaging and US can safely be used in patients severely allergic to iodinated contrast agents or with renal insufficiency.

Surgeon preference and strengths of individual radiology departments still plays an important role in determining which study is performed. When clinically indicated, our surgeons still request catheter-based angiograms on living liver donors. Despite advances in CT and MR imaging conventional catheter-based diagnostic angiography is still performed in select cases. One such area is portal vein occlusion seen on CT. Selective superior mesenteric artery arteriography with portal vein imaging can demonstrate the condition of the superior mesenteric vein, which can be used as a site for portal vein allograft anastomosis using an interposition venous graft.
Normal Vascular and Biliary Reconstructions

A successful LT requires at least 1 arterial, 2 venous, and 1 biliary anastomosis. More than 75% of livers derive their entire arterial supply from the celiac axis, allowing the creation of a single arterial anastomosis. In the case of aberrant hepatic vasculature, complex arterial anastomoses may need to be created on the operating room table.

The Carrell patch is the arterial anastomosis of choice. Here the donor celiac trunk is preserved with a small segment of the surrounding donor aorta and anastomosed to the recipient common hepatic artery. This is usually followed by ligation of the donor splenic, left gastric, and gastroduodenal arteries. However, sometimes these vascular stumps are used as anastomotic sites for on-table attachment of accessory vessels, such as a variant right hepatic artery from the superior mesenteric artery.

In retransplantation, or in cases in which a successful attachment to the recipient cannot be performed (e.g., celiac axis stenosis, short donor hepatic artery), a donor iliac artery interposition homograft or, rarely, a prosthetic graft may be utilized. These may be attached to the recipient’s infrarenal aorta or, in rare cases, other areas such as the suprarenal abdominal aorta, the splenic artery, and even the inferior epigastric artery. It is important for the IR to be aware of these various anastomoses both for diagnostic and interventional purposes.

A direct end-to-end portal anastomosis is usually performed. In the case of portal vein thrombosis, a surgical thrombectomy may be needed or an interposition graft may be utilized from the recipient superior mesenteric vein.

Two common hepatic venous reconstructions are utilized. A piece of the donor intrahepatic inferior vena cava (IVC) with the attached native hepatic veins may be interposed into the recipient’s IVC, creating a suprahepatic and infrahepatic anastomosis. An alternate anastomosis is the “piggyback” anastomosis. This is created by suturing together the hepatic veins to form a cloaca, which is then directly anastomosed to the donor suprahepatic IVC with ligation of the donor infrahepatic IVC.

The choledochocoledochostomy and the Roux-en-Y choledochojejunostomy are the 2 main biliary recon-
structions utilized. The choledochocholedochostomy is an end-to-end anastomosis between the donor and recipient common bile ducts. Alternate anastomoses include a choledochojejunostomy or a hepaticojejunostomy to a Roux-en-Y loop of jejunum.

DIAGNOSTIC INTERVENTIONS

Percutaneous Liver Biopsy

Image-guided, directed, and random liver biopsies are often called upon in the LT patient population. Arguments against image-guided liver biopsy are made for cost effectiveness and whether they add to the diagnostic yield of the procedure in the non-LT patient. However, imaging with US and in some cases CT allows visualization of other abnormalities such as ascites and vascular structures that can be avoided, thereby reducing complication rates. In patients with split-liver transplants, image guidance is required to safely perform the biopsy and avoid entering the bowel or other adjacent organs. In cases of extensive ascites, percutaneous liver biopsy is avoided due to the higher risk of peritoneal bleed. If a directed biopsy is needed, a drainage catheter can be placed into the ascites prior to the biopsy.

Figure 3. (A) No filling of the hepatic artery seen on celiac arteriogram. (B) Revascularization was done via an anastomosis to an hepatic branch from the SMA. Note kink and stenosis of the HA. Because the patient was three days postoperative from the transplant, this was treated surgically.

Transjugular Liver Biopsy

Indications for random transjugular liver biopsy include the need for a nondirected biopsy in patients with coagulopathy, thrombocytopenia, or massive ascites. In such cases, transjugular liver biopsy has been shown to yield adequate tissue with a high diagnostic yield and a lower bleeding complication rate than conventional percutaneous biopsy. Furthermore, it allows the IR to obtain wedged hepatic venous pressures if there is clinical concern for portal hypertension.

POSTOPERATIVE INTERVENTIONS

Postoperative complications may occur in up to 25% of LT recipients. Any decline in liver function should prompt an early search for a potentially reversible cause. US provides a noninvasive and portable means of quickly evaluating the vascular flow within the allograft as well as evaluating for intrahepatic biliary dilation. At the same time US also provides a safe means of performing a percutaneous liver biopsy at the bedside, if required. CT and MR imaging also provide noninvasive evaluation of the transplanted liver. Not only can vascular and biliary complications be easily identified, but postoperative fluid collections can be demonstrated. Three-dimensional reformats often provide diagnostic angiography quality images.

Arterial Complications

Hepatic artery stenosis and especially hepatic artery thrombosis (HAT) may result in arterial insufficiency to the LT.

Hepatic Artery Thrombosis

HAT rates in the LT recipient range from 4 to 42% with the higher rates seen in the pediatric population, in which complex, technically demanding anastomoses are created on much smaller vessels. Risk factors linked to HAT include increased cold ischemia
time, ABO blood group incompatibility, small donor vessels, rejection, arterial kinks, and reduced flow secondary to hepatic artery stenosis (HAS). Ishigami et al. also reported a higher risk of hepatic arterial complications in patients with variant hepatic artery anatomy.

Mortality rates from HAT have been reported to be greater than 80% without emergent retransplantation or revascularization. Sheiner et al. reported that out of 1,026 liver transplantations at their institution, 32 patients (3.1%) developed HAT. Of these, only 20 (62.5%) were symptomatic. However, they found that graft salvage in asymptomatic patients undergoing revascularization was 82% vs. 40% in symptomatic patients resulting in a 1-yr patient survival of 92% in asymptomatic patients vs. 65% in the symptomatic patients.

The hepatic artery provides the only vascular supply to the biliary tract epithelial lining of the allograft. Thus HAT is usually associated with biliary ischemia and resultant strictures, necrosis, leaks with biloma formation, and intrahepatic abscesses (Fig. 2).

US offers a relatively inexpensive, portable, noninvasive, and readily available method of evaluating the liver parenchyma and hepatic arterial flow. Flint et al. correctly identified 92% of HAT by Doppler US examination. The resistive index and systolic acceleration times can be calculated from the Doppler waveform seen in the transplant hepatic artery. A resistive index

Figure 4. (A) Severe hepatic artery stenosis seen on celiac arteriogram. (B) Balloon angioplasty was performed using a 5mm balloon. (C) Excellent angiographic result seen post angioplasty.
of less than 0.5 or systolic acceleration times of greater than 0.08 seconds is highly suggestive of stenosis or thrombosis of the vessel.\textsuperscript{131}

Three-dimensional helical CT arteriography with maximum intensity projection and shaded surface display techniques offers a noninvasive approach to the diagnosis of vascular complications after LT. A sensitivity rate of 100% with a 89\% specificity and accuracy of 95\% has been demonstrated.\textsuperscript{110}

Initial experience with implantable Doppler probes at the time of LT for continuous blood flow monitoring for a short time period after LT has also been described and may be beneficial.\textsuperscript{132}

Once an abnormal US and/or CT result is obtained, an arteriogram is usually performed. Severe HAS may be hard to differentiate from HAT on US, but needs to be aggressively looked for, since HAS may be a treatable complication and prolong the life of the allograft. Catheter-based arteriography is usually performed at our institution to confirm and treat HAS.

Prior to arteriography it is vital that the IR be fully aware of the surgical vascular anastomoses that were utilized in the patient. If a standard Carrel patch was utilized we usually begin with a celiac arteriogram. Standard angiographic catheters such as a Cobra (Cook Incorporated, Bloomington, IN) or Sos (Angiodynamics, Queensbury, NY) are utilized since they can be gently placed in the origin of the celiac trunk without the guidewire needing to be advanced across the anastomosis. This is important since it may be difficult to
differentiate guidewire associated spasm/dissection vs. stenosis/occlusion.

In cases of an infrarenal graft, we initially perform a lateral abdominal aortogram with an aortic flush catheter. This allows adequate delineation of the graft origin and can be followed by selective graft catheterization to define the intrahepatic vasculature and identify delayed filling of intrahepatic branches via collaterals. Sometimes a variant anastomosis may be in place and could be missed if the operative note is not reviewed.

Although many potential collateral pathways are severed during LT, extensive extrahepatic arterial collaterals may form in the posttransplantation patient following HAT. If such collateral pathways are identified and the occlusion is believed to be acute, endovascular revascularization techniques may be pursued.

There are many reports of restoration of flow with catheter directed thrombolytic therapy and mechanical thrombectomy devices. Once the thrombus is cleared an underlying stenosis may be uncovered and can then be treated with percutaneous transluminal balloon angioplasty (PTA) and/or stent placement. Urgent surgical intervention may be needed for cases in which percutaneous techniques fail to improve flow.

Hepatic Artery Stenosis

HAS rates as high as 11% have been reported. Early recognition and intervention may help prevent significant ischemic organ damage and progression to HAT. The vast majority of HAS occurs at the surgical anastomosis and is linked to technical factors, clamp injury, kinked vessels, fibrosis, edema, and thrombus formation. Non-anastomotic stenoses may be secondary to allograft rejection or clamp injury. A redundant hepatic artery with kinks can simulate HAS both physiologically and angiographically and may be best managed surgically. Immediate postoperative HAS is most likely related to surgical technique and is also best managed surgically. Early postoperative PTA may lead to vascular rupture (Fig. 3). We have pursued PTA as early as 10 days after LT at our institution.

Initial reports of PTA were based on older balloon
technology in which 5-French (Fr) balloon catheters were utilized over 0.035-inch guide wires. This made balloon angioplasty within tortuous vessels cumbersome and sometimes impossible. Advancements in balloon technology have resulted in lower profile balloons that can easily track around curves, often seen in the LT patient. Many of these balloons can be used over thin 0.014 inch and 0.018 inch guidewires that can be placed through 5 Fr low profile guiding sheaths positioned at the origin of the celiac axis (Figs. 4 and 5). The guiding sheaths allow easy exchange of catheters and the ability to inject contrast material around the balloon. Additionally, if PTA is unsuccessful or is complicated by a dissection, lower profile stent delivery systems designed to be placed over 0.018 inch guide wires can be placed through the guiding sheath. Unfortunately, the presence of stents may complicate retransplantation, but if needed extraanatomic bypass grafts can be used.

Many of these patients have liver dysfunction with resultant coagulopathy. The development of percutaneous femoral artery closure devices and pads allow percutaneous access site hemostasis in the face of poor coagulation with ease though they are not completely free of complications.141-147 Data on liver function recovery after PTA are scant, but several small series indicate allograft function may improve with the timely performance of PTA for HAS.140,148-150 Previous data from our institution151 showed significant improvement in mean aspartate aminotransferase and alanine aminotransferase levels within 1 week after successful PTA. However, severe initial allograft dysfunction is a poor prognostic sign and is often associated with allograft loss and the eventual need for retransplantation, regardless of the success or failure with PTA.152

PTA and stent placement can be a safe procedure in

Figure 7. (A) Stenosis of the MPV at the surgical anastomosis is demonstrated on US. (B) Severe anastomatic stenosis is demonstrated on portal venogram performed via the transhepatic approach. (C) Note the waist in the mid portion of the 16mm angioplasty balloon. (D) Note obliteration of the balloon waist upon further dilation to maximum pressure. (E) Minimal residual stenosis at the surgical anastomosis is seen on final post angioplasty venography.
experienced hands but is also fraught with complications, including spasm, dissection, occlusion, and pseudoaneurysm formation.

**Hepatic Artery Graft**

Both stenosis and thrombosis of the hepatic artery graft can be seen and are treated no differently than HAS or HAT. In cases of graft stenosis they may occur at the proximal or distal anastomosis.

**Hepatic Artery Pseudoaneurysm**

Hepatic artery pseudoaneurysm (PA) formation and arteriovenous fistula represent some of the other less commonly seen arterial complications post-LT (Fig. 6). These may be due to surgical anastomotic breakdown from technical factors or infection or may be related to posttransplantation iatrogenic injuries such as from balloon angioplasty, percutaneous biliary drainage, or biopsy. The diagnosis of PA can usually be made by noninvasive imaging such as US or CT. Since the PA may rupture, they must be repaired to avoid potentially serious complications such as hemoperitoneum, hemobilia, or massive gastrointestinal tract bleeding. Traditional treatments for such abnormalities have relied on surgical exploration and resection. Percutaneous endovascular treatments may be employed to treat some of these complications. The treatment of choice should be based on the nature and extent of the pseudoaneurysm and the health status of the patient.
these complications. Transvascular coil embolization may be performed if there is an adequate neck to the PA or if the arteriovenous fistula can be catheterized. Newer technology detachable coils such as the NXT (Micro Therapeutics, Irvine, CA) developed for neurovascular procedures may play a role in occluding more complex aneurysms. These coils are placed into the aneurysm through microcatheters. Once they are in position and felt to adequately fill the space needed and are stable, they can be released by a low voltage electric charge through the attachment wire. If the IR is not satisfied with coil placement or if the distal flow is compromised it can simply be withdrawn without detachment. Occasionally, if there is extreme tortuosity of the vessels, direct percutaneous access may be utilized for embolization or thrombin injection into the PA. As stent technology improves, low profile covered stent grafts can be placed to occlude a PA or the venous communication in an arteriovenous fistula.

Portal Vein Complications

Portal vein stenosis may be seen in less than 3% of adult LT recipients and rates of 7% have been reported in the pediatric population, with some progressing to portal vein thrombosis. Most occur at the surgical anastomosis and may be related to surgical technique, a redundant vein, or the use of a bypass graft. Patients may be asymptomatic or present with the clinical signs of portal hypertension. Portal vein thrombosis generally presents with elevation of liver enzyme levels as well as signs of portal hypertension such as variceal bleeding, ascites, or splenomegaly. Noninvasive imaging usually demonstrates the stenosis and any associated thrombus. Direct venography is usually performed to confirm the diagnosis and to treat the complication. The portal vein can be accessed via a transhepatic, transjugular, or even a transsplenic approach. At our institution we prefer the transhepatic approach. After gaining transhepatic access, a 5-Fr diagnostic catheter can be placed into the splenic or superior mesenteric vein for portal venography followed by PTA. On average, large-sized balloons in the order of 10 to 16 mm may be needed to treat main portal vein stenosis in adult LT recipients (Fig. 7). Unsuccessful PTA or recurrent stenosis can be treated with stent placement (Fig. 8). Once the treatment is completed the intraparenchymal tract can be embolized with coils or gelfoam to prevent any bleeding into the peritoneal space. If a large amount of ascites is present, it should be drained prior to access.

There have been several reports of successful treatment of portal vein stenosis using PTA and stents when needed. Funaki et al. successfully treated 19 of 25 pediatric LT patients with percutaneous techniques. Twelve patients needed to be stented with patency maintained at 46 month mean follow-up. Surgical thrombectomy and placement of intraoperative stent placement has been reported. The treatment of portal vein thrombosis by percutaneous transhepatic portal vein thrombolysis and stent placement if needed as well as via a transjugular approach has been described.

Inferior Vena Cava and Hepatic Venous Complications

IVC stenosis or thrombosis is seen in less than 1% of LT recipients. Most occur at the surgical anastomosis and may be related to surgical technique, a redundant vein, or the use of a bypass graft. Patients may be asymptomatic or present with the clinical signs of portal hypertension. Portal vein thrombosis generally presents with elevation of liver enzyme levels as well as signs of portal hypertension such as variceal bleeding, ascites, or splenomegaly. Noninvasive imaging usually demonstrates the stenosis and any associated thrombus. Direct venography is usually performed to confirm the diagnosis and to treat the complication. The portal vein can be accessed via a transhepatic, transjugular, or even a transsplenic approach. At our institution we prefer the transhepatic approach. After gaining transhepatic access, a 5-Fr diagnostic catheter can be placed into the splenic or superior mesenteric vein for portal venography followed by PTA. On average, large-sized balloons in the order of 10 to 16 mm may be needed to treat main portal vein stenosis in adult LT recipients (Fig. 7). Unsuccessful PTA or recurrent stenosis can be treated with stent placement (Fig. 8). Once the treatment is completed the intraparenchymal tract can be embolized with coils or gelfoam to prevent any bleeding into the peritoneal space. If a large amount of ascites is present, it should be drained prior to access.

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Inferior Vena Cava and Hepatic Venous Complications

IVC stenosis or thrombosis is seen in less than 1% of LT recipients. They mostly occur at the surgical anastomosis or less often, are due to extrinsic compression and mass effect from surrounding fluid collections or hematoma formation. Suprahepatic IVC stenosis may present with ascites and pleural effusions with a Budd-Chiari-like syndrome. Infrahepatic stenoses may present with lower body edema due to poor venous return. The incidence of upper and lower caval anastomotic stenosis is approximately equal. Endovascular techniques can help alleviate these problems. PTA, stent placement, and thrombolysis can provide minimally invasive methods of treating these patients. Despite the current availability of large-sized balloons, single balloons may not be large enough to dilate the IVC. Simultaneous inflation of multiple balloons has been described in these cases (Fig.
Resistant stenoses or those with elastic recoil may need to be treated with large stents.  

Hepatic venous stenosis may be seen in 4 to 5% of post-LT patients. The higher numbers are often seen in partial LT. On US they show flattened monophasic flow with decreased velocities of less than 10 cm/second. They can present with vascular engorgement and biopsy results that indicate passive liver congestion. PTA is once again the first line of treatment (Fig. 10). A jugular approach is preferred in patients with a piggyback anastomosis as it is easier to access. Stent placement can be problematic since they often have to be extended into the IVC but can be pursued if needed (Fig. 11).

**Biliary Intervention**

Biliary tract complications post-LT were once reported to be as high as 48%, with more recent reviews indicating a 10 to 15% range. The choledochocholedochostomy and the Roux-en-Y choledochojejunostomy are the 2 preferred biliary reconstructions utilized. Biliary obstruction and leaks are the 2 major groups of LT complications that often require intervention. An endoscopic approach may be difficult with the presence of Roux-en-Y loops. The IR may be called upon to perform diagnostic percutaneous transcatheter cholangiography (PTC) followed by drainage or intervention. Anastomotic strictures are usually related...
to scar tissue and technical factors. Nonanastomotic strictures may be related to hepatic arterial insufficiency, infection, ABO blood group incompatibility, and primary sclerosing cholangitis.\textsuperscript{198-201} The arterial supply to the biliary tree is derived from the right and left hepatic arteries that form a plexus of blood vessels around the right and left ducts that continue into the common duct.\textsuperscript{202,203} In the post-LT patient, collateral supply to the liver is poor, thus any situation such as HAS or HAT may result in biliary ischemia with resultant strictures and obstruction with the eventual possibility of biliary necrosis. Percutaneous interventional techniques, especially with HAS, may be safely used to treat many of these complications.\textsuperscript{204-206}

Until fairly recently, CT and US have provided the only noninvasive means of detecting postoperative biliary complications. Previous data from our institution\textsuperscript{207} has shown that US can miss biliary tract abnormalities after LT. However, newer generation scanners in the hands of experienced ultrasonographers can easily identify biliary abnormalities.\textsuperscript{74}

The rapid evolution of MR techniques and contrast

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**Figure 11.** (A) Severe right hepatic venous stenosis is shown on a right hepatic venogram performed from a right internal jugular vein approach several months post transplantation. (B) During balloon angioplasty, a moderate waist is seen in the balloon lumen at maximum inflation pressure. (C) Residual stenosis is seen post balloon dilation. (D) An endovascular metal stent was placed across the stenotic vein resulting in a wide open hepatic vein.
agents have allowed the creation of MR cholangiopancreatography images that can provide details that were once only appreciated with PTC.\textsuperscript{208–210}

\section*{Percutaneous Transhepatic Cholangiography and Drainage}

PTC is still relied on in questionable cases at our institution. It also allows the prompt drainage of dilated ducts for biliary decompression. The technique is relatively simple in principle but may be difficult and will not be described in detail here.

If after a diagnostic PTC, a guidewire cannot be easily advanced through the obstruction, an external drainage catheter is placed to allow biliary decompression. Extensive initial manipulation can result in the rapid onset of sepsis and should not be pursued. After the biliary tract has drained for a couple of days, advancement through the obstruction can be reattempted with increased chance of success and decreased risk of sepsis.

\section*{Bile Duct Obstruction}

Strictures are the most common cause of biliary obstruction. Anastomotic strictures are often related to scarring and fibrosis at the surgical anastomosis. Non-anastomotic strictures can result from prolonged cold ischemia, vascular insufficiency from HAS, or HAV, and is also linked to cytomegalovirus infection.\textsuperscript{211–213} Strictures may also be secondary to recurrence of primary biliary tract lesions such as from cholangiocarcinoma\textsuperscript{214} and primary sclerosing cholangitis (Fig. 12).\textsuperscript{215}

Mild narrowing at the surgical anastomosis may be secondary to ductal size mismatch and should be differentiated by free drainage into the small bowel. If during PTC the intrahepatic ducts are dilated despite some drainage into the small bowel, an empiric trial of biliary catheter drainage may be pursued to look for improvement in liver enzyme levels. If liver function improves after biliary drainage and a focal lesion is identified on follow-up cholangiography, percutaneous treatment with balloon dilation (BD) can be pursued (Fig. 13). At our institution we usually perform up to 3 sets of serial BDs spread over 1 to 2 weeks for a total of 30 minutes of balloon inflation per session. A drainage catheter is left in place across the narrowing and the patient returns after several weeks for a follow-up cholangiogram. If satisfactory results are seen, the catheter can be removed or the trial extended by placing the catheter above the site of BD. Surgical revision may be pursued in those patients who do not respond to percutaneous BD. Chronic catheters may be left in place in patients who are poor surgical candidates; such catheters may need to be changed every 6 to 12 weeks as tolerated.

Previous published reports from our institution demonstrate 80\% patency at 6 months, decreasing to 60\% at 5 years in 72 patients.\textsuperscript{216} Generally higher rates of surgical intervention are needed in the pediatric population. The presence of a Roux-en-Y loop makes endoscopic retrograde cholangiopancreatography nearly impossible. Percutaneous BD of strictures has been successfully described in the pediatric and living related liver donor transplantation.\textsuperscript{217,218} In fact, Lorenz et al.\textsuperscript{217} recently described 58\% patency of biliary-en-
teric anastomosis 1 yr after BD. Higher patency rates may be achieved after BD in patients with patent hepatic arteries.219

Newer balloons with attached microsurgical blades, the so-called “cutting balloons,” have been used to treat resistant biliary strictures with some success. Further work in this area may prove these balloons to be more superior than standard high pressure balloons alone;
but with 50% restenosis rates at 6 months. However, the risks of biliary leaks has not been established.

Percutaneous metallic stent placement for failed balloon dilation of benign strictures has been described previously. Culp et al. described the placement of 61 metallic stents in 36 LT recipients resistant to BD. Their primary patency was 44% at 3 years and 0% at 5 years; secondary patency with reintervention resulted in 88% patency at 5 years. The presence of metallic stents in the biliary tree may also pose a technical challenge for future retransplantation. The use of temporary, retrievable, covered stent grafts in the biliary tree for such resistant stenosis has been reported with 50% restenosis rates at 6 months. However, as stent graft technology improves, this avenue may prove to be of further value.

Malfunctioning T-tubes or indwelling surgically placed plastic stents can also contribute to biliary obstruction. Once the suture is resorbed, the plastic stents usually migrate into the bowel and are excreted. An occluded stent may lodge at the anastomosis or even the cystic duct remnant, resulting in biliary obstruction. Such stents may be snared percutaneously or endoscopically.

Biliary stones can sometimes be missed during LT or form subsequently, leading to biliary obstruction. The prevalence of bile duct filling defects post-LT has been reported to be 5.7% from our institution. A total of 34% represented stones, 56% were sludge or biliary cast, and 10% were necrotic debris. Endoscopic retrograde cholangiopancreatography may be difficult or impossible to perform in those patients with a Roux loop. Stone fragments can be dealt with in IR by using a Dormia basket for retrieval, or can be advanced into the small bowel after balloon dilating the biliary tract ahead of it.

### Bile Leaks

Bile leaks may be seen in 10 to 15% of LT recipients. Many of them may be asymptomatic and detected on protocol cholangiography as seen in minor T-tube leaks. These may be best followed up with repeat cholangiography to confirm closure. However, bile peritonitis, sepsis, and loculated bilomas may result. PTC and biliary drainage in the face of nondilated ducts is possible but challenging and may provide the only nonsurgical option. Noninvasive imaging with CT and US can easily identify biliary collections and these can be percutaneously drained if needed. Sheng et al. reported bile leaks in 4.3% of 1,363 transplants at our institution. A total of 36% occurred at the biliary anastomosis (95% choledochojejunostomy, 5% choledochocholedochostomy); 36% were seen at the T-tube exit sites and 22% were seen intrahepatically, secondary to biliary necrosis.

Nonanastomotic leaks and leaks secondary to biliary necrosis from HAT are more ominous and although PTC may temporize these patients retransplantation is often needed.

### CONCLUSION

Advances in the field of percutaneous endovascular techniques have progressively increased the importance of the IR in the management of LT patients. The IR should be considered a vital member of the transplantation team, immediately available for consultation, who can help manage pre- and postoperative problems often seen exclusively in this patient population. The timely and judicious use of percutaneous diagnostic and interventional procedures can help decrease patient morbidity and mortality, increase graft survival, and preserve or improve allograft function.

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