Interventional Radiology in the Treatment of the Complications of Organ Transplant in the Pediatric Population—Part 1: The Kidneys, Heart, Lungs, and Intestines

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ABSTRACT

Transplants continue to be the preferred treatment for end-stage organ disease in children. Transplants in children vary from adults due to the different indications and diseases leading to transplant, the smaller body size of children, and the different surgical techniques. These differences have led to a set of complications often seen in the transplanted child as well as interventional solutions tailored to their special needs. This paper will examine each transplanted solid organ (with the exception of the liver) and their associated complications. The interventional technique for each key procedure will be described.

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

Organ transplant is becoming an increasingly popular and life-saving method to treat organ failure. Since 1988, the number of solid organ transplants performed in children has increased from 1,198 to 1,665 in 2003.¹ While the number of transplants has increased, so too has the demand for organs. There are currently 2,218 pediatric patients on the waiting list for an organ transplant.¹

The past 15 years have seen a dramatic change in many of the surgical transplant procedures. Techniques such as the living donor transplant have revolutionized organ procurement. Even with advancements in technique, complications persist. Fortunately, many of these

complications are amenable to treatment with minimally invasive techniques. As a result of the increasing number of interventional procedures and the advances in technology over the last decade, there has been a substantial increase in the number of procedures performed by interventional radiologists on transplant recipients.

The complications and interventional procedures in pediatric patients with organ transplants are, in some circumstances, different than those for adults. These differences are due to multiple factors and include varied surgical techniques, diverse diseases leading to transplantation, different responses to therapies, and smaller sizes of both vessels and ducts. This paper will review

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selected complications and interventional procedures relevant to the kidney, heart, lung and gastrointestinal track while part 2 will focus on the complications of liver transplant.

GENERAL CONSIDERATIONS

There are many differences in the management of the pediatric patient, the knowledge of which will assist the operator in the safe delivery of patient care. These considerations are similar in each of the procedures and are stated here to avoid repetition. In general, there are two absolute contraindications to performing invasive procedures: an unstable patient and an uncorrectable coagulopathy. There are several relative contraindications to performing invasive procedures including a partially corrected coagulopathy, severe anemia and acute or chronic renal failure. For transvenous procedures, however, issues of coagulopathy rarely cause cancellation of the procedure because the risk of severe bleeding is low.

General anesthesia or intravenous conscious sedation is utilized depending on the patient's age and operator comfort level. Children should be made NPO at least six hours prior to the procedure unless it is an infant younger than six months. Infants younger than six months are made NPO two to four hours prior to the procedure. If anything more than a diagnostic study is planned, the patient is placed under general anesthesia.

In the pediatric population, betadine and alcohol are used for skin preparation. Chlorhexidine is used if the child is allergic to or for some other reason betadine cannot be used.

Access to the common femoral artery is obtained using a 19- to 21-gauge needle depending on the size of the child. A vascular sheath with a hemostatic valve is inserted to facilitate repeated arterial entry and to minimize intimal trauma as well as subsequent arterial spasm and thrombosis. Empiric anticoagulation is not used except in infants smaller than 10 kg where the standard dose is 50 units/kg. In small infants (smaller than 10 kg) there is an increased risk of femoral artery thrombosis; therefore, ultrasound guidance for puncture is preferred and careful consideration should be given to the catheter selected and whether or not a vascular sheath is needed to determine the safest approach. For venous access, an ultrasound is performed to select the intended entry site and to guide venipuncture. When the jugular vein is used in younger children, the puncture is often made halfway between the angle of the jaw and the clavicle to avoid the risk of inadvertently passing the needle through the posterior wall of the jugular vein and entering the pleural space. If this occurs in a coagulopathic child, there is an increased risk for an exsanguinating hemothorax that may require a thoracotomy to repair.

Chest radiography should be obtained after thoracic procedures to exclude both a pneumothorax and a hemothorax in the event that there is suspected transgression of the pleura. After major interventions, such as lung or mediastinal biopsy or tracheobronchial PTA, the patient is observed for four to eight hours as needed. For more minor procedures, such as aspiration of a pleural effusion, the patient is placed on bed rest for at least two hours.

Stents have traditionally not been used in children for two reasons. First, stented vessels are susceptible to intimal hyperplasia, which can lead to luminal narrowing or occlusion. Second, as children grow, the stent's fixed diameter may make it a future area of stenosis.

CT, fluoroscopy, and ultrasound can be used to help guide a biopsy. Each modality has advantages and disadvantages, and choosing the correct modality is essential to performing the biopsy safely and easily. CT is the most sensitive modality used and can detect small lesions and give a precise three-dimensional location of the area of interest. The major limitations of CT include the absence of real-time imaging feedback and the overall increased time requirement needed to complete the procedure due to the need for intermittent imaging. Ultrasound is the primary modality used in the abdomen. Besides limiting the radiation dose, ultrasound allows real-time imaging and needle observation. Ultrasound is limited, however, by the biopsy location and does not allow optimal visualization of many locations, including the lungs, GI tract, and other air-filled structures. Ultrasound is also not as sensitive as CT for detecting all lesions. Fluoroscopy is the least frequently used modality for image-guided biopsies. Its primary indication is for large bone lesions.

KIDNEY

The kidney is the most transplanted organ in both adults and children. In 2003, there were 742 kidney transplants performed in children in the United States; of these transplants, 387 were from living donors.¹ The indications for kidney transplant in children are vastly different than those for adults. The most common primary diagnoses leading to transplant in children include obstructive uropathy, hypoplastic/dysplastic kidney disease, focal segmental glomerulonephritis, and reflux nephropathy.²

The potential complications of renal transplantation arise from the key elements of the surgical procedure. There are three main anastomoses in the renal transplant: the renal artery, renal vein, and ureter. Each of these anastomotic sites can be associated with complications.

In recent years, there has been a marked increase in the percentage of living donor allografts in children. In 2003, living donor allografts accounted for 52% of

pediatric transplants.¹ This increased use of living donor allografts is a significant advance and has led to both improved graft outcomes and graft survival rates.

The interventional procedures seen after renal transplant can be divided into vascular and non-vascular interventions.

Vascular Interventions: Arterial

Renal artery complications are a common cause of morbidity and mortality after kidney transplant. Complications such as renal artery stenosis and thrombosis can often lead to re-transplant and, if untreated, death. Fortunately, safe interventions exist that either cure or delay the progression of the disease.

PERCUTANEOUS TRANSLUMINAL ANGIOPLASTY OF THE RENAL ARTERY

Vascular thrombosis is the third leading cause of allograft failure in children behind both chronic and acute rejection, both of which occur in 11.6% of patients.² Children at risk for vascular thrombosis are those who are on dialysis prior to transplant, cadaveric donors younger than five years old, recipients younger than two years old, and those who required retransplantation. An additional cause of allograft failure is transplanted organs with cold ischemia time longer than 24 hours.² The experience of the surgeon is the most important factor in decreasing the incidence of complications as high volume renal transplant centers report rates of vascular thrombosis as low as 2 to 6%.² Renal artery thrombosis is usually not amenable to thrombolytic therapy since it often occurs in the early post-operative period when the surgical incisions and anastomoses are more likely to dehisce.

Renal artery stenosis is another common cause of morbidity following transplant and occurs in 1 to 16% of all recipients.³ Renal artery stenosis, as opposed to thrombosis, is potentially curable. The main symptom of renal artery stenosis is hypertension. Once symptomatic, there are three potential treatment options for children with renal artery stenosis, including primary medical treatment, surgical revascularization, and percutaneous transluminal balloon angioplasty (PTA). Of the three methods, PTA is the current treatment of choice for the primary treatment of significant renal artery narrowing due its low incidence of side effects and its high success rate.

Renal artery stenosis is commonly diagnosed via ultrasonography and both confirmed and treated angiographically (Fig. 1). The procedure is performed under general anesthesia in most settings.

Initially, an abdominal aortogram is performed to assess the proximal portion of the transplanted renal artery, view the renal artery pathology, and help develop a therapeutic plan. Next, a guidewire (frequently a

Figure 1 A six-year-old girl with a renal transplant for medical renal disease. After transplantation her BUN and creatinine became elevated. Angiography demonstrated renal artery stenosis at the anastomotic site (arrows).

glidewire) and directional catheter are used to cross the stenotic segment of the renal artery. Selective contrast injections are performed to characterize the location(s), extent and severity of the stenosis. Significant renal artery stenosis is defined as more than 50% narrowing, significant gradient, and/or collaterals in the presence of clinical symptoms. Pressure gradients are obtained across the lesion pre- and post-angioplasty when feasible. The diameter of the renal artery is measured both proximal and distal to the area of stenosis and an appropriately sized angioplasty balloon is selected. In older children, the size of the balloon is similar to that used in adults. However, in smaller children (< 20 kg), the balloon with the smallest profile and narrowest shaft is preferred. In our practice, we prefer to use small vessel, single or double lumen balloons that are no larger than 5 French. The balloon is inflated to the lowest possible pressure that eliminates the filling defect. The procedure is completed when the pressure gradient is reduced to less than 5mm Hg or there is visual evidence of a near normal luminal diameter.

In most cases stent placement is deferred if possible. However, if a pressure gradient remains after repeated dilations and significant hypertension persists on follow-up, stent placement or possibly treatment with a cutting balloon may be considered. It must be noted that there is currently limited experience with renal artery stenting and the use of cutting balloons in children as a treatment. In general, stenting has been avoided whenever possible since the long-term effects of a stent on a growing renal artery is unknown.

Nonvascular Interventions

Nonvascular interventions are common in children and include the drainage of lymphoceles, perirenal fluid

collections, and abscesses. These interventions are not significantly different than those performed in adults and will not be discussed further.

Percutaneous Nephrostomy

Percutaneous nephrostomy is one of the most frequently performed interventions in the treatment of urinary obstruction and is often the first step of many interventional treatments. Prior to beginning the procedure, a urine analysis with culture is obtained in addition to the standard pre-procedural laboratory tests. If the urine is infected, the patient is treated with antibiotics prior to the procedure.

Most transplants are extra-peritoneal and are located within the iliac fossa. Therefore, the renal pelvis usually faces posteromedially and an anterolateral approach is used to avoid passage through the peritoneal cavity. If the patient has an intraperitoneal transplant, CT guidance may be used to prevent injury to the adjacent bowel.

Ultrasound is used to locate the dilated collecting system and to determine the access trajectory. Trans-renal access to the renal pelvis is obtained via the calyx with real-time ultrasound guidance and the use of either a 21-gauge Chiba needle or 5F sheathed needle (Yeuh needle, Cook Inc., Bloomington, Indiana). Once access is obtained, a guide wire is positioned in the renal pelvis, the track is dilated, and an 8.3F nephrostomy tube is inserted. If the child is less than 10 kg, a 5 or 6F nephrostomy drain is often preferred.

The most common complication following nephrostomy tube insertion is microscopic hematuria, which is often of little clinical significance. Other minor complications include pain, perirenal bleeding, urine extravasation, and local infection. The most serious complications of nephrostomy tube insertion are sepsis and bleeding.

Ureteral Complications

Urologic complications include ureteral obstruction or leaks and occur in 2 to 13% of patients with kidney transplants.⁴ Patients with ureteral complications often present with impaired renal function and increasing creatinine levels and should be treated expeditiously to prevent irreversible allograft dysfunction or loss. Multiple interventional techniques are used to image and treat the obstructed urinary system.

Ureteroplasty with stent placement can be performed either at the time of nephrostomy tube placement or at a later date. In children with significant post-nephrostomy bleeding, further treatment should be delayed to prevent the risk of stent occlusion by blood clot. If a nephrostomy tube was not previously placed,

patient preparation and access should be performed as previously described.

There is associated hydronephrosis in most patients with post-operative ureteral problems. Thus, the initial procedure is a percutaneous nephrostomy, which provides both decompression to prevent progressive renal dysfunction and allows access to the ureter. Whenever possible a calyx at or above the level of the ureteropelvic junction should be entered to facilitate access to the ureter. Access to the transplanted kidney is often easier since it is positioned anteriorly in the abdominal cavity.

Ureteral interventions are usually performed through a sheath positioned in the nephrostomy tract. A directional guide wire or angled guidewire and catheter (JB-1) are utilized. The directional system is positioned at the level of the obstruction or extravasation and contrast is injected to characterize pathology and to plan therapy. If the stricture is tight, it is important to wedge the catheter tip into the origin of the narrowing to facilitate the crossing of the stenosis with the guide wire. Once a catheter is maneuvered across the stricture, a stiff guide wire is coiled in the bladder. If a stricture is present, PTA is performed. A stent is placed without dilatation if extravasation is seen.

Prior to PTA, the width of the ureter both proximal and distal to the stenosis is measured and a high-pressure balloon, 1 to 2 mm wider than the normal ureteral diameter, is selected. Under fluoroscopy, dilatation is performed until the stenosis has resolved. If after five minutes the stricture has not disappeared, the process is repeated up to a maximum of three times. If balloon dilatation fails, the ureteral stricture can be incised with a cutting balloon and a stent may be inserted.

After balloon dilatation, a plastic stent that traverses the stenosis is inserted. Either a universal (internal-external stent) or double-J internal stent (Fig. 2) may be selected based on operator preference. Stent placement can be used to treat both ureteral stenosis as well as urine leaks. Urine leaks are often the result of ureteral necrosis related to either rejection or vascular insufficiency due to inadequate preservation of the blood supply to the ureter during donor nephrectomy.⁴ Urine leaks are seen more commonly in children because of the higher percentage of living donors. Living donors are thought to be at risk for ureteral vasculature insufficiency due to the performance of a more extensive dissection than is performed in a cadaver.

Stent placement begins with the insertion of a directional guide wire (usually an angled guidewire) into the bladder under fluoroscopy. The length of the ureter is then measured using either the bent guide wire technique or a calibrated guide wire; an appropriately sized stent is then selected or created. It should be noted that small children and children with transplants have a

Figure 2 Ten-year-old female with a renal transplant and a ureterovesicular junction stricture. After a percutaneous nephrostomy, a directional wire-catheter system was used to cross the ureterovesicular junction stricture. An 8 cm double-J stent was inserted.

very short ureter, often measuring only six to eight centimeters. These patients require nonstandard lengths and therefore one must make sure that appropriately sized stents are available. Stent positioning can be facilitated via a long suture looped through the distal end-hole.

A nephrostomy catheter is then inserted to maintain renal access if a double-J internal stent has been used. If after 72 hours no further procedures are planned and no complications have developed, the nephrostomy tube may be removed. Prior to removal of the nephrostomy tube, a nephrostogram is customarily performed to ensure proper stent placement and function.

Common complications after stent placement include bleeding, infection, urine leak, and stent occlusion. The ideal duration of stent placement has not yet been determined. However, for renal transplant patients, the stent is left in place for as little time as possible to help prevent further complications in the immunocompromised patient.

HEART

The heart is one of the more frequently transplanted organs in children. In 2003, 265 hearts were transplanted in children in the United States.¹ The indications for cardiac transplantation vary with age. For children younger than one year of age, ~75% of transplants are for congenital heart defects.⁵ As the child advances in age, congenital defects as the cause for transplantation decrease in frequency while myopathies increase. By the time the child has reached the 11- to 17-year-old age group, myopathies account for nearly two-thirds of all cardiac transplants.⁵

Cardiac transplantation has always generated much hope and excitement. The first successful human heart transplant was performed in South Africa in 1967 by Barnard⁶; one year later, the first pediatric heart transplant was performed by Cooley in Texas.⁷ Initially, post-transplant survival was poor due to an insufficient understanding of immunosuppressive regimens and difficulty in assessing rejection. The addition of both oral cyclosporine and surveillance endomyocardial biopsy to the post-transplant regimen has resulted in a dramatic improvement in morbidity, mortality, and quality of life. As the surgical technique improved and the medical regimen was refined, heart transplantation expanded to include conditions that previously had been considered contraindications to transplant.

The initial cardiac transplant surgical technique was to excise the recipient heart and the donor heart, leaving a cuff of tissue around the superior and inferior vena cava (SVC, IVC) and the pulmonary veins. The “cuffs” of tissue were sewn together resulting in large right and left atria. Recently, the surgical technique has been modified and a cava to cava anastomosis is performed. In this technique, the SVC and IVC are used to create the suture line instead of large atrial cuffs. Even with advanced surgical techniques, several post-transplant structural defects can occur. These defects may be related to three etiologies, including a pre-existing defect with the donor heart, a pre-existing defect in the recipient heart or great vessels, and a problem at the site of surgical anastomosis of the donor heart to the recipient vessels. Fortunately, many of these defects can be treated with transcatheter interventional procedures, as performed routinely for non-transplanted hearts.

A Pre-existing Defect with the Donor Heart

All donor hearts are evaluated with echocardiography prior to explantation. The echocardiogram is used to evaluate ventricular function as well as both mitral and tricuspid valve function. Echocardiography is also used to evaluate for any congenital or, less frequently, acquired heart defects. If a minor congenital heart defect is noted, it can be addressed during transplantation.

It should be noted, however, that the echocardiogram might be limited due to an inadequate transthoracic window and/or urgent time constraints; thus, defects may escape detection. Surgical correction of a defect at the time of transplant may unnecessarily prolong the graft ischemic time and thus be contraindicated. Several defects have been treated in the interventional cardiac catheterization laboratory post-transplant, including closure of an atrial septal defect (Fig. 3), ventricular septal defect, and balloon pulmonary valvuloplasty.⁸

After transplant, the donor heart can develop arrhythmias, ranging from bradycardias to tachycardias. Transvenous pacemakers and defibrillators can be implanted to treat these arrhythmias.

A transplanted heart develops coronary artery vasculopathy much faster than a native heart. This vasculopathy usually causes a diffuse narrowing of the coronary arteries, which is often not amenable to angioplasty or stent implant-techniques effective for a focal lesion. Occasionally, angioplasty or stent implant is effective for a localized coronary stenosis.⁹

General transcatheter techniques are applied to these patients. However, a couple of caveats must be taken into consideration when treating this patient group. First, since the child is immunosuppressed, meticulous sterile technique is essential. Second, if a device is to be implanted, prophylactic antibiotics are administered intravenously for 24 hours after the procedure. Exceedingly careful technical performance is mandatory; if a complication occurs that requires emergent surgical

exploration, the surgery will be complicated by the pre-existing intra-thoracic adhesions from the transplant surgery and any prior surgeries.

A Pre-existing Defect in the Recipient Heart or Great Vessels

Usually, a pre-existing defect in the recipient heart or great vessels is addressed prior to transplant, as these defects may worsen the patient's hemodynamic condition. The following procedures have been performed with excellent results and a very low incidence of complications: device closure of a patent ductus arteriosus; balloon angioplasty, with and without stent implant, for coarctation of the aorta; and balloon angioplasty, with and without stent implant, for branch pulmonary artery stenosis. Balloon angioplasty can be effective, but serial procedures are often needed, and there may never be excellent relief of the stenosis. Intravascular stent implant, which has a slightly higher risk, requires a greater level of equipment, personnel, and expertise. However, the hemodynamic result for stent implant is much better, and many stents can be dilated to a larger diameter as the child grows.

A Problem Due to Surgical Anastomosis of the Donor Heart to the Recipient Vessels

As mentioned, with the use of the newer surgical technique to perform a cava-cava anastomosis, there is

Figure 3 Atrial septal defect repair. (A) An angiogram performed in the left atrium (LA) demonstrates contrast shunting left-to-right through a moderate size atrial septal defect into the right atrium (RA). The catheter is across the defect in the LA. Also, the left upper pulmonary vein is filled with contrast. (B) After placement of a CardioSEAL ASD occlusion device (NMT Medical Inc., Boston, MA), an angiogram performed in the RA displays that the double umbrella device is well positioned, resulting in an intact atrial septum.

a greater possibility of developing stenosis at the SVC or IVC anastomosis. Even with an excellent surgical anastomosis, growth of the child can put tension on the anastomosis, which can lead to stenosis. Cannulation for cardiopulmonary bypass can result in stenosis of the SVC and IVC. Balloon angioplasty, with or without stent implant, can be very effective for these types of stenosis (Fig. 4).¹⁰

Fortunately, stenosis of the pulmonary vein is uncommon, but when it occurs, it can be treated with balloon angioplasty or stent implant. Stent implant may provide a better result; however, it is a more technically difficult procedure for this lesion.

Stenosis of the aortic or pulmonic anastomosis is uncommon. Balloon angioplasty would be preferable at the aortic anastomosis, as placing a stent in the ascending aorta would be challenging and controversial. A pulmonic stenosis could be addressed with either technique; if a stent is placed, additional attention is needed to make sure the pulmonary valve is not trapped between the stent and the pulmonary artery.

LUNG

The frequency of lung transplantation has steadily increased over the past decade. In 2003, 47 lung transplants were performed in children, with the majority

occurring in the 11- to 17-year-old age group.¹ The indications for transplant vary by age. In infants, the most common indication for transplant is congenital abnormalities followed by primary pulmonary hypertension. In the older age groups, cystic fibrosis accounts for the majority of lung transplants, again followed by primary pulmonary hypertension.⁵ The surgical complications that can be seen in the early post-transplant period and have potential interventions include anastomotic and lobar bronchial strictures, gastrointestinal dysmotility, and malignancy or infection.

Endobronchial Balloon Dilation

One of the most important aspects of a lung transplant is the bronchial anastomosis. To improve healing at this anastomosis, an omental or pericardial wrap is used. The use of these wrap techniques has decreased the bronchial complication rate significantly. However, peri-anastomotic airway problems still account for 12 to 40% of all post-operative complications.^{11,12} Stenosis at the anastomotic site does continue to occur (Fig. 5A) and is thought to be a result of granulation tissue formation. Symptoms include wheezing, dyspnea, post-obstructive pneumonia, and an obstructive pattern on pulmonary function tests. The treatment of choice for bronchial stenosis is balloon dilation.

Figure 4 Superior vena cava (SVC) stenting. (A) This child gradually developed superior vena cava syndrome following cardiac transplant. An angiogram in the SVC with a 6 French catheter (2 mm diameter) occludes the stenotic SVC, displaying run-off into a dilated azygous vein. (B) A Palmaz 308 stent (Cordis Corp., Miami Lakes, FL) was implanted using a 10 mm balloon. The SVC is widely patent with unobstructed flow into the right atrium (RA), and there is no longer run-off down the azygous vein.

Figure 5 A 17-year-old girl with cystic fibrosis and pulmonary failure status post a double lung transplant. (A) A 3D reconstruction from a chest CT demonstrating severe stenoses of the right mainstem bronchus and the bronchus intermedius with sparing of the right upper lobe bronchial orifice. (B) A bronchial PTA was performed (see "waist" —arrows). (C) The initial results were good. (D) A repeat PTA with stent placement was performed after the patient became symptomatic several months after the initial treatment.

Balloon dilation of a bronchial stenosis is performed under general anesthesia. Using a "Y" adapter, a directional catheter is inserted into the tracheobronchial tree. Selective bronchography is performed using non-ionic contrast, and the area of stenosis is confirmed and analyzed. The width of the bronchus is measured both proximal and distal to the stenosis and an appropriately sized angioplasty balloon is selected. Standard catheter and guide wire technique is used to access the area of stenosis and an angioplasty balloon is then positioned across the stenosis. Under fluoroscopy, the high-pressure balloon is inflated to its recommended pressure. Balloon inflation is maintained for three to five minutes, if tolerated (Fig. 5B). A post-procedural bronchogram is performed to evaluate the area of stenosis (Fig. 5C). The

patient is followed up with repeat bronchoscopy and dilations as needed. It should be noted that in the acute post-procedure period, there may be significant edema and submucosal hemorrhage that narrows the bronchial lumen. Therefore, in many cases the interventionalist cannot use post-procedural imaging to determine the endpoint of the procedure. The endpoint is best determined by the disappearance of the balloon waist during inflation. If either the angioplasty or follow-up suggests a poor result, stent placement may be considered.

While stent placement is common in adults with bronchial stenosis,¹³ it is not currently used in the pediatric population as a primary treatment option because of the potential for airway growth and granulation tissue development. Once the decision to place a

stent has been made, bronchography is again performed. A stent at least two millimeters larger than the normal airway proximal to the stenosis is selected to allow for future airway growth. When the guide wire is distal to the stenosis, the stent may be deployed (Fig. 5D). It is our preference to use Palmaz[®] stents for segments of the airway segments that are relatively straight, such as the right mainstem bronchus and trachea. Alternatively, Wallstents[®] are preferred for segments that are curved or for when a bronchial orifice must be crossed, such as in the left mainstem bronchus. As stent technology progresses, and covered stents, removable stents and drug eluting stents become available, the approach to treatment of tracheobronchial stenosis may change.

Gastrointestinal Motility Catheters

Gastrointestinal complications after lung transplant occur commonly with an incidence as high as 50%.¹¹ GI dysmotility is thought to occur as a result of injury to the vagus nerve during transplant. GI dysmotility can lead to a cascade of complications starting with reflux and leading to micro-aspiration, lung injury, and finally bronchiolitis obliterans.¹¹ Due to the potential severity of this complication, it is important to diagnose GI dysmotility. The use of motility catheters, as described below in the small bowel transplant section, is an important method to determine the cause of dysmotility.

CT-Guided Lung Biopsy

Malignancies after lung transplant are not uncommon and occur in 6.5% and 8.2% of children within the one- and five-year post-transplant period, respectively.¹¹ The most common malignancy is post-transplant lymphoproliferative disorder (PTLD). While there are no interventional radiology procedures to treat PTLD, the image-guided biopsy is used as the initial step to determine the cause of the radiographic abnormality.

When the lesion is large, a core biopsy is obtained. However, in lesions less than one centimeter in diameter, an aspiration biopsy is performed. Unfortunately, in many children's hospitals, there is little expertise in cytopathology, limiting the use of the aspiration technique. For the cases in which a core biopsy cannot be safely performed and no cytopathology expertise exists, the interventionalist may work with the surgeons to use CT guidance to mark the lesion with a breast biopsy (Copers) needle and remove the lesion thoroscopically. This approach provides greater accuracy for the surgeon who cannot see or palpate the lesion. When the marking technique is used, a breast biopsy needle, with the stylet removed, is positioned adjacent to the lesion using CT guidance. After the needle position is confirmed, 0.1 cc of methylene blue is injected, coloring the lung resection site. This ensures correct location of the biopsy even if

the marker hook is unintentionally moved when the child is transferred from the CT suite to the operating room. After injection of dye the hook is inserted and deployed.

When a biopsy is performed, the patient is appropriately positioned on the CT scanner and the skin is prepared and draped in a sterile fashion. A local anesthetic is used at the biopsy site and a skin incision is made. The biopsy needle is then introduced using CT guidance into the mass (Fig. 6), and one or more specimens are obtained either directly, co-axially or using the tandem needle technique. Multiple passes are usually performed to increase the likelihood of a diagnosis.

The main complication of a lung biopsy is a pneumothorax, which occurs in up to 61% of patients.¹⁴¹⁵¹⁶¹⁷¹⁸¹⁹ If the pneumothorax is small and the patient is asymptomatic, the patient can be treated conservatively with observation and 100% oxygen (nitrogen washout). A symptomatic pneumothorax requires treatment. Fortunately, placement of a chest tube has been required in less than 5% of patients. If a large or symptomatic pneumothorax develops, multiple options exist, including the placement of a small or large bore chest tube, a Heimlich valve, or aspiration. A pre-discharge expiratory chest radiograph is mandatory. If the radiograph is negative after two hours, the likelihood of a further complication is minimal and the patient may be discharged.

INTESTINE

Intestinal transplantation is a procedure reserved for children suffering from life-threatening complications of total parenteral nutrition (TPN). In the United States, 70 children received intestinal transplants in 2003, representing almost 65% of all intestinal transplants performed.¹ The primary diagnosis leading to intestinal transplant can be broken into two categories: short gut syndrome and functional intestinal failure. Within each category, there are multiple etiologies of intestinal failure,

Figure 6 A 13-year-old male on immunosuppression after a liver transplant had a chest CT that revealed a pleural-based nodule in the right lung. Using a tandem approach the nodule was biopsied and the diagnosis of PTLD was made.

including necrotizing enterocolitis, volvulus, intestinal atresia, chronic intestinal pseudo-obstruction, and Hirschsprung's disease.²⁰

While intestinal transplantation has become a more common treatment option, it still remains a procedure fraught with morbidity and mortality. Several factors can lead to a better prognosis for the patient. These include a larger transplant center, a transplant performed after 1994, and small bowel-only transplants. Despite the poor reputation of intestinal transplantation, improvements are being made. In a recently reported series the one-and three-year patient survival rates are as high as 75% and 55% respectively at a single institution.²⁰

The major complication of intestinal transplant is rejection. Nearly 80% of patients develop rejection with most occurring within the first three months after transplantation.²⁰ Other complications include infection, post-transplant lymphoproliferative disease, intestinal dysmotility, and intestinal stenosis. Stenosis and thrombosis of the vascular anastomoses have not been reported.

Intestinal Motility Catheters and Manometry

Manometry is the most used and validated technique among the different methods available for the study of gastrointestinal motility in children. Other diagnostic tests, such as traditional fluoroscopy studies or nuclear medicine transit tests, provide an indirect measurement of motility and offer complementary information to manometry. The main shortcomings of the barium and scintigraphic studies are the non-physiologic nature of the ingested contrast mediums, the increased exposure to radiation, the lack of age-related normal values, and the short duration of the tests. Furthermore, observing gastric emptying does not provide direct information on the contractility of the foregut; the stomach may not empty adequately because of either a lack of antral contractions or an excess of duodenal contractions. These differences are important and directly influence treatment. In the first case, therapy aims at increasing contractions, while in the latter, at decreasing motility.

The small size of some children and their lack of cooperation make the placement of manometry catheters challenging.²¹ Upper tract motility catheters are placed through the nose or a gastrostomy site using either endoscopic and/or fluoroscopic guidance. Colonic catheters are almost always placed with the aid of a colonoscope in conjunction with fluoroscopic guidance in the interventional radiology suite.

Manometry catheter placement occurs with the assistance of a gastroenterologist. Before the catheter is placed, the child is sedated or anesthetized. General anesthesia is used in very young or anxious children or

when the anatomy of the colon is thought to be difficult to traverse. Otherwise, the procedure is completed using intravenous sedation. Once the child is comfortably asleep, the colonoscopy is performed. When the tip of the endoscope reaches the desired location, usually in the ascending colon, a 0.052" Teflon-coated, flexible-tipped guide wire is inserted through the biopsy channel. Under fluoroscopy, the endoscope is then removed, aspirating all the air previously insufflated and trying to straighten every loop inadvertently created during the endoscopy. The motility catheter is advanced over the guide wire using fluoroscopy until the tip reaches the desired location in the proximal colon. Finally, the catheter is secured to the patient's thigh using tape.

The motility catheters have numerous lumens with recording sites spaced 5, 10, or 15 cm apart (Fig. 7). The catheter used is based on the age of the child and the length of the colon. When the child awakens and has recovered completely from the sedation or the anesthesia, the testing begins.

The manometry catheter measures the pressure changes in the bowel lumen for four to six hours. Results are obtained both during fasting and after administration of an age-appropriate meal. Medications are given during the test to stimulate motility and evaluate their potential as therapeutic agents in the patient being tested. After motility testing is complete, the catheter is withdrawn.

PANCREAS

Transplant of the pancreas is rare in the pediatric population. Since 1998, there have been 114 pancreas transplants in children. In 2003, only 23 pancreases were transplanted in the United States.¹ Due to the low incidence of pancreas transplantation, there is not an adequate cohort of patients to describe either the complications or interventional radiology management of these patients.

POST-TRANSPLANT LYMPHOPROLIFERATIVE DISORDER

Posttransplant lymphoproliferative disorder (PTLD) is a potential complication after any solid organ transplant and deserves special mention. PTLD occurs much more frequently in children than in adults.²² This discrepancy is seen because most cases of PTLD occur in children who are seronegative for the Epstein-Barr virus (EBV) at the time of transplant. It has been reported that 85 to 90% of cases of pediatric PTLD are caused by EBV, including nearly 100% of cases that occur within the first three years after transplant.²²

The strong association of EBV and PTLD is seen in every solid organ transplant with the exception of the intestine, where seropositive patients frequently develop

Figure 7 Colonic motility catheter. (A) The colonic motility catheter has eight lumena for injection and one larger one for guidewire placement. This catheter has distal markers spaced 3 cm apart. Other catheters have markers 5, 10, or 15 cm apart. (B) Abdominal X-ray showing a lower motility catheter with its tip in the cecum.

PTLD. This exception is thought to be a direct result of the higher levels of immunosuppression needed after intestinal transplant and the large amount of lymphoid tissue in the transplanted organ.¹⁷

The risk of PTLD is highest in the first year after transplant for all organs. The incidence of PTLD is organ dependent and ranges from 1 to 20%. Symptoms of PTLD are nonspecific and include fever, malaise, lethargy, weight loss, sore throat, abdominal pain, GI bleeding, lymphadenopathy, and hepatosplenomegaly.

The diagnosis of PTLD is often first suggested using CT. CT findings of PTLD include pulmonary nodules, diffuse lung consolidation, lymphadenopathy, and extranodal masses in the abdomen.

PTLD is confirmed via biopsy. The two most common methods of biopsy are core needle biopsies using CT guidance (Fig. 8) and excisional biopsies. CT-guided, core-needle biopsy has previously been described in the lungs. The technique in other parts of the body is similar.

Figure 8 CT-guided biopsy of PTLD. (A) With the patient in the prone position, a CT is performed. A soft tissue mass is in the right abdomen posterior to the colon. (B) A needle was advanced into the soft tissue mass and a biopsy was obtained.

DISCUSSION

There are a near record number of children awaiting solid organ transplantation. Children have markedly different indications for and complications of transplantation. Interventional radiology has the ability to diagnose and treat a wide variety of complications in every transplanted organ. Today, the interventional radiologist is an important member of the team caring for these children and must be cognizant of the challenges inherent in treating this specialized population.

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