Impact of Multislice Spiral Computed Tomography on Donor Selection and Surgical Planning in Living-Related Liver Transplant

Ibrahim Abdel Kader Salama,[1] Basma Abdel Moneim Dessouky,[2] Enas Mohamed Korayem,[3] Sayed Abdel Aal[4]

Abstract

Objectives: **Living-donor liver transplant is used with increasing frequency to help compensate for the increasing shortage of deceased-donor liver grafts. However, donor safety is a primary concern, and selection of the preoperative imaging modality is important in preserving donor's health by excluding unsuitable candidates, and tailoring the surgical procedure according to anatomic variations.**

In this study, we evaluate the impact of multislice spiral computed tomography on potential donor selection and surgical planning before living-related liver transplant.

Materials and Methods: **One-hundred seventy-five potential living-liver donors (62 women and 113 men; age range, 23-34 years; mean, 32 years) were included in our study. All subjects underwent multiphasic multislice spiral computed tomography. Postcontrast acquisitions were obtained for the arterial and venous phases. There were 139 potential donors for the right lobe and 36 potential donors for the left lateral segment. All data were analyzed to detect vascular variants, exclude focal liver lesions, and determine hepatic volume, and preoperative findings were correlated with intraoperative findings in 65 patients.**

Results: **Of the 175 potential liver donors evaluated with multislice spiral computed tomography, 56 (32%) were excluded for the following reasons: portal vein anomalies in 11 (19.6%), hepatic venous anomalies in 9 (16.1%), fatty liver in 17 (30.3%), small liver volume in 12 (21.4%), and a focal lesion in the liver in 7 (12.5%). Of the 65 candidates, surgical planning and technique were modified in 24 donors and recipients, in 23 candidates, and the donor only in 1 candidate.**

Conclusions: **Multislice spiral computed tomography provides parenchymal, vascular, and volumetric preoperative evaluation of potential donors for living-related liver transplant and has an effect on surgical planning: It allows the surgeon to reduce postoperative complications by modifying the surgical technique.**

Key words: *Radiologic donor evaluation, Surgical judgment, Liver transplantation*

Living-related liver transplant is an excellent treatment for patients with end-stage liver disease (1). That procedure was initially developed to compensate for the severe organ shortage in pediatric patients requiring a liver transplant, and primarily left lateral segment grafts were used. As experience accumulated in such cases, the practice was extended to include right lobe grafts (2).

An addition to augmenting the transplant organ pool, living-donor liver transplant offers the advantages of performing elective surgery, accessing a graft in best condition, and lowering the likelihood of recipient death during the wait for a suitable organ (3). The combination of improved surgical technique and highly developed immunosuppressive therapy (4) has resulted in recipient survival rates as well as those obtained after conventional liver transplant with full-size deceased-donor organs (5). The critical issue of living-donor liver transplant is the risk to donors, who were healthy before transplant surgery

From the Departments of [1]Hepatobiliary Surgery, [3]Radiology, and [4]Hepatology, National Liver Institute; and the [2]Department of Radiology, Faculty of Medicine, Menoufiya University, Shebin El-Koom, Egypt

Address reprint requests to: *Dr. Ibrahim Abdel Kader Salama, Department of Hepatobiliary Surgery, National Liver Institute, Menoufiya University, Shebin El-Koom, Egypt*

Phone: *+20 18 3004235* ***Fax:*** *+20 48 2234586* ***E-mail:*** *ibrahim_salama@hotmail.com*

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and in whom the transplant-related risk for death is estimated to be 0.5% and that for postoperative morbidity, it is 21% (1, 6, 7). To minimize those risks and prevent donor-recipient mismatches, potential donors must undergo an extensive step-wise evaluation before being considered candidates for liver donation (8). Special attention is focused on determining liver volume (9-12) and recognizing vascular anomalies (13-15). Most candidates are eliminated because of an unfavorable hepatic parenchymal, biliary, or vascular morphologic condition (16).

Selection protocols are of paramount importance in preserving donor health by excluding unsuitable candidates for either medical or anatomic reasons (17). Since the development of new multislice computed tomographic techniques, the radiologist has had a relevant role in providing, with a minimally invasive procedure, valuable information that can be used to select the most-suitable candidates, and to identify anatomic variants that may alter the surgical approach (18).

In this study, we evaluate the impact of multislice spiral computed tomography on potential donor selection and surgical planning before living-related liver transplant.

Patients and Methods

Between April 2003 and December 2008, a total of 175 consecutive potential closely related-living-liver donors (113 men and 62 women; age range, 23-34 years; mean, 32 years) were included in our study. Those subjects were prospectively examined with a multiphasic multislice spiral computed tomography protocol preoperatively and during surgical planning for liver transplant, which was approved by the liver transplant ethical committee board of the National Liver Institute, at Menoufiya University. Subjects were given written, informed consent; and the study protocol conformed to the ethical guidelines of the 1975 Helsinki Declaration. All evaluated 175 potential living-liver donors were genetically related. They were initially classified as right lobe potential donors (139 subjects) and left lateral segment potential donors (36 subjects) and were screened clinically and via laboratory investigations. All donors were clinically free of disease, and the results of laboratory analyses revealed that each had a healthy liver and renal function within normal limits before computed tomographic examination.

Preoperative evaluation of donors

Computed tomographic protocol

Computed tomographic studies were performed with multidetector row computed tomography scanners. A baseline unenhanced scan of each subject was obtained. A multiphasic computed tomography study was then performed after the intravenous injection of a nonionic contrast agent at a dose of 2 mL/kg (maximum, 180 mL) administered through an antecubital vein with a power injector at a flow rate of 3 mL/s. A test-bolus technique was used in all patients; a 20-mL bolus of contrast material was injected at the rate of 3 mL/s. The test-bolus technique reveals time-density curves from the aorta to the level of the celiac artery. The peak enhancement is through to be the beginning of the hepatic arterial phase. Postcontrast acquisitions were obtained at 20 to 25 seconds for the arterial phase and 55 to 60 seconds for venous phase. Then, we performed 180-second delayed computed tomography of the abdomen and pelvis to further evaluate the abdomen and to detect liver abnormalities. Each image set was collected within 1 breath-hold from the dome of the diaphragm to the lower pole of the right kidney. The scanning parameters used were as follows: detector collimation, 0.75 to-1 mm; slice thickness, 0.75-to 1 mm; reconstruction increment, 0.5 to-1 mm; gantry rotation speed, 0.5-seconds; tube voltage, 120 to -140 kV; and current, 300 to -360 mA.

On a separate workstation, multiplanar reformatted, maximum-intensity projection and volume-rendering images were obtained from thin axial images that were used further to analyze the image data particularly those of the vascular anatomy.

Image analysis

Reconstructed models were carefully reviewed and compared with the axial source images to ensure that no important vascular structures had been inadvertently deleted from the vascular model. Electronic calipers were used to determine distances between important vascular structures. Images were considered adequate if the relevant hepatic vasculature in the appropriate phase of contrast material enhancement was depicted sufficiently. Analysis of the image data was focused on the following factors:

- **Assessment of hepatic morphology:** Using computed tomography attenuation measurements from a fixed level along the midright and midleft lobes in the 2 axial images obtained at different kilovoltage settings (80 KV and 140 KV), we evaluated the hepatic parenchyma for fatty infiltration and focal lesions or masses (19).
- **Determination of total liver and graft volumes:** Total liver and graft volumes were measured on the axial venous phase image set after we had traced, by hand, the contours of both the entire liver and the graft (liver segments V to VIII, or II and III). Particular care was taken to exclude the inferior vena cava, extrahepatic portal vein, and major fissures. We defined a virtual hepatectomy plane that corresponded to the plane of the surgical incision and was chosen as follows: For the right lobe, harvest a plane 1 cm to the right of the middle hepatic vein that extended from the level of the suprahepatic inferior vena cava down to the gallbladder fossa; for left lateral segment harvest, a plane along the falciform ligament (Figure 1). Automatic software was used to calculate liver volume from lines drawn by hand on a workstation.
- **Morphology of the hepatic arterial system:** The hepatic arterial anatomy was analyzed in the arterial phase and was assessed for anatomic variants according to the method of Michels (14).
- **Morphologic characteristic of the portal veins:** Venous phase images were used to evaluate the portal venous system, which was assessed for anatomic variants according to the classification of Akgul and colleagues (13).
- **Morphologic characteristic of the hepatic veins:** Venous phase images of the hepatic veins were also evaluated and were characterized according to the classification system of Nakamura and Tsuzuki (20). Special attention was paid to the assessment of branches crossing the dissection line and large accessory branches (those with a transverse diameter of ≥ 3 mm) that necessitated separate anastomosis in the recipient.

Only surgically important variants, those with any affect on surgical management, were considered in our study. In candidates chosen to be donors, preoperative findings were correlated with intraoperative findings.

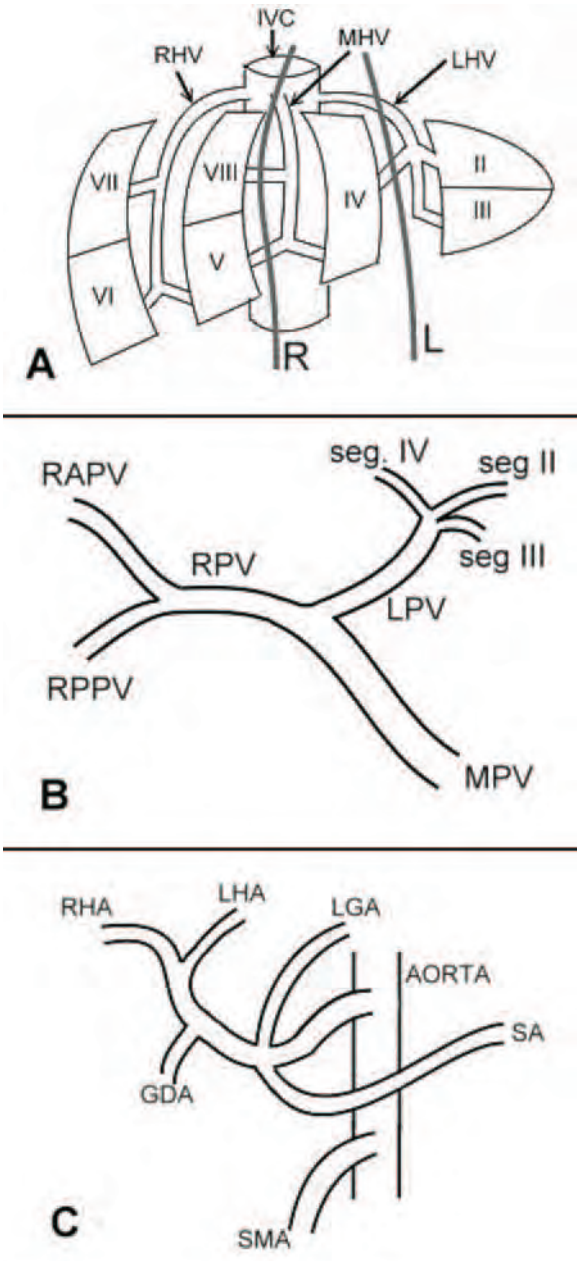

Figure 1. A–C. (A) Schematic drawing of normal segmental anatomy and the draining pattern of hepatic veins. The thick lines drawn in black represent the transection planes in right lobe donors and left lateral segments donors. (B) Schematic drawing of normal portal vein anatomy. The main portal vein splits into the right portal vein and the left portal vein at the portal hilum, the right portal vein splits into the right anterior portal vein and the right posterior portal vein branches, and the left portal vein splits into the branches that feed segments II, III, and IV. (C) Schematic drawing of normal hepatic artery anatomy. The main hepatic artery originates from celiac trunk and divides into the gastroduodenal artery and the proper hepatic artery. The proper hepatic artery then splits into the left hepatic artery and the right hepatic artery.
Abbreviations: CT, celiac trunk; GDA, gastroduodenal artery; IVC, inferior vena cava; L, left lateral segments donors; LGA, left gastric artery; LHA, left hepatic artery; LHV, left hepatic vein; LPV, left portal vein; MHA, main hepatic artery; MHV, middle hepatic vein; MPV, main portal vein; PHA, proper hepatic artery; R, Right lobe donors; RAPV, right anterior portal vein; RHA, right hepatic artery; RHV, right hepatic vein; RPPV, right posterior portal vein; RPV, right portal vein; SA, splenic artery; SMA, superior mesenteric artery.

Operative procedure

The surgeon uses a standard L-shaped incision to expose the donor liver. The suprahepatic vena cava and hepatic veins also are exposed. The hilar anatomic structures are then identified and the gall bladder is excised. The liver dome is visually inspected to identify the suprahepatic portion of the inferior vena cava and the hepatic veins. The radiologist performs an intraoperative ultrasonographic assessment of the donors by using a linear 7- to 10-MHz probe to delineate the intrahepatic vascular anatomy. The arterial, venous, and biliary elements of the corresponding graft are isolated. The probe is placed on the liver dome at the suprahepatic inferior vena cava and is moved along the anterior surface of the liver in the axial and sagittal planes to identify the middle hepatic vein and its main branches, as well as the hepatectomy plane. Then, dissection of the hepatic hilum is performed (right lobe donation: right hepatic artery, right portal vein and right hepatic vein; left lateral segment donation; left hepatic artery, left portal vein and left hepatic vein). The parenchymal transection is performed without inflow occlusion (Figures 2 and 3).

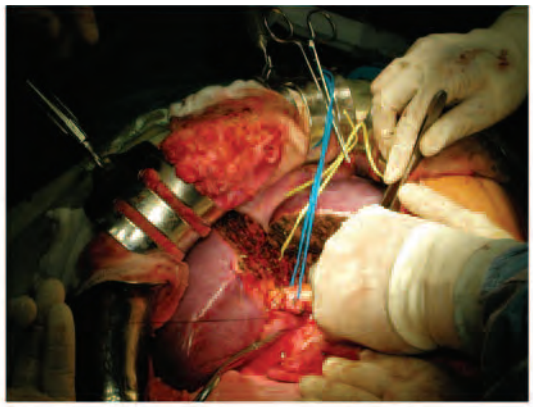

Figure 2. The hepatic vessels are isolated.

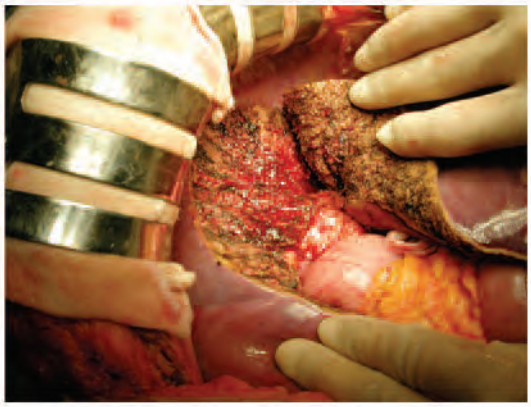

Figure 3. Parenchymal dissection is completed.

The corresponding hepatic artery is ligated, the corresponding portal vein is sutured, and the corresponding hepatic vein is transected and sutured. The liver graft is removed and is flushed successively with histidine-tryptophan-ketoglutarate preservation solution at 4°C through a portal vein cannula. The graft was weighed with a calibrated scale after flushing and preparation.

Intraoperative comparisons

The preharvest, multislice, helical, computed tomography findings regarding parenchymal and vascular morphologic characteristics and the estimated volumes were compared with intraoperative findings, which served as standard of reference. The preoperatively assessed transplant volumes and the intraoperatively determined graft weights were compared on the basis of a 1:1.15 conversion factor, which assumes similar physical densities of water and healthy donor liver tissue, but also takes into account resected graft reperfusion (21, 22). The volumes of potential donor livers determined with computed tomography were matched with the volume needed by the recipient, which was calculated according to body surface area. The volumes of the segment or lobe to be donated and the remnant liver were also calculated. The predicted graft volume according to computed tomography and the actual graft volumes were correlated with the Pearson product moment correlation analysis.

Results

Sixty-five recipients underwent transplant surgery: (right lobe donation: segments V, VI, VII, and VIII in 47 adults; left lateral segment donation: segments II and III in 18 children). The patients were divided into the following 3 groups according to the indications for liver transplant: the cholestatic group (23 patients, 35.4%), the malignant group (12 patients, 18.4%), and the other underlying diseases group (30 patients, 46.2%), which included posthepatitis status (19 patients, 29.2%) and those with Budd-Chiari syndrome (6 patients, 9.2%), congenital hepatic fibrosis (2 patients, 3.2%), and cryptogenic cirrhosis (3 patients, 4.6%) (Table 1).

Computed tomography procedure was technically adequate with optimal arterial and venous opacification that facilitated vascular

Table 1. Indications for liver transplant in the study subjects.

Indications for transplant	No. of patients (%)
Cholestatic group	23 (35.4)
Biliary atresia	10 (15.3)
Byler disease	6 (9.2)
Paucity of bile ducts	7 (10.7)
Malignant group	12 (18.4)
Hepatocellular carcinoma	10 (15.3)
Hepatoblastoma	2 (3.2)
Other underlying disease group	30 (46.2)
Posthepatitis status	19 (29.2)
Budd-Chiari syndrome	6 (9.2)
Congenital hepatic fibrosis	2 (3.2)
Cryptogenic cirrhosis	3 (4.6)

analysis. As a result of multislice helical computed tomography findings of the evaluated 175 potential donors, 56 were excluded from donation (32%) because of anatomic factors, and 65 were selected as donors (37.1%), who then completed the evaluation and screening for donation and underwent transplant surgery. The remaining 54 potential donors (30.9%) did not complete the evaluation, and screening in the late stage owing to social causes and were not included in our results.

Of the 56 potential donors excluded from surgery, vascular variants, which were the most common causes of exclusion, were identified in 20 (35.7%). Portal vein variants (the trifurcation of the portal vein in 6 potential donors [Figure 4], a right posterior portal vein that arose separately from the main portal vein in 3 [Figure 5], and the absence of the main right portal vein in 2, which precluded surgery) resulted in 11 exclusions from the potential donor pool (19.6%).

The following hepatic vein variants resulted in 9 exclusions (16.1%): dominant middle hepatic vein that provided drainage for a large portion of the right lobe in 5 potential donors (Figure 6); and hepatic vein branches larger than 5 mm that drained segments V and VIII, that moved along the hepatectomy plane, and drained into the middle hepatic vein in 4 potential donors (Figure 7).

The second cause of exclusion from donation was fatty infiltration, which resulted in 17 exclusions (30.4%). Those individuals had liver attenuation measuring below -60 HU at 80 kVp that decreased by 8 to 12 HU at 140 kVp (Figure 8). Insufficient liver volume resulted in 12 exclusions (21.4%) (Figure 9), and incidental focal liver lesions (simple hemangiomas in 4 potential donors, focal nodular hyperplasia in 2, and a simple cyst in 1 potential donor; Figure 10) resulted in 7 exclusions (12.5%; Table 2).

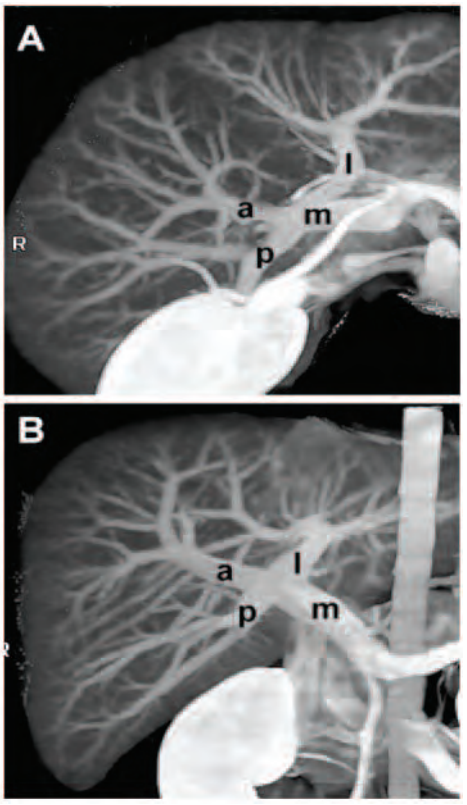

Figure 4. A and B. A 27-year-old male, potential living-liver donor. Portal phase oblique axial (A) and coronal (B) 3-dimensional maximum intensity projection images show the trifurcation of the main portal vein into the anterior, posterior, and left branches. The posterior branch feeds segments VI and VII, the anterior branch feeds segments V and VIII, and the left branch feeds the left lobe. No right portal vein trunk is visible.
Abbreviations: a, anterior branch of the portal vein; l, left branch of the portal vein; m, main portal vein; p, posterior branch of the portal vein.

Of the 65 candidates who were selected as donors and underwent transplant surgery, 41 had conventional vascular anatomy, and 24 had variants of the vascular anatomy that did not preclude surgery but required modification of the surgical technique in both donors and recipients (in 23 candidates) and in the donor only (in 1 candidate) (Table 3).

Modification of the surgical techniques was required because of the following variants detected by multislice, helical, computed tomography: portal vein variants (in 10 candidates), hepatic vein variants (12 candidates), and hepatic artery variants (2 candidates). Portal vein variants included a short main portal vein in 2 donors (in whom more dissection was required to expose the main and right portal veins); which were then elongated by the insertion of the intrahepatic portal vein from the explanted recipient liver. Another portal vein variant was early bifurcation of the right portal vein into the

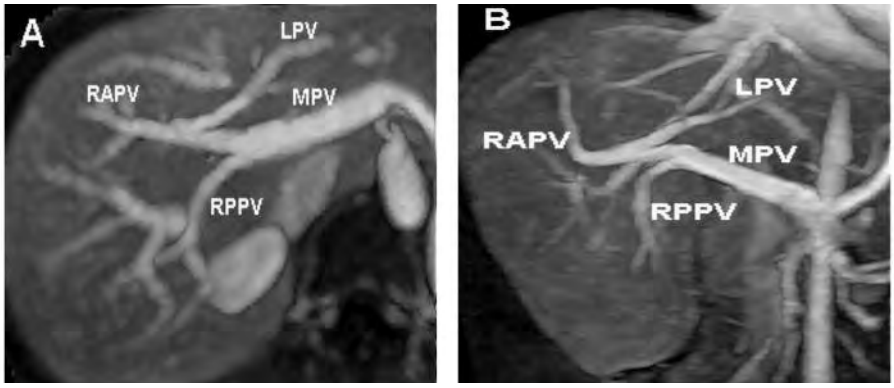

Figure 5. A and B. A 32-year-old male potential living-liver donor. Portal phases axial (A) and coronal (B) 3-dimensional maximum intensity projection images show the main portal vein bifurcating into the right posterior portal vein, which has a separate origin and common trunk that gives rise to the left portal vein and the right anterior portal vein.
Abbreviations: LPV, left portal vein; MPV, main portal vein; RAPV, right anterior portal vein; RAPV-LPV, common trunk; RPPV, right posterior portal vein.

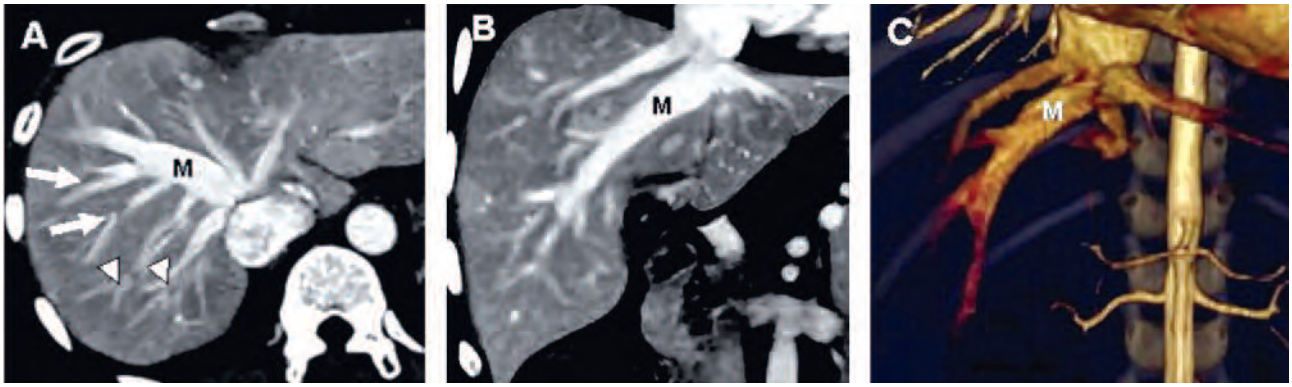

Figure 6. A–C. A 30-year-old female potential living-liver donor. Venous phases axial (A) and coronal (B) 2-dimensional maximum intensity projection and volume-rendering (C) images show a large middle hepatic vein (M) that drains the anterior segments and segment VII (straight arrows). Several right hepatic veins (arrowheads) drain the posterior segments into the middle hepatic vein.
Abbreviations: M, middle hepatic vein; RHVs, right hepatic veins

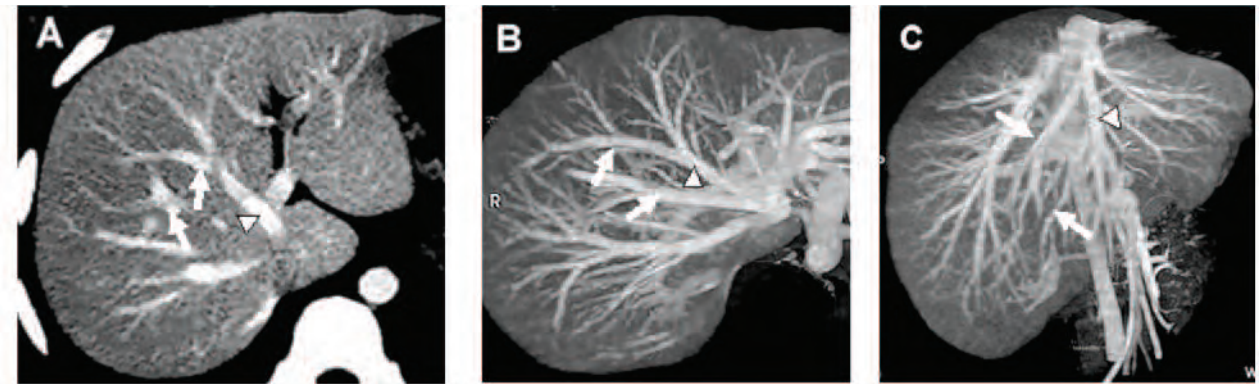

Figure 7. A-C. A 29-year-old potential right lobe living-liver donor. Venous phases axial (A), 3-dimensional maximum intensity projection oblique axial (B), and coronal (C) images show large (> 5 mm) tributary veins (arrows) draining segments V and VIII into the middle hepatic vein. The planned hepatectomy plane intersects the accessory veins before their drainage into the middle hepatic vein (arrowhead).

anterior and posterior branches; a condition detected in 2 donors (Figure 11) in whom more dissection also was required to expose the anterior and posterior portal vein separately, after which dual anastomosis was performed with the right and left portal veins of the recipient. In the fifth donor, the angle between the left portal vein and the main portal vein in the donor was increased, so a stent was implanted in the left portal vein of the donor to prevent postoperative thrombosis.

Hepatic vein variants included the presence of a right inferior hepatic vein larger than 3 mm in 6

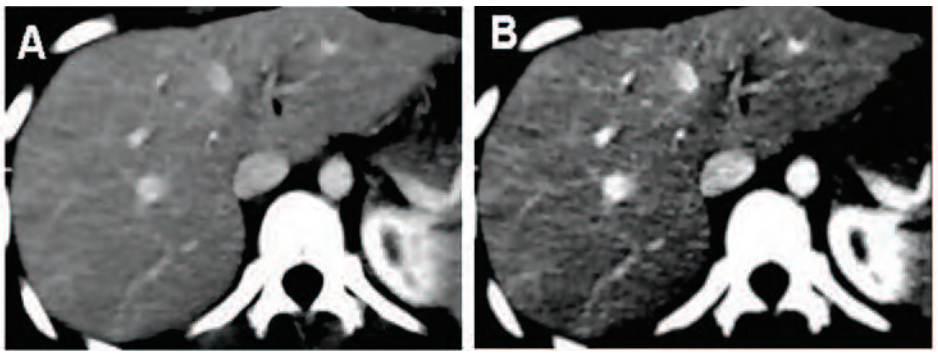

Figure 8. A and B. A 33-year-old female potential living-liver donor. Axial arterial phase images at 80 (A) and 140 (B) kVp show diffuse low-density of the hepatic parenchyma measuring –69 HU in (A) that decreased to –80 HU in (B), a finding that indicates fatty infiltration.

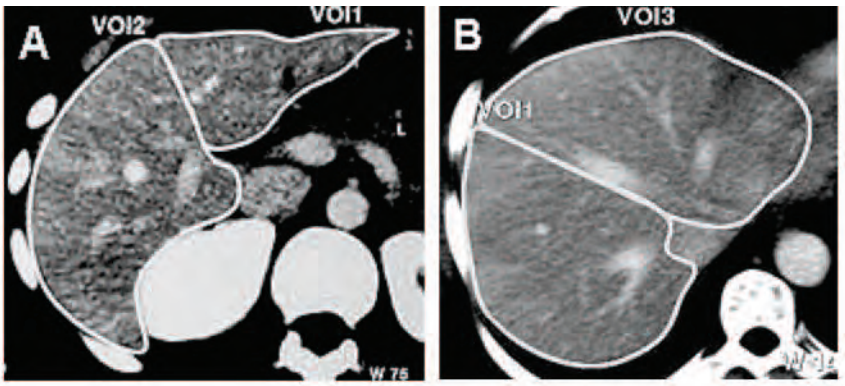

Figure 9. A and B. Liver volume calculation in 2 potential living-liver donors. Note the axial portal phase images (A), the left lateral segments (segments II and III), and (B) the right lobe (segments V-VIII). Those 2 donors were excluded from donation because of insufficient graft volume.

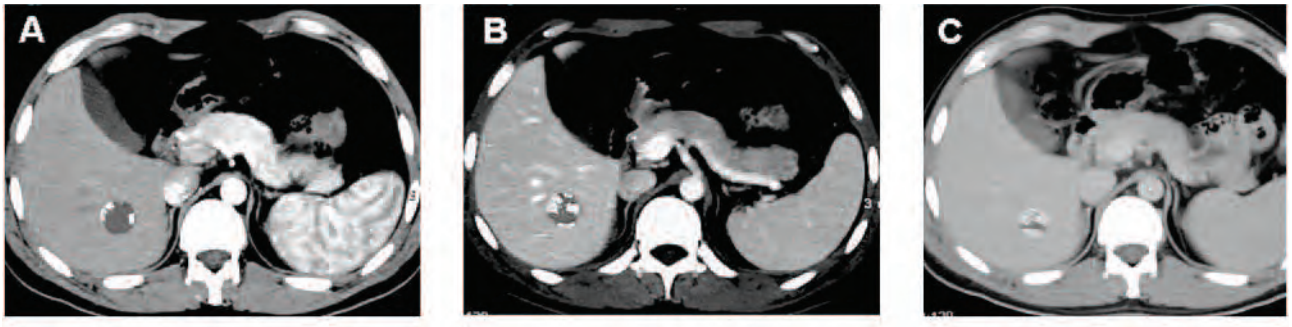

Figure 10. A–C. A 34-year-old female potential living-liver donor. Axial computed tomography images during the arterial (A), venous (B), and delayed (C) phases show typical features of a hemangioma with peripheral nodular enhancement in Figure 10A that increases in a centripetal manner in Figures 10B and 10C

Table 2. Causes of exclusion from liver donation.

Causes of exclusion from liver donation	No. of potential donors* (%)
Vascular variants	
Portal vein anomalies	11 (19.6)
Trifurcation of the portal vein	6 (10.7)
Right posterior portal vein	3 (5.3)
No main right portal vein	2 (3.6)
Hepatic venous anomalies	9 (16.1)
Dominant middle hepatic vein	5 (9)
Segment V and VIII vein	4 (7.1)
Fatty infiltration	17 (30.4)
Insufficient liver volume	12 (21.4)
Incidental focal liver lesions	7 (12.5)

* n=56

donors. Those veins were dissected in the donor and were saved; then, 2 separate anastomoses of the proper right hepatic vein and right inferior hepatic veins to the inferior vena cava of the recipient were performed (Figure 12). Also, 3 donors had a right, inferior hepatic vein and a segment VIII vein larger than 5 mm in diameter that drained into the middle hepatic vein. Those veins were dissected and saved in the donor, and the dissection plane was adjusted to include the segment VIII vein and avoid the middle hepatic vein in the graft. Then, 3 separate anastomoses of the proper right hepatic vein, the

right inferior hepatic vein, and the segment VIII vein to the inferior vena cava of the recipient were performed. Another 3 donors had a segment VIII vein that was larger than 5 mm and near the proper right hepatic vein, so the 2 veins were anastomosed to form 1 stoma in the liver graft, and were then reanastomosed to the right hepatic vein of the recipient (Figure 13).

Hepatic artery variants were identified in 2 donors. In 1 donor, the right hepatic artery arose from the superior mesenteric artery (Figure 14). In that donor, more dissection was performed (until superior mesenteric artery was reached) to expose and lengthen the right hepatic artery; then, a tangential anastomosis was performed with the right hepatic artery of the recipient. That was required because of the discrepancy in the diameters of the graft and the recipient hepatic artery. In another donor, the accessory left hepatic artery arose from the left gastric artery (Figure 15); this artery was saved in the donor and was to be anastomosed to the left hepatic artery of the recipient. Vascular variants detected by multislice, helical, computed tomography in the 24 donors, and their surgical modification techniques in both donors and recipients are listed in Table 3.

All variants of the portal venous, hepatic venous, and hepatic arterial anatomy revealed by computed tomography in the 65 selected donors were confirmed intraoperatively. No further variants were detected and none of the depicted variants was undetectable via multislice computed tomography. Computed tomographic study results showed a strong statistical correlation between the intraoperatively assessed graft volume and the preoperatively calculated liver volume. Pearson correlation analysis showed a correlation of r=0.98 ($P < .001$). In our study, volumes ranged from 754 to 1765 mL for the right lobe, and 187 to 415 mL for the left lateral segments II and III.

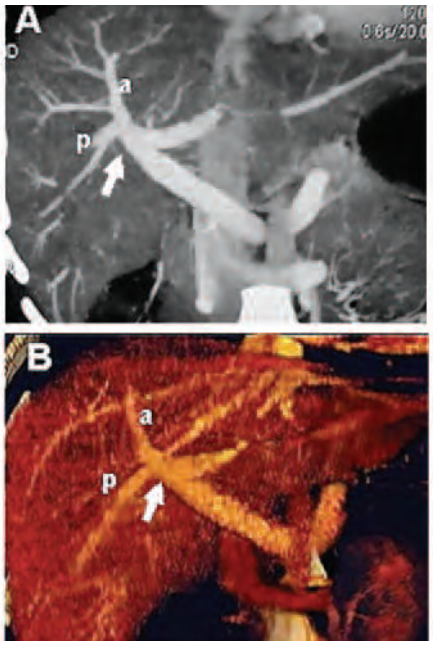

Figure 11. A 27-year-old female potential living-liver donor. Coronal 2-dimensional maximum intensity projection-images (A) and 3-dimensional volume-rendering images show early bifurcation of the right portal vein (arrow) into the anterior and posterior branches.
Abbreviations: a, Anterior right portal vein branch; p, posterior right vein branch.

Discussion

Radiologic evaluation of potential liver donors is important. Because of the complexity of hepatic resection, preoperative imaging has an important role in patient selection and surgical planning. The

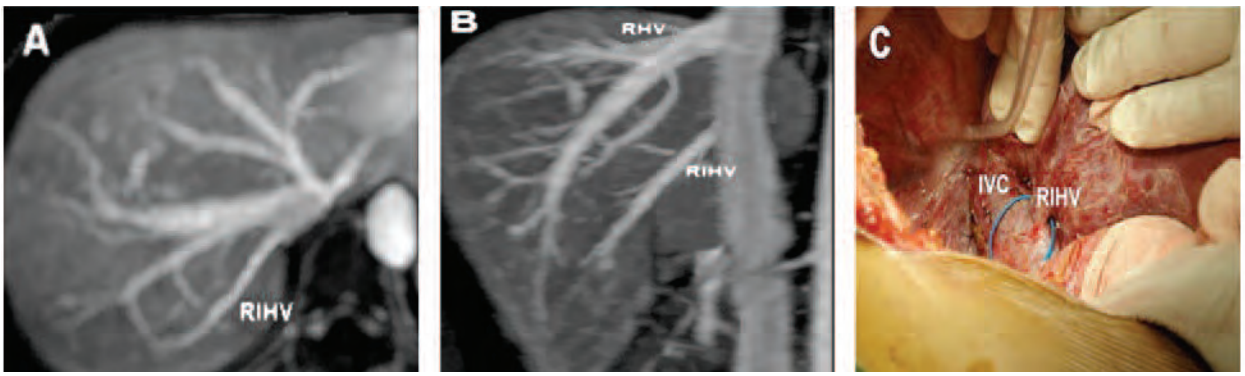

Figure 12. A 25-year-old female potential living-liver donor. Venous phases axial (A) and oblique coronal (B) 3-dimensional maximum intensity projection images of the hepatic veins show a large (> 3 mm) right inferior hepatic vein draining the posterior segment of the right lobe separately into the inferior vena cava. It was located more than 5 mm from the main right hepatic vein. The corresponding intraoperative image (C) clearly shows the right inferior hepatic vein draining into the inferior vena cava as demonstrated in preoperative computed tomography images.
Abbreviations: IVC, inferior vena cava; RIHV, right inferior hepatic vein; RHV, right hepatic vein.

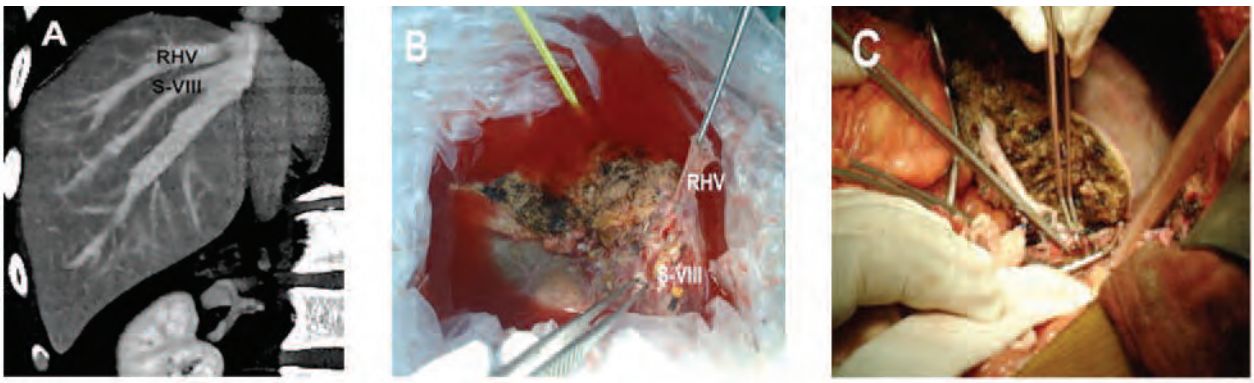

Figure 13. A 29-year-old female potential living-liver donor. A venous phase coronal maximum intensity projection image (A) shows a segment VIII vein larger than 5 mm and near the proper right hepatic vein. Intraoperative images of the right lobe graft (B) clearly shows the segment VIII vein near the proper right hepatic vein with a vein patch between them.
Another intraoperative image (C) shows the anastomosis between the proper right hepatic vein and the segment VIII vein as 1 stoma.
Abbreviation: RHV, Right hepatic vein.

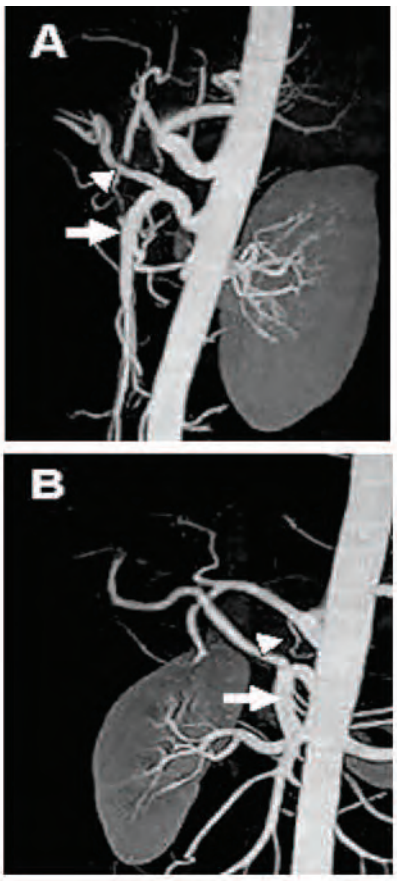

Figure 14. A and B. A 27-year-old female potential living-liver donor. Three-dimensional sagittal (A) and oblique coronal (B) 3-dimensional maximum intensity projection images based on computer tomography scans and obtained during the arterial phase show a replaced right hepatic artery (arrowheads) arising from the superior mesenteric artery (arrow).

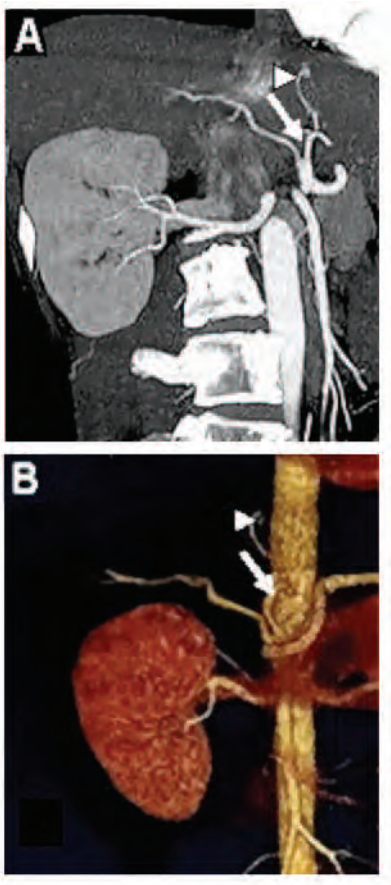

Figure 15. A and B. A 25-year-old male potential living-liver donor. Coronal maximum intensity projection (A) and volume-rendering (B) images based on computed tomographic studies obtained during the arterial phase show an accessory left hepatic artery (arrowhead) arising from the left gastric artery (arrow).

main goal of presurgical imaging is to provide a vascular arterial and venous "road map," which is critical for surgical guidance. In addition, the donor's liver parenchyma must be examined for size, shape of right and left lobes, incidental lesions, fatty infiltration, and other abnormalities. Knowledge of the total and segmental liver volume is equally important to avoid donor-recipient volume mismatches, which can cause graft failure (16).

Table 3. Vascular variants detected by multislice, helical, computed tomography in liver donors* and surgical modifications in liver donors and recipients.

Vascular variants detected by multislice helical computed tomography	Surgical modifications in donors	Surgical modifications in recipients
Portal vein (n=10)		
• Very short main portal vein (n=4).	• More-extensive dissection of the main portal vein.	• Elongation with the intrahepatic portal vein of the recipient.
• Early bifurcation of the right portal vein into anterior and posterior branches (n=5).	• Dissection of the anterior and posterior portal vein branches.	• Dual anastomosis with the right and left portal veins of the recipient (pantaloon anastomosis).
• Increased angle between the left portal vein and the main portal vein (n=1).	• Stenting of the left portal vein.	• No modification.
Hepatic vein (n=12)		
• Right inferior hepatic vein larger than 3 mm (n=6).	• Dissection of the right inferior hepatic vein.	• Two separate hepatic vein anastomoses to the inferior vena cava of the recipient (the right hepatic vein and the accessory right inferior hepatic vein).
• Right inferior hepatic vein and segment VIII vein larger than 5 mm and draining into the middle hepatic vein (n=3).	• Dissection of the right inferior hepatic vein, preservation of the segment VIII vein, and adjustment of the dissection plane to include the segment VIII vein and avoid the middle hepatic vein.	• Three separate hepatic vein anastomoses to the inferior vena cava of the recipient (the right hepatic vein, the accessory right inferior hepatic vein, and the segment VIII vein).
• Vein of segment VIII larger than 5 mm and near the right hepatic vein proper (n=3).	• Anastomosis of the right hepatic vein with the segment VIII vein as 1 stoma.	• Reanastomosis of a single stoma to the right hepatic vein of the recipient.
Hepatic artery (n=2)		
• Right hepatic artery arising from superior mesenteric artery (n=1).	• More-extensive dissection of the artery to the superior mesenteric artery.	• Tangential anastomosis to the right hepatic artery of the recipient.
• Accessory left hepatic artery arising from left gastric artery (n=1).	• Preservation of the artery.	• Reanastomosis of the accessory left hepatic artery with the left hepatic artery of the recipient.

*n=24.

In our experience with individuals examined for potential liver donation; multislice, multiphase, computed tomography of the liver permitted satisfactory parenchymal, vascular, and volumetric preoperative examination. In addition to axial computed tomography data, maximum intensity projections and volume renderings were provided to the transplant surgeon in an easily interpretable form that aided assessment of liver anatomy and planning for the transplant. As a result of multislice, helical computed tomography findings, 56 potential donors in our study (32%) were excluded from surgery because of anatomic variants, and 65 potential donors (37.1%) were selected as donors. The importance of multislice computed tomography is confirmed by other reports that emphasize the role of that tool in the evaluation of arterial and venous anatomy and in the volumetric calculation of the liver portion to be explanted (19, 22, 23).

Resection of the donor liver must be performed with a technique that results in a well-vascularized graft without damage to the remaining liver (23). Therefore, precise preoperative evaluation of the donor, including the detection of anatomic variants in the vascular anatomy, is essential (24). The radiologist must be familiar with both the healthy liver anatomy and be able to identify the presence of variants, especially those that are relative or absolute contraindications for donation, those requiring reconstruction or multiple anastomoses, and those that may alter the surgical approach (25-27).

In our study, classic vascular anatomy served as a guide to understanding the vascular supply and drainage patterns. Using data from multiphase, multislice, computed tomography, we identified important vascular variants that impact patient selection and surgical planning.

For example, the branching pattern of the left and right portal veins from the main portal vein is important in surgical planning (28). Previous studies have reported that some anatomic variations in the portal venous system (eg, trifurcation of the main portal vein, a separate origin of the right posterior sectoral branch from the main portal vein before bifurcation, absence the right portal truncus, a segment IV vein originating from the right portal vein, absence of the left portal vein) are contraindication for surgery, render surgery more

difficult, or increase the risk of postoperative complications (29-31). In our study, portal vein variants led to 19.6% of exclusions. The most common of those variants was trifurcation of the main portal vein (10.7% of the total variants in donors), which was followed by a right posterior portal vein variant that arose separately from the main portal vein before its bifurcation (5.3%) and an absent main right portal vein (3.6%). In such cases, more than 1 portal vein anastomosis is required; this prolongs surgery and increases the risk of postoperative portal vein thrombosis. In individuals with a trifurcated portal vein variant, the left portal vein and the anterior and posterior branches of the right portal vein branch at the same site; this creates a surgical problem because there is no main right portal vein stump that can be used in anastomosis.

Particular attention should be paid to variants (eg, trifurcation or extraparenchymal branching of the anterior branch from the left portal vein) that result in 2 venous opening (32). If the branches are close together, they can be joined to form a single orifice via venoplasty. If they are not close, then they can be anastomosed separately (1 to the right portal vein and 1 to the left portal vein in the recipient) or they can be connected to a Y-shaped vascular graft in a single anastomosis. Therefore, the distance between the 2 branches must be carefully measured (33, 34). Moreover, the shortness of the transverse portion of the left portal vein in such individuals may pose difficulties during the retrieval and implantation of the left lateral segment graft (35). Although variants affecting the left portal vein are uncommon, they also should be identified. Intraparenchymal branching of the anterior branch from the left portal vein and an undivided main portal vein are absolute contraindications for right lobe donation (36).

In our study, the modification of the surgical technique during the dissection and anastomosis of the portal vein were performed by elongating the portal vein, and the subsequent dual anastomosis of the portal vein of the graft with the portal vein of the recipient. In our study, we identified in 10 donors with other important vascular variants of the portal vein that required modifications of the surgical technique, which was optimized for each variant to reduce operative risk. Modifications of the surgical technique were implemented during dissection in the donor and anastomosis in the recipients via elongating the portal vein in 5 donors and dual anastomosis of the portal vein of the graft with the portal vein of the recipient in 4 donors. In only 1 donor, a stent, which prevents postoperative thrombosis, was implanted in the left portal vein because of the increased angle between the main and left portal vein.

A key to successful living-donor liver transplant is to maintain the balance between the blood supply and the venous drainage of the graft. Liver outflow (venous drainage) is a crucial predictor of the success of the graft and of remnant liver function (37-39). Some authors have suggested that the anatomy of the middle hepatic vein is the key to successful right lobe donation, and that the drainage pattern of the middle hepatic vein must be thoroughly evaluated (36). Others have reported that in patients who exhibit dominance of the middle hepatic vein over the right hepatic vein, the middle hepatic vein can provide drainage for a large portion of the right lobe. Large veins draining into the middle hepatic vein from the adjacent segments of the right hepatic lobe (segments V and VIII) require a change in surgical planning to ensure the isolation of those veins in the graft that will be reanastomosed in the recipient (33). As an alternative, the hepatectomy plane can be changed. Otherwise, the transplanted right lobe of the liver could become congested, and organ rejection may occur (37). Several centers have modified their harvesting technique by extending the right lobe graft up to include the middle hepatic vein in the graft (extended right lobe donation), which is a more-compromising procedure for the donor (39).

In our study, 9 potential right lobe donors were excluded from donation because of hepatic venous variants, the most-important of which were the dominance of the middle hepatic vein over the right hepatic vein (a condition identified in 5 potential donors) and the presence of hepatic vein branches larger than 5 mm that drained segments V and VIII and that moved along the hepatectomy plane and drained into the middle hepatic vein. Because the hepatectomy plane in right lobe harvests courses approximately 1 cm to the right of the middle hepatic vein (which is not included in the graft) the transplant recipient is at high risk for congestion because a sizable part of the right lobe is drained primarily by the middle hepatic vein in both conditions.

A venous anomaly relevant in donors is a right inferior hepatic vein that drains directly into the

inferior vena cava and usually drains segment VI, VII, or (rarely) V. That anomaly has been identified in as many as 47% of patients studied (40). In preoperative planning, it is important to highlight not only the presence and number of those accessory veins but also their size and distance from the main hepatic venous drainage site along the inferior vena cava. When the size is more than 3 mm and the distance is more than 4 cm, it may be technically difficult to implant both veins into the inferior vena cava of the recipient with a single stoma. Those veins should be preserved to reduce the risk of graft malfunction (35).

Other hepatic venous variants in our study required 12 surgical modifications in both donors and recipients because of the presence of more than 1 hepatic vein variant in the same graft. Nine donors had a right inferior hepatic vein larger than 3 mm in diameter, and 3 of those 9 also had veins larger than 5 mm in diameter that drained segment VIII into the middle hepatic vein. In those 3 donors, the hepatectomy plane was adjusted a little away from the middle hepatic vein, which was not included in the graft, and the segment VIII vein was dissected. Then, more than 1 anastomosis was performed in the recipients, according to the number of the dissected veins in each graft (a triple anastomosis if there were 3 veins and a double anastomosis if there were 2 veins) because of the long distance between the dissected veins in the grafts. In another 3 donors with a sizable (> 5 mm) segment VIII vein that was adjacent to the proper right hepatic vein, both veins were anastomosed as 1 stoma and were then reanastomosed to the right hepatic vein of the recipient.

In a living-related liver transplant in which a left lobe or right lobe graft is used, preoperative identification of dominant artery that supplies segment IV and arises from the right hepatic artery is important. In hepatectomy of the right liver lobe of the donor, if the main inflow to segment IV originates from the right hepatic artery, then that artery should be clamped distal to the origin of that branch to ensure adequate blood perfusion in the remaining left liver lobe of the donor (41, 42). In hepatectomy of the left lobe of the donor liver, when the dominant artery supplying segment IV arises from the right hepatic artery or arises separately from the proper hepatic artery, both the left hepatic artery and the artery supplying the segment IV are usually prepared for possible anastomosis to the recipient's artery (42-44). For the same reason, identification of the separate origins of these segment II and III branches from the proper hepatic artery is also important in living-related liver transplant in which the left lobe of the donor liver or left lateral segment is used (42).

In our study, we did not face the problem of segment IV arterial supply in surgical planning and selection. Although Kobayaski and colleagues (44) found that 50% of the anomalous hepatic arterial configurations are technically incompatible or exert potentially adverse effects on the outcome of surgery, our liver transplant team did not exclude patients with such variants from being donors. However, knowledge of those variants is vital to the transplant surgeon. In our study, the surgical technique was modified in 2 donors, in 1 donor the right hepatic artery arose from the superior mesenteric artery. To address that variants, the donor artery was dissected to its origin in the superior mesenteric artery (which lengthened that graft), and tangential anastomosis with the right hepatic artery of the recipient was performed because of the discrepancy between the diameters of the anastomosed arteries. Another donor had an accessory left hepatic artery that arose from the left gastric artery. This necessitated a separate anastomosis to the left hepatic artery of the recipient.

In our study, 36 of 56 potential donors were excluded from donation for reasons other than vascular variants. Seventeen potential donors were excluded (30.3%) because fatty infiltration of the liver, 12 because of insufficient liver volume (21.4%), and 7 because of incidental focal liver lesions (12.5%).

Preoperative detection of fatty infiltration of the liver is critical. That condition may be associated with impaired liver function and possible failure of the implanted graft because the working hepatic mass is much less than the calculated mass (31, 45). Computed tomography is sensitive in detecting fatty infiltration of the liver, and dual-energy computed tomography may be used to quantify the degree of fatty infiltration. When scanned with 80 and 140 kVp, fatty livers exhibit a greater decrease in attenuation than that found in healthy livers. Mild fatty infiltration (< 25%) is associated with a decrease of 6 H. Moderate (50%) and severe (> 75%) fatty infiltration are associated with a decrease of 11 H and 20 H (2, 16, 19).

In our study, we used a dual-energy computed tomography method to diagnose fatty infiltration. We were careful to measure homogeneous regions of the liver, and paired measurements were identical in size and location of measurements. Because fatty infiltration may be focal, we took 2 measurements; 1 in the right lobe and 1 in the left lobe. To avoid erroneous measurements related to volume averaging, density measurements did not include the periphery of the liver.

When the donor is evaluated, lobar and total liver volumes must be known before transplant. Total liver volume has been reported to have a relatively constant association with body weight; however, lobar volumes are quite variable (46). The ratio between graft weight and recipient body weight or between graft volume and the estimated standard liver volume of the recipient has been used to determine the ideal liver volume for recipients. It is considered acceptable when those parameters are at least 0.8% and 40%, respectively, if the liver parenchyma is normal and without fatty infiltration. The recipient requires a minimum of 40% of healthy liver or an amount of healthy liver equal to 1% of body mass (23, 24, 31). A liver-remnant volume of 30% to 40% of the total liver volume is sufficient for donor survival, if the liver parenchyma is normal and without fatty infiltration (2, 5, 7, 24).

In our study, the liver volume was determined on the basis of computed tomography images, although in the literature, there are many reports about volumetric evaluation based on computed tomography and magnetic resonance images (12, 16, 19). Our choice was determined by the high-quality and definition of the computed tomography images obtained with our equipment. The results of volumetric evaluations were matched and confirmed by surgical data in all donors and data from the literature (16, 19, 24, 27) agree with our findings.

We found incidental focal masses in 7 potential donors who were then excluded from donation. Those masses had typical features and were diagnosed with our computed tomography imaging protocol. To exclude diffuse liver disease and hepatic masses that can compromise liver function in the remnant or the transplant hepatic graft, imaging that provided dynamic data sets of the arterial and portal-hepatic venous phases were performed (16, 19).

In conclusion, multidetector computed tomography is a valuable tool in the evaluation of potential living-liver donors; it provides accurate and comprehensive information about the hepatic vascular anatomy, and the liver parenchyma, as well as volumetric measurements that are critical in selecting the most-suitable potential donor and the safest surgical approach. That modality contributes to donor safety, which is the highest priority during the selection process; assists surgical planning; and ensures that an optimal graft that can maintain the balance between the blood supply and venous drainage will be obtained. We suggest that communication between the radiologist and the operating surgeon is essential, so that the surgical approach can be tailored and optimized for each patient and the technical success of this challenging procedure can be improved.

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