Living related liver donor: pre-operative radiological evaluation and surgical techniques for adult and pediatric recipients.

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Learning objectives

Organ scarcity is being overcome thanks to living liver donation. Living related donor liver transplantation is the newest and both technically and ethically most challenging evolution in liver transplantation and has contributed to reduction in donor shortage.

The aim of this poster is to present the criteria of selection of the potential living liver donor, the radiological assessment and the surgical procedure of right and left hepatectomy and reimplatation of the graft in the recipient.
Background

LIVING-DONOR SELECTION

In living-donor transplantation, the evaluation and selection of a donor, usually a parent or first-degree relative is performed on the assumption that donor safety can be assured and that the donor's liver function is normal. Donors should be 18-55 years of age, and have an ABO-compatible blood type. Following a satisfactory medical and psychological examination by physicians who are not directly involved with the transplantation program, radiological assessment is performed.

Assessment of potential living liver donors requires:

Evaluation of liver parenchyma to identify steatosis or lesions;

Evaluation of intra and extrahepatic biliary and vascular anatomy to identify congenital variants and, overall, to detect the dominant arterial branch to segment 4 to prevent accidental removal at surgery;

Estimation of the volume of both liver lobes to exclude complications related to graft volume (small-for-size grafts or large-for-size grafts, characterized by a graft-to-recipient weight ratio (GRWR) less than 1%, and more than 3%, respectively).
**Imaging findings OR Procedure details**

**RADIOLOGICAL ASSESSMENT OF POTENTIAL LIVER DONORS**

**US** is usually the first imaging modality for the evaluation of potential donors because it can identify hepatic lesions, obtain important information on the anatomy of the great vessels, such as hepatic veins and portal system, and evaluate the presence of steatosis. Due to a lack of accepted methods for quantification of steatosis on imaging, in many hospitals a biopsy is incorporated in the work-up, while in other centers a biopsy is performed only in cases of suspicion based on clinical or imaging grounds.

**MDCT** is the most important tool in the assessment of potential donors. MDCT can precisely depict congenital variants, if present, that can influence the surgical technique, identify focal lesions (hemangiomas, focal nodular hyperplasia, adenomas) or diffuse liver diseases (steatosis, hemochromatosis), and calculate the volume of the two liver lobes.

Congenital arterial variants are frequent, and are found in approximately 45% of donors. The identification of the dominant arterial branch to segment 4 is very important because its integrity is indispensable for the regeneration of the residual left hemiliver. This artery usually arises from the left hepatic artery (LHA), while in 25% of cases it arises from the right hepatic artery (RHA) or from both the LHA and RHA (Figure 1).

Anatomical variants of the portal system occur in 20% of the donor population; although the anomalies are not a contraindication to surgery, they must be known because they may require multiple portal anastomoses during the implantation of the right lobe into the recipient (Figure 2).

Identifying the hepatic venous anatomy is a fundamental step because it determines the heptectomy plane that runs 1 cm to the right of the middle hepatic vein (MHV). Both accessory hepatic veins of the right inferior lobe (68% of the donor population), and large branching veins (> 5 mm) draining into the MHV from the right lobe require separate anastomosis to prevent venous congestion in the graft (Figure 3).

Accurate volume of both liver lobes needs to be estimated to ensure that the hepatic mass is adequate for both liver donor and recipient.

MDCT scan studies are performed with and without iodinated c.m.i.v. at a dose ranging from 1.5 mL/kg to 1.8 mL/kg of body weight, and at a rate of 4 - 5 mL/s. Images of the liver are acquired in the craniun-caudal direction, during a single breath-hold acquisition, with slice thickness 1.25 mm or 0.625 mm, collimation 2.5 mm and table speed 7.5 mm per gantry rotation. Before the study, patients receive 500 mL of water as an oral contrast agent. Usually, a triple-phase protocol is used: unenhanced phase, arterial phase, and portal venous phase. Bolus tracking or test bolus technique (10 mL of contrast
material at 4/5 mL/s) is used to calculate the correct time of the arterial phase. The peak enhancement plus 2 s is deemed as the start of the arterial acquisition to depict the arterial system. The portal venous phase is generally taken 70 s after the contrast agent has been injected to determine the exact delineation of the portal and hepatic veins. MIP and VR image reconstruction of the artery and portal venous system are usually created in the post-processing stage. The portal-venous acquisition is used for the volumetric evaluation, using dedicated software, in the postprocessing of right and left lobe.

The selection of a graft with an adequate parenchymal mass is critical to success. The minimal hepatic mass necessary for recovery is not clearly established, and its calculation must take into account the temporary loss of hepatocytes caused by the donor's injury or treatment, as well as preservation injury, acute rejection, or technical problems. When selecting donors of partial grafts, a graft fraction of 1%-3% of the recipient body mass is optimum, while a graft-to-recipient weight ratio < 0.7 is usually associated with inferior overall allograft and patient survival. When the donor-to-recipient body weight ratio is between 2 and 12, the graft is considered for split liver (Figure 4).

**Magnetic resonance cholangio-pancreatography (MRCP)** is currently considered the primary imaging tool for biliary anatomy evaluation in potential living liver donors. In fact, it is performed with new generation units equipped with high performance gradient and phased-array coils, allowing for high quality heavily T2-weighted images with increased spatial resolution in a few seconds or with respiratory triggering, eliminating most motion-related artifacts.

Only 57% of donors have a conventional biliary anatomy (Figure 5). Although the congenital variants of biliary anatomy do not represent a contraindication to liver donation, they must be identified before surgery to prevent ligation of major branches of the right lobe in the recipient and/or of the liver lobe in the donor. Multiple biliary anastomoses during the implantation of the right lobe into the recipient can be required to avoid atrophy due to biliary obstruction.

Improvements in hepatocyte-specific contrast agents with biliary excretion (mangafodipir trisodium and gadobenate dimeglumine) seem to have increased the accuracy of MRI in depicting the biliary system (Figure 6).

Some studies propose MRI as a single imaging modality for the preoperative assessment of potential donors to depict the arterial, portal and venous anatomy using MR-angiography with 3D sequence after the administration of extracellular c.m.i.v. However, MR-angiography can rarely depict the artery supplying segment 4.

**SURGICAL TECHNIQUE**

**Living Donor for Pediatric Recipient.**
The graft for pediatric recipient is usually composed of segments 2 and 3 (left liver lobe).

Intraoperative cholangiography is performed, as intraoperative ultrasound, to confirm the transection plane.

In the left hepatectomy a section of the liver is made along the falciform ligament to obtain a left graft, including the left hepatic vein, the left branch of the portal vein, and the left branch of the hepatic artery, along with the common hepatic artery and the celiac tripod, and a right graft, composed of segments 1 and 4 to 8, including the vena cava, the right branch of the hepatic artery, and the portal vein along with the origin of the mesenteric and splenic veins.

The hepatogastric ligament is preserved when exist an accessory left hepatic artery originating from the left gastric artery. When this vessel is not detected, the ligament is sectioned. The common hepatic artery is then identified and dissected from the gastroduodenal artery up to its division into the right and left hepatic arteries. The left hepatic artery is then encircled (Figure 7A). If present, branches for the fourth segment originating from the left hepatic artery should be identified and divided. The base of the round ligament is exposed by dividing the small bridge of parenchyma that connects the lower portion of segment 4 to the left lateral section of the liver. The round ligament is dissected and completely mobilized with isolation and division of its venous connections to the fourth segment. Once the round ligament is dissected, the extrahepatic portion of the left branch of the portal vein can be identified just below the left hepatic artery. This vein must be carefully dissected and encircled (Figure 7B). The left lateral section is rotated laterally on the right side and the ligamentum venosum is dissected up to left lateral hepatic vein, which can be isolated and encircled (Figure 7C). The bile ducts of the left lateral segment are included in the porta hepatis and should not be dissected. On the contrary, the porta hepatis must be encircled and divided sharply (Figure 7D).

The section of the parenchyma can now be performed along the falciform ligament (Figure 7E). It is helpful when identifying the plane of the dissection to pass the cotton tape, which encircles the left hepatic vein on the posterior surface of the liver in the fossa of the ductus venosus, laterally to the left branch of the hepatic artery and of the portal vein (Figure 7F and G). Pulling up on this tape, the dissection of the parenchyma is usually easy. At this point, the procedure continues as a standard donor operation with heparinization, cannulation and cross-clamping of the aorta, perfusion, and cooling of the abdominal cavity. The left hepatic vein is then sectioned close to the vena cava. Care must be taken to identify a distal bifurcation of this vein. A double left hepatic vein significantly increases the technical difficulty of the implantation of the graft. In this case, the vessel should be removed with a cuff of vena cava to allow a single vascular anastomosis with the recipient vena cava. The left branch of the portal vein is sectioned close to the parenchyma. The right hepatic artery is sectioned close to its origin, and the hepatic artery is dissected up to the celiac trunk, which is removed along with an aortic cuff.
Living Donor for Adult Recipient.

The graft for adult recipient is usually composed of segments 5-8 (graft lobe).

Intraoperative cholangiography is performed, as intraoperative ultrasound, to confirm the transection plane. Mobilization of the right liver lobe and skeletonization of the retrohepatic inferior vena cava with ligation of all accessory hepatic veins is performed using the usual piggyback technique but with preservation of accessory veins larger than 0.8 cm in diameter. Isolation of the right hepatic artery is always performed, and isolation of the right portal vein is performed prior to the parenchymal transection only when feasible. The middle hepatic vein always remain with the donor. The following 4 sequential techniques were performed for the hepatic parenchymal transection: parenchyma tissue fragmentation and skeletonization of biliovascular structures with the ultrasonic dissector or water pressure dissector; vascular hemostasis and biliostasis of the minuscule biliary ducts using microsurgical clips and a radiofrequency dissector; sectioning of fibrous and vasculobiliary structures with electrocautery; and suction of organic and irrigation fluids mixed with parenchymal detritus using and aspirator and the integrated aspirator in the ultrasonic dissector. The division of the biliary duct is performed just before the end of the parenchymal transection, and always sharply. In the case of a double portal vein for the right lobe, a Y graft to the main bifurcation of the recipient portal vein was performed on the backtable in 4 cases. Jump grafts for accessory hepatic veins were performed with interposition iliac vein grafts from cadaveric donors, always on the backtable. Once removed, the right lobe was flushed with 3 L of University of Wisconsin solution, only through the portal system (Figures 8-10).

Pediatric Recipient.

Hepatectomy is performed with preservation of the native inferior vena cava).

Assuring an adequate venous outflow requires a careful technique of anastomosis between the left hepatic vein of the graft and the inferior vena cava of the recipient and a proper positioning of the graft itself, which is rotated clockwise 45° on a transversal plane and slightly on a frontal plane. The final position of the cut surface of the parenchyma, including the new hilum of the graft, is high and posterior, so that the portal vein and hepatic artery have a course that is curved and longer than usual.

The outflow anastomosis is end-to-side between the left hepatic vein of the graft and the inferior vena cava of the recipient, with the triangulation technique described. The ostium of the left hepatic vein may be treated in the same fashion, to obtain a further enlargement of the opening, or suture-closed. The opening is then enlarged by cutting the anterior face of the vena cava to obtain a wide reversed triangular orifice. The cuff of the left hepatic vein of the graft is trimmed as short as possible, to avoid kinking. Three 5/0 vascular monofilament sutures are placed, taking the three corners of the graft and
recipient orifices (Figure 5). The graft is then placed in the hepatic fossa of the recipient and the triangular anastomosis performed with three running sutures.

The second anastomosis is the portal one, performed in an end-to-end. As already mentioned, the length should be sufficient for the vessel to make a gentle curve that reaches the hilum of the graft; as for the section, the limiting factor is the size of the graft cuff. In the majority of cases, the recipient’s vessel matches this size rather well. If not, it can be cut at its bifurcation, to obtain a branch patch. In case of real hypoplasia of the recipient's portal vein, frequent in patient with biliary atresia, the confluence of the mesenteric and splenic vein can be clamped, the vessel sectioned at this level and a venous graft from the donor (usually the splenic or the external iliac vein) interposed between the confluence and the portal vein of the new liver. After completion of the anastomosis the graft is reperfused.

The arterial anastomosis comes next. The arterial axis of the graft usually includes the proper and common hepatic artery, in continuity with the celiac artery, and a patch of the aorta. The level of the anastomosis is chosen at any place along the recipient's arterial axis, and the two vessels are trimmed to obtain a similar section and an adequate length, according to what has already been stated concerning the portal vein. The anastomosis is performed end-to-end with a running suture. If the recipient's arterial axis is deemed inadequate, the aorta can be clamped at the origin of the celiac artery or just below the renal arteries, and an end-to-side anastomosis can be performed at one of these sites. In the latter case, the interposition of an arterial graft from the donor, usually represented by an iliac artery, may be necessary.

The final stage is biliary reconstruction, which is always a hepaticojejunostomy with a Roux-en-Y loop.

**Adult Recipient.**

The recipient operation is usually started when in the donor the surgical exploration and cholangiography have confirmed that the operation is technically feasible without risk. The recipient bile duct is dissected free up to the confluence of right and left branch that can be both used for anastomosis in case of double right branches in the right lobe graft. Also the hepatic artery are dissected up to their right and left branches. The native vena cava is dissected free from the liver by dividing between ligatures or clips the small hepatic veins. The middle and left hepatic veins are cut and sutured, while the right hepatic vein is divided after the vena cava is cross/clamped below and above the liver. Is preferred to use a veno/venous bypass in recipient of LRLT to maintain the patient as hemodynamically stable as possible without the need for high central venous pressure maintenance during the anhepatic phase which, upon reperfusion might damage the graft.
The first anastomis is performed between right hepatic vein and to the recipient vena cava using the triangulation technique. The right portal branch of the graft is anastomosed with the main portal vein or in some cases with the right portal vein of the recipient.

The liver is then reperfused and later the right hepatic artery is anastomosed with the right hepatic artery or in some cases with the main hepatic artery of the recipient. When possible the right bile duct of the graft is anastomised with the main bile duct to the recipient with end-to-end anastomisis over a T-tube. If is not technically possible, a Roux-en- Y hepatico/jejeunostomy could be performed.

**Biliary Considerations.**

Of note that the biliary anastomosis could be single or multiple, and it depends by the conventional or not conventional anatomy of biliary tree, in both pediatric (Figure 11) and adult (Figures 12-14) recipient.
**Fig. 0:** 35-year-old male, potential living liver donor. Early bifurcation of hepatic artery. GDA: Gastroduodenal artery; LHA: Left hepatic artery; RAHA: Right anterior hepatic artery; RPHA: Right posterior hepatic artery; S4: Artery to segment 4.

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**Fig. 0:** 32-year-old male, potential living liver donor. Volume rendering reconstruction shows a right anterior branch arising from left portal branch. SMV: Superior mesenteric vein; SpIV: Splenic vein; LPV: Left portal vein; RAPD: Right anterior portal vein; RPPV: Right posterior portal vein.

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Fig. 0: 41-year-old male, potential living liver donor. Volume rendering reconstruction shows a normal anatomy of hepatic veins. The right lobe and red, the left lobe are green. An accessory hepatic vein draining S6 are present (blue vein).

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Fig. 0: 34-year-old female, potential living liver donor. Volume rendering reconstruction shows a whole liver, the left and right lobe and the corresponding volumes. A cut-plane runs 1 cm to the right of the middle hepatic vein.

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**Fig. 0:** Normal anatomy of biliary tree.

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RPD and RAD drain respectively S6-S7 and S8-S5; RHD is formed by confluence of RPD and RAD. LHD drains S2-S3. S1-S4 can be drained by LHD or RHD. The CHD (common hepatic duct) arising from the confluence of RHD and LHD.
Anatomical variant of biliary tree

RPD (1) draining in LHD (2), accessory LHD (3) and accessory RPD (4) draining in MHD (5).

Fig. 0: Anatomical variant of biliary tree.

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Fig. 0: Left hepatectomy in living donor for pediatric recipient.

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Fig. 0: Right hepatectomy in living donor for adult recipient.

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Fig. 0: Right hepatectomy in living donor for adult recipient.

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Fig. 0: Right hepatectomy in living donor for adult recipient.

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Fig. 0: Number of biliary anastomosis according to the anatomical variant.

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Conclusion

Organ scarcity is being overcome thanks to living liver donation, and we think that is important to know also the surgical procedure.

Knowledge of surgical technique is helpful for radiologist involved in the pre-operative evaluation of potential living donor.
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