Interventional Radiology in the Treatment of the Complications of Organ Transplant in the Pediatric Population—Part 2: The Liver

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ABSTRACT

Organ transplantation continues to grow in demand in the pediatric population. The liver is the second most common organ that is transplanted in the pediatric population, but it results in the greatest number of interventional procedures. Transplant continues to be the preferred treatment for end-stage liver failure in children and has been shown to prolong life. There are several significant differences in liver transplantation between adults and children. They include different indications and diseases leading to transplant, the smaller body size of children, and differences in the surgical techniques used to implant the liver. These differences have led to a set of complications that is unique to or is more frequently seen in the transplanted child. The complications require interventional solutions tailored to the special needs of children. This paper will examine the complications that are encountered and the technical challenges that the interventionalist must address to successfully treat this subgroup of children. The purpose of this paper is to present the techniques and “pearls” that we have found to be helpful in treating this group of patients that in many ways is the most challenging in all of pediatric intervention.

KEYWORDS: Pediatric transplant, transplant complications, interventional radiology, interventional technique, liver transplant

Objectives: Upon completion of this article, the reader should be able to (1) discuss the differences between pediatric and adult liver transplant, (2) summarize the main complications of pediatric liver transplantation, and (3) describe the interventional procedures used to treat the complications of pediatric liver transplant.

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Liver transplantation is a safe and effective treatment for children with end stage liver disease and is now the standard of care for this subset of children. After the kidneys, the liver is the second most transplanted organ in children. There were 546 liver

transplants performed in children in the United States in 2003.¹ Of all the organs that are commonly transplanted, the liver most frequently has complications that require open surgical or minimally invasive therapies. In addition, hepatobiliary interventions are among the most

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technically challenging of all pediatric interventional procedures. There are five main anastomoses in the liver transplant: the hepatic artery, the portal vein, the inferior vena cava, the common bile duct, and the roux-en-Y. Each of these anastomotic sites can be associated with adverse events.

The recently popularized split liver transplant technique has increased the number of livers available to children and has led to a change in many of the interventional procedures. The interventional procedures performed after a liver transplant can be broken down into three main categories: biopsies, biliary, and vascular interventions; each of which will be discussed in detail in this paper.

There are many differences in the management of the pediatric patient compared with the adult. The knowledge of these differences can assist the operator in the safe delivery of patient care. These considerations are similar to many of the procedures performed in other organs and are stated in the general considerations section of part 1 of this series to avoid repetition.

BIOPSIES

The liver biopsy is critical in the diagnosis and management of liver disease both before and after transplantation. Over the past decade, technical modifications of the standard biopsy techniques have been developed to circumvent the relative contraindications of the standard percutaneous liver biopsy. These contraindications include ascites, an uncorrectable coagulopathy, and small or segmental livers that are not in contact with parietal peritoneum. These modified techniques, including percutaneous biopsy with track embolization and the transjugular liver biopsy, are often used in children.

Percutaneous Liver Biopsy with Track Embolization

In our practice, a percutaneous liver biopsy with track embolization is performed in a child with an increased risk of bleeding secondary to a mild ($PT < 18$, $PTT < 38$, platelets $< 50,000/mm^3 > 30,000/mm^3$) or correctable coagulopathy. This technique can be used with either a right- or left-lobe approach. It is not used when the liver is not in contact with the parietal peritoneum, such as with significant ascites and after a segmental liver transplant (unless the left lobe is approachable), when the platelets are below $30,000/mm^3$, or if there is an uncorrectable coagulopathy.

Technically, this approach to biopsy is similar to the standard liver biopsy except that a co-axial approach is necessary. The right lobe is generally the preferred site of biopsy due to technical ease; however, the left lobe may be used as it is also a safe and effective approach. The procedure is begun after the child is sedated. An

Figure 1 Ultrasound-guided percutaneous liver biopsy performed in a 16-month-old female to evaluate for rejection. A 16-gauge needle was inserted in the liver parenchyma using ultrasound guidance. An 18-gauge needle was then inserted co-axially and one to three biopsy specimens were obtained. At the conclusion of the procedure, the track was embolized with Gelfoam pledgets.

ultrasound is performed and a site for biopsy is selected between the anterior and mid-axillary line. Under real-time ultrasound guidance, a 16-gauge needle is inserted into the liver avoiding major vessels (Fig. 1). An 18-gauge needle is then inserted co-axially, and between one and three biopsy specimens are obtained. We prefer to limit the biopsy to three or fewer passes at any one location to minimize potential complications.² Once the specimens have been obtained, the biopsy needle is removed leaving the 16-gauge guide needle in place. Gelfoam pledgets, Avitine slurry or coils are then inserted into the tract to the level of the liver capsule as the guide needle is slowly withdrawn.

After the procedure is completed, an ultrasound and chest radiograph is performed to identify complications such as active bleeding, hematoma, pneumothorax, or hemothorax.

Transjugular Liver Biopsy

The first transjugular liver biopsy was performed in 1967 by Hanafec.³ Continued experience in adults and children has shown that the transjugular approach is a safe and effective biopsy technique that allows for the diagnosis and monitoring of severely ill patients with liver failure.^{3,4,5,6,7,8} The advantage of the transvenous liver biopsy in high-risk children is that, provided the liver capsule remains intact, bleeding will either remain localized to the tissue around the biopsy site or track back into the hepatic vein. Thus, this approach can be performed in even the sickest children as long as their vital signs are stable pre-procedurally.

The transjugular approach is increasingly used in children after liver transplantation and is chosen any time the percutaneous approach is contraindicated such as in children with an uncorrectable coagulopathy, massive

ascites, or a segmental liver transplant. Contraindications of the transjugular approach include an unstable patient and occlusion in any of the veins in the catheter's expected path. It is important to remember that while it is possible to utilize the left internal jugular vein as an access route in adults and larger children, this is not the case in children smaller than 10 to 20 kg. In this subgroup of children, the angle of the left jugular vein to the superior vena cava is such that there is substantial deformity of the inflow veins. In addition, there is a steep lateral angulation at the level of the hepatic vein that makes this approach potentially dangerous.

Using ultrasound guidance, an 18-gauge needle is inserted into the internal jugular vein (Fig. 2A). A guide wire is placed and advanced to the right atrium or inferior vena cava under fluoroscopy. The needle is then removed and in older children a 7 or 9F introducer with hemostasis valve is placed. In smaller children, the sheath is often not inserted because of the size of the internal jugular vein. A 5F directional catheter is then

introduced. Under fluoroscopy, the guide wire and catheter are advanced into the right or middle hepatic vein (Fig. 2B). The catheter is exchanged for a 7 or 9F long vascular sheath and placed with its tip about two to three centimeters into the hepatic vein. A 5F diagnostic catheter is placed within the sheath and advanced distally into the hepatic vein and a hepatic venogram is performed (Fig. 2C). Free and wedged hepatic venous pressure measurements and a wedged hepatic venogram can be performed depending on the patient's needs and operator preference. After the hepatic venogram, the diagnostic catheter is removed and a 7F-angled metal cannula is placed approximately three centimeters into the selected hepatic vein. An 18-gauge long biopsy needle inserted through this metal sheath and one or two biopsy specimens are obtained (Fig. 2D). Again, the number of passes is limited to three or less in any one location in an attempt to minimize complications. It is important to remember that the needle needs to be thrust into the liver parenchyma using a short, forward

Figure 2 Transjugular liver biopsy in a 12-year-old female with liver failure, portal hypertension and uncorrectable coagulopathy. (A) A standard transjugular biopsy set (Cook Inc., Bloomington, IN). (B) Long sheath in the middle hepatic vein. (C) Hepatic venogram showing a normal middle hepatic vein. (D) The biopsy needle deployed before obtaining a liver specimen.

motion to exit from the elastic hepatic vein. Once through the venous wall, the needle should not be advanced more than a few millimeters. This will minimize the risk for capsular perforation and bleeding or injury to adjacent organs. Although we prefer to direct the biopsy anteriorly, some pediatric interventionalists prefer a posterior direction guided by intra-procedural ultrasound. A post-biopsy venogram is performed prior to the removal of the vascular sheath in an attempt to identify capsular perforation – a complication that can occur in up to 3.5% of cases.⁸ If the capsule is perforated and the bleeding site is identified, tract embolization can be performed. A post-biopsy chest radiograph is taken to exclude both a pneumothorax and a hemothorax.

If the transjugular approach is not possible, a transfemoral biopsy can be considered. This technique offers several advantages to the transjugular method: there is no risk of arrhythmias, there is a decreased risk of capsular perforation, and a greater number of specimens can be obtained. The major disadvantage of this technique is that the biopsy specimens are smaller and access to the hepatic vein is challenging, especially in smaller children. As a result, this approach is rarely utilized. The main technical difference, besides the access site, is that forceps are used to obtain the biopsy instead of an automated tru-cut type biopsy needle.

BILIARY INTERVENTIONS

The biliary anastomosis has been called the “Achilles heel of liver transplantation.”⁹ Biliary tract complications continue to be a common source of morbidity and mortality after liver transplant with an incidence estimated to be ~13 to 30%.^{10,11} The most common complications are bile leaks and anastomotic strictures. Risks for biliary complications include the patient being less than 10 kg, hepatic artery thrombosis, ABO transplant incompatibility, partial organ transplant, and cytomegalovirus infection.^{10,12,13}

Percutaneous Transhepatic Cholangiography

Intrahepatic bile ducts may not be dilated in pediatric patients even when they are obstructed, making traditional imaging studies misleading. Since most pediatric liver transplants are performed using a Roux-en-Y biliary-enteric anastomosis, endoscopic retrograde cholangiopancreatography (ERCP) is not possible. In addition, a T-tube is not often used at the biliary anastomosis because in children, a choledochojunostomy is used for biliary drainage instead of a choledochocholedochostomy. Because of these differences, a percutaneous transhepatic cholangiography (PTC) is the method of choice to evaluate the biliary system.

PTC was first described in 1921,¹⁴ but it was not until 1974 that the modern, thin-needle technique was

first described.¹⁵ This technique not only allowed the PTC to move out of the operating room, but it also significantly decreased the complication rate.

Due to the nonspecific nature of symptoms of post-transplant biliary complications, there are several indications for PTC, the most common of which is an elevation of the patient's liver enzymes. Other indications can include fever, sepsis, and bile leak. Relative contraindications of the procedure include ascites, a vascular tumor, or a previously documented anaphylactic reaction to iodinated contrast. Ascites reduces the tamponade effect of the abdominal wall on the liver and makes the propensity for hemorrhage more likely. Therefore, whenever possible, ascites is drained prior to PTC. If the ascites cannot be drained, the procedure is most often postponed.

The patient is placed on broad-spectrum antibiotics, usually ampicillin and gentamycin, two to four hours prior to the start of the PTC. The procedure is either performed under general anesthesia or intravenous sedation depending on the likelihood of further intervention. The patient is placed in the supine position with the right arm abducted. The needle is inserted under fluoroscopy just anterior to the mid-axillary line between the seventh and tenth ribs and parallel to both the table and the inferior edge of the liver and approximately one-third of the distance from the caudal edge of the liver. The puncture is performed just above the superior edge of the rib to avoid the intercostal vessels running along the inferior margin. It should be noted that the pleural reflection extends as low as the tenth rib in the mid-axillary line and therefore if this site is selected, the puncture may be transpleural.

Under fluoroscopy, with suspended respiration (if possible), a 22-gauge Chiba needle is inserted in one steady motion. The needle is inserted until its tip is just lateral to the spine. At this time, a syringe of non-ionic contrast is attached to the needle via flexible tubing. The needle is then slowly withdrawn as contrast is injected. When the bile ducts opacify, spot fluoroscopic views are obtained (Fig. 3A). The bile ducts are identified by the slow movement of contrast toward the hilum and the branching pattern. If no ducts are opacified, and the needle reaches the edge of the liver, the needle should again be inserted in a manner fanning out from the first pass. In general, we limit ourselves to 20 passes before considering the procedure unsuccessful. The needle should not be removed from the liver capsule, as multiple punctures of the capsule can increase the risk of post-biopsy bleeding. After the procedure, the patient is kept at bed rest for four to six hours with his or her right side down. A chest radiograph and post-procedure hemoglobin and hematocrit are obtained.

An alternate technique should be used in patients who have received a segmental liver transplant. In this case, the liver should be punctured using an anterior,

Figure 3 Percutaneous transhepatic biliary dilation and drain placement. (A) A percutaneous transhepatic cholangiogram was performed. There is a stricture in the common bile duct. (B) Percutaneous transluminal angioplasty was performed at the site of the stricture. (C) After balloon dilation, the stricture was no longer seen and a biliary drain was placed.

sub-xiphoid approach as the cut edge of the liver abuts the right abdominal wall. Using this technique, the needle is inserted just below the xiphoid and aimed toward the right side at an angle between 30 and 40 degrees. The main disadvantage to this approach is that the fluoroscopist's hands are in the X-ray beam. Hand exposure can be minimized using instruments, intermittent fluoroscopy, pulsed fluoroscopic units, and via angulation of the X-ray source.

The success rate of PTC is often dependent on whether the bile ducts are dilated. In adults, the success rate of biliary opacification has been reported to be 99% with ductal dilatation and 60 to 80% without dilata-

tion.¹⁶¹⁷ In one retrospective study of 120 PTCs in children after liver transplant, the overall success rate of opacifying the biliary tree was reported to be 96%.¹¹ When the population was subdivided into dilated and nondilated ducts, the success rate is still quite high with 100% and 92% opacification, respectively.¹¹ The success reported in this study may be due either to the adjunct use of ultrasound in locating bile ducts or performing as many as 25 passes with up to five punctures. This is not a common experience. Many interventionalists have difficulty opacifying non-dilated ducts and report failure rates exceeding 25%. The success in this study was countered with an increased incidence of complications

of 12.5%.¹¹ This incidence is compared with a large study of almost 3600 patients, which reported a 3.28% complication rate.¹⁶ The complications of PTC include sepsis, bile leak, intraperitoneal hemorrhage, pneumothorax, and hepatic arteriovenous fistulas.

Percutaneous Biliary Drainage

Due to the risk of infection, any biliary obstruction should be decompressed. The most common complications of pediatric liver transplant are strictures and bile leaks. The placement of biliary drainage catheters is often the initial treatment used for these complications.

There are multiple causes of biliary strictures, including ischemia, infection, rejection, or a direct relation to the surgical anastomosis. Bile leaks generally occur within the first two weeks after transplant at either the anastomotic site or along the free liver edge.

Biliary drainage is among the most technically difficult procedures in pediatric intervention. Biliary drainage is initiated with a PTC. When bile leaks or strictures are diagnosed via PTC, a biliary drainage catheter is placed using one of two techniques. In the single-stick technique, the primary puncture site is used for both PTC and drain placement. The single-stick approach is used whenever possible. The disadvantage of this technique is that the primary puncture site may be within a duct that is not suitable for drainage due to its size, location, or angle with the bile duct. In this situation, the double-stick technique is used. A cholangiogram is performed with the primary puncture site. This allows an appropriate bile duct to be selected for drainage. The duct is accessed via a second puncture and a guide wire is inserted into the biliary tree. Once the guide wire is in a stable position, the track is dilated and a 5 to 8F biliary drainage catheter is placed. Once the catheter is in position, a cholangiogram is performed to confirm its location (Fig. 3C). If a stricture exists it may require dilation before a drainage catheter can be positioned. If PTA is needed, the catheter should have its side holes positioned both proximally and distally to the stricture. However, regardless of the technique used, it is technically challenging to direct the guide wire past the stricture and then dilate the track over the 0.018" guide wire that must be used with a Chiba needle. In small children, it is often difficult to pass a dilator through the liver parenchyma into a biliary radical. This is due to the difference between the resistance of the liver and the biliary radical as well as the angle of entry. To overcome this problem, a transitional dilator system that allows the subsequent insertion of a 0.035" to 0.038" wire and provides enough pushing power to overcome this obstacle is used in most situations.

Complications of percutaneous biliary drainage may be either acute or delayed in onset. Acute complications occur in 5 to 10% of patients and include sepsis,

hemorrhage, bile leak, pneumothorax, hemothorax, and biliary-pleural fistula. In general, the best protection against acute complications is the placement of a stable drainage catheter achieved via firm securement. Adequate drainage will decrease the risk of cholangitis and bile leak, while hemorrhage and pleural complications are less likely if the tract is tamponaded by the indwelling catheter.

Delayed complications are more likely the longer the biliary catheter is left in place. The most common delayed complications are related to catheter malfunction, including blockage or migration, and can be treated with either catheter repositioning or exchange. Delayed hemorrhage is an uncommon complication.

Percutaneous Transhepatic Biliary Dilation

Biliary dilation is another method used to treat strictures. Percutaneous biliary dilation was first described in 1975¹⁸ and has been shown to be relatively safe in adults with a morbidity of 10 to 20% and a mortality of less than 1%.¹⁹ There are currently no large series in children describing the success rates of this procedure; however, in our experience, the morbidity is less than 10% with 0% mortality.

Usually, biliary dilation procedures are performed two to five days after a biliary drainage catheter has been placed, allowing the biliary tree to decompress and inflammation to subside. Biliary dilation is a painful procedure and general anesthesia is often used.

After the patient is prepared, an angled guidewire is placed into the distal biliary tree or roux loop via the biliary drain. The drainage catheter is then exchanged for a vascular sheath with a sidearm. A second guide wire (safety wire) is placed to provide rapid access if the sheath is dislodged. A cholangiogram is performed through the side-arm and the stricture is located (Fig. 3A). It is important at this time to measure the diameter of the bile duct both proximal and distal to the stricture as well as the stricture site itself and select a balloon size corresponding to the ductal measurements. It is our preference to use a 5F high pressure PTA catheter system that facilitates entry into the biliary tree. The balloon is inflated while monitoring the pressure with a gauge. The waist of the stricture should disappear with the expansion of the balloon (Fig. B, C). In general, the balloon is inflated for at least five minutes per inflation; for more resistant strictures, the balloon may remain inflated for up to 30 minutes.

The child is brought back for a repeat cholangiogram after four weeks. If a residual stricture is seen, the dilation is repeated and a new drain is placed. This process is repeated every 8 to 12 weeks until no residual obstruction is seen. When removal of the biliary stent is contemplated, the drain is repositioned proximal to the stricture and clamped for two to four weeks, at which

time another cholangiogram is performed. If no obstruction is noted at this time, the drain is removed. It is not uncommon for the drainage catheter to be required for four to six months or longer.

While metallic biliary stenting is common in the adult population, it is not performed in children. There have been no studies beyond case reports detailing the safety of biliary stenting in children. The potential complications as well as the lack of long-term results in growing children suggest that stent placement should be used as a last resort to maintain biliary patency and should be contraindicated if it will interfere with re-transplantation.

VASCULAR INTERVENTIONS: ARTERIAL

Hepatic artery complications are a common cause of morbidity and mortality after liver transplant. Complications such as hepatic artery stenosis and thrombosis can often lead to re-transplant and, if untreated, death. Fortunately, the hepatic artery is easily accessible via angiography and interventions exist that are curative or able to bridge the patient to re-transplantation.

Hepatic Arteriography with Percutaneous Transluminal Angioplasty

Hepatic artery thrombosis is the most frequent vascular complication after liver transplant. It has been observed to occur more frequently in children than adults with a frequency ranging from 6 to 38%.²⁰ The risks for hepatic artery thrombosis include children younger than three years old and/or weighing less than 10 kg due to smaller vessel size. Other risks are related to external compression or decreased donor artery size and include increased abdominal pressure, a graft-to-recipient weight ratio greater than 5%, or grafts from donors younger than three years old or weighing less than between 6 to 15 kg. The final group of risk factors involves processes that damage the artery, make the blood more likely to thrombose (such as prolonged cold ischemia time, increased use of fresh frozen plasma, hemoconcentration, low flow states, hypercoagulability), or rejection.²⁰ Hepatic artery thrombosis has a variable presentation. Because the biliary system viability depends on hepatic arterial flow, most of the complications arise from biliary ischemia and include bile leaks, cholangitis, strictures, and abscesses related to duct necrosis.

In general, hepatic artery thrombosis is treated with re-transplantation. In children, the graft may remain viable due to the formation of collateral vessels. Although there have been several reported cases of the successful use of thrombolysis to treat hepatic artery thrombosis in adults, its use in pediatrics has been limited. The use of thrombolytics is often contraindicated due to its close temporal relationship to surgery and the increased risk of hemorrhage.

Hepatic artery stenosis occurs less frequently than hepatic artery thrombosis and commonly occurs at the level of the anastomosis. It is usually related to operative technique,²¹²²²³²⁴ while intrahepatic stenoses may indicate rejection or hepatic necrosis.²⁵²⁶ HAS generally occurs within the first three months after transplant and can be clinically significant and lead to graft failure. The diagnosis of hepatic artery stenosis is important because pre-emptive intervention prevents hepatic arterial thrombosis.

HAS is generally diagnosed with ultrasound. If the stenosis is detected in the immediate post-operative period, it is usually related to technical problems that require surgical intervention. Outside of the peri-operative period, HAS can be treated with PTA. There are no absolute contraindications to performing hepatic angiography, but relative contraindications exist and include an uncorrectable coagulopathy and unstable vital signs. The complications of hepatic artery PTA include intimal dissection, spasm, or rupture.²⁷ These complications can be minimized by the selection of the correct balloon diameter. The largest study of hepatic artery PTA following liver transplant included 21 adult patients and showed a success rate of 81%.²⁸ There are no large studies exploring the efficacy of PTA in children. In our experience, the treatment of hepatic artery stenosis is reserved for either subacute or chronic strictures. PTA is effective in these selected cases.

Abdominal aortography, celiac and selective hepatic arteriography are performed to characterize the stenosis (Fig. 4A). The hepatic artery segment on either side of the stenosis is measured. An angioplasty balloon is then selected based on these measurements. In children with small hepatic arteries that are further narrowed by stenoses, it is important to cross the lesion atraumatically to avoid intimal injury that will further predispose the artery to thrombosis. We prefer to use a 3 to 5F RC-1 or RIM catheter with a directional guide wire to pass the stricture. The balloon is then inflated to the indicated pressure or until the waist is observed to resolve, whichever occurs first. After angioplasty, a repeat arteriogram and pressure measurement is performed to evaluate the effect of treatment (Fig. 4B). Stenting is rarely considered because of the potential for making re-transplantation more difficult and the lack of published results.

VASCULAR INTERVENTIONS: VENOUS

Venous complications are noted to occur less frequently than do arterial complications. The most common venous complications include portal vein stenosis or thrombosis, inferior vena cava stenosis or thrombosis, and arteriportal fistulas. There are multiple ways to access and image the hepatic venous system, including the transhepatic, transjugular, and transfemoral approaches.

Figure 4 A 12-year-old boy after liver transplant with elevated liver enzymes and sonographic suggestion of hepatic artery stenosis. (A) Selective hepatic artery injection demonstrates a proximal hepatic artery stenosis (arrows). (B) An excellent result after PTA is seen with a near normal hepatic artery.

Hepatic Venography

The most common indication for hepatic venography after liver transplant is to evaluate for stricture or thrombosis. Hepatic venous complications are rare in adults because there is not usually an anastomosis between hepatic veins; the anastomosis is at the inferior vena cava. However, because of the more frequent use of the split liver and living donor techniques in children, a hepatic venous anastomosis is required. Unfortunately, a donor hepatic vein of sufficient length for reconstruction is rarely obtained. This limitation has led to an increased incidence of venous outflow obstruction ranging from 6.7 to 16.6%.²⁹ When outflow obstruction is seen in the early post-operative period, technical factors, such as a tight anastomosis, donor-recipient size discrepancy, kinking of a redundant hepatic vein, or caval compression from a large graft, are usually to blame.²⁹ When the onset of venous outflow obstruction is delayed, external compression or luminal narrowing is often the culprit.²⁹ Symptoms of hepatic venous stenosis are usually non-specific and can include ascites, hepatomegaly, abnormal liver enzymes, lower extremity edema, and pleural effusions. The treatment of choice for hepatic vein stenosis is hepatic venography with PTA and, when necessary, stent placement.

There are no absolute contraindications of hepatic venography. Either the transjugular or femoral approach may be used for hepatic vein catheterization; however, the jugular vein is most often selected. An ultrasound is performed to select the entry site and to guide needle puncture. At this point, the needle is removed and a vascular sheath followed by a 4 or 5F directional catheter is placed. The directional catheter is positioned in the hepatic vein and a venogram is performed (Fig. 2C). If

needed, selective venography and pressure measurements can be obtained.

If an area of stenosis is seen, the pressure both proximal and distal to the stenosis should be measured. A pressure gradient greater than 3 mm Hg has been reported to be hemodynamically significant. Clinical symptoms usually develop when the gradient is greater than 5 to 6 mm Hg.²⁹ If the pressure gradient is great enough and, more importantly, if the patient is symptomatic, dilatation of the stenosis should be performed using a high-pressure angioplasty balloon. If PTA is to be performed, an appropriately sized balloon, usually 5F with an 8 to 12 mm balloon, is inflated under fluoroscopy and the area of stenosis is treated. Inadequate or ineffective dilatation is suggested when the post dilatation venogram shows residual stenosis. If the stricture is resistant to dilatation, stenting, with or without a cutting balloon pre-treatment, may be considered. Using angioplasty alone, there is a high re-stenosis rate. Therefore, because of the high failure rate of angioplasty, stent placement is considered a viable alternative. Unfortunately, there is limited experience in both adults and children documenting whether stenting is the ideal next step.

Stents have not traditionally been used in children for two reasons. First, stented vessels are susceptible to intimal hyperplasia, which can lead to luminal narrowing or occlusion over time. Second, as children grow, the stent's fixed diameter may make it a future area of stenosis. This reasoning has recently been called into question. Because angioplasty has a high failure or re-stenosis rate, it is unlikely that stents will fail more often. In addition, because most livers in pediatric patients come from adults, the size of their hepatic veins is as

large as those of an adult.²⁹ Despite these arguments, there have been only case reports touting the efficacy of hepatic vein stenting in children.²⁹

When needed, the stents that have been used most frequently are the Palmaz® and Wallstent®. The stent selected is usually one to two millimeters greater than the measured normal venous lumen. This helps prevent stent migration. The stent is advanced so it is centered over the area of stenosis where it is then expanded using a balloon catheter.

After completion of either PTA or stent placement, another hepatic venogram is performed and the pressure gradient is again measured. If the pressure gradient is less than 6 mm Hg, the procedure is considered complete. If the gradient is greater than 6 mm Hg, further dilatation may be performed.

Transjugular Intrahepatic Portosystemic Shunt

In adults, the transjugular intrahepatic portosystemic shunt (TIPS) procedure has been widely used to treat complications of portal hypertension, most notably gastrointestinal bleeding and intractable ascites. In children, there is very little published experience of this procedure. TIPS placement has the potential to be useful in children with portal hypertension who have significant gastrointestinal bleeding despite multiple attempts at sclerotherapy or intractable ascites. While the TIPS procedure is not used to treat a complication of transplant, it is used in the same patient population and it deserves mention herein as an interventional bridge to transplant.

The major advantage of the TIPS procedure over repeat sclerotherapy or surgical shunting is the avoidance of a major surgical procedure and its associated morbidity in an unstable, coagulopathic patient. The main contraindication in performing the TIPS procedure is the lack of access to the venous system from the right internal jugular vein to the portal vein.

After the patient is prepared in the usual manner, the right internal jugular vein is cannulated in the same manner as the transjugular liver biopsy. The standard Colapinto set is utilized for most children. However, for small children and those who require a left neck approach, it is necessary to use a more flexible set like the Ring set. Unfortunately, these children may not be a candidate for the procedure because of the anatomic limitations of a left jugular approach. A short vascular sheath with a hemostasis valve is placed in the neck and a 5F directional catheter is advanced into the right atrium and then into the right hepatic vein. Pressure measurements are obtained in both the right atrium and the hepatic vein. The right hepatic vein is selected because it tends to be the largest of the three hepatic veins and has the most optimal orientation to the right portal vein. After the position in the right hepatic vein is confirmed

via venography, a long sheath is advanced into the hepatic vein. The puncture of the portal vein is the most challenging aspect of the procedure especially in small children. Although blind puncture of the portal vein is often performed, over time there has been more interest in methods to identify the location of the portal vein. Guidance methods that we have found successful include intra-procedural ultrasound, wedged hepatic vein venography and wedged hepatic vein carbon dioxide injection. A directional metal guiding cannula with a 16-gauge Colapinto needle is advanced to the proximal right hepatic vein. The guiding cannula is directed both cephalad and anteriorly and the needle is inserted 3 to 5 cm into the liver using a sharp thrust. As the needle is slowly withdrawn, suction is applied via a contrast-filled syringe. Once blood is aspirated, contrast is injected to confirm the position within the portal vein. A stiff guide wire is then advanced through the needle into the portal vein. The needle is removed and an angiographic catheter is placed and pressure measurements are obtained in the main portal vein. In older children, the angiographic catheter is then exchanged for a 5F, 8 mm × 4 cm balloon, while in younger children, a 6 mm balloon is favored. The balloon catheter is used to dilate the intra-parenchymal tract (Fig. 5A) after which an appropriately sized metallic Wallstent® is placed bridging the hepatic and portal veins. With ideal stent placement, there should be at least one centimeter of stent above the entry site in the hepatic vein and below the parenchymal tract within the portal vein. The stent should not protrude into the inferior vena cava or extrahepatic portal vein, as this could interfere with future transplant. A portal venogram and pressure measurements in the portal vein and right atrium (Fig. B, C, D) are again obtained. The goal of the TIPS procedure is to reduce the pressure gradient between the right atrium and portal vein below 12 cm H₂O and cause the redirection of blood flow, thus preventing the varices from filling. If varices persist, they are embolized.

The main technical differences between adults and children in the TIPS procedure are related to the size of the patient. In children, more acute angles are needed in the Colapinto needle guiding sheath; the distances between intra-hepatic structures and the length of the intra-parenchymal tract are shorter. Furthermore, the diameter of the involved vessels is less, thus requiring shorter and smaller stents.

In adults complications occur in ~10% of patients³⁰ and include hepatic artery injury, portal venous rupture, splenoportal venous thrombosis, biliary duct puncture, and hemoperitoneum. Complications can be related to the stent and include either acute or delayed stenosis or occlusion, stent dislodgement or migration. Hepatic encephalopathy is a frequent complication that occurs in 5 to 35% of patients as a result of portocaval shunting.³¹

Figure 5 TIPS: A 7-year-old male with cystic fibrosis and severe portal hypertension. (A) A 6 mm PTA balloon was seen within the parenchymal track after the puncture of the portal vein via the hepatic vein. (B) The portal vein was injected with contrast and gastric varices are seen. (C) Selective coil embolization of the multiple varices. (D) Contrast injection demonstrating a patent stent creating the TIPS anastomosis and no variceal filling.

There have been several small studies reporting the efficacy of the TIPS procedure in children. A meta-analysis suggested that the success of TIPS in children is comparable to that of adults and ranges from 75 to 90%.³² The complication rate among pediatric patients is similar to the adult rate, with the exception of a decreased incidence of encephalopathy. The most common complication in children is extra-hepatic puncture.

Portal Venography

Portal vein stenosis and thrombosis are uncommon complications of liver transplant in adults. Prior to the reduced-size liver transplant era, they were also uncommon in children, occurring in less than 0.6% of pa-

tients.³³ However, in the era of reduced-size liver transplants, the incidence of portal vein stenosis has been reported to be as high as 19%.³⁴ The increased incidence in children with split liver transplants has been attributed to several factors. Because of the geometric orientation of the graft in the recipient, the portal vein anastomosis is under tension. In the past, this led to an increased incidence of early portal vein thrombosis. In an effort to alleviate the tension, an interposition graft was placed at the anastomosis site. While this solved the problem of early portal vein complications, an increased occurrence of portal vein stenosis was seen. More recently, the use of a portal vein conduit has been discontinued and the incidence of portal vein stenosis has decreased to 6%.³⁵

Figure 6 Portal venography performed in a three-month-old female with a history of liver failure due to short gut syndrome. (A) After injection of 0.67 mg/kg of papaverine in the celiac axis, an indirect portal venogram was performed by injecting contrast into the splenic artery. The splenic artery (*) and spleen (S) are visualized. (B) Delayed phase imaging shows opacification of the splenic vein as well as the diminutive, transplanted portal vein.

Symptoms of portal vein stenosis are variable and can include the sequelae of portal hypertension (ascites, splenomegaly, variceal or gastrointestinal tract bleeding) and elevated liver enzymes.³⁶ Portal vein stenosis is often diagnosed via ultrasound. If portal vein stenosis is suggested, portal venography is performed. There are several different technical approaches that can be used to evaluate the portal vein: arterial (or indirect) portography, splenoportography, or transhepatic (or direct) portography. Both indirect and direct portography will be discussed.

If portal vein stenosis is suspected, the diagnosis should be confirmed via angiography before treatment. A 4F or 5F RC-1, cobra, or RIM catheter is used to select the superior mesenteric artery via a femoral artery access. Once the SMA is selected, papaverine (0.75 to 1.0 mg/kg, to a maximum of 45 mg) is injected intra-arterially three to five minutes before contrast administration to produce vasodilation and increase portal venous blood flow. Contrast is injected over the course of five to seven seconds, and images are obtained until the portal vein is opacified, which usually takes less than 30 seconds (Fig. 6A, B). If further evaluation of the portal vein is needed, the celiac axis can be accessed and a sub-selective splenic artery injection can be performed. The contrast volume utilized depends on the size of the child and the velocity of blood flow. We have found that in small children, an injection rate of 2 to 3 mL/second for five seconds is usually appropriate. In older, larger children, an injection rate of 5 mL/second for five seconds is a good starting point. If portal vein stenosis

is confirmed, percutaneous venoplasty should be performed.

With the child supine and the right arm abducted, ultrasound of the liver is performed to discern the most direct route to the portal vein. Because most patients with portal vein stenosis have a split liver graft, the subxiphoid approach is more commonly used. Under real-time ultrasound guidance, a 22-gauge Chiba needle or a 4 or 5F sheathed needle is used to puncture the intrahepatic portal vein. When a Chiba needle is used, a co-axial introducer is needed to dilate the track so that the 0.018" guide wire can be exchanged for a 0.035" or 0.038" guide wire. If a sheathed needle is used, the larger guide wire can be inserted directly.

Once the needle is seen within the vein, contrast is injected to confirm the needle position. The location in the portal vein can be confirmed by contrast moving rapidly to the periphery of the liver. Now the track is dilated and a vascular sheath may be advanced into the main portal vein. A portal venogram is obtained and both the area of stenosis and a pressure gradient are ascertained. The portal venogram is followed by dilatation using an appropriately sized angioplasty balloon. If a pressure gradient of 5 mm Hg or greater exists, the area can either be re-dilated or a metallic stent can be placed.

The early, mid-, and long-term results of portal vein angioplasty and stent placement have been reported from a single series.^{34,37,38} Early success with angioplasty possibly followed by stent placement was seen in all patients with portal vein stenosis. Half of the patients that had angioplasty alone required a second intervention

for recurrent stenosis. If angioplasty failed, a stent was placed. After as long as five years of follow-up, all of the stents remained patent and did not require repeat dilatation. In the instances that the patient required retransplantation, the stent did not impede the surgery.

It should be noted that venoplasty was not successful in patients who had portal vein thrombosis. In these patients, the best non-surgical option may be thrombolysis followed by angioplasty and stent placement. There have been no reports describing portal vein thrombolysis in children; however, in adults, a single case report with two patients exists with excellent results.³⁶

DISCUSSION

The management of children with a liver transplant is challenging. The diagnosis and treatment of complications in these patients offers several unique and technically difficult interventional procedures in both the pre- and post-transplant state. In children with liver transplants there are three possible sites for complications: the arterial and venous systems and the biliary tree. Each anastomosis has the potential to test the interventionist's skill and creativity.

With the split liver technique becoming commonplace, more livers are available to the pediatric population. Consequently, there will be more complications to identify and treat. The increased frequency of transplantation as well as the complexity of the liver transplant makes the knowledge of both the potential complications as well as the minimally invasive techniques essential.

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