Liver Transplantation in Children: Techniques and What the Surgeon Wants to Know from Imaging

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Disclosure

• In the past 12 months, I have had no relevant financial relationships with the manufacturer(s) of any commercial product(s) and/or provider(s) of commercial services discussed in this CME activity.
Objectives

• Discuss preoperative imaging in the pediatric liver transplant recipient and in potential living donors.
• Discuss techniques in pediatric liver transplantation.
• Discuss use of imaging in evaluating and managing post-transplant complications.
Liver Transplantation in Children: Indications

- Biliary atresia – 55%
- Cirrhosis/Cholestatic – 20%
  - Alagille syndrome
  - \( \alpha1 \)-antitrypsin deficiency
  - Autoimmune/PSC
  - Cryptogenic cirrhosis
- Fulminant hepatic failure – 15%
- Metabolic disorders – 5%
  - Urea cycle defects
  - Tyrosinemia
- Primary hepatic malignancy – 5%
End-Stage Liver Disease (ESLD): Manifestations

- Progressive deterioration in liver function
  - Jaundice
  - Poor synthetic function
    - Coagulopathy (increased INR)
    - Hypoalbuminemia
- Portal hypertension
  - Hypersplenism
  - Variceal bleeding
  - Ascites
- Nutritional and growth failure
Organ Allocation

• Status 1a/1b
• Pediatric End-Stage Liver Disease (PELD)
  – Albumin
  – Total bilirubin
  – INR
  – Age
  – Growth

• Model for End-Stage Liver Disease (MELD)
  – Used for patients 12 years and older
  – Total bilirubin, INR, Creatinine

PELD Score = \((0.436 \times \text{Age (<1 Yr)}) - 0.687 \times \ln(\text{albumin g/dL}) + 0.480 \times \ln(\text{total bilirubin mg/dL}) + 1.857 \times \ln(\text{INR}) + 0.667 \times (\text{Growth failure (<-2 Std Deviations present})) \) \times 10

MELD Score = \((0.957 \times \ln(\text{creatinine mg/dL}) + 0.378 \times \ln(\text{bilirubin mg/dL}) + 1.120 \times \ln(\text{INR}) + 0.643 \) \times 10
Recipient Considerations

- Knowledge of etiology of ESLD
- Assess hepatic vascular anatomy
- Any contraindications to transplantation?
  - Extrahepatic malignancy
- Assess severity of disease (PELD/MELD)
- Assess cardiopulmonary reserve
- Manage complications of ESLD/portal HTN
- Ensure normal childhood immunizations
- Improve malnutrition
- Aggressive treatment of possible infections
Biliary Atresia

• **Perinatal (Acquired): 80%**
  – Destruction of fully formed biliary ducts → inflammatory

• **Embryonic (Fetal): 20%**
  – Polysplenia or asplenia
  – Malrotation
  – Cardiac Anomalies (50%)
  – Heterotaxy (50%)
  – Portal vein anomalies
    • Pre-duodenal (60%)
  – Interrupted IVC (40%)
Tumors

• Imaging for liver nodule characterization
• Liver disease etiologies at increased risk for HCC
  – Hereditary tyrosinemia
  – Type 1 glycogen storage disease
  – Type 2 progressive familial intrahepatic cholestasis
  – Longstanding cirrhosis

Screening with AFP and U/S with cross-sectional imaging if concern
Presence of liver lesion → listing, increased allocation priority

• Hepatoblastoma
  – Complete surgical resection is crucial for long-term survival
  – Unresectable by conventional operation → liver transplantation
  – Multidisciplinary care with oncology
Portal Vein Thrombosis (PVT)

- **Common complication of cirrhosis, ESLD**
  - 10% of patients undergoing liver transplantation
  - Hypercoagulability, low flow state of PV, prothrombotic mutations

- **Intraoperative challenges**
  - Pre-transplant cross-sectional imaging demonstrating PVT has implications on surgical approach
  - Thrombectomy or alternative vascular reconstructions (interposition grafts)

Replaced Hepatic Arteries

• Small caliber native hepatic artery increases complexity in liver transplant
• Variant hepatic artery anatomy coexists with small caliber native common HA
• Higher rate of complications in recipients with variant arterial anatomy (21% versus 3%)\(^1\)
• RHA in donor liver also adds complexity for reconstruction

\(^1\)Ishigami et al. AJR 2004;183:1577-1584.
Organ Considerations

• Supply of donor organs is single limiting factor in liver transplantation
• Long waiting times, waiting list mortality
• Advancement of surgical innovation to expand donor pool
Donor Organ Selection

WHOLE

REDUCED SIZE

LD / SPLIT DD

2/3 Surgical Variant Grafts
Anatomic Liver Segmentation

Couinaud’s segments

Right posterior section
Right anterior section
Left medial section
Left lateral section

Right hepatic vein
Middle hepatic vein
Left hepatic vein

1. Hepatic duct
2. Inferior vena cava

3. Gall bladder
4. Cystic duct
5. Bile duct
6. Portal vein
7. Hepatic artery
8. Hepatic duct

https://www.slideshare.net/pankajkaira/radiological-anatomy-of-hepatobiliary-system
Reduced-size Liver Transplant

• First described by Bismuth in 1984
  – Excellent graft and patient outcomes
  – Decreased waiting list mortality among children
• Both deceased donor split liver transplantation (SLT) and living donor (LDLT) evolved from reduced-size liver transplantation
Split Liver Transplantation

• What has driven increase in popularity of splitting livers?
  – Better understanding of intrahepatic anatomy
  – Better established donor criteria for splitting
  – Better established recipient criteria for SLT
  – In situ split technique

• Most commonly, split grafts are shared between one child and one adult
Left Lateral Section / Right Trisection
Left Lateral Section / Right Trisection
Left Lobe / Right Lobe Split
In Situ Left Lateral Section Dissection

- Left Hepatic Vein
- Middle Hepatic Vein
- Left Portal Vein
- Left Hepatic Artery

Left Hepatic Vein
Left Lateral Section Allograft
### Table 1. Donor Selection Criteria for Liver Splitting

<table>
<thead>
<tr>
<th>Donor</th>
<th>Intraoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &lt;50 y</td>
<td>Macroscopic appearance: Soft liver with sharp edges</td>
</tr>
<tr>
<td>ICU stay &lt;3 days</td>
<td>No or minimal yellow hue when fingerprint test is done</td>
</tr>
<tr>
<td>Last serum Na &lt;150 mEq/L</td>
<td>Liver biopsy: macrovesicular steatosis &lt;10%</td>
</tr>
<tr>
<td>ALT: up to 2–3 times normal</td>
<td>Bile production: yellow, viscous bile.</td>
</tr>
<tr>
<td>Hemodynamic stability: No vasopressor support or dopamine ≤10 μg/kg/min</td>
<td>Liver anatomy: Normal vascular and biliary anatomy.</td>
</tr>
</tbody>
</table>
Who should get a split graft? Pediatric Recipient

- Donor : Recipient Weight Ratio
  - Left Lobe Graft = 2 – 5 : 1
  - Left Lateral Section Graft = 6 – 10 : 1

- Disease severity
  - Status I
  - PELD > 15
  - Any patient for whom a reduced-size graft is being considered
Who should get a split graft? Adolescent Recipient

• Size considerations
  – Right Trisection Graft → size match
  – Right Lobe Graft
    • Graft : Recipient weight ratio (GRWR)
      – Deceased donor > 1%
      – Living donor > 0.8%

• Recipient disease severity
  – Lower MELD ~ “lower risk”
  – Less portal hypertension / hyperdynamic splanchnic circulation
Where to Split?  
In situ versus Ex vivo

**In Situ**
- **Benefits**
  - Clearer sense of perfusion of both grafts
  - Less cold ischemia time
  - Avoids graft rewarming
  - Cut surface controlled
- **Risks**
  - Longer donor OR time
  - Potential risk of HD instability which could affect other organs
  - Greater donor transfusion

**Ex Vivo**
- **Benefits**
  - Shorter OR time
  - Less risk to other organs
- **Risks**
  - Perfusion of both grafts unknown
  - Longer cold ischemia time
  - Graft rewarming
  - Cut surface bleeding and bile leak

*In situ splitting may be preferable*
Allocation of Vessels and Biliary Tract

- **Cross-sectional imaging usually unavailable**
- Hepatic artery
  - LLS / Right trisection split: ligation of prominent segment IV artery may result in necrosis
- Portal vein
- Hepatic veins / Inferior vena cava
  - *Intraop ultrasound* – allows delineation of major segment V and VIII hepatic veins draining into MHV
- Bile duct
  - *Intraop cholangiography* – mandatory for Right / Left split
- Extra vessels for reconstruction
  - Iliac artery and vein
  - Others: Inferior mesenteric artery, carotid artery
Split Graft Complications

- **Biliary tract (10 – 35%)**
  - Cut surface leak
  - Bile duct leak and stricture
- **Vascular (2 – 20%)**
  - Hepatic artery thrombosis
  - Portal vein thrombosis
  - Hepatic venous outflow obstruction
- **Bleeding from cut surface**
- **Small-for-size syndrome: “functional size”**
  - Prolonged cholestasis, intractable ascites, coagulopathy, failure to thrive
Pediatric recipients: biliary and vascular complications similar between SLT-LLS, LD-LLS and whole organs

Adult recipients of SLT-RTS: 10% biliary and 7% vascular complications, but no difference in patient or graft survival vs. “optimal liver” whole organ group

Biliary complications and PVT were more common in all technical variant grafts

Split and reduced graft recipients: slightly lower probability of survival, and all 3 technical variants grafts had slightly lower probability of graft survival

Must be balanced with gains in survival to transplant
Living Donor Liver Transplant

http://www.surgery.usc.edu/hepatobiliary/pediatricsurgeryandtransplant.html
Living Donor vs. Split Liver DD

http://www.surgery.usc.edu/hepatobiliary/pediatricsurgeryandtransplant.html
Living Donor Imaging Evaluation

• Multiphase CT angiography
  – Parenchymal abnormalities, exclude fatty infiltration
  – Liver volume
  – Vasculature

• MRCP
  – Biliary system

• Intraoperative cholangiography

Table 1
Technical details of pretransplant imaging by computed tomography and MR imaging

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Sequence Details</th>
<th>Structures Evaluated</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-contrast</td>
<td>2-4 thick slices through the liver at 140 and 80 kVp</td>
<td>Parenchyma (steatosis)</td>
</tr>
<tr>
<td>Arterial phase</td>
<td>Limit field of view (FOV) to abdomen Iterative reconstruction Low kVp</td>
<td>Arterial anatomy Parenchyma (focal lesions)</td>
</tr>
<tr>
<td>Combined Portal venous/ Hepatic venous phase</td>
<td>Limit FOV to abdomen Iterative reconstruction Weight-based kVp (80 kVp if &lt;150 lbs, 100 kVp if 150-200 lbs, 120 kVp if &gt;200 lbs)</td>
<td>Portal and hepatic venous anatomy Parenchyma (focal lesions)</td>
</tr>
<tr>
<td>MR imaging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Pre-contrast</td>
<td>Chemical shift imaging Dixon method imaging</td>
<td>Parenchyma (steatosis and iron quantification)</td>
</tr>
<tr>
<td>T2 SSFSE</td>
<td>Coronal and axial planes</td>
<td>Biliary system</td>
</tr>
<tr>
<td>T2 3-dimensional MRCP</td>
<td>—</td>
<td>Biliary system</td>
</tr>
<tr>
<td>T1 Postcontrast 2-dimensional or 3-dimensional GRE gradient echo (GRE)</td>
<td>Coronal and axial planes Arterial, portal venous, delayed phases</td>
<td>Arterial, portal venous, and hepatic venous anatomy Parenchyma (focal lesions)</td>
</tr>
<tr>
<td>T1 Post-contrast MRCP</td>
<td>20 min delayed phase</td>
<td>Biliary system</td>
</tr>
</tbody>
</table>

Liver Volume

• CT volumetrics
  – Residual donor liver > 30% TLV
  – Graft providing GRWR > 0.8%

Correct transection plane is critical to avoid over- or underestimation
Vascular Anatomy

- Hepatic artery: replaced/accessory LHA
- Portal vein variants
- Hepatic veins
  - MHV branches
Biliary Anatomy

- MRCP to assess for variant biliary anatomy
- Posterior sectoral hepatic duct arising from left hepatic duct
- Intraoperative cholangiogram is critical
Surgical Variant Allografts
Standard Vascular Reconstruction

Bicaval Anastomoses

Suprahepatic

Infrahepatic
Piggyback Technique for Outflow
Piggyback Technique for Outflow
Donor Portal Vein and Celiac Axis
Infrarenal Aortic Conduit

Ishigami et al. AJR 2004;183:1577-1584.
After Revascularization
Roux-en-Y Biliary Reconstruction

Clinical Liver Disease, Vol 2, No 4, August 2013

Operative Complications

• Primary non-function
• Thrombosis, stenosis, pseudoaneurysm
  – Hepatic artery
  – Portal vein
  – IVC/Hepatic vein
• Bleeding, hemoperitoneum
• Biliary complications: most common
  – Bile leak
  – Biliary stricture
Hepatic Artery Thrombosis

- More common in children (8 – 9%)
- Risk factors: graft type, anastomosis, graft edema, recipient hypotension or hypercoagulability
- Ultrasound with Doppler as primary screening
- Acute HAT with graft failure → urgent re-transplant
- Thrombectomy and salvage if graft still functional
- Biliary complications due to ischemia of bile ducts
  - Bile leaks, sepsis, biliary strictures
Portal Vein Thrombosis

- Incidence: 2 – 6%
- Asymptomatic, elevated liver enzymes, or varices
- Ultrasound with Doppler as primary screening
- Early PVT → thrombectomy and/or revision
- Rule out hypercoagulable condition
- If uncorrected, PVT can result in graft failure or long-term portal hypertension with variceal bleeding and ascites
Bile Leak

- Anastomotic leak can occur early
  - Localized or generalized peritonitis
  - Drain output is yellow-green and bilirubin level is higher than serum bilirubin level
  - Elevated serum bilirubin
  - Etiology: technical or hepatic artery thrombosis
- Leak from cut surface of technical variant graft
- Diagnosis: cross-sectional imaging
- Management: percutaneous drainage of collection
  - If cut surface leak, patience, as most will resolve
  - If anastomotic leak, reoperation vs. ERCP/stent vs. PTC
Cut Surface Bile Collection
Biliary Stricture

• Delayed complication, incidence 10%
  – At duct-to-duct or Roux-en-Y biliary anastomosis
  – Technical or result of hepatic artery thrombosis

• Presentation
  – May be asymptomatic with dilated bile ducts on U/S
  – May present with elevated bilirubin or jaundice
  – May present with cholangitis

• Interventions
  – PTC with balloon dilation
  – ERCP with dilation and stent
  – Operative revision
Biliary Stricture: PTC and Drain
Conclusions

• Preoperative cross-sectional imaging is critical for potential recipient and living donor candidate for preoperative planning

• Technical variant allografts have decreased waiting list mortality and maximized organ utilization in pediatric liver transplantation

• Close collaboration between transplant surgeon and radiologist is necessary to ensure optimal pediatric liver transplant outcomes
Questions?

The Risk of any Journey must be appreciated by all parties.....
(Prior to beginning the Journey !)