

Adult-to-Adult Living Donor Liver Transplantation Using Right-Lobe Grafts: Results and Lessons Learned From a Single-Center Experience

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Living donor liver transplantation (LDLT) for adults is now a practical alternative to cadaveric liver transplantation. Use of right-lobe grafts has become the preferred donor procedure. Because of the complexity of this operation, a learning curve is to be expected. We report the outcome of our first 41 LDLTs at the University of Colorado Health Sciences Center (Denver, CO). We also discuss the lessons learned and the resultant modifications in the procedure that evolved during our series. Patient records were retrospectively reviewed between August 1997 and February 2001 for the following end points: recipient survival, graft survival, and donor and recipient complications. Thirty-eight of 41 living donor liver transplant recipients (93%) are alive and well postoperatively with a mean follow-up of 9.6 months. Four patients required retransplantation secondary to technical problems (9.8%); all 4 patients were in our initial 11 cases. Modification of the donor liver plane of transection resulted in venous outflow improvement. Also, biliary management was modified during the series. Donor complications are listed; all 41 donors have returned to normal pretransplantation activity. Our results indicate that LDLT can be performed safely with excellent donor and recipient outcomes. Dissemination of our experience can help shorten the learning curve for other institutions. (*Liver Transpl* 2001;7:680-686.)

Living donor liver transplantation (LDLT) has undergone an evolution from its beginnings in pediatric transplantation using left lateral segments to adult-to-adult left-lobe transplantation to the now fairly well-accepted standard of adult-to-adult right-lobe transplantation.¹⁻⁵ We published a report of our first 2 cases using this technique and the rationale for our approach.⁶ Since these initial cases, we have accu-

mulated to date a series of 41 adult-to-adult right-lobe LDLTs. The results of this series and the lessons learned from these cases are presented to show that this can be a safe and effective procedure.

Justification for the use of adult-to-adult liver transplantation is based on the critical shortage of adult organs available for cadaveric transplantation. A growing number of people are being listed for transplantation, whereas the availability of cadaveric donor organs is remaining fairly constant. The increasing use of marginal donor organs may increase this number, but what cost this will have on short- and long-term survival of the organs is yet to be determined. Waiting-list mortality remains a problem and is approximately 10% per year.⁷ Using LDLT has been shown to decrease waiting time on the list for the transplant recipients while freeing organs for the remainder of the recipient pool who may not have potential living donors.⁸ When introduced for the pediatric population, LDLT reduced mortality and waiting times for pediatric liver recipients.⁹ Applying this concept to adults remained difficult because left lateral segments would not provide sufficient liver mass to meet an adult transplant recipient's needs. Left-lobe grafting in the adult-to-adult setting was initiated with mixed results, with concerns of inadequate hepatic mass.¹⁰ The right-lobe graft has several advantages over the left lobe. These include increased hepatic mass, better anatomic position for anastomoses, and less concern for hepatic venous outflow obstruction.

Of utmost importance in the use of this procedure is donor safety. Adequate liver volume must be left in place to avoid hepatic dysfunction. Technical resection of the right lobe of the liver has to be performed in a setting in which donor morbidity and mortality are minimal. Based on large surgical series of major hepatic resections, this donor operation should be able to be performed with a quoted mortality risk of less than 1% in experienced centers.¹¹ Several reports document the safety of living donor surgery in liver transplantation.^{12,13} Realistic expectations for recovery include normal daily activity in 1 month, return to predonation

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work at 2 to 3 months, and a full recovery to normal at 3 to 4 months. This report describes our series of 41 patients undergoing this procedure and outcomes of both donors and recipients. We also focus on the technical aspects of the surgery that have changed during this period.

Methods

Forty-one cases of adult-to-adult right-lobe LDLT were performed at the University of Colorado Health Sciences Center in Denver, CO, from August 1997 to March 2001. The frequency of this operation has increased over time, with 12 cases performed over the past 6 months. Donor demographics are listed in Table 1. Only one donor was not related to the recipient. Donor age ranged from 19 to 54 years. Details of our donor evaluation are presented elsewhere.⁸ All donors presented on a strictly voluntary basis and were never solicited. Each donor underwent a thorough physical examination and laboratory evaluation. Imaging modalities of the donor included magnetic resonance angiography and cholangiography in all cases. Conventional angiography was used as a confirmatory test in patients with arterial anomalies, especially when there was a question of more than one artery supplying the right lobe. Absolute liver volume of the right lobe was calculated based on these scans, but the judgment and experience of the senior transplant physicians were used to determine adequacy of mass, mainly based on donor and recipient body size, along with the imaging studies. Full psychological and social evaluations were performed on each donor, and a stable support system was documented. Liver biopsies were performed infrequently; only 3 of the 41 eventual donors underwent a biopsy. Biopsies were not deemed necessary for patients considered to be at low risk for fatty liver disease.

Recipient demographics are listed in Table 2. Of the 41 transplant recipients, 35 were United Network for Organ

Table 2. Recipient Demographics

Sex (M/F)	24/17
Age (yr)	45.0 ± 8.6
Median waiting time (d)	124
Mean LOS (d)	21.5 ± 19.5
Median LOS (d)	12

NOTE. Values expressed as number or mean ± SD.
Abbreviation: LOS, length of stay.

Sharing (UNOS) status IIB at time of transplantation. Two recipients were status I with a diagnosis of fulminant hepatic failure, and 4 transplant recipients were status IIA. Transplant recipients were evaluated and screened for listing similarly to other liver transplant candidates. After being informed of the option for LDLT and only after the recipient and/or donor presented voluntarily, further assessment was performed to ensure good candidacy. This included the absence of morbid obesity, limited previous major upper-abdominal surgery, good size matching between the pair, and stricter age criteria (only 1 of 41 recipients was older than 60 years). Risks and benefits of surgery for both donor and recipient were methodically explained, including minimal risk for donor mortality.

Donor hepatectomy is performed under general anesthesia, with a thoracic epidural catheter used for postoperative pain management. A right subcostal incision with upper midline extension similar to that performed on the transplant recipient is used. Mobilization of the right lobe of the liver proceeds, with care focused on leaving the attachments of the left lobe intact to prevent future twisting or torsion. Accessory hepatic veins are ligated and divided to free the vena cava. Branches greater than 1 cm are preserved. After cholecystectomy, an intraoperative cholangiogram is obtained. Vascular isolation of the right hepatic artery, right portal vein, and right hepatic vein is then completed. A transection line is marked on the liver with electrocautery. Using electrocautery and ligatures, parenchymal transection proceeds. As our series progressed, the line of transection shifted to run left of and parallel to the middle hepatic vein branch draining segments 5 and 8. This right branch of the middle hepatic vein is left intact on the edge of the graft and transected superiorly at its junction with the middle hepatic vein. The right hepatic bile duct is transected, leaving a small cuff so as not to stricture the main hepatic duct. Accessory posterior right-lobe bile ducts draining to the left hepatic duct are identified on intraoperative cholangiography and also carefully identified at the transection plane, with the remaining left stumps oversewn. Autologous blood transfusion systems were available for all donor operations. Parenchymal transection is completed, leaving both lobes of the liver with intact blood supply. No inflow occlusion is used. The raw surface of the liver is then packed and re-evaluated 20 to 30 minutes after transection to ensure no detectable bleeding or bile leak is present.

The transplant recipient is taken to the operating room

Table 1. Donor Demographics

No. of donors	41
Sex (M/F)	26/15
Mean age (yr)	30.8 ± 11.2
Mean LOS (d)	6.3 ± 1.6
Relationship to recipient	
Son	12
Brother	7
Sister	5
Daughter	6
Wife	2
Father	1
Other	8

NOTE. Values expressed as number or mean ± SD.
Abbreviation: LOS, length of stay.

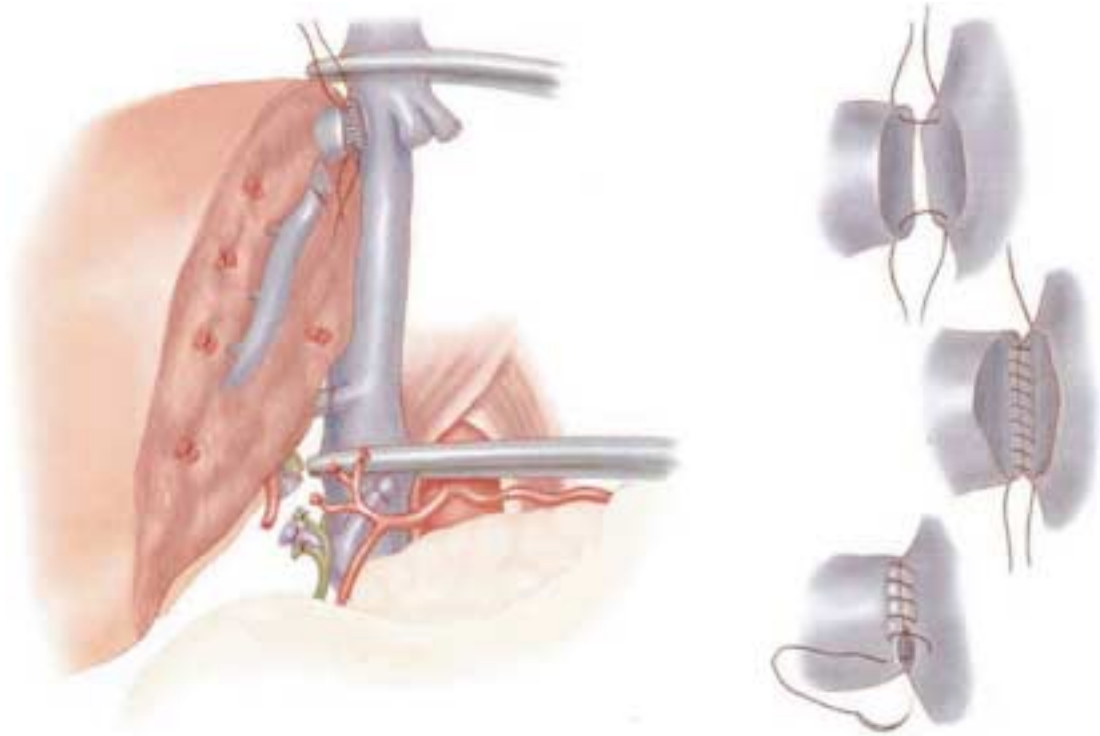


Figure 1. Donor hepatic vein anastomosis to recipient vena cava.

after the donor operation has started and shows no contraindications to proceeding. No donor operations were aborted in our series. Two transplant recipients with diagnoses of cancer underwent exploratory surgery to ensure that there was no extrahepatic spread of disease before the donor operation commenced. The recipient native hepatectomy proceeded in standard fashion, with extreme care used to ensure adequate hepatic artery and portal vein length. The piggyback technique was also necessarily used in all cases.

With the recipient team in the room, the vasculature to the right lobe of the donor liver is transected and the liver is passed to the back table. The vascular stumps on the donor are then closed with running monofilament vascular suture. The graft is immediately flushed through the portal vein with 1 L of heparinized (10,000 U/L) iced saline followed by a second liter of iced saline. No systemic anticoagulation with heparin is used in the donor.

The liver is transported to the recipient room, where the native hepatectomy is completed. In most cases, we use a complete cross-clamp to allow easy access to the recipient vena cava. No venovenous bypass is used. The recipient middle and left hepatic veins are oversewn, and the right hepatic vein cuff is extended down the anterior surface of the vena cava, creating an orifice to match the right hepatic vein size on the donor graft. The right hepatic vein is anastomosed to the caval opening with a running 5-0 vascular suture (Fig. 1). The recipient portal vein is then anastomosed to the right portal vein orifice using a running 6-0 vascular suture. The right lobe is reper-

fused at this point. The recipient right hepatic arterial branch is then spatulated and anastomosed in an end-to-end fashion to the spatulated donor right hepatic artery using a running 7-0 vasculature suture. Bile duct reconstruction then proceeds. Thirteen of 41 cases were reconstructed in a duct-to-duct fashion over an internal stent. The remainder of these reconstructions were performed using a standard Roux-en-Y small-bowel limb anastomosis to the right hepatic duct with interrupted 6-0 sutures over an internal stent. Secondary and occasional tertiary anastomoses were performed to the same Roux limb with any significant (>3 mm) accessory bile ducts. Small accessory bile ducts (<3 mm), particularly those in a very posterior position that would be technically difficult to reconstruct, are oversewn. Routine abdominal wall closure follows in both the donor and recipient. One Jackson-Pratt drain is left in the donor between the hilum and the cut surface of the liver. The recipient has 2 to 3 drains placed, with 1 drain also along the cut liver surface. The donors recover in the recovery room and are transferred to the ward. Twenty-three of the recipients went to the surgical intensive care unit postoperatively, and the remainder were transferred to the ward from the recovery room.

Results

All 41 donors are alive, well, and have returned to normal predonation activity. Donor complications are

listed in Table 3. Of 41 donors, 2 required nonautologous blood transfusions (5%). One of these was for a large hemothorax secondary to a central venous catheter placed preoperatively by the anesthesia department. The second was in a patient whose hematocrit decreased on postoperative day 2 and stabilized after 2 units of packed red blood cells were administered. Three patients had postoperative bile leaks. Two of these patients were returned to the operating room and underwent direct repair of a leaking bile duct stump within 3 days of the hepatectomy. One of these stumps was the cystic duct, whereas the other was the right hepatic duct stump. The other patient was treated conservatively with percutaneous drainage, resulting in resolution of the leak from the cut liver surface. One large incisional hernia was repaired in a patient who returned to lifting concrete bags 2 weeks after her surgery. One Jackson-Pratt drain was retrieved surgically after it snapped off during its removal. One idiosyncratic medication reaction caused donor lethargy that resolved postoperative day 3. Also, a temporary neuropraxia occurred in the dominant hand of one donor. All 41 donors are alive, well, and have returned to normal activity.

Postoperative laboratory values are shown in Figure 2. Aspartate aminotransferase and alanine aminotransferase levels peaked postoperative day 3, with a return to normal by day 7. Serum bilirubin levels peaked slightly later. Mean hospital stay for donors was 6.3 days.

Forty-one right-lobe adult-to-adult LDLTs have been completed using this technique. Thirty-eight of 41 recipients (93%) are alive and well, with a mean follow-up of 9.6 months. Thirty-six of 41 grafts are functioning, for a graft survival rate of 88%. Four patients required retransplantation with cadaveric grafts (9.8%). All 4 of these retransplantations occurred in our initial 11 cases, initiating several technical adjustments described next. Two retransplantations were performed for hepatic dysfunction resulting from hepatic venous outflow obstruction. These were performed postoperative days 14 and 5. In both cases, the clinical

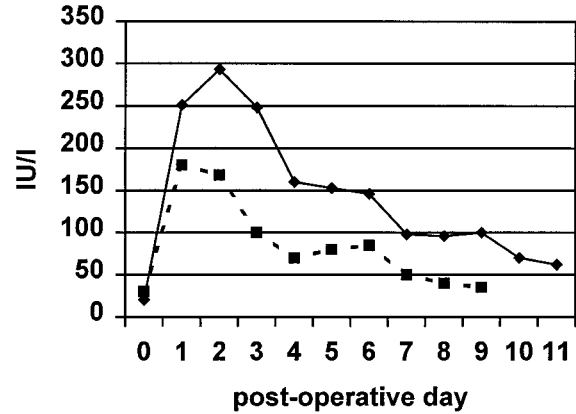


Figure 2. Donor aspartate aminotransferase (AST) (■) and alanine aminotransferase (ALT) (◆) levels versus postoperative day.

setting was consistent with poor graft function based on worsening laboratory values and a deteriorating clinical picture. Ultrasound evaluation showed patent vessels with no evidence of venous obstructions. Venous congestion was confirmed on gross inspection and microscopic analysis of the explanted liver. One retransplantation was performed for hepatic artery thrombosis postoperative day 12. The fourth retransplantation was performed for a persistent bile leak that 2 surgical repairs failed to resolve. This patient underwent retransplantation postoperative day 50 and died of sepsis 4 weeks after retransplantation. The second of the 3 deaths occurred 15 months posttransplantation because of uncontrolled chronic rejection, whereas the third death was in a patient who developed multiple strokes on postoperative day 1 and died of a cardiac arrest on postoperative day 5.

Forty-four percent of transplant recipients underwent multiple bile duct reconstructions, with one patient requiring 3 bile duct anastomoses. Overall biliary complication rates were 34%. This includes 3 anastomotic leaks treated surgically (1 duct-to-duct, 2 Roux-en-Y). Three patients developed postoperative strictures. The first occurred in a duct-to-duct anastomosis, which was converted to a Roux. The other 2 strictures were in patients with Roux limb anastomoses, and these were successfully treated with percutaneous transhepatic cholangioplasty. Nine patients developed cut surface leaks; 6 patients were treated with prolonged drainage and 3 patients underwent reoperation. Eight of the 9 leaks resolved; the exception was the patient who died after retransplantation.

Four patients required a second hepatic vein anastomosis because of an accessory hepatic vein greater than

Table 3. Donor Complications

Bile leak, reoperation	2
Bile leak, external drainage	1
Incisional hernia, surgical repair	1
Neuropraxia, transient	1
Drain retrieval, reoperation	1
Hemothorax from venous access	1

1 cm. One of these patients had 2 accessory hepatic veins. Three patients underwent 2 portal venous anastomoses without complications.

Discussion

Our results suggest that adult-to-adult LDLT using a right hepatic lobe graft is a safe and effective operation for people requiring liver transplantation when careful donor and recipient screening is performed. Graft and patient survival rates in our series are equal to our current cadaveric transplantation results. Donor safety is of utmost importance for this procedure, and although there have been reported donor complications and deaths,^{5,14} our series shows excellent donor outcomes with 100% survival and return to normal activity.

Despite these results, it should be stressed that a learning curve exists with this procedure: as experience and level of comfort increased, so did our overall success rates. The four retransplantations described during our early experience led us to 2 important technical changes. Specifically, our significant changes during this procedure have been improvements in graft hepatic venous outflow and the understanding of the need for intraoperative cholangiography to help show and reconstruct accessory right bile ducts.

In our early experience, we transected the liver to the right of the middle hepatic vein, even if the middle hepatic vein contributed drainage to segments 5 and 8. Using this technique, 2 transplant recipients had severe graft congestion and poor function requiring retransplantation. Their clinical picture was consistent with poor graft function despite ultrasound evaluation showing patent vessels and no obstruction. We now believe that primary nonfunction of these grafts is very unlikely, and if the postoperative clinical course mimics this picture, it is likely caused by a technical issue. These cases prompted us to change our plane of transection to the left. The right branch of the middle hepatic vein is preserved with the right-lobe graft and ligated superiorly at its junction with the main middle hepatic vein. We believe this prevents disruption of collateral drainage between the right hepatic vein and the right branch of the middle hepatic vein. We do not believe it is necessary to connect this middle hepatic vein branch to the cava using a jump graft. When the graft is reperfused, this right branch of the middle hepatic vein is well decompressed, presumably by collaterals in the graft. It has been our experience and also recently reported that postoperative ultrasound examination of the graft drainage shows reversal of flow in the right middle hepatic vein branch ultimately emptying into

the right hepatic vein system.¹⁵ Since moving our transection plane in this manner, we have not experienced outflow problems causing graft dysfunction. Another venous drainage issue is that of accessory hepatic veins draining into the vena cava. Previous series of right-lobe transplants have reported reanastomosis of any accessory vein greater than 5 mm.¹⁶ We have been more selective in our series, and of the 41 grafts, have performed accessory venous anastomoses in only 4 patients. We routinely reconstruct accessory veins greater than 0.8 to 1 cm.

Arterial anatomy is often quite variable in both donor and recipient. Most commonly, the major right hepatic artery of the donor graft can be directly anastomosed to the recipient artery at either the bifurcation of the right and left branches or a bifurcation patch created at the branch of the cystic artery. We attempt to maximize right hepatic arterial length in the recipient but stay extraparenchymal in this dissection. On donor workup, a replaced right hepatic artery is not a contraindication; this frequently makes the operation technically easier because of a longer length of graft artery. In this situation, an angiogram is often obtained to assess whether this right branch off the superior mesenteric artery is completely replaced or whether it is an accessory branch. This allows us to conclude whether a second arterial anastomosis is required. We have studied arterial flow postoperatively with duplex ultrasonography on a daily basis through postoperative day 5. Patients are started on 81 mg of acetylsalicylic acid when a stable postoperative hematocrit is present. To date, we have had one hepatic artery thrombosis, which is similar in incidence to our cadaveric recipient population, and concerns of greater thrombosis rates caused by smaller vessels have not been realized. Arterial anastomoses are performed with $3.5 \times$ loupe magnification with a running monofilament 7-0 vascular suture. In 2 cases, the donor right hepatic artery bifurcated into anterior and posterior branches that encircled the common bile duct. In the first instance, the anterior branch was small and therefore was ligated. In the second case, both arteries were of equal size. The anterior artery was transected at the time of graft removal to free it from the bile duct and was then repaired, with an end-to-end anastomosis performed on the back table.

Portal vein inflow has been adequate in all patients. Direct end-to-end anastomosis of the donor right portal vein to the right branch or common portal vein of the recipient was performed in all but 3 cases. In these cases, there were 2 separate major portal veins to the right lobe. In 1 of these, 2 anastomoses were performed; one each to the right and left branches of the recipient

portal vein. In the other 2 cases, the graft veins were very close to each other, with liver parenchyma providing a common back wall, and the donor had a large native portal system. A single anastomosis of the donor veins to the native portal vein branch was performed.

A preoperative ultrasound showed one transplant recipient to have a thrombosed portal vein, with patent splenic and superior mesenteric veins. This LDLT was delayed until a cadaveric donor iliac vein of compatible blood type was available to use as a jump graft. At surgery, a successful thrombectomy allowed for adequate inflow and no vascular graft was used. To date in our series, we have not had to use an arterial or venous graft for reconstruction; however, we routinely repeat an ultrasound examination of the recipient 1 week before surgery to rule out portal vein thrombosis. The use of a recipient saphenous vein graft may be required in a setting in which the right lobe has 2 arterial inflows, i.e., an accessory right branch as opposed to a totally replaced system.

The second change in technique is in regard to our biliary management. Magnetic resonance cholangiography (MRC) imaging is used as preoperative screening of donor biliary anatomy. This has proven to be a relatively accurate assessment of major biliary structures. In our early cases, a transplant recipient experienced a bile leak from an accessory posterior duct that had not been recognized on the MRC or at the original donor surgery. Despite reoperation and oversewing, the leak persisted, eventually leading to retransplantation, sepsis, and death. We have since instituted routine intraoperative cholangiography and have identified and reconstructed accessory bile ducts in 44% of our right-lobe grafts. On one occasion, a patient underwent 2 accessory biliary reconstructions. Identification and drainage of this important posterior branch has prevented biliary complications in a significant number of right-lobe grafts, and we have not performed a retransplantation for a biliary complication since. In 2 instances, we have oversewn a small (<3 mm) posterior right duct, avoiding reconstruction. Neither of these 2 cases had a leak or signs of cholangitis in this small undrained biliary section of hepatic parenchyma. These smaller ducts are usually located in a more posterior location than the previously mentioned accessory duct, which is significant and is reconstructed.

Biliary reconstruction is performed with choledochocholedochostomy when possible. The need for Roux limb drainage is obvious in the case of primary sclerosing cholangitis or when multiple anastomoses must be performed, and these are performed to separate openings of the intestinal limb, each over an individual

internal stent. In addition, Roux drainage is performed in cases of a single bile duct when there is concern about tension or blood supply. We do not use t-tubes or other external biliary drainage catheters. Biliary complications have occurred in 34% of transplant recipients. This is similar to rates previously reported in living donor liver surgery.¹⁷⁻¹⁹ Most of our leaks (60%) have been raw surface leaks. These are usually managed conservatively with external drainage if the patient is clinically stable. These usually occur while the surgical drains are still in place. Our experience has been that these will spontaneously seal, allowing for drain removal. If the patient shows signs of uncontrolled leakage, such as pain or increasing bilirubin levels, they are treated surgically. Biliary leak rates are slightly greater in the Roux-drained patients, but this is likely influenced by the fact that this group includes patients with multiple duct drainage.

Postoperative management of living donor liver transplant recipients has been similar to that of recipients of cadaveric grafts. Overall, 56% of recipients went to the intensive care unit postoperatively. This decreased to 40% in the second half of our series as our level of comfort with these cases has increased. An increase in frequency of surveillance ultrasonography is performed, but this has not shown greater thrombosis rates. Hospital length of stay averaged 21.5 days for the transplant recipients. We believe that this is lengthened somewhat because of the increase in biliary complications compared with our cadaveric transplant recipients and a less predictable decrease in postoperative liver function test results, leading to a heightened vigilance for potential complications and rejection. However, graft and patient survival rates ultimately are equal to cadaveric results.

These results must be viewed cautiously because candidates are carefully selected for LDLT and in general are not the sickest liver transplant recipients. We believe that the optimal candidates for this procedure are patients who are UNOS status IIB and have a good donor available. Status III patients should rarely undergo transplantation until more experience has been gained to justify the risk to the donor. The use of LDLT is especially valuable in the patient population who has a suspicion for or proven small hepatocellular carcinoma (status IIB), but would unlikely be able to receive a cadaveric graft before their cancer progressed to a nontransplantable stage. The role of this procedure as palliation for large hepatocellular cancers is still being debated. Our center has not performed this procedure on a patient who would otherwise not be a candidate for a cadaveric graft.

In conclusion, LDLT is a safe and effective procedure for well-selected patients. We report a large series of right-lobe grafts with similar graft and patient survival statistics to our cadaveric transplant recipients. Donor safety has been maintained throughout the series. This procedure will continue to grow in importance in the national transplant community as a way to alleviate some of the pressure of growing waiting lists and stagnant cadaveric donor availability.

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