complement fractions as they do for immunoglobulins, and complement fractions return to their initial level within 12 hr (*4, 24*). Therefore, in this work, the prolongation of xenograft survival time seems to be correlated with the decrease in natural cytotoxic antibodies.

The reason the association between plasma exchanges and CsA is the most efficient protocol remains unanswered because the effects of all 3 immunosuppressive methods on the antibody titers are of the same magnitude. The higher efficiency of CsA may be due to its selective effects on some B cell subsets (*25*).

In conclusion, plasma exchanges in association with CsA allow the delay of hyperacute rejection of guinea pig hearts grafted into rats, and the efficiency of the treatment is correlated with the decrease in natural antiguinea pig cytotoxic rat antibodies.

REFERENCES

1. Sadeghi AM, Robbins RC, Smith CR, et al. Cardiac xenograft survival in baboons treated with cyclosporin in combination with conventional immunosuppression. Transplant Proc 1987; 19: 1149.
2. Hardy MA, Todd G, Reemtsma K. Xenotransplantation. In: Slavin S, ed. Bone marrow and organ transplantation. Amsterdam: Elsevier Science, 1984: 515.
3. Bier M, Beavers CD, Merriman WG, Merkel FK, Eiseman B, Starzl TE. Selective plasmapheresis in dogs for delay of heterograft response. Trans Am Soc Artif Int Organs 1970; 16: 325.
4. Merkel FK, Bier M, Beavers CD, Merriman WG, Wilson C, Starzl TE. Modification of xenograft response by selective plasmapheresis. Transplant Proc 1971; 3: 534.
5. Linn BS, Jensen JA, Portal P, Snyder GB. Renal xenograft prolongation by suppression of natural antibody. J Surg Res 1968; 8: 211.
6. Moberg AW, Shons AR, Gewurz H, Mozes M, Najarian JS. Prolongation of renal xenografts by the simultaneous sequestration of preformed antibody, inhibition of complement, coagulation and antibody synthesis. Transplant Proc 1971; 3: 538.
7. Mozes MF, Gewurz H, Gunnarson A, et al. Xenograft rejection by dog and man: isolated kidney perfusion with blood and plasma. Transplant Proc 1971; 3: 531.
8. Settaf A, Merrigi F, Van de Stadt J, et al. Delayed rejection of liver xenografts compared to heart xenografts in the rat. Transplant Proc 1987; 19: 1155.
9. Adachi H, Rosengard BR, Hutchins GM, et al. Effects of cyclosporine, aspirin and cobra venom factor on discordant cardiac xenograft survival in rats. Transplant Proc 1987; 19: 1145.
10. Charpentier B, Houssin D, Lang P, Fries D. In vivo and in vitro correlates of anti-idiotypic immunization in inbred strains of rats. Transplant Proc 1979; 11: 1613.
11. Kemp E, Kemp G, Starklint H, Larsen S. Immunosuppression with cobra venom factor, antiplatelet aggregator, and ciclosporin A in renal xenotransplantation. Transplant Proc 1982; 14: 116.
12. Homan WP, Williams KA, Fabre JW, Millard PR, Morris PJ. Prolongation of cardiac xenograft survival in rats receiving ciclosporin A. Transplantation 1981; 31: 164.
13. Kemp E, Starklint H, Larsen S, Dieperink H. Ciclosporin in concordant renal hare-to-rabbit xenotransplantation and modification of rejection, and adverse effects. Transplant Proc 1985; 17: 1351.
14. Sugimoto K, Shelby J, Corry RJ. The effect of ciclosporin on cardiac xenograft survival. Transplantation 1985; 39: 218.
15. Krombach F, Hammer C, Gebhard F, Danko I, Scholz S, Gokel M. The effect of ciclosporin on wolf to dog kidney xenografts. Transplant Proc 1985; 17: 1436.
16. Dieperink H, Steinbruchel D, Starklint H, Larsen S, Kemp E. Improvement in hare to rabbit kidney transplant survival. Transplant Proc 1987; 19: 1140.
17. Hammer C, Chaussy CH, Brendel W. Preformed natural antibodies in animals and man. Eur Surg Res 1973; 5: 162.
18. Giles GR, Boehmig HJ, Lilly J. Mechanism and modification of rejection of heterografts between divergent species. Transplant Proc 1970; 2: 522.
19. Shons AR, Bier M, Jetzer T, Najarian JS. Techniques of in vivo plasma modification for the treatment of hyperacute rejection. Surgery 1973; 73: 28.
20. Stuart FP, Reckard CR, Ketel BL, Schulak JA. Effect of splenectomy on first cadaver kidney transplants. Ann Surg 1980; 192: 553.
21. Downing TP, Reitz BA, Aziz S, Stinson EB, Shumway NE. Increased efficacy of ciclosporin A with splenectomy prolonging the survival of rat heart allografts. Transplantation 1981; 32: 76.
22. Alexandre GPJ, Squifflet JP, De Bruyère M, et al. Splenectomy as a prerequisite for successful human ABO-incompatible renal transplantation. Transplant Proc 1985; 17: 138.
23. Berden JHM, Bogman MJJT, Hagemann JFHM, Tamboer WPM, Koene RAP. Complement dependent and independent mechanisms in acute antibody-mediated rejection of skin xenografts in the mouse. Transplantation 1981; 32: 265.
24. Euler HH, Krey U, Schroder O, Loffler H. Membrane plasmapheresis technique in rats. Confirmation of antibody rebound. J Immunol Methods 1985; 84: 313.
25. Kunkl A, Klaus GGB. Selective effects of ciclosporin A on functional B-cell subsets in the mouse. J Immunol 1980; 125: 2526.

Received 6 March 1987.
Accepted 17 July 1987.

0041-1337/88/4503-519$02.00/0
TRANSPLANTATION

Vol. 45, 519–523, No. 3, March 1988
Printed in U.S.A.

LIVER TRANSPLANTATION WITH REDUCED-SIZE DONOR ORGANS[1]

CHRISTOPH E. BROELSCH, JEAN C. EMOND, J. RICHARD THISTLETHWAITE, DALE A. ROUCH, PETER F. WHITINGTON, AND J. LANCE LICHTOR

Department of Surgery, Pediatrics, and Anesthesia, The University of Chicago, Chicago, Illinois 60637

Orthotopic liver transplantation (OLT) of the pediatric patient is often limited by the availability of a size-matched donor organ. Use of reduced liver transplantation (RLT) can increase the proportion of candidates transplanted and may reduce overall mortality. We report herein the initial clinical application of RLT in the United States.

Indications for RLT included fulminant hepatic failure (n=2), acute hepatic artery thrombosis (n=3), and chronic liver disease unresponsive to inpatient support and more than 30 days on transplant list (n=4). Donor hepatectomy was performed using standard techniques. Formal hepatic resection was performed ex-vivo to create a size-matched graft, from the larger donor organ, which was implanted in the orthotopic position.

Between 11/84 and 4/87, 70 pediatric patients were evaluated for OLT, and 33 of these were transplanted. During this period only 5 patients (7%) died awaiting OLT. Of 33 patients treated at the University of Chicago, 5 received RLT. Donor: recipient weight ratios ranged from 2:1 to 8.1:1. For RLT median operative blood loss was 1.7 blood volumes (range 0.5–11.7) with an operative time of 9.3+3.5 hr.

Acceptable early graft function was observed in five patients, all of whom were discharged from the hospital. Four of these five patients are alive between 2 and 48 months after transplantation. Marginal graft function with cholestasis and coagulopathy was associated with acute intracranial hemorrhage and neurologic death in one case. One patient died intraoperatively with nonfunction caused by the use of a liver from a donor with steatosis and a poor size match. Another patient died on day 5 with primary nonfunction and persistant hemorrhage. Systemic cytomegalovirus infection was the cause of death in the other two cases.

RLT can provide life-sustaining liver function in urgent clinical settings. The graft can serve as a temporary or permanent liver replacement. With evolution of the technique RLT could eventually be offered to more elective candidates and increase the utilization of available donors by reducing size limitations in OLT.

Rapid development of liver transplantation for the therapy of end-stage liver disease has occurred since the NIH consensus conference on liver transplantation in 1983 (*1*). The growing pool of candidates for transplantation has led to an increasing scarcity of donor organs. Pediatric candidates have experienced the greatest delay in receiving suitable organs, with 20–50% dying on the waiting list (*2*, South Eastern Organ Procurement Foundation, personal communication, February 1987).

The requirement for a size-matched donor liver has contributed to the difficulty in obtaining organs for pediatric recipients, which is most severe when the indication for transplantation is urgent. These indications arise most commonly with acute failure of a transplant, fulminant hepatitis, or deterioration of the very small child with chronic liver disease in whom the usual wait for an organ can be as long as 3–6 months (*2*). In contrast, due to the larger pool of adult donors, locating a size-matched organ for an adult is usually possible even in urgent settings. By reducing size constraints, the technique of reduced liver transplantation may lead to an increase in available donors for pediatric recipients.

The transplantation of reduced-size livers was initially conceived to solve the problem of space in experimental heterotopic liver transplantation (HLT) (*3, 4*). *Development of HLT as a clinical therapy has been limited, however, by physiologic disadvantages (*5, 6*) and the disappointing experiences with limited clinical application (*6*). The successful use in patients of reduced-size livers transplanted into the orthotopic position was initially reported by Bismuth in 1983 (*7*) and Broelsch et al. in 1984 (*8*). Since these reports, several groups are actively pursuing this option in the treatment of pediatric patients.

In this report we present our initial clinical experience—methods, indications and results—in 9 pediatric patients receiving reduced liver transplantation (RLT). Four patients are alive between 2 and 48 months after transplantation. We propose, at this stage, that the method is feasible, and can be used to offer liver transplantation to urgent candidates—and that by overcoming size limitations RLT can increase the proportion of livers utilized in available adult multi-organ donors.

MATERIALS AND METHODS

Patients. Between 11/84 and 4/87, 70 pediatric patients were evaluated for transplantation in the University of Chicago liver transplant program conducted jointly by the departments of surgery, medicine, and pediatrics. These patients have been classified into 5 groups based on their status as of 5/1/87 (Table 1). Thirty-three children have undergone liver transplantation at the University of Chicago, receiving a total of 41 transplants. Seven RLT were performed in 7 recipients at the University of Chicago. Two other patients were treated previously at the Medizinische Hochschule Hannover, FRG. These 9 patients receiving RLT form the basis of this report with a follow-up on surviving patients of between 2 and 48 months. The data presented in this report were collected in a retrospective review of clinical records.

The indications for transplantation in pediatric recipients are presented in Table 2. Biliary atresia was the principal indication in primary grafting, with 5 of 33 patients receiving more than one transplant (15%). For patients treated at the University of Chicago, RLT was

[1] Presented at the 13th annual meeting of the American Society of Transplant Surgeons, Chicago, Il May 1987.

* Abbreviations used: CMV, cytomegalovirus; FHF, fulminant hepatic failure; HLT, heterotopic liver transplantation; RLT, reduced liver transplantation.

performed in 5/33 primary transplants (15%) and 2 of 9 retransplants (22%).

RLT was performed when expected survival was less than 48 h, (n=5), and in patients with chronic liver disease who were on the transplant list as inpatients at least four weeks and had progressive deterioration despite maximal inpatient medical support (n=4).

The preoperative status of patients receiving RLT is presented in Table 3. Four of 9 patients were in stage 4 hepatic coma at the time of grafting, and 5 required ICU care with 4 of 9 receiving ventilatory assistance. Severe ascites was present in 5, with severe nutritional depletion in 5. Mean serum bilirubin was 17.3±11 mg/dl, with a range between 2.1 and 32.7. The mean prothrombin time was 25.6±13 sec, ranging from 13.4 to 52.4.

Surgical techniques. Surgical approaches to RLT were reported previously (*7, 8*) and will be described in detail elsewhere.[2] In general, donor and recipient hepatectomies were performed using conventional techniques. The donor liver was perfused in situ with limited preliminary dissection. With one exception the reduced graft was prepared in the recipient operating room with assessment of the recipient abdominal cavity and determination of the appropriate reduction of the donor liver. The reduction was accomplished by anatomic dissection of the liver based on its segmental anatomy as described as Couinaud (*9*) (Fig. 1) and applied to hepatic resection (*10, 11*). Grafts were prepared using the entire R lobe (n=2), the entire L lobe (n=4), the L lateral segment (segments 2 and 3) (n=2), and the extended R lobe (with segment 4) (n=1).

The ex-vivo hepatectomy was performed in the cold-perfused graft on the back operating table while a second surgical team completed the recipient hepatectomy. Figure 2 illustrates the dissection for the preparation of an L lateral lobe graft. In 8 of 9 cases the decision to reduce graft was made preoperatively, while in 1 case the decision was made in the recipient operating room when the donor organ was unexpectedly found to be too large for the recipient.

The graft was implanted in the orthotopic position with end-to-end reconstitution of the inferior vena cava and the portal vein in all cases. The hepatic artery was based on the donor celiac trunk with or without an aortic patch and was revascularized from the recipient common hepatic artery (n=7) or supraceliac aorta (n=2). End-to-side cholangiojejunostomy to a Roux-en-Y loop was used for biliary reconstruction in all cases. Primary abdominal closure was possible in 7 of 9 cases; in the other cases temporary closure was accomplished with a Goretex or a reinforced silastic patch.

Postoperative care. Patients were managed using standard protocols applied to all liver transplant patients at the University of Chicago. Immunosuppression was based on cyclosporine and steroids with antilymphocyte preparations as reported previously (*12*). Rejection episodes were treated with bolus steroids in all cases.

[2] Manuscript submitted for publication.

TABLE 1. Fate of pediatric patients evaluated for liver transplantation (University of Chicago 1984–1987)

Category	n	Percentage
Not endstage	20	29%
Transplanted	38[a]	54%
Alternative therapy	3	4%
Withdrawn	4	6%
Died awaiting transplant	5	7%
Total	70	100%

[a] 5 patients transplanted elsewhere.

TABLE 2. Operative indication in 41 liver transplants in 33 children (University of Chicago experience 1984–1987)

Diagnosis	n	Percentage
Primary liver disease:		
Biliary atresia	21 (3)	63%
Fulminant hepatitis	5 (2)	16%
A-1-antitrypsin deficiency	3	9%
Alagille's syndrome	1	3%
Tyrosenemia	1	3%
Byler's disease	1	3%
Hepatoblastoma	1	3%
Retransplants (21% of all transplants):		
Thrombosis	3 (2)	33%
Rejection	4	44%
Primary nonfunction	2	23%

Number of reduced liver transplants in parentheses.

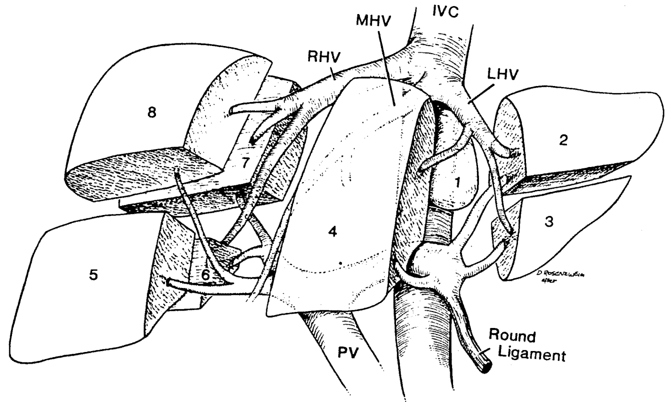

FIGURE 1. The segmental anatomy of the liver. Segments 2 and 3 correspond to the left lateral lobe Segments 2, 3, and 4 form the whole left lobe, while 5, 6, 7, and 8 form the right lobe. (Redrawn after Bismuth [11] and Couinaud [10].

TABLE 3. Preoperative clinical status of patients receiving a reduced liver transplant

n	Age	Weight	Diagnosis (kg)	Indication for RLT	Encephalopathy (0–4)	ICU (0, 1)
1	36 Months	11	Bil. atresia	Retx (art. thrombosis)	1	1[a]
2	24 Months	8	Bil. atresia	Deterioration (12 weeks on list)	2	1
3	11 Months	9	Bil. atresia	Deterioration (5 weeks on list)	2	0
4	15 Years	61	Fulm. hep.	Coma	4	1[a]
5	15 Months	10	Bil. atresia	Retx (art. thrombosis)	4	1[a]
6	48 Months	16	Fulm. hep.	Coma	4	1[a]
7	6 Months	7	Bil. atresia	Retx (art. thrombosis)	4	1[a]
8	4 Months	6	Bil. atresia	Deterioration (5 weeks on list)	1	0
9	6 Months	7	Bil. atresia	Deterioration (4 weeks on list)	0	0

[a] On ventilator.

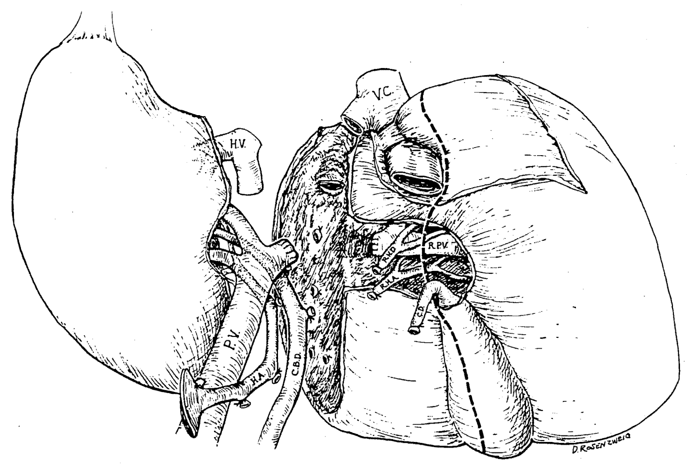

FIGURE 2. The dissection of the liver as it would appear ex-vivo on the back table. The illustrated plane of section would create a left lateral lobe graft while dissection along the main fissure (dotted line) would create a right or left lobe graft.

TABLE 4. Donor/recipient size match in reduced-sized liver transplants

n	Recipient Age/ Weight (kg)	Donor Age/ Weight (kg)	Weight ratio (D:R)	Graft (lobe used)
1	3 Years/11	16 Years/47	4.3:1	Right
2	2 Years/8	42 Years/65	8.1:1	L lateral
3	11 Months/9	12 Years/33[a]	3.6:1	Left
4	15 Years/61	37 Years/90	1.5:1	Left
5	15 Months/10	22 Years/64	6.4:1	Left
6	4 Years/19	45 Years/70	3.7:1	L lateral
7	6 Months/7	2 Years/13[a]	2:1	Right
8	4 Months/6	7 Months/11[a]	2:1	Right +4
9	8 Months/8	15 Years/25[a]	3.1:1	Left

[a] Pediatric donors.

RESULTS

Donor/recipient size match. The relationship between the donor and recipient age and weight, and the graft eventually prepared is presented in Table 4. These tabulated data demonstrate no consistent relationship between donor and recipient age and weight and eventual graft used. In addition to overall size of the donor liver there is variation in the relative size and shape of the hepatic segments. The donor:recipient weight ratio ranged from 2:1 to over 8:1. A Left lateral lobe graft was used in the patient with the largest size disparity. Pediatric donors were used in 4 of 9 cases. However, in one case the decision to reduce the graft was made when whole liver grafting was deemed feasible due to an unexpected size mismatch.

Intraoperative data. Table 5 presents a comparison of intraoperative data for the series of RLT and whole-liver transplants in pediatric recipients. Operative blood replacement and operative time were significantly greater in RLT group. Ischemia time was similar in the two groups. In Figure 3 operative blood loss in all pediatric transplants is presented. RLT was associated with the highest intraoperative blood replacement and was significantly higher than that in elective transplants. However, blood loss in RLT was not significantly greater than in urgent candidates receiving a size-matched whole-liver transplant.

Patient survival. Survival times and the cause of death are presented in Table 6. In all, 4 of 9 patients (44%) are alive between 2 and 48 months after transplantation. Patient 3 died on postoperative day 5 following an intracranial hemorrhage. Graft function was marginal at the time (PT: 17 sec, bilirubin: 9.8 mg/dl, Platelets: 74,000) and may have contributed to the complication. The presence of severe hypertension (150/100 mmHg) in this infant also complicated the clinical picture. Two early deaths (pts. 4 and 5) were directly related to failure of the transplant. Primary nonfunction led to death in patient 4 with the development of coagulopathy and hemoperitoneum. In patient 5, transplanted in stage 4 coma secondary to acute thrombosis with respiratory and acute renal failure, a marginal donor was accepted. The organ was fatty and reduction to a left lobe graft was still too large for the infant recipient. Reperfusion was poor and persistent coagulopathy developed leading to intraoperative death. Patients 2 and 6 died secondary to complications of severe gastrointestinal cytomegalo virus (CMV) infection at 3 and 6 months with near-normal function of the transplant.

Graft-related complications. Complications related to the graft are presented in Table 7 and fall into three general

TABLE 5. Comparison of intraoperative data for reduced and whole liver transplants in children

Parameter	Reduced (n=7)	Whole organ (n=34)	Significance
Blood loss during operation[a]			
Mean ± SD	4.4±4.6	2.2±2.3	$P<.05$
Median	1.7	2.1	P=ns
Range	0.5–11.7	0–10	
Operating time (hr)			
Mean ± SD	9.3±3.5	6.9±2.6	$P<.05$
Median	9	6.5	$P<.01$
Range	6.2–16	3.8–12	
Ischemia time (hr)			
Mean ± SD	7±1.5	6.4±1.7	P=ns
Median	8	6	P=ns
Range	4.5–8.5	2–11	

[a] Intraoperative blood replacement (blood volumes).

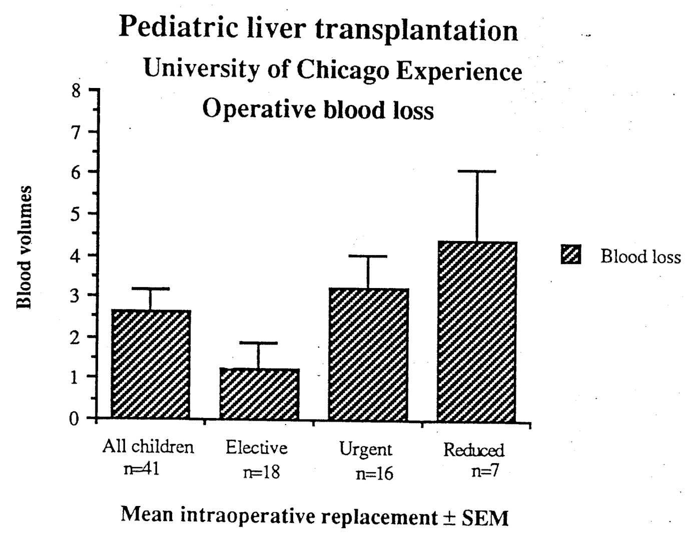

FIGURE 3. Blood loss in pediatric liver transplantation in Chicago.

TABLE 6. Patient survival

n	Graft (lobe)	Follow-up	Alive	Cause of death
1	R	48 Months	1	
2	LL	3 Months	0	Systemic CMV GI bleeding
3	L	5 Days	0	Intracranial hemorrhage
4	L	5 Days	0	Nonviable graft
5	L	None	0	Intraoperative death
6	LL	6 Months	0	Systemic CMV GI bleeding
7	R	6 Months	1	(Retransplanted)
8	R +4	7 Months	1	
9	L	2 Months	1	

TABLE 7. Graft-related complications

Complication	Lobe	Management	Outcome
Size disparity	R	Retransplantation	Alive
	L		Intraoperative death
	LL	Secondary closure	6-Month survival
Nonviable graft	L		Died awaiting retx.
Bile duct necrosis	LL	Revision hepaticojejunostomy	6-Month survival

categories. Size disparity was a problem in several cases and underlines the difficulty of assessing the type of reduction of the graft necessary for an optimal fit. In 3 cases (pts. 5, 6, 7) the organ was too large for abdominal closure. In patient 6 a left lateral lobe was used—however, the donor was an adult male with an unusually large left liver. In the other 2 cases inappropriate choice of the size reduction was made. Secondary abdominal closure was possible in patient 6. In patient 7 the graft continued to increase in size postoperatively because of secondary ischemic change and edema, and retransplantation with a size-matched organ was performed 10 days after transplantation despite intact synthetic function and production of bile by the graft. Primary nonfunction directly caused the death of patients 4 and 5 and poor function may have contributed to the death of patient 3.

Bile duct necrosis occurred in a single case (pt. 6) and was managed by revision of the hepaticojejunostomy. In this case an L lateral lobe was used and the blood supply to the duct may have been compromised in the dissection of the hilus. Revision of the anastomosis required creation of a long jejunal loop because of the position of the bile duct high in the right upper quadrant.

Extrahepatic complications (Table 8). Severe extrahepatic complications were observed in several patients, leading to death in patients 2, 3, and 6. Clinically significant CMV infection occurred in 4 patients (44%). Gastrointestinal bleeding led to death in 2 of these 4 patients despite antiviral therapy. Acute pulmonary failure developed in patient 9 who required 4 weeks of ventilatory support with resolution without the identification of a causative organism. Rejection episodes manifested by abnormalities of liver tests and a supportive histologic picture occurred in patients 1, 2, 8, and 9, and responded to bolus steroid therapy in all cases.

TABLE 8. Extrahepatic complications

Complication	Patient	Management	Outcome
CMV infection			
Systemic	1	Antiviral globulin	Resolved
GI bleeding	2	Bowel resection	Death
GI bleeding	6	DHPG; bowel resection	Death
Hepatitis	7	Lowered immunosuppression	Resolved
Acute pulmonary failure	9	Prolonged ventilatory support	Resolved
Intracranial hemorrhage	3		Death
Rejection	1, 2, 7, 8, 9	Bolus steroids	Resolved

DISCUSSION

The series reported here is the first clinical experience with reduced liver grafting in the United States. Bismuth et al. in Paris, Pichlmayr in Hannover, FRG, and Otte et al. in Belgium are actively pursuing this modality in Europe where the shortage of pediatric organs is even more severe. The European groups have used RLT in elective recipients and have observed morbidity and mortality comparable to that of whole-liver grafting in their institutions (personal communications). The experience with RLT reported here represents the use of RLT exclusively in urgent settings where results of OLT have, in general, been less favorable (*13*). Despite the high-risk setting 4 of 9 patients were rescued, making it reasonable to pursue expanded application of RLT.

In the Illinois procurement area in 1986, only 40% of 143 cadaver renal donors were also liver donors (Illinois Transplant Society, 1986). This figure is consistent with national experience. The inability to find a size-matched liver recipient at the time the donor was available was one of several factors contributing to this disparity, particularly in large adult donors. An increase flexibility in the use of available cadaver organ donors could be anticipated with the use of RLT in both elective and urgent clinical settings. The ability to offer RLT to the urgent candidates will reduce the overall loss of pediatric patients waiting on the transplant lists. At the University of Chicago the loss of pediatric patients on the transplant list was only 7% (Table 1).

Review of the indications of RLT in this series demonstrated three categories: emergency retransplants, fulminant hepatic failure (FHF), and chronic liver failure in small children. The role of retransplantation in acute graft failure with coma and multi-organ failure is difficult to assess. Survival of patients in stage 4 hepatic coma at the time of retransplantation has not been reported, and Shaw et al. (*13*) have argued that retransplantation is contraindicated in that setting. To successfully salvage patients with acute thrombosis or nonfunction, retransplantation must be done quickly and the rapid availability of a donor becomes critical.

Recent results of OLT in the therapy of FHF have been encouraging (our unpublished observations and [*14*])—however, transplantation must be performed rapidly, often within 48 h of admission. In FHF the use of RLT is often the only option for rapidly obtaining a graft for children and small adults.

Determination of the need for RLT in chronic liver disease is more difficult. Approximately 1/3 of patients with biliary

atresia develop progressive liver failure before their 2nd birthday (*15*). Many of these small children are less than 10 kg, although the abdominal cavity can usually accomodate a graft from a donor up to twice as large because of distension and massive ascites. If the graft is too large, size-reduction may be preferable to avoid the complications of inadequate perfusion and respiratory compromise. This occurred once in our experience in which the donor organ was larger than anticipated from preoperative size matching. These small infants can also be transplanted electively with a partial graft from an adult donor if a size-matched organ is not available in a timely fashion. This will probably be the principal application of RLT in the future.

In the technical application of RLT, the problems of size-matching and the choice of the lobe for use as a reduced-sized graft remain the key obstacles. The use of the entire L lobe as a graft provides a fit and orientation that is most similar to whole-liver transplantation. The large A-P diameter of segment 4 (quadrate lobe) acts as a new right lobe and fills the right upper quadrant of the recipient, correctly orienting the vena cava and hilar structures. The use of a left lobe graft is usually not feasible if the weight ratio exceeds 5:1. With a larger size disparity, only the L lateral lobe can be used—however, use of this graft requires careful reconstruction of the vena cava and introduces a left-to-right orientation of the structures of the hilus that must be carefully managed to avoid portal vein obstruction. The creation of a Roux-en-Y loop provides the flexibility to manage the bile duct, even with an abnormal orientation. Because of its large AP diameter, the use of a right liver graft with a large donor-recipient size-mismatch should be avoided. The fit is poor, resulting in poor perfusion of the large bulk of parenchyma, unfavorable orientation of the vessels, and difficulties in abdominal closure that can cause respiratory compromise.

Since there is great variability in the size and shape of liver lobes a back-up adult recipient should be ready to avoid wasting of the donor if the anatomy is unfavorable for use as a reduced graft. At least two independent surgical teams should be involved for the optimal application of RLT, so that the recipient hepatectomy can be performed at the same time the graft is being prepared. Several early RLT in this series were performed with a single surgical team, resulting in longer ischemic periods, perhaps contributing to poor or absent graft function observed in three cases. On-site donors provide optimal timing, but this situation is not mandatory.

As a result of the extended operative procedure, blood loss was greater in RLT (Fig. 3)—however, multivariate analysis of blood loss in 85 liver transplants at the University of Chicago[3] has indicated that the preoperative condition of the recipient has the strongest correlation with blood utilization. In RLT bleeding from the transected parenchyma was minimal due to careful ligation of each structure during preparation of the graft and the vasospasm that occurs early upon reperfusion making it possible to control any bleeding that occurs. Bleeding from the cut section occurred only with nonfunction of the transplant in cases 4 and 5 because of diffuse coagulopathy. The operating time was longer in RLT group due to the additional procedure and technical adjustments—however, this can be minimized with the use of two teams. The comparable ischemic times presented in Table 5 were due to a higher incidence of long-distance procurement in the group receiving whole-liver grafts.

The principal medical complication in the patients receiving RLT was clinically significant CMV disease, which occurred in 44% patients, an incidence much higher than that observed in whole-liver grafting (*16*). Of concern was the observation of eventually fatal involvement of the GI tract in two patients: patient 2 was seronegative preoperatively and received a graft from a seropositive donor, patient 6 was seropositive preoperatively and received a graft from a positive donor. This high incidence of clinically significant disease may warrant the prophylactic application of anti-CMV therapy in children receiving an adult organ until the serostatus of both donor and recipient is known. The optimum use of such therapy is unclear and will require further investigation.

In conclusion, this initial clinical experience indicates the following: (1) long-term survival with RLT is possible, and the procedure could also serve as a temporary support measure if the graft were not ideal until an optimal donor could be located; (2) although there is insufficient experience at present, it is possible that with further development of the technique the operative risk will be comparable to that of whole-liver grafting; (3) experience with planning and execution of the size reduction and the use of two operating teams is mandatory and optimal application of RLT; (4) Antiviral precautions should be considered in transplantation of an adult liver into a pediatric recipient; and (5) by overcoming size limitations RLT can increase utilization of available donors.

[3] Manuscript submitted for publication.

REFERENCES

1. NIH Consensus Development Conference Statement. Liver transplantation, June 1983. Hepatology 1984; 4: 1075.
2. Zitelli BJ, Malatack JJ, Gartner JC, et al. Evaluation of the pediatric patient for liver transplantation. Pediatrics 1987; 78: 559.
3. Price JB, Voorhees AB, Britton RC. Partial hepatic autotransplantation with complete revascularization in the dog. Arch Surg 1967; 95: 59.
4. Van der Heyde MN. The role of functional competition in auxiliary liver transplantation. Transplantation 1966; 5: 78.
5. Marchioro TL, Porter KA, Dickinson TC, Faris P, Starzl TE. Physiological requirement of heterotopic auxiliary liver transplants. Surg Gynecol Obstet 1965; 121: 17.
6. Fortner JG, Yeh SDJ, Kim DK, Shiu MH, Kinne DW. The case for and technique of heterotopic liver grafting. Transplant Proc 1979; 11: 269.
7. Bismuth H, Houssin D. Reduced-sized orthotopic liver graft in hepatic transplantation in children. Surgery 1984; 95: 367.
8. Broelsch CE, Neuhaus P, Burdelski M, Bernsau U, Pichlmayr R. Orthotope transplantation von lebersegmenten bei kleinkindern mit gallengangsatresien. Orthotopic transplantation of hepatic segments in infants with biliary atresia. In: Koslowski L, ed. Chirurgisches Forum '84 f. experim u. klimische Forschung Hrsg. Berlin/Heidelberg: Springer, 1984.
9. Couinaud C. Le foie: etudes anatomigues et chirurgicales. Paris: Masson, 1957.
10. Bismuth H. Surgical anatomy and anatomical surgery of the liver. World J Surg 1982; 6: 3.
11. Starzl TE, Bell RH, Beart RW, Putnam CW. Hepatic trisegmentectomy and other liver resections. Surg Gynecol Obstet 1975; 141: 429.
12. Emond J, Thistlethwaite JR, Baker A, et al. Rejection in liver