Evaluation of the Donor Liver for Living Donor Liver Transplantation

David Brandhagen,* Jeff Fidler,† and Charles Rosen‡

Key Points
1. Accurate assessment of the donor liver is an important component of the living donor liver evaluation and is critical to ensure a successful outcome for both donor and recipient.
2. Liver biochemistry tests, viral hepatitis serological tests, tests to exclude chronic liver disease, and volumetric computed tomographic or magnetic resonance (MR) imaging of the liver are performed routinely as part of the donor evaluation.
3. Liver biopsy should be a standard component of the donor evaluation in all donors, with the possible exception of those with a body mass index less than 25 who have normal liver test and abdominal imaging study results and no risk factors for chronic liver disease or hepatic steatosis.
4. The maximum acceptable percentage of steatosis in the donor liver is unknown, but most centers use an upper limit of 10% to 30%.
5. A graft-recipient body weight ratio of at least 0.8% provides the recipient with adequate hepatic mass in most situations.
6. Anatomic variants in donor biliary and hepatic vascular anatomy are common.
7. Evaluation of donor vascular anatomy varies among centers and includes MR or computed tomographic angiography and hepatic angiography.
8. Evaluation of biliary anatomy is performed most commonly using intraoperative cholangiography. Some centers use MR cholangiography or endoscopic retrograde cholangiopancreatography in selected situations. (Liver Transpl 2003;9:S16-S28.)

Living donor liver transplantation (LDLT) has become an acceptable alternative for adults in need of orthotopic liver transplantation (OLT) who are not likely to receive a deceased donor (cadaveric) organ in a timely fashion. The need for LDLT has arisen because of a persistent shortage of adult deceased donor livers. Since 1991, there has been a 10-fold increase in adult registrations on the United Network for Organ Sharing (UNOS) liver transplant waiting list, whereas the number of liver transplantations has increased by only approximately 50% during the same period. Currently, 17,232 adults are registered on the UNOS liver transplant waiting list, and in 2001, a total of 4,269 adults were recipients of deceased donor livers. Although the number of registrations on the UNOS liver transplant waiting list has decreased since the implementation of the Model for End-Stage Liver Disease score for allocation of donor livers, the number of sick patients has remained the same. The number of deaths also is increasing, and currently, approximately 10% of adults on the waiting list die each year. Most transplant centers have expanded their deceased donor selection criteria to include the use of livers from donors who are older, overweight, and/or drug or alcohol abusers. Expanding donor selection criteria will not completely solve the donor shortage and may increase recipient morbidity and mortality.

This critical shortage of donor organs has fostered the development of LDLT. The first successful LDLT was performed in 1989 and involved transplantation of the left-lateral liver from a mother to her son. Throughout the 1990s, left-lateral and left-liver LDLT became established as a successful procedure in pediatric patients with end-stage liver disease. Although left-liver LDLT also was successful in some Asian adults, it was not performed frequently in the United States because the left liver provides inadequate hepatic mass for most US adults. The first adult-to-adult right-liver LDLT was reported from Japan in 1994. Adult-to-adult right-liver LDLT was first performed in the United States in 1997. Since then, there has been a rapid proliferation of right-liver LDLT in the United States. The number of procedures has increased from 56 in 1996 to 509 in 2001. It was estimated that 5% of adult patients on the waiting list may be able to undergo LDLT.

Although LDLT has become a viable option in selected adults in need of OLT, it is not without risk. Morbidity occurs in 15% to 30% of donors and is usually minor, such as a wound infection or ileus. More serious complications, such as a bile leak or stricture or need for reoperation, are less common. In the United States, one donor underwent OLT for liver failure, and there have been three reported donor deaths, for an...
estimated risk for mortality of 0.5%. Although morbidity and mortality are always concerning, they are especially so in a previously healthy person who does not need an operation. Patient and allograft survival in living donor liver transplant recipients is acceptable, but may be slightly lower than in deceased donor transplant recipients, and morbidity clearly is greater. The goals of any LDLT program must be to minimize donor morbidity, avoid mortality, and obtain acceptable recipient outcomes to justify the risk to the donor. This review focuses on evaluation of the donor liver for LDLT. Accurate evaluation of the donor liver is critical to a successful outcome for both the donor and recipient.

**Evaluation of the Donor Liver**

An algorithm summarizing the evaluation of the donor liver is shown in Figure 1. The donor liver evaluation can be subdivided into three components, which include assessment of the hepatic parenchyma, volume, and vascular and biliary anatomy. As with the donor evaluation in general, diagnostic studies typically progress from least to most invasive. A recent survey of liver transplant programs performing LDLT confirmed there is a great deal of variability among individual centers regarding components of their standard living donor evaluation protocols. Liver biochemistry tests, hepatitis serological tests, and blood tests to exclude

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**Figure 1. Preoperative diagnostic algorithm for evaluation of the donor liver.** *Aspartate aminotransferase, alanine aminotransferase, alkaline phosphatase, bilirubin, albumin, international normalization ratio. **Serum transferrin saturation, ferritin, ceruloplasmin, α1-antitrypsin phenotype, antinuclear antibody, smooth muscle antibody, antimitochondrial antibody. ***Not routinely performed at all centers.
chronic liver disease are performed routinely as part of most protocols. In addition, volumetric computed
tomography (CT) or magnetic resonance (MR) imaging (MRI) is a standard part of the evaluation. Variabil-
ity exists among centers in the performance of other diagnostic studies, such as liver biopsy, hepatic angiog-
raphy, and cholangiography. Table 1 lists results of the survey for the number of centers that perform each of
these studies.

### Parenchyma

The donor hepatic parenchyma is evaluated to assess for the presence of chronic liver disease and steatosis. Each
of these could have potential implications for both the donor and recipient. The evaluation typically begins
with liver biochemistry tests, including aspartate aminotransferase, alanine aminotransferase, bilirubin, alka-
line phosphatase, albumin, and international normalized ratio. These tests may be performed locally and
sent to the transplant center for review. After a potential donor is seen at the transplant center, blood tests to
exclude chronic liver disease often are performed early in the course of the evaluation. These tests typically
include serum transferrin saturation, ferritin, ceruloplasmin, α1-antitrypsin phenotype, antinuclear antibo-
dy, smooth muscle antibody, antimitochondrial antibody, and hepatitis serological tests (hepatitis B sur-
face antigen and antibody, hepatitis B core antibody, and hepatitis C antibody). In general, donors with evi-
cence of underlying chronic liver disease or a positive hepatitis C antibody, hepatitis B surface antigen, or
core antibody result are excluded from further consider-
ation. There is no consensus on the use of donors who are α1-antitrypsin phenotype MZ or hemochromatosis
C282Y heterozygotes.

### Table 1. Transplant Centers Reporting the Use of Liver Biopsy, Arteriography, and ERCP or MR Cholangiopancreatography as
Part of the Evaluation of Potential Living Donors

<table>
<thead>
<tr>
<th>Procedure</th>
<th>All Donors</th>
<th>Selected Donors</th>
<th>No Donors</th>
</tr>
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<tbody>
<tr>
<td>Liver biopsy</td>
<td>6 (14)</td>
<td>25 (60)</td>
<td>11 (26)</td>
</tr>
<tr>
<td>Arteriography</td>
<td>6 (14)</td>
<td>11 (26)</td>
<td>25 (60)</td>
</tr>
<tr>
<td>Cholangiopancreatography*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERCP</td>
<td>20 (50)</td>
<td>4 (10)</td>
<td>2 (5)</td>
</tr>
<tr>
<td>MR</td>
<td>14 (35)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Data were missing for two transplant centers.

NOTE. Values expressed as number of centers (percent).

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### Steatosis

**Overview.** Assessment of the liver for steatosis is a critical part of the donor evaluation because nonalco-
holic fatty liver disease (NAFLD) is common, and hepatic steatosis may impact on donor and recipient
outcomes. The obesity epidemic has contributed to making NAFLD the most common cause of abnormal
liver test results in the United States.7 Obesity is present in 22.5% of US adults 20 years or older.8 Steatosis is
present in more than two thirds of the obese population, and steatohepatitis affects 3% of lean and 19% of
obese individuals.9,10 Hepatic steatosis is common in deceased donor livers and may be a risk factor for poor
graft function.11 In addition, steatosis has been reported in one third to one half of living donor candidates
undergoing liver biopsy as a standard part of the donor evaluation.12,13

Hepatic steatosis can be characterized histologically as microvesicular or macrovesicular. Macrovesicular
steatosis is more common and is the type of steatosis present in most cases of NAFLD. Microvesicular stea-
tosis refers to fat globules within the hepatocyte that are smaller than the hepatocyte nucleus. In general,
microvesicular steatosis is regarded as a benign lesion and often is asymptomatic, whereas macrovesicular stea-
tosis often is more serious and typically associated with mitochondrial dysfunction.14 If present in the donor
liver, hepatic steatosis usually would be expected to be macrovesicular. This was confirmed in a study that
found microvesicular steatosis in only 5% of donor livers.13 Microvesicular steatosis was always mild (<7%)
and always combined with macrovesicular steatosis.

Hepatic steatosis can adversely affect the recipient allograft and donor remnant. This was shown in an
animal model in which obese Zucker rats with steatotic
livers had delayed hepatic regeneration and diminished survival after 70% hepatectomy. Other studies confirmed that steatotic rat livers show impaired regenerative capacity. Hepatic steatosis also may adversely affect hepatic allograft function. Several studies have shown that the risk for primary allograft nonfunction increases with increasing severity of steatosis.

Hepatic steatosis also may adversely affect the donor. A retrospective study of patients undergoing major hepatic resection found that moderate to severe hepatic steatosis correlated with increased surgical time, transfusion requirement, morbidity, and mortality. Steatotic livers may not function as well because they are more susceptible to injury from general anesthesia and ischemia-reperfusion. In addition, steatosis has been shown to increase cold ischemic injury and impair hepatic regeneration. Aside from the reduction in functional hepatic mass, the mechanism by which steatosis causes hepatic dysfunction is unknown. It has been suggested that steatosis may cause hepatic dysfunction by altering cell membrane fluidity or disrupting the microcirculation.

Acceptable amount of steatosis. There currently is no widely agreed on percentage of steatosis that serves as a cutoff value for safe performance of LDLT. Because steatosis can adversely affect donor and recipient outcomes, it is critical to determine a maximal amount of steatosis above which liver donation should be deferred. Steatosis reduces functional hepatic mass for the donor and recipient and also may reduce hepatic regenerative capacity and increase the risk for injury caused by cold ischemia. Because steatosis reduces functional hepatic mass, some advocate subtracting the percentage of steatosis from the estimated liver mass before calculating the final mass of the hepatic allograft and remnant.

Several studies have shown that livers from deceased donors with less than 30% steatosis can be transplanted with results similar to organs without fat. Other reports found that only deceased donor livers with greater than 60% steatosis were at risk for primary graft nonfunction. Steatosis may be less of a problem for a living donor liver transplant recipient because cold ischemia time is minimal. The maximal acceptable amount of steatosis in the donor liver varies among LDLT programs and ranges from 10% to 30%. One study found no difference in donor or recipient liver function or regeneration if donor hepatic steatosis was less than 30%. Another study found no significant difference in the rate of death or serious complications among LDLT recipients who received grafts with greater than 10% steatosis compared with those who received grafts with less than 10% steatosis. Our institution considers living donor liver transplants from donors with up to 20% steatosis. Additional studies are needed to better define the acceptable amount of steatosis in the donor liver that will ensure a safe and successful operation for both the donor and recipient.

Biochemical and anthropometric parameters. Liver biopsy is the gold standard for evaluation of hepatic steatosis. Although generally safe, it is an invasive procedure with the potential for complications. For this reason, several noninvasive tests to detect hepatic steatosis have been evaluated. Liver biochemistry tests are notoriously inaccurate in the evaluation of hepatic steatosis. They are not sensitive or specific and may even show normal results in those with advanced hepatic fibrosis. Other methods, such as body topography and lipid levels, have shown a weak correlation with hepatic steatosis. Of all biochemical parameters, serum triglyceride level appears to have the strongest correlation. Of anthropometric techniques, waist-hip ratio seems to be the best predictor of steatosis. An increased waist-hip ratio, which is present more commonly in men, is associated with a greater risk for hepatic steatosis.

Body mass index. Of all noninvasive methods for assessment of hepatic steatosis, body mass index (BMI) may have the greatest utility. Several studies have shown a correlation between hepatic steatosis and increasing BMI. One study also found that hepatic fibrosis and cirrhosis were more common in those with a BMI greater than 25. Two recent studies attempted to correlate BMI with hepatic steatosis in potential donors undergoing liver biopsy as a standard part of an LDLT evaluation. These studies reached different conclusions.

The study by Rinella et al compared the accuracy of liver biochemistry tests, BMI, and abdominal imaging studies for the detection of hepatic steatosis in 33 potential liver donors. They found that liver biochemistry tests were not sensitive or specific for the detection of hepatic steatosis. There was a correlation between increasing BMI and grade of steatosis. Hepatic steatosis was not present in the seven potential donors with a BMI less than 25, whereas it was present in 33% of those with a BMI between 25 and 28 and 76% of those with a BMI greater than 28. The investigators concluded that liver biopsy could be avoided in donor candidates with a BMI less than 25 who did not have other risk factors for steatosis, such as diabetes or hypertension.

The second study also compared the accuracy of liver biochemistry tests, BMI, and abdominal imaging
studies for the detection of hepatic steatosis in 100 donor candidates. The investigators observed only a weak correlation between BMI and hepatic steatosis. In contrast to the study by Rinella et al, in which steatosis was not observed in any potential donors with a BMI less than 25, it was found that 9% of potential donors with a BMI less than 25 had greater than 10% hepatic steatosis. Hepatic steatosis was present in approximately half the potential donors with a BMI greater than 25, but usually was mild. They concluded that liver biopsy should be performed in all potential donors. Because many of those with a BMI greater than 25 had only mild degrees of steatosis, the investigators suggested that performing a liver biopsy on these subjects may expand the donor pool.

Abdominal imaging. Abdominal imaging studies, including ultrasound, CT, and MRI, also may detect the presence of hepatic steatosis. Their sensitivity and specificity are technique and operator dependent and also may vary based on degree of steatosis. Sensitivity of the imaging studies increases with increasing degree of steatosis. A recent study compared the ability of abdominal ultrasound, CT, and MRI to detect biopsy-confirmed steatosis. The investigators found that the presence of greater than 33% fat on liver biopsy was optimal for the detection of steatosis. The imaging modalities were not able to quantify the amount of steatosis or distinguish between simple steatosis and steatohepatitis. There also was a fair amount of interobserver variability in the interpretation of steatosis among different radiologists.

Table 2 lists results of hepatic imaging studies for the detection of biopsy-confirmed steatosis in living donor candidates reported from three transplant centers. All three studies found that hepatic imaging was insensitive for the detection of hepatic steatosis. As was the case in the study by Saadeh et al, the accuracy of abdominal imaging studies increased as the percentage of histological steatosis increased to greater than 30%. The study by Rinella et al found that abdominal imaging studies were 100% specific, but this was not the case in the other two studies. Newer imaging modalities, such as dual-echo and gradient-echo MR sequences, may provide increasing accuracy for the detection and quantification of hepatic steatosis. At present, the routinely available abdominal imaging studies do not appear to be sufficiently sensitive or specific to replace liver biopsy in most situations.

Liver biopsy. Liver biopsy is the gold standard for the assessment of hepatic parenchymal disease, including steatosis. In general, liver biopsy is a very safe procedure with a low risk for serious complications. A recent study from our institution reported on the safety of percutaneous liver biopsy performed on 1,086 patients by a physician’s assistant using bedside ultrasonography. Liver biopsy was safe, with no reported deaths and a low rate of major complications (0.4%) and need for hospitalization (0.6%). Overall, 10% of patients had pain requiring the use of narcotic analgesics. Other series reported a risk for death of approximately 1 in 10,000 and serious complication and hospitalization rates of 1% and 5%, respectively. In addition, hematomas are common after percutaneous liver biopsy, occurring in approximately 25% of cases in one series. At our institution, one large hematoma occurred after an ultrasound-guided percutaneous liver biopsy. The patient required blood transfusions and arterial embolization to stop the bleeding. The hematoma delayed plans for liver donation and took several months to resolve.

In addition to assessing for the presence of steatosis, liver biopsy also is useful in excluding occult chronic liver disease. A recent study reported results of liver biopsy in 100 consecutive living donor candidates. The investigators noted hepatic histological findings in 38% of those undergoing liver biopsy. Most findings were mild and nonspecific and did not ultimately prevent donation. Three individuals were excluded as donors based on liver biopsy findings. All three individuals had normal liver test results. One individual had bridging fibrosis and likely would have donated had it not been for findings detected by liver biopsy. Other series reported chronic hepatitis in approximately 10% to 25% of living donor candidates undergoing liver biopsy.
The appropriate use of liver biopsy in the evaluation of living donor candidates is an area of continuing controversy. A recent survey of transplant centers reported that liver biopsy was performed in all donors by only 14% of centers and never performed at 26% of centers. Most centers performed a liver biopsy in selected donors. Because the risk for a major biopsy complication seems to be approximately equal to the chance of detecting a clinically significant occult hepatic pathological state, we believe it is best to perform a liver biopsy in most, if not all, donor candidates. The one group in which a liver biopsy reasonably may be avoided is patients with a BMI less than 25 who do not have diabetes, hypertension, or a history of excess alcohol consumption. In addition, they also should have normal liver test results and lipid levels and undergo tests to exclude chronic liver disease and hepatic imaging studies. This likely will be a very small proportion of all donor candidates. Additional studies are needed to better determine if a liver biopsy should be performed routinely in all donors, and if not, which donors may reasonably forgo a biopsy.

**Volumetric Assessment**

Determination of adequate hepatic mass is critical for successful outcomes for both donor and recipient. Height and weight of the donor and recipient pair allow an approximate estimate of adequacy of hepatic mass. Height and weight can be useful in excluding a very small donor when the intended recipient is large, but is not accurate enough in most other situations. For this reason, centers routinely perform a volumetric imaging study of the liver.

The liver is the largest single organ of the body and makes up approximately 2% of total body mass. In his review on LDLT, Marcos summarized the issue of hepatic mass by stating, “Neither the minimum transplantable hepatic mass nor the optimal mass have been accurately determined. In all likelihood, these values are dependent on both donor- and recipient-specific characteristics and could never be determined with precision. It is probably only necessary and far more practical to determine what is always enough and never too much.” If donors are left with too small a hepatic remnant, they may develop liver failure. Liver failure has been reported in two donors, one of whom required a liver transplant. Recipients of too small a graft may develop early graft dysfunction, characterized by prolonged cholestasis, increased susceptibility to infection, histological features of ischemic injury, and liver failure with increased posttransplantation mortality. This entity has been termed small-for-size graft syndrome. Based on studies of hepatic resection in animals and humans, it appears that the minimum amount of liver necessary to sustain normal hepatic function is approximately 30% of total liver volume, which corresponds to 0.8 g/kg of body weight.

To assist in the determination of adequate hepatic mass, most centers calculate graft-recipient body weight (GRBW) ratio or estimate graft weight as a percentage of standard liver mass. There is an excellent linear correlation between the two, and either is acceptable. A GRBW ratio of 1% is approximately equal to 50% of standard liver mass. Several studies have shown that liver grafts that represent less than 40% of standard liver mass (GRBW ratio < 0.8%) show impaired graft function that usually is reversible. One series of 276 living donor liver transplant recipients showed a statistically significant association between graft loss in recipients of a donor liver with a GRBW ratio less than 1%, but only one allograft was lost acutely. As previously described, it probably is reasonable to correct the GRBW ratio for steatosis by subtracting the percentage of steatosis noted on liver biopsy from the functional hepatic mass. Patients with Child’s class A cirrhosis or those without portal hypertension may not need as much hepatic mass and therefore could receive an allograft with a GRBW ratio greater than 0.6%. In general, a GRBW ratio of at least 0.8% appears to be a safe lower limit for most adult living donor liver recipients.

Volumetric assessment of the hepatic segments can be performed using either CT or MRI. Total volume can be calculated by the addition of the areas on individual slices. To calculate segmental volumes, the images are reviewed on a dedicated workstation. The borders of the desired segment’s boundaries must be electronically traced on individual slices. This can be a time-consuming process depending on the number of slices acquired. Software is available that allows the computer to automatically interpolate the area on images between those images that have been manually traced. This reduces postprocessing time; however, images need to be reviewed to ensure that the computer has accurately traced the borders. The user can fine-tune any errors.

In general, hepatic mass estimated by volumetric imaging correlates well with actual hepatic mass determined at the time of hepatectomy. A study of 155 living donors showed good linear correlation between right hepatic liver volume determined by volumetric CT and actual weight at the time of surgery. Another study reported good interobserver agreement in volu-
metric measurement of the right liver by CT. Finally, one study reported variation between 3.9% and 12.5% for liver volumes determined by MRI compared with actual weight at surgery in 17 donors undergoing right or left hepatectomy. An example of volumetric CT of a donor liver is shown in Figure 2.

**Donor Liver Anatomy**

Thorough knowledge of the donor liver vascular and biliary anatomy is extremely important for donor selection and to maximize the chances of a safe and successful operation for both donor and recipient. Hepatic arterial, portal venous, venous, and biliary anatomy have been well defined, and variations are common. Some situations preclude donation, and others are favorable. Preoperative imaging studies include MR angiography and cholangiography, computed tomographic angiography, endoscopic retrograde cholangiopancreatography (ERCP), and mesenteric angiography. Preoperative imaging studies are able to accurately detect most variations, which enables preparation and may aid surgical dissection. A number of studies have shown excellent correlation between MRI or computed tomographic angiography and conventional angiography in the delineation of hepatic vascular anatomy. Other studies have concluded that computed tomographic and MR angiography are inadequate for the detection of portal and hepatic arterial anatomy.

The choice of imaging varies by center and is dependent on institutional experience and expertise. Table 1 lists the number of transplant centers performing arteriography, ERCP, and MR cholangiography as part of the donor liver evaluation. Only 14% of centers perform conventional arteriography in all donors, whereas angiography is not performed at all at 60% of centers. Examples of MRI of hepatic vascular and biliary anatomy are shown in Figure 3, and examples of CT of vascular anatomy are shown in Figure 4.

Common arterial variations include replaced right and left hepatic arteries with and without the presence of proper, right, and left hepatic arteries. These variations are usually detectable by CT or MR angiography (Fig. 4A). Conventional angiography is favored by most centers when these imaging studies suggest a right liver arterial variation. A replaced left hepatic artery increases donor safety because the artery is away from the surgical field and less prone to injury during right hepatectomy. A completely replaced right hepatic artery is a favorable situation for both donor and recipient (Fig. 3A). It is longer than a right hepatic artery, remote from the left liver arterial in-flow, and more amenable to dissection from surrounding tissue. The presence of both replaced and standard right hepatic arteries introduces more complexity. Reconstruction before implantation is possible with a bifurcated recipient proper hepatic artery graft, or the arteries can be sewn separately to the recipient right and left hepatic arteries. Nevertheless, the presence of two arteries increases the risk for thrombosis. Occasionally, a right hepatic branch may arise from the left hepatic artery or a left hepatic branch may arise from the right hepatic artery; both situations may preclude donation.
The most common portal venous variation is separate right anterior and posterior portal venous trunks. Preoperative knowledge of this variation enables proper preparation and facilitates dissection during procurement. This variation is readily detectable by CT, MRI, or a portal venous phase during angiography (Fig. 4B).

Separate right anterior and posterior portal venous trunks require reconstruction before implantation (most commonly with a bifurcated venous graft) or separate anastomoses during implantation to the recipient right and left portal veins. As with arterial anatomy, a sizable left portal branch arising from the right portal vein may require reconstruction or separate anastomoses.

Figure 3. MR (A-C) angiography and (D) cholangiography. (A) Replaced right hepatic artery arising from the superior mesenteric artery (arrow), (B) normal portal vein anatomy, (C) normal hepatic vein anatomy, and (D) accessory right hepatic duct arising from the common hepatic duct (arrow).
system or a right branch from the left system may preclude donation.

Hepatic venous anatomy also is variable. Most commonly, there are two tributaries to the middle hepatic vein within the liver. These tributaries arise within the anterior segments of the right liver, segments V and VIII. The need for reconstruction of these tributaries in the recipient remains controversial. Some centers routinely reconstruct both veins, others reconstruct them when large, and others never do. Both are readily visible on CT and MRI (Fig. 4C). Intraoperative ultrasonography is helpful, as well. Larger caudate veins also are common. They often are seen by preoperative imaging studies, and they are detected easily during the procurement operation. Most centers reimplant caudate veins larger than 0.5 cm.

Biliary anatomy is even more variable than vascular anatomy, but usually does not affect candidacy for living donation. For this reason, preoperative delineation of biliary anatomy is less important, and many centers defer cholangiography until the operation. The most common variations are multiple right hepatic ducts that

Figure 4. Computed tomographic angiography of the donor liver using a maximum intensity projection (MIP) reconstruction algorithm. (A) Multiple accessory hepatic arteries arising from the main right hepatic artery, (B) coronal MIP showing an anomaly of the portal vein with separate anterior (arrow) and posterior (arrowhead) trunks arising from the right portal vein, (C) middle hepatic vein with segment V (arrow) and VIII (arrowhead) tributaries, and (D) coronal MIP image showing a large inferior accessory hepatic vein draining the right lobe of the liver into the inferior vena cava (arrow).
require separate anastomoses in the recipient, but are of little consequence to the donor. Occasionally, a left duct arises from the right system, but these ducts usually are small and can be safely divided during right hepatectomy. Table 1 lists the number of transplant centers that use ERCP and MR cholangiography as part of the donor evaluation. ERCP and MR cholangiography were performed in all donors at 50% and 35% of centers, respectively. Because variants in biliary anatomy rarely preclude donation, the risk of performing preoperative ERCP in all donors may outweigh the benefit. MR cholangiography, a noninvasive method of determining biliary anatomy, may be a reasonable alternative for centers that want to routinely obtain preoperative biliary imaging (Fig. 3D). This study may be particularly useful when variations in biliary anatomy are likely, such as the presence of separate right anterior and posterior portal venous trunks.

### Outcome and Cost of the Donor Liver Evaluation

Evaluation of the donor liver is expensive. Average Medicare reimbursement for individual components of the donor liver evaluation is listed in Table 3. Also adding to the cost of LDLT, evaluation of the donor liver may detect abnormalities that preclude donation. A recent review of LDLT summarized exclusion criteria for 89 potential donors. Conditions detected through evaluation of the donor liver resulted in exclusion of approximately one third of donors. These included hepatitis B core antibody positivity (n = 4), hepatitis C (n = 5), and abnormalities detected on MRI (n = 4), liver biopsy (n = 15), and angiography (n = 1). In several other series, abnormalities detected at the time of evaluation of the donor liver led to exclusion of 43% to 75% of donors. This is consistent with conclusions of a recent study that compared the comprehensive cost of LDLT with that of deceased donor liver transplantation. The total cost of LDLT, including evaluation of donors who were accepted and rejected, donor follow-up care for 1 year, and recipient pre-OLT and post-OLT care, was 21% greater than similar care provided to deceased donor recipients, but this difference did not reach statistical significance.

### Conclusion

Accurate assessment of the donor liver is an important component of the living donor liver evaluation and critical to ensure a successful outcome for both donor and recipient. Liver biochemistry tests, viral hepatitis serological tests, tests to exclude chronic liver disease, and volumetric CT or MRI of the liver are a standard part of the living donor evaluation. There is a great deal of variability among transplant centers in the use of other diagnostic procedures, such as liver biopsy, ERCP, MR cholangiography, MR angiography, and hepatic angiography. Liver biopsy should be included as a standard component of the donor evaluation in all donors, with the possible exception of those with a BMI less than 25 who have normal liver test and abdominal imaging study results and no risk factors for chronic liver disease or hepatic steatosis. The acceptable maximum percentage of steatosis in the donor liver is unknown, but most centers use an upper limit of 10% to 30%. A GRBW ratio of at least 0.8% provides the recipient with adequate hepatic mass in most situations. Anatomic variants in donor biliary and hepatic vascular anatomy are common. Techniques used for evaluation of the donor biliary and vascular anatomy vary among centers and include MR angiography, MR cholangiography, ERCP, and hepatic angiography. The choice of individual modalities is dependent on institutional experience and expertise.

### Table 3. Standard Medicare Reimbursement for Selected Diagnostic Tests to Evaluate the Donor Liver

<table>
<thead>
<tr>
<th>Test</th>
<th>Standard Medicare Reimbursement (US $)</th>
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<tr>
<td>Liver chemistries*</td>
<td>41.28</td>
</tr>
<tr>
<td>Viral serological†</td>
<td>82.32</td>
</tr>
<tr>
<td>Tests for chronic liver disease‡</td>
<td>111.66</td>
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<tr>
<td>Abdominal ultrasound with Doppler</td>
<td>248.23</td>
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<td>335.40</td>
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<td>MRI of the liver</td>
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<td>ERCP</td>
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<td>Liver biopsy</td>
<td>717.55</td>
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<td>Hepatic angiogram</td>
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*Aspartate aminotransferase, alanine aminotransferase, alkaline phosphatase, bilirubin, albumin, and international normalized ratio.
†Hepatitis A antibody, hepatitis B surface antigen and antibody, hepatitis B core antibody, and hepatitis C antibody.
‡Serum transferrin saturation, ferritin, ceruloplasmin, α1-antitrypsin phenotype, antinuclear antibody, smooth muscle antibody, and antimitochondrial antibody.
deceased donor liver transplantation. Future studies should address such areas of uncertainty as optimal hepatic mass for donor and recipient, maximum acceptable amount of donor hepatic steatosis, and most appropriate diagnostic tests and procedures for evaluation of the donor liver. As these elements are better defined, it is anticipated that donor and recipient outcome will continue to improve and the cost of the donor evaluation will decrease.

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