that sHLA concentrations could be studied over a considerable amount of time. Further, current immunosuppressive therapy is so effective that allografts seldom fail from acute rejection. This is especially true in liver transplants where failure from acute rejection approaches zero (*35*).

An intriguing aspect of these data is the period of instability in concentrations of sHLA after transplantation. This period is usually short after liver transplantation and long after kidney transplantation. The reliability of the ELISA indicates that this observation is dependable. Since others have shown the presence of CICs in posttransplant sera (*36, 37*), we wondered whether the observed variations related to the production of anti-donor HLA antibodies. It seemed reasonable to expect that the presence of anti-donor sHLA would produce CICs and result in low concentrations of C1q and donor sHLA. We found no evidence to support this concept. In fact, the positive controls in the test system devised to detect HLA in CICs suggested that the sHLA would be detected even if it were complexed.

The potential for study of donor sHLA relates to whether some concentration present over some period can be used to indicate partial or complete tolerance and what, if anything, this material has to do with the induction of tolerance.

Individuals with soluble HLA from two genotypes are by definition chimeras. The relationship between serologic allogeneic chimerism and cellular allogeneic microchimerism is of interest. These two terms may describe two facets of the same phenomenon. The source of donor sHLA in a serologic chimera is not certain, but sHLA may be produced, at least in part, by donor immunocompetent cells. Such cells are known to produce sHLA (*28, 38*).

These data lend support to the thesis that sHLA secreted from the liver has some relationship to the tolerogenic activity of liver transplants. They also show that organs other than the liver secrete such material.

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TRANSPLANTATION

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IN SITU SPLITTING OF THE CADAVERIC LIVER FOR TRANSPLANTATION[1]

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Background. **The shortage of cadaveric donor livers is the rate-limiting step in clinical liver transplantation. Split liver transplantation provides a means to expand the cadaveric donor pool. However, this concept has not reached its full potential because of inferior patient and graft survival and high complication rates when traditional ex vivo split techniques are used. Therefore we sought to evaluate the safety, applicability, and effectiveness of a new technique for split liver transplantation.**

Methods. **This study consists of 15 in situ split liver procurements, which resulted in 28 liver transplants. In situ splitting of selected livers from hemodynamically stable cadaveric donors was performed at the donor hospital without any additional work-up or equipment being needed. In situ liver splitting is accomplished in a manner identical to the living-donor procurement. This technique for liver splitting results in a left lateral segment graft (segments 2 and 3) and a right trisegmental graft (segments 1 and 4–8). This procedure required the use of the donor hospital operating room for an additional 1.5–2.5 hr and did not interfere with the procurement of 30 kidneys, 12 hearts, 7 lungs, and 9 pancreata from these same donors.**

Results. **The 6-month and 1-year actuarial patient survival rates were 92% and 92%, respectively, while the 6-month and 1-year actuarial graft survival rates were 86% and 86%, respectively. The 6-month and 1-year actuarial patient survival rate of patients who received a left lateral segment graft was 100% and 100%, respectively, while those who received a right trisegmental graft had 6-month and 1-year rates of 86% and 86%, respectively. The actuarial death-censored graft survival rates at 6 months and 1 year were 80% and 80%, respectively, for the left lateral segment grafts, and 93% and 93%, respectively, for the right trisegmental grafts. Allograft and patient survival was independent of United Network for Organ Sharing status at the time of liver transplantation. No patient developed a biliary stricture, required re-exploration**

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for intra-abdominal hemorrhage, or suffered from portal vein, hepatic vein, or hepatic artery thrombosis

Conclusions. **In situ split liver transplantation can be accomplished without complications and provides results that are superior to those obtained previously with ex vivo methods. It abolishes ex vivo benching and prolonged ischemia times and provides two optimal grafts with hemostasis accomplished. This technique decreases pediatric waiting time and allows adult recipients to receive right-sided grafts safely. In situ splitting is the method of choice for expanding the cadaveric liver donor pool.**

For close to 15 years, orthotopic liver transplantation has been established as the definitive therapy for patients with end-stage liver disease. During this evolutionary period, improved patient and graft survival have been achieved, and thus the list of indications for the procedure has naturally expanded (*1*). The full potential for liver replacement is far from being realized because of the widening disparity between the increasing number of potential recipients who vie for a constant donor supply. This is clearly illustrated when considering that 7279 patients were listed for hepatic transplantation in 1995 and only 3922 donor livers were available. The donor shortage is particularly critical for children and small adults, who experience an inordinate and regrettably high incidence of pretransplant mortality.

Several novel approaches have been used in an attempt to alleviate the organ shortage in children and small adults. These approaches have primarily involved reduced-size allografts and living-related liver donation (LRD*). The former, however, does not increase the scarce donor organ resource and in fact works against the adult recipient pool. The latter, LRD, has been used extensively, with nearly 1000 cases having been reported; however, there are still unresolved concerns about the safety of the donor. Split liver transplantation (SLT), in which an adult cadaveric liver is divided into two functioning allografts, not only overcomes the drawbacks of reduced size grafts and LRD but also increases the total number of donor organs. The concept of SLTx was introduced clinically in 1988 (*2–5*). While early reports described the feasibility of this novel technique (*4*, *5*), patient and graft survival rates (60% and 43%, respectively) were inferior to those for whole organ orthotopic liver transplantation. Ex vivo SLT as it was described initially was also associated with a high incidence of biliary complications, primary nonfunction of the right graft, ischemic necrosis of segment 4, and intra-abdominal hemorrhage (*6–11*). A modification of the ex vivo splitting technique is in situ splitting, which is an extension of the techniques established for LRD procurement that is applied to the heart-beating cadaveric donor. Rogiers et al. (*12*, *13*) described the in situ splitting of the cadaveric donor liver and reported lower rates of biliary complications, intra-abdominal hemorrhage, and nonfunction of the right side liver allograft as compared with other series utilizing the ex vivo split liver techniques.

We first attempted in situ SLT in 1992 before our establishment of the LRD program. Our experience was not favorable|only one of four grafts survived. However, after successfully performing over 30 LRD procedures, we once again began an SLT program in 1996 using the in situ methods that had been established in the living-donor procurement. In this article, we detail our experience to date with the systematic application of in situ SLT. Specific areas that are addressed include donor and recipient selection, operative technique, patient and graft survival, complication rates, and factors predictive of patient outcome.

* Abbreviations: LRD, living-related liver donation; SLT, split liver transplantation; UNOS, United Network for Organ Sharing.

PATIENTS AND METHODS

Study population. This study is based upon 15 in situ split liver procurements which resulted in 28 liver transplants by the University of California Los Angeles liver transplant team performed between July 1, 1996, and May 1, 1997. During this same period, 197 cadaveric whole organ allografts and 2 living-related donor grafts were used for liver transplantation. In situ split liver allografts comprised 13.2% of the liver transplants performed at our center during this time period. All operations were performed by the same surgical team under the direction of the senior author (R.W.B.). In situ division of cadaveric livers was performed at the donor hospital in hemodynamically stable multiorgan donors. During these procurements, 30 kidneys, 12 hearts, 7 lungs, and 9 pancreata were also obtained for transplantation from these same donors, and the early graft function of these extrahepatic organs has been excellent. The median follow-up period for this group of patients was 89 days (range, 1–292 days).

Donor selection and in situ split liver technique. Livers from 12 male and 3 female donors with a median age and weight of 17 years (range, 12–36 years) and 58 kg (range, 35–76 kg), respectively, underwent in situ splitting. Only hemodynamically stable cadaveric multiorgan donors were considered for this procedure. Evaluation of the donor was performed according to our previously described protocol (*14*) and did not require any special or additional invasive or noninvasive tests. Donor hospitals and other transplant teams were notified as soon as possible of the decision to split the liver in situ, and participation was on a voluntary basis. Standard surgical facilities for a multiorgan procurement were utilized in all cases, and no special equipment was requested.

The procurement operation began with an exploratory laparotomy through a midline incision; additional exposure was obtained via a sternotomy. The infrarenal aorta and inferior mesenteric vein were identified and controlled to permit rapid perfusion in the event of donor instability. The vascular anatomy and parenchyma of the liver were then evaluated, and if deemed suitable, the left lateral segment of the liver (segments 2 and 3, Fig. 1) was mobilized in a manner identical to the procurement of the left lateral segment from a living donor (*15*, *16*). The first vascular structure isolated was the left hepatic artery throughout its entire length. Throughout this dissection, attention was paid to the arterial branch to segment 4, which was preserved whenever possible. This was followed by isolation of the entire left portal vein, which requires ligation and division of all the branches entering the caudate lobe (segment 1) of the liver. The portal vein branches to segment 4 of the liver were ligated and divided to the right of the umbilical fissure. Extrahepatic mobilization of the left hepatic vein was accomplished. After total vascular control of segments 2 and 3 was achieved, the liver parenchyma was divided, using electrocautery and suture ligation as required, between the left lateral segment (segments 2 and 3) and the medial segment of the left hepatic lobe (segment 4, Fig. 1). During the parenchymal division, electrocautery was never used near the hilar plate in order to not devascularize the left hepatic bile duct. The left hilar plate and bile duct were always divided sharply with a scissors close to the cut surface of hepatic parenchyma. Additionally, special vigilance is needed to avoid injury of both the left and middle hepatic veins, which could compromise the venous outflow of either segments 2 and 3 or segments 4, 5, and 8 of the liver. When this dissection was completed, as shown in Figure 1, two liver grafts (right, segments 1 and 4–8; left, segments 2 and 3) had been separated, each with its own vascular pedicles and venous drainage. At this time, the donor liver was perfused in situ with University of Wisconsin solution, 2–3 L in the aorta and 1 L in the portal vein. After perfusion, the left graft was removed first and packaged. The right graft was subsequently removed in the usual fashion and stored at 4°C in University of Wisconsin solution as described previously (*17*). While the right graft was being prepared on the bench, the cut vascular and biliary branches were oversewn individually.

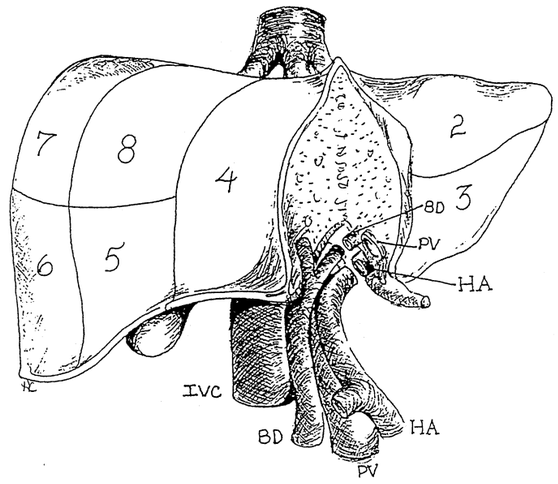

FIGURE 1. Schematic representation of in situ liver splitting. The liver is split between segment 4 and segments 2 and 3 after isolation of the left hepatic artery, left portal vein, and left hepatic vein in the heart-beating cadaver. The left hepatic duct is divided in a sharp fashion before the liver is flushed with University of Wisconsin solution. BD, biliary duct; HA, hepatic artery; IVC, inferior vena cava; PV, portal vein.

Recipient selection and surgical procedures. Potential adult recipients were identified at the time of their initial liver transplant evaluation. We usually excluded patients with hemodynamic instability, obesity, multiple upper gastrointestinal surgeries, and severe debilitation. We did not exclude patients who required retransplantation or who had fulminant hepatic failure. Pediatric recipients (weight between 4 and 25 kg) who would be considered appropriate for living-donor liver transplantation were selected at the time of their evaluation. We have decided not to offer in situ SLT to children with hepatoblastoma because of the need to preserve the vena cava for implantation of segments 2 and 3. Retention of the vena cava would potentially preclude obtaining a tumor-free margin. All appropriate recipients were informed of the possibility of and gave consent for whole or split liver transplantation at the time of evaluation. When called in for transplantation, the patients were again evaluated and informed of the details of in situ SLT and asked to reaffirm their consent.

Right graft. After procurement, the right liver allograft was prepared on the bench in a manner identical to a whole liver with preservation of the full length of the celiac axis, portal vein, bile duct, and vena cava. Hepatectomy was performed as described previously (*14*). Although we did not retain the vena cava in this series, this modification could be easily applied. The right trisegmental liver allograft was implanted in the same manner as a whole organ (*14*). With portal reperfusion completed, the left margin of segment 4 often appears dusky; however, after arterial blood flow is established, perfusion appears homogeneous and no further surgical intervention or postoperative evaluation is necessary. In all but three cases, the biliary reconstruction was performed via a choledochocholedochostomy over a T-tube. At the completion of the liver transplant, a cholangiogram was obtained to evaluate the biliary anastomosis as well as the donor and recipient biliary tracts, but most importantly to assure the absence of a bile leak from the cut surface of segment 4. In patients in whom the biliary reconstruction was via a Roux-en-Y hepaticojejunostomy, an external anastomotic stent was utilized and was exited through the Roux-en-Y limb.

Left graft. In all cases, the left liver allograft was transplanted in a fashion similar to that utilized for living-related liver transplantation (*15*, *16*) with preservation of the recipient inferior vena cava (Fig. 2). All arterial reconstructions were performed utilizing microvascular techniques as described previously (*18*) without vascular interposition grafts. Biliary reconstruction was always with a Roux-en-Y hepaticojejunostomy using microsurgical techniques and an internal stent. To prevent venous outflow obstruction, attention was paid to leaving the left hepatic vein short as described by Emond et al. (*19*) and to securing the graft into position by reapproximating the donor and recipient falciform ligaments.

Postoperative care. No special posttransplant care was required for recipients of right trisegmental grafts; these patients were managed according to our established protocol for whole organ liver transplantation, including a cholangiogram on posttransplant day 7. Recipients of the left graft underwent Doppler ultrasound on postoperative day 1 to evaluate hepatic artery, portal vein, and hepatic vein flow. With the exception of one case, throughout the hospital stay, all left graft recipients were maintained on low molecular weight dextran (Rheomacrodex, Pharmacia, Piscataway, NJ), which was followed by aspirin therapy upon discharge. One pediatric recipient who was being retransplanted with an in situ split left lateral segment for previous hepatic artery thrombosis was maintained on heparin while in the hospital and coumadin as an outpatient. Recipients of left grafts underwent an HIDA scan on postoperative day 7 to assess the integrity of the hepaticojejunostomy.

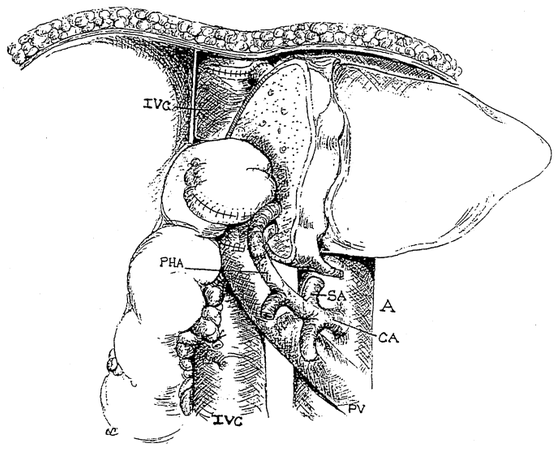

FIGURE 2. Schematic representation of the implantation of the left lateral segment liver allograft. The patients vena cava is left intact. The donor left hepatic vein is sutured to the confluence of the recipient middle and left hepatic veins after the right hepatic vein is oversewn. The donor left portal vein is sutured to the recipient portal vein, and the donor left hepatic artery is anastomosed to the recipient common hepatic artery in a microvascular manner without extension grafts. The biliary tract is reconstructed via a Roux-en-Y hepaticojejunostomy. The donor and recipient falciform ligaments are reapproximated to prevent torsion of the liver allograft. A, aorta; CA, celiac axis; IVC, inferior vena cava; PHA, proper hepatic artery; PV, portal vein; SA, splenic artery.

Statistical evaluation. The Kaplan-Meier product limit estimate was used for univariate calculations of time-dependent patient and graft survival events. Statistical comparisons between groups were done via the log-rank test.

RESULTS

Donor in situ split liver procurement. Twenty-six in situ split liver procurements on hemodynamically stable multiorgan donors were attempted. However, in eight cases, the donor liver was not suitable (steatosis, n=5; rounded edges and prolonged hospitalization, n=2; trauma, n=1), two donors became hemodynamically unstable during the procurement, and one donor was not able to undergo the split liver procurement because of medical-legal prohibition. In situ split liver procurement was performed in the remaining 15 donors. No procedures were abandoned because of intraoperative technical complications, no blood transfusions were required, and no extrahepatic organs were jeopardized. Both anesthesiology and nursing personnel were provided by the donor hospital with no special surgical instrumentation beyond that of a whole organ harvest being required. In comparison to a conventional liver harvest, in situ liver splitting required an additional 0.75–4.5 hr (median, 1.67 hr). As we gain experience, the harvest time has continued to decline; the median additional time to perform the in situ liver splitting in the last six donors was approximately 1.25 hr. Cold ischemia time ranged from 118 to 386 min for all grafts. The median cold ischemia time was 167 min (range, 118–219 min) and 216 min (range, 191–386 min) for right trisegmental and left lateral segment allografts, respectively.

Pretransplant recipient demographics. The pretransplant demographics of the 26 patients who underwent 28 in situ SLTs (14 right trisegmental and 14 left lateral segment grafts) are outlined below. The patient population included 14 adult and 12 child recipients. There were 13 male and 13 female patients. Age and weight ranges were 4 months to 62 years and 4.1–77 kg, respectively. The median age and weight of the 14 adult patients was 47 years (range, 20–62 years) and 62 kg (range, 53–77 kg), respectively; the 12 children had a median age of 2 years (range, 4 months to 10 years) and weight of 10 kg (range, 4.0–27 kg). Seven of the 12 pediatric patients (58%) were 2 years of age or less with a median weight of 7.1 kg at the time of in situ SLT. The most common etiology of end-stage liver disease in the pediatric population was congenital biliary atresia (n=6) followed by progressive familial intrahepatic cholestatic disorder (n=4). Chronic active hepatitis C, the most common cause of end-stage liver disease in the adult population, occurred in three patients, while two patients each received transplants for primary sclerosing cholangitis, fulminant hepatic failure, alcoholic liver disease, and autoimmune hepatitis. At the time of transplantation, 10 patients (38.5%) were confined to the intensive care unit (United Network for Organ Sharing [UNOS] status 1), 5 patients (19.2%) were hospitalized (UNOS status 2), and 11 patients (42.3%) were awaiting transplantation at home (UNOS status 3).

Patient and allograft survival. Of the 26 patients who underwent 28 in situ SLTs, 24 (92.3%) are currently alive. Overall 6-month and 1-year actuarial patient survival rates were 92% and 92%, respectively (Fig. 3); the 6-month and 1-year actuarial graft survival rates were 86% and 86%, respectively (Fig. 3). Twenty-two patients (84.6%) received a single allograft and four patients required retransplantation (one allograft each). The indications for retransplantation were primary nonfunction in three cases and humorally mediated allograft rejection in one case. Two of the four retransplants were also in situ split livers, which have functioned well.

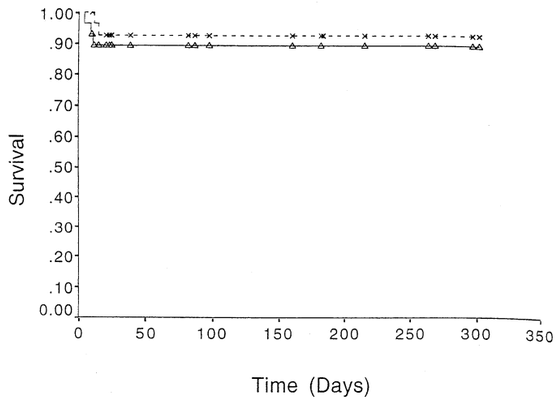

FIGURE 3. Kaplan-Meier survival curve demonstrating 6-month and 1-year actuarial overall patient (×) and liver allograft (△) survival rates.

The 6-month and 1-year actuarial patient survival rates of those patients who received a left lateral segmental allograft were 100% and 100%, respectively, while for those patients who received a right trisegmental allograft, it was 86% and 86%, respectively (Fig. 4, P=NS). The actuarial death-censored allograft survival rates at 6 month and 1 year were 80% and 80%, respectively, for the left lateral segmental allografts and 93% and 93%, respectively, for the right trisegmental grafts.

Kaplan-Meier patient survival curves were performed based on UNOS status at the time of in situ SLT. As shown in Figure 5, UNOS status 2 and 3 patients had 6-month and

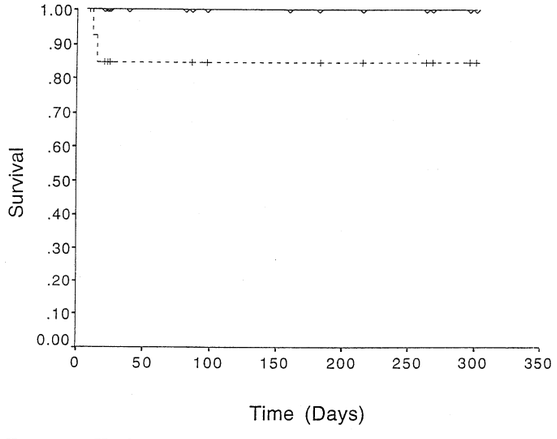

FIGURE 4. Kaplan-Meier survival curve demonstrating 6-month and 1-year actuarial patient survival curve for left lateral segment (v) allograft recipients and right trisegmental (+) allograft recipients.

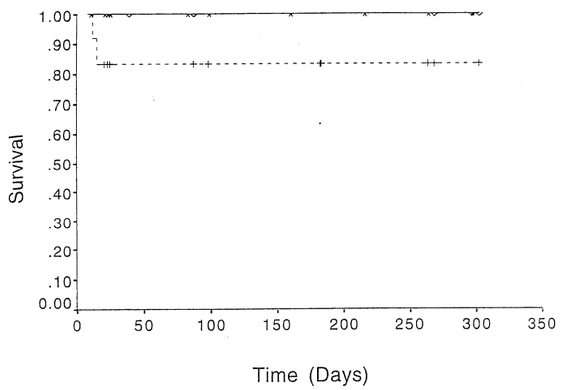

FIGURE 5. Kaplan-Meier 6-month and 1-year actuarial patient survival curves for UNOS status 3 (v), UNOS status 2 (∧), and UNOS status 1 (+) patients.

1-year actuarial survival rates of 100% and 100%, respectively, whereas survival rates of UNOS status 1 patients at 6 months and 1 year were 80% and 80%, respectively. These data demonstrate that in situ liver splitting can be applied to the critically ill patient and results that are comparable to whole organ liver transplantation can be expected.

Recipient perioperative mortality. Perioperative mortality occurred in two patients (7.6%) after in situ SLT. The first patient (patient 14), a 44-year-old woman initially received a transplant for autoimmune hepatitis and developed hepatic artery thrombosis requiring retransplantation with an in situ split right trisegmental allograft. Allograft function and patient condition in the immediate posttransplant period were excellent; however, on posttransplant day 4, the patient became acutely hypotensive with substernal chest pain and suffered a fatal myocardial infarction. Postmortem examination revealed an intact liver allograft with patent vascular anastomoses and no intra-abdominal pathology. A fresh thrombus in the left anterior descending coronary artery was determined to be the cause of death.

The second patient (patient 18), a 52-year-old woman, underwent liver transplantation for primary biliary cirrhosis. Approximately 30 days after trransplantation, the patient presented with fever, rash, and diarrhea. Skin biopsy and HLA typing revealed graft-versus-host disease. The disease course progressed despite discontinuation of immunosuppression and administration of anti-HLA antiserum. The decision was made to remove the source of donor antigen, and the patient underwent retransplantation of the liver with an in situ split right trisegmental allograft. Her condition deteriorated with the development of aplastic anemia and an invasive *Aspergillus* fungal infection, which subsequently led to a fatal intracranial bleed. At the time of death, allograft function was good (total bilirubin, 3.7 mg/dl; conjugated bilirubin, 1.9 mg/dl; aspartate aminotransferase, 87 IU/L; alanine aminotransferase, 91 IU/L; alkaline phosphatase, 234 IU/L; prothrombin time,12.8 sec; international normalized ratio, 1.4).

Recipient morbidity and technical complications after in situ SLT. No technical complications associated with the hepatic artery, portal vein, hepatic vein, or biliary anastomoses were encountered in this series of 28 in situ SLTs. Additionally, all patients were free of re-exploration for intra-abdominal hemorrhage, and no cases of segment 1 or 4 ischemic necrosis were encountered. However, four patients who received in situ split liver allografts required retransplantation (biopsy and immunohistochemically proven humorally mediated allograft rejection, n=1; primary nonfunction, n=2; delayed nonfunction in an in situ left lateral segment graft [transplanted into an adult] that was small for size and represented less than 50% of the recipient's ideal liver volume, n=1), and one patient had a bile leak from the cut surface of a right trisegmental allograft that required exploratory laparotomy.

Expansion of liver donor pool using in situ SLT. Since the systematic application of in situ SLT at UCLA, 26 patients have benefited over a 10-month period utilizing 17 livers. Of these, four patients needed retransplantation (one with a whole organ adult cadaveric allograft, one with a living-donor left lateral segment allograft, and two with in situ split liver allografts). If these 26 patients had received transplants without split liver techniques, 30 livers (26 primary transplantations and 4 retransplantations) would have been needed. Thus, with in situ liver splitting, a net gain of 13 livers over 10 months was realized, representing an increase in the amount of total available liver allografts of 6.6% (13/197). More importantly, in situ splitting of these 15 ideal livers allowed 13 additional liver transplants to be performed, which represents an increased utilization of this specific resource of 43% (13/30) and demonstrates that in situ liver splitting, while not appropriate for all donor livers, if used selectively, can increase substantially the number of transplant recipients.

In addition, in situ SLT has virtually eliminated waiting time for small infants on our list and has reduced our need to resort to living-donor liver transplantation. Only two urgent living-related donor liver transplants were performed during this same 10-month time period (one case of humorally mediated rejection and one case of fulminant hepatic failure). In situ SLT is our technique of choice for pediatric transplantation and has supplanted LRD for pediatric transplant recipients before they become critically ill, allowing us to avoid hepatectomy on their family members.

DISCUSSION

The lack of organ availability has become the major obstacle to the further application of liver transplantation, particularly in the pediatric age group, where mortality in the pretransplant setting exceeds posttransplant mortality. While hepatocyte and xenotransplanstation may be options in the future, living-donor and split liver transplantation are currently the only consistently reliable methods of enlarging the donor pool.

Living-donor liver transplantation results in excellent patient and graft survival rates; however, it still requires that a liver resection be performed on a healthy relative of the patient. Furthermore, the potential hazards to the donor have worked against its widespread acceptance, except in countries where cadaveric organs are not available or in large pediatric centers where long waiting times result in pretransplant mortality. Successful application of cadaveric SLT expands the donor pool with no specific downside to the potential recipients. The first clinical attempt at SLT was by

Pichlmayr et al. (2) in 1988, who performed a transplant on a 2-year-old child with biliary atresia and on a 63-year-old woman with primary biliary cirrhosis. The first reported series of split liver transplants was by Broelsch et al. (*6*) in 1990. As shown in Table 1, while technically feasible, ex vivo SLT has not gained widespread acceptance because of inferior patient and graft survival rates as well as a high incidence of complications (*6–11*). Two recent reports by Rogiers et al. (*12, 13*) demonstrating improved outcomes utilizing in situ split liver techniques and extensive experience with living-donor liver transplantation at our institute stimulated us to initiate a program of in situ SLT.

Previous attempts at ex vivo SLT have been associated with an increased rate of primary nonfunction, especially of the right-sided allografts. It has been stated that these inferior results were owing to the large number of high-risk patients receiving transplants. As shown in Table 1, the median percentage of high-risk patients receiving transplants in these series reporting patient clinical condition was 33%, and several transplant centers have made specific efforts to avoid performing transplants on high-risk patients with split liver grafts. Therefore, it appears that while patient selection undoubtedly plays an important role in graft and patient outcome, other factors must also be considered. Ex vivo splitting of the liver allograft on the bench is a lengthy procedure and thus results in a long ischemic interval. Prolonged ischemia times and the required dissection and manipulation of the ischemic graft compound the deleterious effects of ischemia alone, resulting in poor liver allograft function. Prolonged ischemia has also been associated with an increased expression of MHC class II antigens (*21*) leading to an increased inflammatory response upon reperfusion. Rewarming of the liver allograft, which can occur during the long benching procedure, even if slight, has been found to be associated with increased susceptibility to hepatic ischemia/reperfusion injury (*22*). In situ splitting of the liver eliminates the extended benching procedure, prolonged ischemia, and the risk of allograft rewarming. The right trisegmental allograft is prepared as a normal whole organ graft would be, and the left graft requires no benching procedure at all. These benefits have been shown previously to decrease the ischemic damage to both the left and right grafts (*13*). Furthermore, in contrast to some of the previous ex vivo series, which transplanted the left lateral segment allografts first, we believe both grafts should be transplanted simultaneously to minimize the ischemic interval.

TABLE 1. Review of ex vivo split liver series[a]

Author	Year	Graft no.	%HR	Patient survival (%)	Graft survival (%)	BC (%)
Emond	1990	18	28	67	50	27
Broelsch	1990	30	40	60	43	27
Shaw	1990	10	70	50	50	40
Otte	1990	4		50	50	0
Houssin	1993	16	56	75	69	25
Sloof	1995	15		73	67	
Otte	1995	29	27	71	67	17
de Ville	1995	98	33	68	62	23
Bismuth	1995	30	7	93	90	23
Bismuth	1996	27	4	79	78	22
Broelsch	1996	19	58	63	58	16

[a] Abbreviations used in table: HR, high-risk patient; BC, biliary tract complication.

Upon reperfusion of the split liver allograft, bleeding from the cut surface has been a formidable challenge. Approximately 20% of ex vivo split liver recipients required re-exploration for intra-abdominal hemorrhage. More recently, techniques have been developed utilizing collagen mesh and polyglactin 910 mesh with fibrin glue (*11*) to reduce bleeding. However, this technique requires the suturing of the these materials on the bench, thereby prolonging the ischemia time. With in situ liver splitting, hemostasis is achieved at the time of allograft procurement when the donor's normal coagulation factors are operative. Upon reperfusion of the in situ split liver allograft, there is no bleeding from the cut surface of the liver, and in our series, none of the recipients required transfusion therapy or re-exploration for intra-abdominal hemorrhage after transplantation.

Biliary complications have long been recognized as a major complication of ex vivo SLT and, as shown in Table 1, occur in approximately 20–25% of the patients. It is thought that these biliary complications are because of devascularization of the biliary bifurcation during the benching procedure. During in situ liver splitting, the biliary tract is handled as in living-donor procurement. The right portion of the hepatoduodenal ligament is left undissected. The tissues near the right hepatic artery, proper hepatic artery, common hepatic duct, and common bile duct are not handled to avoid interruption of the bile duct vasculature. The left hepatic duct is sharply transected within the hepatic parenchyma of segment 3, and electrocautery is never used near the hilar plate. The injection of University of Wisconsin solution retrograde into the common hepatic duct while preparing the right trisegmental allograft also identifies small biliary leaks. The preferred biliary anastomosis for the right trisegmental allograft is choledochocholedochostomy over a T-tube. In one patient who received a right graft, the biliary reconstruction was via a Roux-en-Y hepaticojejunostomy and a small leak developed from the cut surface of the liver. To avoid this complication when a Roux-en-Y hepaticojejunostomy is needed, we now utilize an external stenet (no. 8 pediatric feeding tube through the Roux limb) to traverse the biliary-enteric anastomosis. The left lateral segment biliary tract reconstruction is uniformly via a Roux-en-Y hepaticojejunostomy over an internal stent. In approximately 20% of the cases, two or more bile ducts draining the left lateral segment will be encountered and must be incorporated into the anastomosis.

Ischemia of segment 4 of the liver has also complicated ex vivo splitting of the liver. While splitting the liver in situ and ligating and dividing the portal branches to segment 4, special attention is paid to preserving the arterial inflow to segment 4 throughout the dissection. Additionally, care must be taken to ensure that the middle hepatic vein does not to obstruct venous outflow from segments 4, 5, and 8. Because the in situ split procedure is performed in the heart-beating cadaveric donor, the perfusion of segment 4 can be assessed continuously and is never a question.

In the period analyzed in this report, the total number of transplantable liver allografts was increased by 6.6%. This increase has had the most significant impact on the pediatric population at our transplant center. Since the inception of this program, we have virtually abolished the size-matched cadaver allograft shortage, dramatically decreased the pediatric waiting time, and eliminated pretransplant waiting list mortality. Given the improvements that the in situ split liver technique provides, we believe that, whenever possible, this technique should be offered before living-donor liver transplantation for elective procedures and in countries where cadaveric donors are available. Additionally, because organ shortage also persists in the adult population, reduced-size liver transplantation for children should only be considered when in situ SLT cannot be performed.

This report demonstrates that in situ splitting of the donor liver provides two allografts of optimal quality for both adult and pediatric liver transplantation. This technique has shortened ischemia times, abolished long benching procedures, and decreased the incidence of primary nonfunction, as well as decreaed the incidence of biliary complications and re-exploration for posttransplant intra-abdominal hemorrhage. In situ splitting of the ideal donor has dramatically decreased the pediatric waiting list time and should be considered the optimal method of expanding the donor pool.

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