Right Lobe Living Donor Liver Transplantation:
A Review
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The continuing shortage of organs for adult transplant recipients has generated enthusiasm for adult-to-adult living donor liver transplantation (LDLT). The major concern has been the ability to resect a graft of adequate size without subjecting the donor to undue risk. The right hepatic lobe is generally large enough for adult recipients, but because of the real and perceived risks of right lobe (RL) resection, surgeons have been hesitant to offer this option to their patients. The first series of RL resections that included a significant number of patients was reported in 1999, and the results were encouraging. Only minor complications occurred in donors, and the recipients fared quite well. Enthusiasm for these donor resections is growing, and more centers are beginning to perform them. There is a good deal of global experience with pediatric LDLT but little with adults, and there are unique considerations in this population. This review examines donor selection criteria for adult recipients, highlights technical points critical for good outcome, and examines the early results and complications in both donors and recipients. If the preliminary results continue to be reproduced, RL LDLT could have significant impact on the worsening organ shortage.

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Approximately 11,500 people are currently listed for liver transplantation with the United Network for Organ Sharing (UNOS), more than four times the number listed in 1988.1 With more than 4 million Americans with hepatitis C, 25% to 30% of whom will develop cirrhosis,2 the transplant community must anticipate dramatic increases in new listings. The number of liver transplantations performed each calendar year has consistently increased, but not at the same pace as new listings.1,3 Cadaveric donations appear to be reaching a plateau, and the definition of what constitutes an acceptable graft has already been significantly relaxed.1,4 The median waiting time is approaching 500 days for some groups, 10 times that in 1988.1 Excessive waiting time translates to greater morbidity and mortality, both before and after transplantation.3,5 Few would argue that an alternative to conventional cadaveric donor liver transplantation is necessary for the adult population.

Livers for pediatric patients have always been relatively scarce. The transplant community appropriately responded first with reduced-size (cut-down) transplants, then with living donor liver transplants, and most recently with split-liver transplants. The use of these techniques has significantly impacted on pediatric waiting list mortality at many centers.6-9 With refined surgical techniques, the results of alternative transplantations (living donor and split-liver) are as good as the results of conventional cadaveric transplantations.5,7,10-14 Reduction is forbidden by the ability to split a cadaveric liver,7,11 and the transplant community should make a focused effort to eliminate the use of size-reduced grafts. With optimal organ allocation and usage, splitting could even eliminate the need for living donors for pediatric patients.11,12

When a liver is split with the intention of performing transplantation on a child and an adult, the plane of transection is to the left of the porta hepatis, and division does not require manipulation of the main vascular and biliary structures that accompany the right side of the liver.11,15 Two grafts of adequate size for the intended recipients result, and the vasculature and bile ducts on the right are largely undisturbed. When a liver is split for 2 adults, these advantages are lost. The organ must be divided into right and left lobes with significant manipulation of the main vessels and ducts of both grafts. The imaging studies required to accurately estimate the mass of the grafts are not practical for cadaveric donors, and it can only be determined after division. Left lobes are usually too small for adults, and even right lobes (RLs) may be inadequate at times. If the products of the split (inappropriately small grafts with compromised vasculature and biliary drainage) are transplanted, 2 adults might require urgent retransplantation and a viable organ could be wasted. Needless to say, this would do little to alleviate the organ shortage. The adult population will probably never see a benefit from liver splitting, so attention has appropriately turned to the...
option of adult-to-adult living donor liver transplantation (LDLT).

The primary benefit of living donors is the ability to perform transplantation when it is medically indicated, before serious decomposition occurs or the death of the intended recipient intervenes. The complications associated with organ preservation are minimized, and primary nonfunction is rare. Although the immunologic benefit of LDLT has been minimal for the pediatric population, it appears to be more significant in the adult population. There are a few disadvantages that cannot be ignored, however. The risk for donor death or serious complications, although low, is real and may be related to the type of resection. Although the early results are encouraging, a greater incidence of technical complications in adult recipients of grafts from living donors must be anticipated. Modification of surgical technique could undoubtedly resolve most recurring problems, however.

### Graft Mass

Grafts of adequate size are more difficult to obtain for adults than for children, and the success of segmental transplantation is dependent on the provision of adequate initial hepatic mass. 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. There is a sizeable body of scattered data that can set guidelines, but some definitions are necessary to compare the results obtained by various groups. Some centers report graft-to-recipient body weight (GRBW) ratios, and others report graft weights as a percentage of standard liver mass. There is an excellent linear correlation between the two values and either is acceptable if consistently applied. For the sake of comparison, a GRBW ratio of 1% is approximately 50% of standard liver mass.

Some generalizations can be made based on the various analyses of the relationship of graft size to function. Segments that represent less than 40% to 50% of standard liver mass (GRBW < 0.8% to 1%) consistently show delayed functional recovery. The impairment is generally reversible, but urgent retransplantation is sometimes necessary. Liver segments representing as little as 20% of standard liver mass have been transplanted and have functioned well; nonetheless, the risk for graft loss increases with decreasing size.

The concept of correcting the estimated and real graft weights for the degree of steatosis is new and is based on the premise that fat is not functional and does not contribute to the restoration of hepatic mass. Each percentage of fat, either microvesicular or macrovesicular, determined by biopsy is assumed to decrease the functional mass of the graft by 1%. In adults receiving RLs with corrected GRBW ratios between 0.62% and 1.7%, complete functional recovery took slightly longer than for cadaveric organs, but all grafts ultimately functioned well. There was no difference in the laboratory or clinical profiles of RL recipients of grafts with corrected GRBW ratios greater or less than 1%. However, only 1 patient received an RL with a GRBW significantly less than 0.8%.

Analysis of the long-term results of 276 LDLTs showed a statistically significant association between graft loss and GRBW less than 1%, but only one graft was lost acutely. Interestingly, infectious complications were the most common cause of graft loss and mortality in this series, and their relationship to graft size is not entirely clear.

Histological examination of grafts representing less than 50% of ideal hepatic mass uniformly shows cholestasis, ischemic changes, and regeneration. No evidence of irreversible damage has been noted, however. Regeneration promptly restores hepatic mass, explaining the reversible nature of impairment. Hyperperfusion has been proposed as the mechanism of injury sustained by small grafts, and there are some experimental data that support this theory.

The mass requirements of children may be greater than that of adults because the liver represents a larger fraction of body mass in children. Most of the available data are derived from the pediatric population, thus the needs of adults are less well defined. It has been suggested that patients with fulminant hepatic failure may also require greater initial hepatic mass to compensate for the profound metabolic disturbances associated with this condition. A GRBW of 0.8% appears to be a safe lower limit for adults, however, regardless of the cause of disease.

Excessively large grafts, more than approximately 150% of standard liver volume, are associated with a different set of complications. Rejection is more frequent, perhaps because of the greater immunologic stimulus. Vascular complications also appear to be more common and could be attributable to lower relative blood flow or extrinsic compression of the vasculature. Abdominal closure over an excessively large graft is sometimes necessary.
large graft can also be challenging.\textsuperscript{7,17} Large graft size is seldom an issue in adult-to-adult transplantation, however, and will not be considered further.

**Liver Regeneration**

The ability of the liver to regenerate rapidly after resection or other insults has been appreciated for some time. Despite considerable effort to define the role of cytokines, growth factors, hormones, and blood flow in the process, it is still poorly understood.\textsuperscript{36,37} Most of the data from human subjects have been gathered in the context of liver pathology. Liver donors for adult recipients are the first group without preexisting pathological states to undergo such major resections, and adult recipients of these grafts are the only group of transplant recipients receiving organs significantly smaller than their native organ. The safety and success of these procedures are dependent on regeneration, but the clinical implications are still largely unknown.

Regeneration begins immediately after transplantation or donor resection and continues until some predetermined liver mass is attained.\textsuperscript{21,29,38,39} Liver mass, determined by magnetic resonance imaging (MRI), is almost completely restored in RL donors after only 2 weeks, and a similar phenomenon occurs in recipients (Fig. 1). The mass of both the transplanted RL and the remnant left lobe increases by approximately 100% within 7 days of surgery, suggesting that the sum of the factors unique to transplantation (ischemic injury, immunosuppression, and so on) do not significantly impair the process.\textsuperscript{31} The effect of each factor might prove to be very different if considered independently, however. Regeneration complicates the interpretation of laboratory data after resection or transplantation, but laboratory profiles from both RL donors and recipients follow a predictable pattern in the absence of complications.\textsuperscript{31}

A primary focus of transplant physicians has been the avoidance of ischemic injury. Through direct and/or indirect mechanisms, ischemia compromises the function of transplanted organs. One proposed mechanism of injury with particular relevance to partial liver transplantation in adults is apoptosis, and the experimental results of several groups support its role.\textsuperscript{40-42} Ischemia creates a biochemical milieu that favors apoptosis, and the induction of programmed cell death causes damage beyond the direct injury caused

![Figure 1. MRIs of a donor and recipient pair. (A) Preoperative image from a donor. The RL is outlined. (B) The remnant liver 14 days after surgery. Dramatic growth of the left lobe is apparent. (C) The RL in the recipient 30 days after transplantation. Again, dramatic growth can be appreciated.](image-url)
by lack of perfusion. Regeneration could be impaired by both the absolute decrease in cell number and the environment favoring cell death rather than division. Regeneration is impaired by ischemia in rats, but studies of humans are lacking. The previously stated arguments lead to the conclusion that ischemia should be avoided if at all possible. There is another side that deserves examination, however. Short periods of ischemia followed by reperfusion (ischemic preconditioning) increase the tolerance of the liver to a later sustained period of ischemia. Some recent experimental work showed that ischemic preconditioning of the murine liver decreased apoptosis and conferred a survival advantage to animals later subjected to prolonged hepatic ischemia. Ischemic preconditioning also seems to accelerate liver regeneration in rodents. The effects in humans are less well studied, but there are data showing that preconditioning improves the function of liver remnants subjected to inflow occlusion during resection.

There is not a unified consensus about the use of inflow control during donor hepatectomy. It is advocated by some as a means of decreasing blood loss during parenchymal transection and is avoided by others, including our group, because of the risk for ischemic injury. Inflow control could be viewed as ischemic preconditioning for the graft and may create more favorable conditions for regeneration. There does not seem to be a need to augment the regeneration process, but the use of limited inflow control under these circumstances cannot be condemned.

There are probably a multitude of other physiological, nutritional, and pharmacological factors that influence the efficiency and extent of regeneration. Liver regeneration is currently the focus of intense research, and a greater understanding of the process and its clinical implications is forthcoming.

### Patient Selection

#### General Considerations

The two overall goals of LDLT are zero donor morbidity and mortality and uniformly good recipient outcome. Whereas neither goal is universally attainable, every effort should be made to achieve these ends. Donor characteristics can be primary determinants of outcome for both patients, and careful evaluation and selection are therefore mandated. The physical well-being of the donor should clearly be the first priority, but psychological outcome must also be considered.

Donor consent is undoubtedly based to some degree on the expectation that their liver will be a life-saving, permanent part of the recipient, and every effort must be made to optimize immediate and long-term graft function.

The published donor evaluation protocols are very similar. The protocol followed at this institution is listed in Table 1. In general, simple noninvasive studies are performed first. Most potential donors are excluded based on the initial studies, and further testing is not indicated until the previous results are verified. Selection protocols should be rigid, with no exceptions made to accommodate the needs of a recipient, and multidisciplinary teams should review donor candidacy after every step. Table 2 lists the
Estimation of Graft Mass

Estimation of the mass of individual segments from donor body weight is fairly unreliable, and some type of volumetric imaging study is a mandatory part of the donor workup. Computed tomography (CT) has been the traditional modality for liver-mass estimation and seems to be sufficiently accurate. More information can be obtained with MRI, including a gross estimate of the degree of steatosis, and it can be performed repeatedly without concern about exposure to radiation or complications of intravenous contrast. MRI has recently been shown to predict RL mass quite consistently and has some advantages over CT. More information can be obtained with MRI, including a gross estimate of the degree of steatosis, and it can be performed repeatedly without concern about exposure to radiation or complications of intravenous contrast. Simultaneous evaluation of the liver with magnetic resonance angiography (MRA) and cholangiography (MRC) reliably defines the anatomy of the hepatic veins and excludes most extrahepatic biliary pathological states. Figure 2 is an MRC image from a donor showing the intrahepatic and proximal extrahepatic biliary tree in good detail. Unfortunately, images of similar quality do not always result, and, to date, we do not believe MRC can substitute for intraoperative cholangiography and should only be used to rule out extrahepatic anomalies. Either MRI or CT is acceptable for the determination of hepatic mass if applied consistently.

Preoperative Arteriography

The significance of the information obtained from the donor arteriogram is different for pediatric and adult recipients. When planning donor resections for pediatric recipients, preoperative arteriography is necessary to assess the anatomy and quality of the vasculature of the resulting graft. When planning resection for adult recipients, it is mainly performed to ensure adequate portal and arterial inflow to the remnant lobe after resection. The vasculature should be divided in a way that results in a well-vascularized graft but still preserves the inflow to the remnant liver. This is especially critical after RL resection. The RL represents approximately 60% of liver mass, and overt ischemia or even suboptimal perfusion of the left lobe could impair liver regeneration or function in the donor. Preservation of the vasculature to segment IV is mandatory.

Figures 3 and 4 are celiac- and portal-phase angiograms showing main arterial and portal branches to segment IV originating from the right side. This anatomy cannot be appreciated intraoperatively without significant dissection at the porta hepatitis. The images clearly define the optimal points for transection of the artery and portal vein during RL LDLT to preserve the viability of segment IV.

Although angiography is a relatively invasive study with the potential for complications, the information is

| Table 2. Exclusion Criteria of 89 Potential Donors, Medical College of Virginia |
|---|---|---|
| Step | Exclusion Test | No. |
| 1 | Clinical evaluation | 5 |
|  | Blood type | 40 |
|  | Diabetes | 2 |
|  | Hepatitis B (core Ab +) | 4 |
|  | Hepatitis C | 5 |
|  | Chest radiograph | 1 |
| 2 | Psychological evaluation | 2 |
|  | Substance abuse | 5 |
|  | Pregnancy test | 1 |
|  | MRI findings | 1 |
|  | MRI volumes (no steatosis-GRBW) | 3 |
|  | Cardiac evaluation | 2 |
|  | Liver biopsy (steatosis-GRBW) | 15 |
| 3 | Angiography | 1 |
| 4 | Second consent | 2 |

Abbreviation: Ab, antibody.
essential for surgical planning and donor safety. Unfortunately, the techniques for imaging the smaller vascular structures with noninvasive imaging modalities (MRA and spiral CT) are still in evolution and not yet reliable enough for these purposes.60,61

**Preoperative Liver Biopsy**

Percutaneous liver biopsy is frequently included in donor evaluation protocols,16,50,62 but the risks of the procedure demand its justification. The information is relevant to mass estimation, and occult liver disease is occasionally recognized.31,62 Furthermore, histological examination can either rule out pathological states or render a diagnosis in donors with mildly elevated liver enzyme levels.63 The incidence of complications after percutaneous biopsy is less than 1% in patients undergoing the examination for suspected pathological states and is probably less in patients without liver disease.64 In the most acute situations (status I recipient), biopsy can be safely omitted if the segment intended for resection is not of marginal size, there is no gross evidence of steatosis noted on imaging studies, and liver function test results are completely normal.

**Steatosis in Grafts**

Cadaveric organs with severe macrovesicular steatosis should not be used, but those with less than 30% macrovesicular or microvesicular steatosis can be transplanted with immediate and long-term results similar to those of organs without fat.65-67 The combination of steatosis and cold ischemia results in reversible (usually) graft dysfunction, presumably caused by microcirculatory disturbances and alterations of the cell membrane.68 Livers from living donors are not subjected to significant cold ischemia, and the contribution of steatosis to graft dysfunction should therefore be minimal. The results of several series support this hypothesis. The function of RL grafts from living donors with less than 30% steatosis did not differ from fat-free grafts, and their regeneration was unimpaired.31 In another analysis of grafts from living donors with varying degrees of steatosis, only severe steatosis greater than 60% was associated with poor graft function and outcome.69

Mild to moderate steatosis does not mandate donor exclusion, but significant steatosis may represent undis-
covered or evolving donor pathological states that deserve attention. Correction of GRBW ratios for the degree of steatosis is prudent for the adult transplant recipient population. Although steatosis itself is unlikely to impair the regeneration or function of the graft or remnant, the measured mass is not fat free. Provision of adequate functional hepatic mass is the primary concern, and even small amounts of fat could result in donor exclusion based on an inadequate GRBW. If this principle is applied to all living donors for adult recipients, the question of whether a donor should be excluded based only on the presence of steatosis will seldom need to be answered.

Use of Living Donors With Hepatitis

The transplantation of organs from cadaveric donors with positive hepatitis C serological results is increasingly common, and there does not seem to be a difference in the short- or long-term survival of these grafts. Although hepatitis C probably does not represent a serious problem for the already infected recipient, it may be of significant consequence to a living donor. The probability of long-term complications is high, and an infected donor is more likely to need a transplant or hepatic resection in the future. Previous liver donation would at least complicate future resection and transplantation and may make the former impossible. Furthermore, the effect of a major hepatic resection on the natural history of the disease is not known, and an accelerated course could be precipitated by resection and the regeneration process that invariably follows. Positive hepatitis C serological results should be considered a contraindication to living donation.

Organs from both living and cadaveric donors with positive hepatitis B serological results have been transplanted, and there are quite a few reports of viral transmission from liver donors with no evidence of active or chronic infection. In all cases, donors were core antibody positive, suggesting that low levels of the virus lie dormant in the liver, reactivating under appropriate conditions. Clearly, transplant recipients with negative serological results should not be exposed, but it may be tempting to use grafts from positive donors for recipients already infected. Hepatitis B frequently recurs after transplantation for its complications, regardless of the status of the donor, and prophylaxis is generally indicated. Donor serological
results may then have little to do with the outcome of an already infected recipient, but the potential consequences for a living donor must be the primary concern. Because it seems that the virus can be reactivated in transplant recipients, a similar phenomenon must be assumed to be a possibility in donors. Evidence of exposure to the hepatitis B virus other than through immunization should be considered a contraindication to liver donation.

Intraoperative Donor Evaluation

Donor evaluation continues until the graft has been safely resected. Although it would be unusual to discover overt pathological states on exploration, nothing can be taken for granted. The results of preoperative imaging and testing should be verified by visual inspection. Intraoperative cholangiography and ultrasonography (IU S) are valuable for surgical planning.

Cholangiography

Anatomic variations of the biliary tract are quite common and are of considerable significance in LDLT. Only 60% of donors have normal biliary anatomy on either the left or right. Anomalous anatomy is not usually a contraindication to liver donation, but variations frequently go unnoticed without imaging. Intraoperative cholangiography is still the best way to evaluate the donor biliary tract. Noninvasive studies (MRC or CT) do not yet reliably image the smaller ducts, and the morbidity of endoscopic retrograde cholangiopancreatography is too high to justify its routine use.

Inadequate drainage of a segment, either in the donor or recipient, can result in atrophy of the segment or infectious complications. The cholangiogram accurately maps the anatomy, preventing inadvertent ligation of significant branches draining the remnant or the graft. Isolation of the ducts that accompany the graft can be achieved with minimal manipulation and the optimal points for division determined. Dissection near the ducts can be minimized, and much of the remnant can be left undisturbed if the anatomy is clearly defined in advance. The donor surgery should be terminated with cholecystectomy if ducts draining the remnant lobe would have to be sacrificed to resect the graft or if division of the ducts would threaten the integrity of the common bile duct.
Recipient Considerations

All contraindications to cadaveric donor liver transplantation should also be considered contraindications to LDLT, and potential recipients must first be listed with UNOS. The possibility of graft failure after LDLT must be recognized, and the need to urgently obtain a cadaveric organ for someone who did not originally meet UNOS criteria would create an awkward situation. Offers for cadaveric organs should be considered without regard to the status of living donors.

Whether living donors should be considered for a listed patient is a matter of debate. Poor recipient outcome is more disappointing if the graft came from a living donor because of the additional risk accepted. For status I recipients, the timely availability of an organ is a primary determinant of outcome. Most of the complications associated with acute hepatic failure are reversible if transplantation can be performed early. These patients are well served by living donors.16

Stable patients with chronic liver disease also benefit from living donors. Transplantation can be performed electively before decompensation and complications can safely undergo transplantation with left lobes, but recipients weighing more than 60 kg are essentially excluded.29 Simple observation suggests that the average American adult weighs significantly more than 60 kg. Left lobes from living donors clearly do not represent a solution to the organ shortage.

Left lobectomy involves resection of Couinaud segments II, III, and IV, with or without segment I, and grafts weighing 300 to 500 g generally result.19,20,21,29,48,53 Larger children and small adults can safely undergo transplantation with left lobes, but recipients weighing more than 60 kg are essentially excluded.29 Simple observation suggests that the average American adult weighs significantly more than 60 kg. Left lobes from living donors clearly do not represent a solution to the organ shortage.

The RL (Couinaud segments V, VI, VII, and VIII) represents approximately 60% of liver mass. In the largest published series, RL grafts averaged 875 g, and a 140-kg recipient successfully underwent transplantation. In the same series, less than 15% of patients evaluated for living donation were excluded based on inadequate GRBW ratios.16 Extended right lobectomy (Couinaud segments IV, V, VI, VII, and VIII) has also been performed for living donation.28 Inclusion of segment IV increases the complexity of the procedure for both the donor and the recipient and seems to be associated with a greater incidence of donor complications.26 The GRBW ratios obtained are not significantly different than those obtained from right lobectomy.16,26,28,29 leaving no advantage other than improved outflow from inclusion of the midhepatic vein. If the ultimate goal is to develop an alternative to conventional cadaveric transplantation that will benefit a significant number of adult recipients, donor right lobectomy clearly holds the most promise.

When major hepatic resection is performed for pathological states, morbidity and mortality consistently occur in 25% to 35% and 5% to 10% of patients, respectively.85-89 These statistics cannot be directly applied to healthy donors, but they raise
appropriate concern. Left lateral segment resection is sufficiently safe, but relatively few extensive resections have been performed in this population. There is a great deal of variability between studies, but liver failure is the immediate cause of 40% to 80% of deaths after major hepatic resection, and cirrhosis and extensive resections are frequently associated.

Several recent studies including large numbers of patients failed to show an association between the extent of resection and morbidity and mortality, probably reflecting the appropriate exclusion of those at high risk. In a series of patients with positive hepatitis serological results, liver failure did not occur in any patient with a remnant liver volume greater than 250 mL. Morbidity and mortality for a series of 300 patients who underwent liver resection for metastatic colon cancer were only 1% and 17%, respectively, highlighting the contribution of underlying liver disease to adverse events. It has been suggested that pathological states induce hypertrophy in the uninvolved liver segments, making extensive resections performed in the face of pathological conditions safer than those performed for donation. Potential donors with a remnant liver mass that is even marginal or with preexisting liver disease will be uniformly excluded, and these factors will not influence outcome in this population. Those with underlying medical illnesses will also be deferred. Technical factors will probably prove to be the only controllable variable influencing donor outcome, emphasizing the need for meticulous technique.

**Right Versus Left Lobes**

As previously noted, the left lobe is frequently inadequate for adult recipients. Donor right lobectomy has been largely avoided until recently because of the real or perceived risk for complications. The previous discussion suggests that the risk for more extensive resection in the donor population will be much less than anticipated, and excess donor morbidity will not necessarily result from routine use of RL grafts. As long as segment IV remains viable, right lobectomy should not present a challenge to a healthy donor. Forty-one donors in our series were left with a mean of 39% of their initial liver mass. Liver dysfunction did not occur, and there were no serious complications.

**Technical Advantages of Donor Right Lobectomy**

Right lobectomy has several important technical advantages over left lobectomy that can influence the outcome for both the donor and recipient. The caliber of the vessels is greater, and microscopic anastomosis is not required. The RL sits in its natural position in the right upper quadrant, and the complications resulting from graft malposition (kinking or twisting of the vessels) are uncommon. The position of the graft puts the donor vessels in the proximity of the recipient vessels, and jump grafts are usually unnecessary. Anatomic variations of the RL can usually be managed without elaborate reconstructions or jeopardizing the remnant.

The anatomy of living donors for adult recipients is the anatomy of segment IV, and it is easily protected during right lobectomy. The arterial blood supply to segment IV usually takes origin from the left hepatic artery or a combination of left and right system (Fig. 5), but in a substantial number of patients (~30% in our series), all or a significant portion of the arterial inflow arises from the right hepatic artery. Portal blood usually originates from the left main branch as well, but significant branches arising from the right portal vein are not uncommon. When performing right lobectomy, division of the right hepatic artery and/or portal vein distal to the branches to segment IV preserves its inflow, ensures that the remnant is well vascularized, and does not compromise the vasculature to the graft. Figure 6 shows the arterial and portal variations of segment IV. The points of transection of the right hepatic artery or portal vein are chosen to accommodate the vascular anatomy of segment IV when performing a right lobectomy. When the left lobe is resected, vascular branches to segment IV arising from the right cannot easily be preserved and reconstructed, even with the aid of a microscope. It has been suggested that the observation of pulsatile back bleeding from smaller arterial branches implies adequate blood flow and the branches can be safely ligated. Unfortunately, back bleeding cannot be observed until the artery is divided. Reanastomosis would at least be cumbersome, if not impossible, and the transplanted segment IV would be at risk. This is not simply a theoretical risk. Atrophy and necrosis of segment IV with or without abscess formation have been reported in recipients of left lobe grafts. In our series of RL transplants, the portal and arterial supply to segment IV were uniformly preserved. Postoperative MRI electively performed in all our donors shows that segment IV contributes significantly to restoration of donor hepatic mass, and neither atrophy nor necrosis of segment IV has been observed in our series (Fig. 7). Careful preservation of the vasculature to this segment is absolutely essential.
RL Donor Hepatectomy: Technique Summary

The technical points of donor right lobectomy have been highlighted throughout but are summarized here. A detailed description has been reported elsewhere.

Intraoperative cholangiography and IUS are performed first, and the plane of transection is marked. The attachments of the RL are taken down, but mobilization of the remnant left lobe is avoided. The main vascular structures (hepatic artery, portal vein, hepatic vein) are isolated, including accessory veins greater than 5 mm. The bile ducts are visualized using only sharp dissection, and the parenchyma is finally transected. With routine use of the Cavitron Ultrasonic Aspirator (Valleylab, Boulder, CO) and intraoperative cell salvage, donors seldom need banked blood. In our series of 41 donors, no heterologous transfusions were administered. The bile ducts are cautiously divided during transection of the last third portion of the parenchyma, making sure that the common duct or left hepatic duct is not in jeopardy. After transection, the vasculature is clamped and divided and the RL is removed, flushed with University of Wisconsin solution, and prepared for the recipient. The point at which the portal vein is divided is particularly critical.

Recipient

Outflow and the Issue of the Midhepatic Vein

Provision of adequate outflow is necessary for optimal graft function. The manifestations of limited outflow depend on the degree and range from mild graft dysfunction and/or ascites to rapidly progressive liver failure and/or refractory ascites. The drainage pattern of the liver and the anatomic relationships of the hepatic veins dictate which veins are taken with the resected segment for LDLT. There is a great deal of overlap between the venous drainage territories, and the veins can be managed in more than one way without deleterious consequences for the graft or the remnant lobe. The RL is principally drained by the right hepatic vein. There are frequently accessory veins from the right that drain directly into the vena cava, augmenting outflow from this segment. The
midhepatic vein is shared by the medial portion of the RL and segment IV. The extrahepatic portion of the right hepatic vein is anatomically separate, and it is readily isolated from the other veins. The midhepatic vein and left hepatic vein have an intimate anatomic relationship and frequently form a common trunk before joining the inferior vena cava.\textsuperscript{98}

Donor right lobectomy is usually performed in one of two ways. Either the lobe is resected with both the right and midhepatic veins or with only the right hepatic vein.\textsuperscript{16,28,47,84} The midhepatic vein is undoubtedly beneficial for the RL graft, and the remnant left lobe is probably not hurt by its absence, but its intimate relationship with the left hepatic vein is dangerous.\textsuperscript{98,99} The left hepatic vein could be injured during dissection or narrowed by the closure of the orifice of the midhepatic vein, leaving the remnant left lobe with compromised outflow. The midhepatic vein should remain with the left lobe. Preservation of accessory hepatic veins greater than 5 mm with anastomosis to the inferior vena cava is an alternative means of augmenting the outflow of the RL.\textsuperscript{16} Little ischemic time is added, and the left lobe is not put in jeopardy. The significance of these veins to the outflow of the isolated segment cannot be fully appreciated by in situ clamping. The right hepatic vein can be isolated with sufficient length for direct end-to-end anastomosis to the recipient right hepatic vein.\textsuperscript{16,47} RL grafts sit
in their normal anatomic position, and outflow obstruction due to malposition should not occur.

The incidence of clinically significant outflow obstruction is approximately 5% for left lateral segments and left lobe grafts and is not expected to be worse with RLs. Slowly evolving or minimal obstruction at the anastomosis can almost always be managed nonoperatively and is generally without permanent consequences. Acute obstruction can result in rapidly progressive liver failure and graft loss.

Vascular Complications

Hepatic artery thrombosis has been a problem in the pediatric population undergoing both split-liver and living donor transplantation, but microvascular anastomosis has significantly decreased the incidence. Microvascular anastomosis is usually unnecessary in adult recipients, especially with RL grafts, because of the larger caliber of the artery. Furthermore, cold ischemia is minimal in LDLT and should not be a contributing factor. The published data suggest that hepatic artery thrombosis may actually be uncommon after adult-to-adult LDLT, but the true incidence remains to be determined.

Biliary Complications

Biliary complications occur in 10% to 30% of whole-organ cadaveric transplants and as many as 35% of segmental transplants (left or left lateral segments). The data for RL transplants are still limited, but the initial incidence in our series was similar. Several factors unique to partial grafts contribute to the greater incidence of biliary complications. Many small ducts are divided during the parenchymal transection, and even with meticulous technique, some may be missed, resulting in leakage from the cut edge. Early edema of an enteric anastomosis may contribute to biliary stasis, and back pressure can promote leakage from the cut edge or from the anastomosis itself. The smaller size of the main bile ducts makes the anastomosis more challenging, and stenosis and leakage are more likely. Multiple ducts are common and present a technical challenge. When duct-to-duct anastomoses are constructed, significant size disparity may also have a role. Aggressive dissection near the ducts can cause direct injury or compromise the blood supply.

The optimal technical management of the bile ducts in adult recipients has yet to be determined. Choledochojjunostomy is universally used for biliary drainage of segmental transplants in the pediatric population. Duct-to-duct anastomoses have been constructed in adult recipients of partial grafts, but there are only a few reports of outcome. Multiple small-caliber ducts commonly result from living donor resections and can only be managed with enteric drainage. If only a single duct results, size disparity...
would commonly prohibit choledochocholedochos-
tomy. Intra-abdominal infections resulting from ma-
ipulation of the bowel may be more common with
enteric drainage, and ascending infection of the biliary
tract is a theoretical risk. Leaks and strictures fre-
quently occur with enteric anastomosis, however, and
further modification of surgical techniques will be
necessary.

Systemic stenting has been shown to dramatically
decrease the occurrence of biliary complications after
RL transplantation. Larger ducts can be stented with a
Turcotte catheter witzelled through the Roux limb and
drained externally. Small ducts can be internally
stented. The external drainage catheter can be used
for imaging if needed.

The cut edge of partial grafts is a common source of
bile leakage. Interestingly, this complication occurs less
frequently in RL donors despite the same raw surface
area. This observation may be related to edema of the
enteric anastomosis. Careful ligation of all ducts at the
cut edge is advocated. A closed suction drain placed
along the cut edge can prevent some of the sequelae of
bile leakage.

Results
Rigid adherence to donor selection criteria and consis-
tent surgical technique have been rewarded, in our
experience. We have performed 41 RL transplantations
and followed up donor and recipient pairs for a mean
of almost 200 days, 7 of whom underwent transplanta-
tion more than 1 year ago.

Donors have without exception done very well. Our
mean intraoperative donor blood loss was 674 mL, and
banked blood products have not yet been required.
Donor surgical time averages 7.2 hours but varies
considerably, and intensive care unit admission is
seldom required. Only minor donor complications
have occurred. Intraoperative pressure sores have been
the most frequent problem to date. No major complica-
tions have occurred in a donor, and they are
discharged after a mean of 5 days. There have been no
readmissions or interventions secondary to complica-
tions. Liver function test results evolved appropriately
after surgery in all donors and were invariably normal
within the first postoperative week (Table 3). The
average RL weighs almost 900 g. Rapid regeneration of
the remnant left lobe, particularly segment IV, oc-
curred in all donors within 14 days. MRI failed to
show vascular or biliary abnormalities in the 41
donors.

Recipients were mainly UNOS status IIB, although
we performed LDLT on 6 status IIA patients. Two
recipients were status I. Surprisingly, hepatitis C was
not the most common indication for LDLT (62%).
Most adult recipients weighed approximately 80 kg,
and the average GRBW was 1.1%. Cold ischemic time
was limited to approximately 1 hour and warm
ischemic time to approximately 30 minutes, even with
preservation of accessory hepatic veins. Initial hospital
stay was similar to that of cadaveric recipients but
seems to be trending down with increasing experience.
RL transplant recipients were readmitted less fre-
quently than cadaveric transplant recipients, however,
and we have yet to see acute rejection in this popula-
tion. There have been no instances of primary nonfunc-
tion or delayed graft function. Biliary complications
were common initially, but modification of our tech-
nique has almost eliminated their occurrence. There
have been no vascular complications to date. Graft and
patient survival rates are 88% and 90%, respectively.
Four recipients died of overwhelming sepsis, all more
than 30 days after transplantation with working grafts,
and 3 of them were status IIA at transplantation.

Potential Impact of Living Donors in the
New Millennium
This summary confirms that RL donor heptectomy
can be performed with an acceptably low incidence of
complications. LDLT using the RL provides adequate
hepatic mass for most adult transplant recipients and
gives recipient results similar to conventional cadaveric
transplantation. Its more widespread adoption has the
potential to alleviate the critical organ shortage. The
impact of this technique will be limited by donor
availability and selection. In our experience, only

<table>
<thead>
<tr>
<th>Postoperative Day</th>
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<tr>
<td>1</td>
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<tr>
<td>Total bilirubin (mg/dL)</td>
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<td>PT (sec)</td>
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<td>PTT (sec)</td>
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<td>AST (U/L)</td>
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<td>ALT (U/L)</td>
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<td>Factor VII (%)</td>
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NOTE. Values expressed as mean.
Abbreviations: PT, prothrombin time; PTT, partial thrombo-
plastin time; AST, aspartate aminotransferase; ALT, alanine
aminotransferase.
approximately 35% of those listed have 1 or more potential donors evaluated, and at least 68% of donors are excluded. Approximately 40% of donors at our center were unrelated to the recipient (spouses, friends), and their candidacy adds significantly to the donor pool. Despite these limitations, LDLT compensated for close to a 42% decrease in the supply of cadaveric organs at our center, emphasizing the tremendous potential of this procedure. This technique is still at a very early stage. Frequent critical review of the results will further promote donor safety and improve recipient outcome.

References

after right lobe adult-to-adult living donor liver transplantation. Transplantation 1999; (in press).


