Transplantation of Two Patients with One Liver

Analysis of a Preliminary Experience with 'Split-liver' Grafting

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Surgical reduction of donor livers to treat small children has been performed successfully in several centers. While this procedure improves the allocation of livers, it does not increase the organ supply. We have extended reduced-size orthotopic liver transplantation (OLT) to treat 18 patients with 9 livers, accounting for 26% of our transplants during a 10-month period and have evaluated the results. In 18 split liver OLTs, patient survival was 67% and graft survival was 50%. In comparison, for 34 patients treated with full-size OLT during the same period, patient survival was 84% (p = 0.298) and graft survival was 76% (p = 0.126). Biliary complications were significantly more frequent in split grafts, occurring in 27%, as compared to 4% in full-sized grafts (p = 0.017). Primary nonfunction (4% *versus* 5.5%) and arterial thrombosis (6% *versus* 9%) occurred with similar frequency in split and full-size OLT (p = not significant). These results demonstrated that split-liver OLT is feasible and could have a substantial impact in transplant practice. We believe that biliary complications can be prevented by technical improvements and that split-liver OLT will improve transplant therapy by making more livers available.

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ORTHOTOPIC LIVER TRANSPLANTATION (OLT) has evolved into a frequently used and effective treatment for patients with advanced liver disease. A major limitation to its more widespread application is availability of donor organs. While the supply of cadaver donors is adequate for adult patients, there is a critical shortage of donors for small children. As an example of the magnitude of the problem, in a recent report from the University of Pittsburgh, 25% of children accepted as candidates died while awaiting transplantation.[1] The risk is even higher for infants. Indeed we estimate that in the United States between 25% and 50% of infants who are transplantation candidates die before transplantation due to limitations in the organ supply.

We have analyzed the causes for the high pretransplant mortality rate in children.[2] This excessive mortality rate is caused by the disparity between the epidemiology of pediatric liver disease, primarily affecting infants and small children, and that of brain death and organ donation, which occurs more often in adults and school-aged children. In 1982, prior to widespread application of liver transplantation, National Health Statistics data demonstrated a bimodal mortality distribution for children with liver disease.[3] The majority of children (55%) died before they reached 2 years of age. Very few deaths occur between 2 and 10 years of age, when accidents are the major cause of death. Despite the prevalence of liver disease, OLT has been performed in relatively few infants until recently. For example, only 10% of 250 patients receiving OLT in the largest pediatric experience yet reported were younger than 1 year of age.[4] A major reason for this is the scarcity of donors in this age group.

We and others[5-10] have addressed the shortage of small donors by the development of reduced-size OLT, in which cadaver livers from larger donors are reduced in size to fit into the abdominal cavity of smaller recipients. During these procedures part of the donor organ is removed along anatomic lines and discarded. In a 2-year period, while implementing a strategy in which reduced-sized OLT and standard OLT were used essentially interchangeably to treat small children, we limited the pretransplant mortality rate to 2% while achieving a post-transplant survival rate of 79% for patients receiving reduced-size grafts and 82%

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with full-sized grafts.[2] During this time, two thirds of the pediatric patients treated were less than 12 kg in size.

Although reduced-size OLT clearly improves the distribution of organs, it does not increase the overall supply of livers. Since July 1988 we have performed split-liver transplantation in 18 patients, 26% if transplants performed during a 10-month period. Using this technique, a second patient is treated with the portion of liver that would be discarded during preparation of a reduced-size graft. This, in effect, doubles the supply of livers available from a given donor population. In this report we analyze the results of our preliminary experience with this technique.

Patients and Methods

Study Population

This study includes all OLT performed by our surgical team between July 1988 and May 1989, during which 29 adults and 27 children were treated. Nine patients (16%) received more than one transplant. Of 68 grafts transplanted during this period, 24 (36%) were reduced-size grafts, of which 17 came from split-liver procedures. In addition the right lobe from one split-liver procedure was taken to another institution for emergency treatment of a patient in coma due to primary graft failure. Among children reduced-size and split-liver transplants accounted for 59% of grafts. Seventy-one per cent of pediatric patients were younger than 2 years, of whom 79% received reduced-size grafts. Overall we treated 56 patients with 52 donors.

Preoperative Management and Patient Selection

Medical management and selection of adult patients was according to standard clinical practice. Children were frequently assessed with regard to nutritional status, growth, and liver function by quantitative testing.[11] Patients were categorized into four groups depending on the level of medical support required before OLT: group 1, medically stable as outpatients; group 2, medically stable, but requiring inpatient support; group 3, medically unstable, requiring intensive care; group 4, in intensive care, requiring ventilator support. Priority was assigned according to the medical category. The weight range of acceptable donors was expanded to accommodate the performance of a reduced-size OLT under the following circumstances: (1) deterioration of stable patients to higher medical categories, (2) existence of all group 3 or 4 candidates, and (3) presence of small infants who were very unlikely to receive size-matched organs. Split grafts were performed when pairs of patients with appropriate size and urgency were present on the waiting list.

Operative Techniques

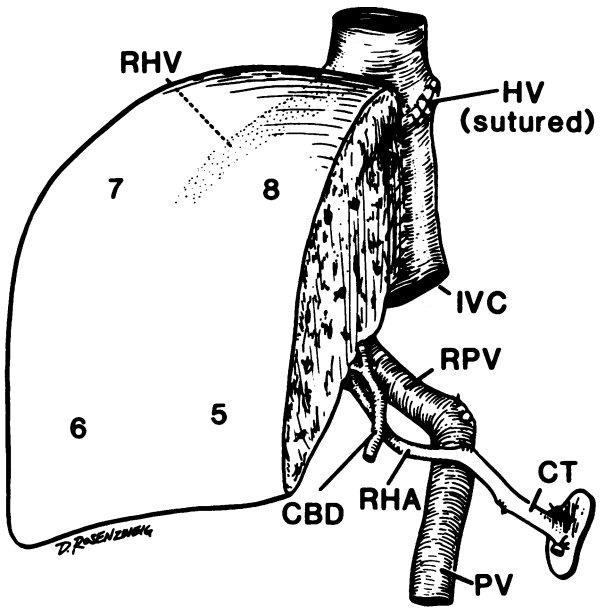
Procurement and graft preparation. Livers were procured according to standard techniques of multiple organ retrieval. All were perfused through the aorta with University of Wisconsin (UW) preservation solution.[12] Cholecystectomy was performed and the biliary tree was flushed. The livers were packed on ice in a bath of preservation solution for transportation.

The grafts were prepared in the operating room at our institution. The liver was submerged in ice cold preservation solution during the *ex vivo* dissection. The vascular and biliary structures in the hilus were dissected and lobar branches were identified. The left bile duct, hepatic artery, and portal vein were divided from the common bile duct, proper hepatic artery, and portal vein, respectively. The left and middle hepatic veins joined into a common trunk that was isolated and divided from the inferior vena cava. Orifices on the main trunks were sutured closed.

Anatomic dissection of the liver was according to the principles described by Couinaud[13] and Bismuth,[14] and as described elsewhere.[8] The donor liver was split along the main portal scissure separating the right and the left lobes (Fig. 1) when recipients were nearly the same size. In five cases in which the patient receiving the left lobe was much smaller, the parenchymal transection was made in the plane of the falciform ligament for the creation of a left lateral lobe graft (segments 2 and 3). Segment 4 was retained with the right lobe graft in three cases to maximize the amount of parenchyma transplanted. In all cases penetrating vessels and ducts were suture ligated with fine polypropylene monofilament thread, and fibrin sealant was spread on the raw surface of both grafts. The right lobe graft consisted of segments 1 and 5 to 8, with segment 4 in three cases. All common structures (*i.e.*, portal vein, celiac trunk, common bile duct, and inferior vena cava) remained attached to the right lobe grafts. The left graft consisted of segments 2 to 4 in 4 patients, and segment 2 and 3 in 5 patients. The left lobar branches constituted the vascular and biliary structures for these grafts. To increase the length of the vessels for anastomosis, interposition grafts consisting of the external iliac artery in continuity with the common iliac artery and the terminal inferior vena cava or iliac vein from the donor were sewn to the left hepatic arterial and portal venous branches, respectively (Fig. 2). The preparation of the two grafts required 3 to 4 hours.

Recipient Operations

Recipient hepatectomy in the first patient was performed during preparation of the first graft, which was then implanted immediately, while the second graft was being prepared. The second recipient hepatectomy was performed during preparation of the second graft. Graft



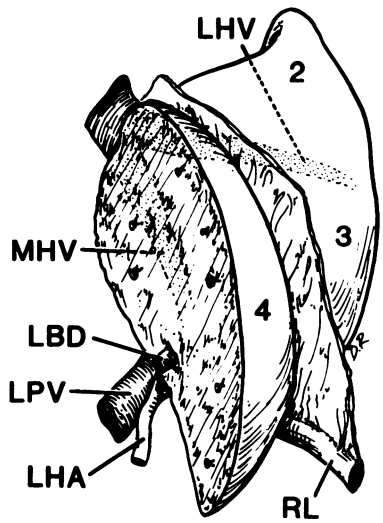


FIG. 1. Diagram of the two grafts after preparation from one donor liver. Note that all the main vascular and biliary structures remain attached to the right lobe and that the left lobe is supplied by lobar pedicles. IVC, inferior vena cava; PV, portal vein; CT, celiac trunk; CBD, common bile duct; HV, hepatic vein; RPV, right portal branch; RHA, right branch of hepatic artery; RHV, right hepatic vein; LHA, left branch of the hepatic artery; LPV, left portal branch; LBD, left bile duct; LHV, left hepatic vein; MHV, middle hepatic vein. Numbers indicate hepatic segments according to Couinaud[9].

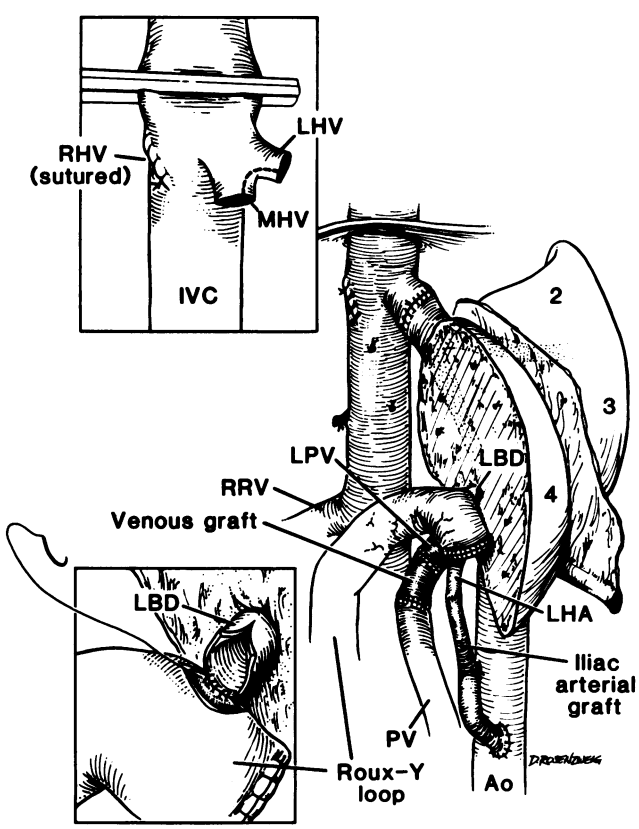


FIG. 2. The left lobe graft after revascularization, as in patients A2 and B2. Note the preservation of the inferior vena cava and the anastomoses of the segmental pedicles using interposition grafts. Upper square shows the preparation of the inferior vena cava and hepatic veins using the common trunk of the left and middle hepatic veins for suprahepatic venous anastomosis. Lower square shows the anastomosis of the Roux-Y loop on the left hepatic duct, which is enlarged by an anterior spatulation.

ischemia ranged from 7.5 to 21 hours. Recipient operative times ranged from 5.5 to 12 hours.

In patients receiving the right lobe graft, the native liver, including the retrohepatic vena cava, was mobilized and removed. The graft was implanted orthotopically by suturing the inferior vena cava above and below the graft, the portal vein, and the hepatic artery. All anastomoses were similar to standard OLT and interposition grafts were not required. Biliary reconstruction was done with a Roux-en-Y cholangiojejunostomy or to a single right hepatic duct in eight cases and incorporating a secondary segmental bile duct in one other.

Implantation techniques varied in several respects for patients receiving left lobe grafts and are summarized in Table 1. The hilus of the recipient's liver was dissected with division of the hepatic artery and common bile duct. The liver and the inferior vena cava were then mobilized from the retroperitoneum, and vascular exclusion of the liver was achieved by clamping the vena cava above and below the liver and division of the portal vein. The liver was then removed with preservation of the inferior vena cava in seven of nine cases. In these cases the caval orifice of right hepatic vein and several smaller accessory hepatic veins were sutured closed and the common trunk of the middle and left hepatic veins was used for the hepatic vein anastomosis (Fig. 2). Patient 2L had organized thrombosis with complete obliteration of the subhepatic cava. The left hepatic vein of the graft was anastomosed directly to the remaining suprahepatic cava. In patient 9L, excision of the vena cava with the liver was performed as in standard OLT, with creation of a vena cava replacement from the middle hepatic vein of the graft, as de-

TABLE 1. *Split-liver OLT: Technical Details of Left Lobe Grafts*

Patient	Graft*	Artery†	Portal Vein‡	Hepatic Vein§
1L	2–4	I, A	I	LHV
2L	2–4	I, HA	I	VC
3L	2, 3	IH	E	LHV
4L	2–4	IH	I	LHV
5L	2, 3	IH	I	LHV
6L	2, 3	IH	I	LHV
7L	2–4	IH	I	LHV
8L	2, 3	IH	E	LHV
9L	2, 3	IH	E	VC

* Hepatic segments implanted (Couinaud).
† Arterial anastomosis: IA—iliac artery interposition graft to recipient aorta.
IH—iliac interposition graft to recipient common hepatic artery.
‡ Portal vein anastomosis: I—iliac vein interposition graft.
E—direct anastomosis without graft.
§ Hepatic vein anastomosis: LHV—Left hepatic vein end-to-end.
VC—Replacement of vena cava with middle hepatic vein.

scribed by Ringe et al.[15] The portal vein was sewn end-to-end to an interposition graft in six cases, while direct anastomosis was possible in three. In recipient 1L, the interposed iliac artery was passed through a retropancreatic tunnel and anastomosed to the infrarenal aorta, while in the remaining cases, the interposed iliac artery was anastomosed to the common hepatic artery. The left bile ducts measured 1 to 5 mm and were enlarged by anterior incision (Fig. 2), and Roux-en-Y cholangiojejunostomy was performed in all cases. Inclusion of more than one ductal orifice in the biliary enterostomy was required in four of nine cases.

Data Analysis

Proportions were compared using 2 × 2 contingency tables and calculating chi^2 with Yates correction for continuity.

Results

Recipients and Operative Data

Preoperative data on 18 patients receiving split transplants is summarized in Tables 2 and 3. Pretransplant diagnoses were similar to our overall transplant experience,[10] with a predominance of biliary atresia in children. The oldest child treated was 32 months and all children weighed 12 kg or less. Overall 7 of 18 recipients of split-liver grafts were critically ill before the transplant, with 5 patients requiring ventilator support. Six were stable at home. Table 4 presents sizes and blood types of donors and recipients size and the grafts used. Donors ranged in weight from 16 to 75 kg.

TABLE 2. *Preoperative Data from 13 Children Receiving Split-liver Transplants*

Patient	Age	Weight	Indication for Transplantation	Status*
1R	7 mo.	4.8 kg	Alpha-1-antitrypsin deficiency	1
1L	3 mo.	2.1 kg	Subacute liver failure	4
2R	16 mo.	9.3 kg	Biliary atresia	1
2L	5 mo.	4.1 kg	Biliary cirrhosis	3
3L	9 mo.	5.1 kg	Biliary atresia	2
4R	8 mo.	6.4 kg	Biliary atresia	1
4L	4 mo.	4.9 kg	Neonatal hepatitis	1
5L	11 mo.	9 kg	Biliary atresia	2
6L	14 mo.	11 kg	Biliary cirrhosis	1
7R	25 mo.	9 kg	Biliary cirrhosis	3
7L	11 mo.	6 kg	Biliary atresia	2
8L	32 mo.	8.2 kg	Biliary cirrhosis	2
9L	24 mo.	12 kg	Primary graft nonfunction	4

* Status: 1 = at home; 2 = in hospital; 3 = ICU bound; 4 = ICU bound, on ventilator.

Deaths and Complications (Table 5)

Early deaths (within 7 days of OLT). Three patients died within 96 hours of transplantation. Patient 1L was a 2.1-kg infant with tetralogy of Fallot and idiopathic cirrhosis who developed congestive heart failure and died 48 hours after OLT. Biochemical indices of graft function and histology were satisfactory. Patient 7L developed infarction of the entire midgut and liver. The graft was ABO incompatible and neither arterial nor venous thrombosis was identified at laparotomy or subsequent pathologic examination. Patient 9R was at another institution and was 5 days after having received a primary OLT. He was *in extremis* due to graft nonfunction. After preparation of the left lateral lobe graft for patient 9L in our institution, the right lobe was flown to the second institution and implanted after 18 hours of cold ischemia. The patient was unstable during the procedure and suffered cardiac arrest after reperfusion, which was apparently due to metabolic causes.

Late Deaths

Three other patients died between 25 and 45 days after transplantation. Patient 5R was a 20-year-old man with

TABLE 3. *Preoperative Data of Five Adults Receiving Split-liver Transplants*

Patient	Age	Weight	Indication for Transplantation	Status*
3R	20 yrs.	50 kg	Cirrhosis	1
5R	20 yrs.	60 kg	FHF	4
6R	57 yrs.	68 kg	Chronic rejection; graft infection	2
8R	36 yrs.	51 kg	Cirrhosis	4
9R	49 yrs.	65 kg	Nonfunction	4

* Status: 1 = at home; 2 = in hospital; 3 = ICU bound; 4 = ICU bound, on ventilator.

TABLE 4. *Split-liver OLT: Operative Data for Donor and Recipients*

Donor		Recipient (R) Lobe					Recipient (L) Lobe				
Wt (kg)	Blood Type	Pt	Wt	Blood Type	Graft*	Time†	Pt	Wt (kg)	Blood Type	Graft	Time
16	O	1	4.8	B	5–8	15	1	2.1	A	2–4	18
16	B	2	9.3	B	5–8	14	2	4.1	O	2–4	13
31	O	3	50	AB	4–8	17	3	5.1	B	2, 3	20
17	O	4	6.4	O	5–8	10	4	4.9	O	2–4	7.5
47	B	5	60	O	4–8	11	5	9	B	2, 3	10
64	O	6	68	O	4–8	19	6	11	O	2, 3	21
32	A	7	9	A	5–8	12	7	6	O	2–4	12.5
61	O	8	51	O	5–8	12	8	8.2	A	2, 3	13
75	O	9	65	B	5–8	18	9	12	O	2, 3	12

* Hepatic segments according to Couinaud.

† Total ischemic time (hours).

fulminant hepatic failure. He was transplanted while in stage IV coma. An ABO-incompatible right lobe graft was used, which included segment 4. After operation the patient awoke, recovered nearly normal liver function, and was discharged from the intensive care unit. Fourteen days after the procedure, he developed biochemical and histologic evidence of rejection. This was steroid unresponsive and was treated with 12 days of OKT3 (Ortho Pharmaceuticals, Raritan, NJ). The patient developed a biliary leak and was returned to the operating room where arterial thrombosis was identified. In addition to bile duct necrosis, segment 4 was also infarcted. Retransplantation was performed, but the patient died of septic complications 30 days later.

Patient 6R was 57 years old with chronic rejection and an intrahepatic abscess 5 months after primary OLT for the treatment of sclerosing cholangitis. He was treated with an ABO-compatible right lobe graft that included segment 4. Seven days after operation the patient developed massive hemorrhage due to disruption of the arterial anastomosis and complicated by necrosis of segment 4. The patient developed septic complications and died 25 days later after a third OLT.

Patient 7R was a cachectic 25-month-old child with biliary cirrhosis. At the time of transplantation, the patient was in the intensive care unit because of recurrent variceal hemorrhage. The patient received an ABO-compatible right lobe graft. After initial good graft function, the patient developed severe rejection, which was refractory to therapy, and died 25 days later of septic complications shortly after a second OLT.

TABLE 5. *Surgical Complications in 18 Split-liver Graft Transplants*

Complication	Incidence	Patient
Hemoperitoneum	6/18 (33%)	1L, 4L, 5L, 6R, 7L, 8R
Biliary leakage	5/18 (27%)	3L, 5R, 5L, 6R, 8R
Partial necrosis	2/18 (11%)	5R, 6R
Graft nonfunction	1/18 (6%)	6L
Arterial thrombosis	1/18 (6%)	8R
Portal vein thrombosis	1/18 (6%)	5L
Intraoperative cardiac arrest	1/18 (6%)	9R
Mesenteric infarction	1/18 (6%)	7L
Postoperative cardiac failure	1/18 (6%)	1L

Graft Failure Successfully Treated with Retransplantation

Patient 4L was treated with a left lobe graft but developed intractable ascites after transplantation. Ultrasound examination and biopsy demonstrated extensive fibrosis of the graft, although the hepatic artery, portal vein, and hepatic veins were patent. At the time of retransplantation, partial obstruction of the hepatic vein anastomosis was identified. The patient is alive with normal liver function 5 months after retransplantation.

Patient 5L received a left lateral lobe graft prepared from a donor in which segment 4 was preserved with the right lobe. The patient had three separate biliary radicals anastomosed to the primary Roux-en-Y. Biliary necrosis occurred and attempted repair of the biliary fistula lead to obstruction. The graft was replaced with good results.

Patient 6L received an ABO-compatible left lobe graft with a cold ischemic time of 21 hours. The graft failed to function and was replaced within 24 hours, and the patient was discharged 10 days later without further difficulties.

Overall Graft and Patient Outcome

Split grafts. Graft and patient outcome for 18 split liver grafts is summarized in Table 6. Nine of 18 patients are alive with good function of the primary split graft after a postoperative follow-up from 2 to 12 months. Three additional patients are alive with a second graft. Overall 12 of 18 (67%) patients are alive after split-liver grafting. Graft survival for these split liver grafts is 50%.

Comparison of Results of Split and Full-size OLT

In 36 patients who received full-size grafts during this period, 84% of the patients are alive between 1 and 10

TABLE 6. *Graft and Patient Outcome for 18 Split-liver Transplants*

Status*	Incidence	Patients	Follow-up (months)
Alive with primary graft	9/18 (50%)	1R, 2R, 2L, 3R, 3L, 4R, 8R, 8L, 9L	2–12
Alive with retransplant	3/18 (17%)	4L, 5L, 6L	6–8
Died	6/18 (33%)	1L, 5R, 6R, 7R, 7L, 9R	
Total actual patient survival	67%		
Total graft survival	50%		

* Status as of July 1, 1989.

months, with a primary graft survival of 76%. These results were better than those achieved with split-liver procedures, but the differences were not statistically significant ($p = 0.298$ for patient survival and 0.126 for graft survival). Patients receiving a full-size graft were predominantly adults and older children. The level of preoperative medical support was slightly less severe for patients receiving full-size grafts. Forty-seven per cent of patients receiving a full-size graft were waiting at home at the time of transplantation, in contrast to 33% for patients receiving split grafts. Twenty-eight per cent of patients receiving full-size grafts were in intensive care as compared to 38% of patients receiving split grafts.

Blood group incompatibility resulted in poor survival in both groups: only one of five patients receiving ABO-incompatible grafts survived. The one survivor was patient 2L, who received a split left lobe graft. The other four, two receiving split-grafts and two receiving full-size grafts, died.

In general complications were more frequent in patients receiving split-liver OLT. Hemoperitoneum occurred in 33% of split grafts and in 14% of full-size grafts ($p = 0.086$). Biliary leakage complicated 27% of split OLT and 4% of full-size OLT ($p = 0.017$). In contrast to these clear differences, arterial thrombosis (6% *versus* 9%) and primary graft nonfunction (6% *versus* 4%) occurred with similar frequency in the two groups. No trends could be identified in the occurrence of extrahepatic complications.

In the small group of 7 reduced-size OLT performed during this period, graft survival was 100%. Hemoperitoneum occurred in one case (14%). There were no biliary leaks, vascular complications, or nonfunctioning grafts in this group. Complications due to the parenchymal transection, including partial graft necrosis, or leakage of blood or bile from the cut surface did not occur.

Function of Split-liver Grafts

Biochemical parameters of graft function are presented in Table 7. The functional parameters, in particular the serum bilirubin and prothrombin times, are within the normal range for all patients. Representative ^{99}Tc-HIDA excretion scans are shown in Figure 3 to demonstrate the anatomic positioning of right and left lobe grafts.

Discussion

The results of the present series demonstrate that split-liver transplantation can be used successfully to treat two patients with one donor. In this preliminary experience, patient survival was 67% and graft survival was 50%. While the outcome was not as good as in our patients receiving full-size OLT during this period (who experienced 84% survival and 76% graft survival), the results clearly demonstrate the feasibility of the procedure.

The circumstances that prompted us to perform the first split-graft liver transplants in infants illustrate how this procedure can alter the practice of liver transplantation. Patient 1L was the smallest patient ever to receive a liver transplant. He was in an intensive care unit, dying of liver disease. No whole organ, not even a newborn's liver, could have served his needs because of his size. Thus he required a reduced-size transplant. However it seemed that the extreme complexity of the case would limit the chances for successful transplant, which made it difficult to justify using a pediatric donor just to provide a reduced-size graft. By splitting the liver, the impact of transplanting this child, who had a marginal chance for success on the pediatric donor pool, was lessened. Patient 2L, who was also very small and had other congenital anomalies, is another example of such reasoning with a better outcome. Patients 1R and 2R were relatively stable at the time of operation but were small and had rapidly progressing liver disease. As long as they remained at home, and therefore at relatively low priority, the United Network for Organ Sharing (UNOS) would have been unlikely to provide them with appropriate-sized grafts. Obviously they could be best served by transplantation before the onset of severe complications and the need for hospitalization. Thus the split-liver procedure also improved their care by allowing

TABLE 7. *Function of Split-liver Transplants*

Name	Follow-up	Total Bilirubin (mg/dL)	ALT (IU/L)	Alk • Phos. (IU/L)	Prothrombin Time (seconds)
1R	12 mo.	0.4	20	217	12.6
2L	9 mo.	0.5	26	221	12.4
3L	7 mo.	1.5	176	458	12.0
8L	5 mo.	0.8	29	464	12.0
9L	6 wks.	0.8	19	421	15.2
4R	6 mo.	0.3	53	259	12.6
2R	9 mo.	0.3	189	3529*	12.5
3R	6 mo.	0.8	18	24	12.6
8R	5 mo.	1.1	24	62	11.5

* All 'bone' isoenzyme in rapidly growing infant.

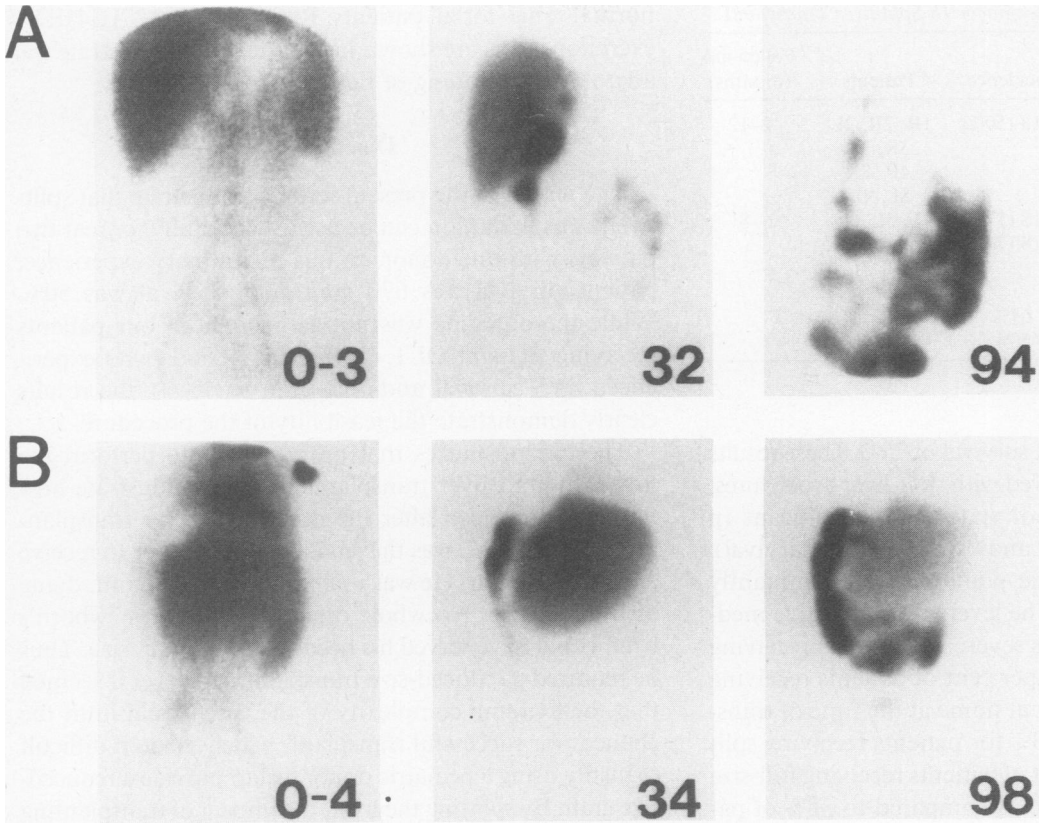


FIG. 3. Representative ^{99}Tc-HIDA excretion scans are shown for two patients. (A) demonstrates normal function of a right lobe graft in patient 3R, a 20-year-old woman 5 months after OLT. Postinjection times 0-3, 32, and 94 minutes are shown. (B) Slightly delayed parenchymal excretion in patient 9L, a 24-month-old boy during a rejection episode one month after OLT. Postinjection times 0-4, 34, and 98 minutes are shown.

them to be transplanted at the priority level of the left-lobe recipients.

While the use of reduced-size and split-liver transplants is justified in small children, their role in adult transplantation is at issue. The principal difference at this time is the relative abundance of donors for the two groups. In our previous analysis of donor use in Illinois in 1987, we found that livers were used in 100% of visceral organ donors less than 4 years of age, whereas less than 50% of adult donors supplied livers.[2] The use of livers is increasing steadily; however while in 1987 livers were procured from 36% of organ donors, this figure has increased to 52% in 1988, and 71% in 1989 (Regional Organ Bank of Illinois, personal communication). Within the coming years, adults will probably face the same shortage of donors presently experienced in children.

In our initial efforts to treat adults with split transplants, we selected patients in relatively stable medical condition, which is probably not appropriate at this time. However our selection of an elective patient was based on our confidence with earlier results of reduced liver grafting and the relative safety demonstrated for recipients of right lobe grafts.[2] Our last three adult experiences have been in critically ill patients who required ventilator support in whom there was an urgent need for a graft and in which exceptional measures were justified. The last case represents a unique experience in which two patients in coma due to primary graft failure, a child in our institution and an adult in another institution, were treated with left and right lobe grafts from a single donor. At the time of donor procurement there were 20 patients in the most critical status for liver transplantation in the UNOS computer registry.

Analysis of the failures in our experience indicates several problems that can be overcome by modification of the technique. The quadrate lobe (segment 4) must be handled properly for the procedure to be successful. Although based on external morphology, it seems to be part of the right lobe of the liver; because it lies to the right of the falciform ligament,[14] segment 4 is functionally part of the left lobe of the liver.[13] Its blood supply and biliary drainage originate at the trifurcation of the left portal vein at the base of the round ligament. Efforts to preserve segment 4 with the right lobe can cause dangerous complications for both grafts. For the right lobe graft, the blood supply and the hepatic venous drainage for this segment can be compromised, with resulting necrosis. Two adults who received a right lobe graft, which included segment 4, died of sepsis complicating tissue necrosis. Leaving segment 4 with the right lobe can also compromise the left lobe graft because preservation of the biliovascular pedicle of segment 4 involves dissection of the biliary confluence

of segments 2 and 3. In two of the children receiving left lobe grafts in which the segment 4 remained with the right lobe, biliary dehiscence occurred.

These complications, that is necrosis of the segment 4 in the right lobe grafts and compromise of the biliary radicals for the left lateral lobe graft, can be avoided in the following manner. First, if the split-liver graft is being performed for the treatment of two infants of relatively equal size, a complete right lobe and a complete left lobe provide optimal positioning and parenchymal mass for both patients. The dissection of the hilar elements for the left lobe should be extremely limited and extend just to the left of the primary bifurcation of the portal vein and the confluence of the right and left hepatic ducts. Proximal dissection of the bile duct to the level of the round ligament, where the left duct structures trifurcate, is dangerous and unnecessary. The right lobe graft created by division of the liver along its principal fissure provides an adequate amount of parenchyma, a single bile duct in nearly all patients, and intact common vessels, including the artery, portal vein, and vena cava. Complications of the transected surface are minimal, as we have shown elsewhere,[2] and the properly used right lobe graft should confer minimal additional risk to the recipient. If the two recipients are very different in size, necessitating the use of the left lateral lobe graft, segment 4 should be removed by a parenchymal dissection without disturbing the integrity of the left portal pedicle. In that way the common left bile duct, left hepatic artery, and left portal vein are available for anastomosis, even though the graft is reduced in size. The pedicle of segment 4 is encountered in the parenchyma and transected well to the right of the round ligament, in that way avoiding any compromise of the biliary structures for segments two and three. This strategy is essential for the performance of left lateral lobe grafts and is applicable for split-liver transplantation and reduced-size transplantation.

The reconstruction of the hepatic vein for the left lobe graft is another area of interest. Although we were not able to document it radiographically, we remain concerned that in using end-to-end left hepatic vein-to-hepatic vein anastomosis the graft is free to move, causing a potential partial obstruction of the hepatic vein outflow. Detrimental effects of even minor elevations in hepatic venous pressure have been demonstrated previously in heterotopic transplant models.[16,17] Partial hepatic vein obstruction was documented at the time of retransplantation in patient 4L. In patient 9L a vena cava was fashioned using the common trunk of the left and middle hepatic vein, replacing the vena cava of the infant with the middle hepatic vein of the donor.[15] This permits the preservation of a completely intact right lobe graft, as well as the creation of a left lateral lobe graft with a vena cava prosthesis. In this way conventional total hepatectomy with excision of the vena cava can be performed in the recipient of the left lobe. The fact that the middle hepatic vein and left hepatic vein retain their common fibrous sheath preserving their normal anatomic relationship may prevent kinking and partial obstruction of the outflow of the liver.

The final technical issue is the requirement for portal vein and arterial interposition grafts in the implantation of the left lateral lobe graft. This portal interposition graft, fashioned from the donor iliac vein, is frequently of much larger caliber than the infant portal vein perfusing it, which creates serious flow disparities and led to thrombosis in patient 5L. Because of the flexibility of the portal vein, it has been possible to perform primary anastomosis without interposition graft in three recent cases. It is probably preferable to avoid interposition graft when possible for the portal vein anastomosis. In contrast, however, arterial thrombosis has not been more frequent in split-liver OLT than in full-size OLT, despite the use of iliac artery interposition grafts for left lobe transplants. In fact among children in the present series, arterial thrombosis was more frequent in full-size grafts (10%) than in reduced-size (0%) or split-liver grafts (8%). This compares favorably with an arterial thrombosis rate of 26% observed in a large series of children younger than 10 years old receiving full-sized grafts.[18]

What are the constraints to split-liver transplants? Only that neither recipient is imperiled by the procedure. Recipients of the right lobe grafts in reduced-size OLT have an outcome equal to that of full-size liver recipients in our experience,[2] so with a similar approach that does not include segment 4, the recipient of the right lobe in a split-liver OLT should not be imperiled. Split-liver OLT requires more dissection and the use of vascular interposition grafts for the left lobe as compared to reduced-size OLT. The recently introduced UW preservation solution extends the period that hepatic allografts can be safely stored,[12] minimizing the consequences of the increased time required for graft preparation. Vascular interpositions have been used widely in overcoming a variety of technical problems in hepatic transplantation and do not appear to have conferred increased risk in the present series. Our results indicate that split grafting, while complex, is feasible. Improved results should be realized as more are performed.

An inadequate supply of donors limits the potential usefulness of orthotopic liver transplantation in the pediatric population, particularly small children. Many children with chronic liver disease die while awaiting a donor organ, with most of these deaths occurring in infants. Graft size, urgency of need, and an inadequate supply of donor organs are problems that must be overcome before the full potential of orthotopic liver transplantation in small infants can be realized. Split-liver transplants can

help to solve them all. This innovation also may be valuable in adults, particularly in urgent conditions.

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