potential for developing chronic rejection in this subset is obviously diminished.

We also observed that relative risk for development of chronic rejection is higher in children of black origin. This unusual finding could be explained based on our observation that a focal and segmental sclerotic lesion is the most common cause of nephrotic syndrome in black children (*26*). We posit that a genetic predisposition toward a proliferative response to insult or injury induces the greater frequency of chronic rejection graft failure noted among black children in our study.

Two primary observations emerged from our study: (1) acute rejection is a strong risk factor for developing chronic rejection graft failure, and (2) multiple acute rejection episodes have the highest potential for graft loss due to chronic rejection. These cardinal observations indicate that prevention of the initial acute rejection episode is a critical necessity in the posttransplant management of renal allografts. We have also shown that there is a significant trend toward decreased frequency of chronic rejection in the more recent years of our registry data (1991 and onward). This coincides with the better graft survival in our patient population in the mid-1990s. Since 71% of all cadaver donor transplants and 56% of all living related donor transplants experience an acute rejection episode by the second year after transplantation (*27*), we suggest that a more intensive effort toward inhibiting acute rejection would pay dividends by reducing the incidence of chronic rejection.

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Received 3 August 1995.
Accepted 25 October 1995.

0041-1337/96/6107-1059$03.00/0
TRANSPLANTATION
Vol. 61, 1059–1061, No. 7, April 15, 1996
Printed in U.S.A.

ONE YEAR OF EXPERIENCE WITH EXTENDED APPLICATION AND MODIFIED TECHNIQUES OF SPLIT LIVER TRANSPLANTATION[1]

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As organ donation rates decreased in Europe, the authors started a systematic approach of liver splitting in their center in 1994. During this 1-year experience, 73 cadaveric liver transplantations were performed in 66 patients. Sixteen of these transplantations were the result of split-liver transplantation (21.9% of grafts, 24.2% of patients). Patient and graft survival rates at 3 months were 81.2% and 75%, compared with 89.1% and 76.9% for whole organs. Two modified techniques were developed, based on the technique of living related liver procurement, and applied in 10 cases. With these new techniques, patient and graft survival rates were 90% and 90%. This systematic approach allowed the total number of transplantations in our program to be maintained, despite the decrease in organ availability.

One of the major challenges facing organ transplantation toward the end of the century will be the organ shortage. This is particularly true for lifesaving organs such as the heart, lungs, and liver.

During the second half of 1993 and in 1994, a marked decrease in the number of organ donors was observed in the Eurotransplant area and more specifically in Germany (*1*). In the meantime, the number of indications for transplantation increases steadily. The lack of donors was particularly critical for children and small adults.

Split-liver transplantation (SLT*) is one of the possible strategies to counteract this organ shortage (*2–11*). The procedure is hampered, however, by technical and organizational problems.

In view of the organ shortage, the authors decided to optimize the use of split cadaveric livers in their center. They changed the technique, mainly to reduce two types of complications of SLT: bile duct complications and primary poor function due to long ischemic times (*3, 4*). Good quality organs were systematically split. In this article, the techniques, their application, and the results are described.

MATERIALS AND METHODS

From January 1, 1994, to December 31, 1994, 85 liver transplantations were performed at the University of Hamburg. Twelve of these used living related grafts and 73 used cadaveric grafts. Informed consent was obtained systematically for whole organ, reduced size, or split-liver transplantation from every patient awaiting cadaveric liver transplantation. Fifty-two whole organ (7 children), 5 reduced size (4 children), and 16 split liver (8 children) transplants (21.9% of cadaveric grafts, 24.2% of cadaveric patients, 42% of pediatric cadaveric transplants) were performed in 66 patients.

Thirteen whole organs (25%), no reduced grafts, and seven split grafts (43.7%) were transplanted in high urgency status.

Among the recipients of split grafts, seven were United Network for Organ Sharing (UNOS) status 1, four were UNOS status 2, two were status 3, and three were status 4 (UNOS classification 1995). Nine right and seven left graft transplantations were performed. Three grafts were shipped from other centers and one was shipped to another center.

In the course of the year, two new techniques for splitting were developed, which we named in situ splitting and second generation ex situ splitting. Avoidance of dissection of the bile duct bifurcation and primary parenchymal division at the level of the ligamentum falciforme are the common denominators of these techniques (Fig. 1, A and B). These techniques resulted in 10 grafts, one of which was transplanted at the university of Essen, Germany (Dr. J. Erhardt).

In situ splitting. In the in situ splitting technique, a left lateral hepatectomy (segments II and III) is performed in the heart-beating cadaveric donor (*12*). For this we used the technique described for living related liver procurement by our group. The hemostasis of the hepatectomy cut sections is obtained in the donor, with the help of the donor's coagulation, using standard surgical techniques. The left lateral segment is perfused on the back table and can then be transported immediately for transplantation. The remaining right liver is subsequently procured in the normal way with close observation of the perfusion and blanching of segments IV and I. If needed (in one of the two splitting procedures) these segments are removed, which leaves an ample amount of liver tissue around the liver hilum (Fig. 1A).

Modified ex situ splitting. The liver is procured as a whole organ. The splitting takes place on the back table. First the portal vein and then the artery are approached from the posterior and left sides of the hepatoduodenal ligaments. The site of division of the artery and portal vein is dependent on the anatomy and relative size of the right and left branches. Parenchymal transection is performed 0.5 cm to the right of the falciform ligament (Fig. 1 A). The bile duct is transected blindly, that is, without dissection of the bifurcation, at the level of the line of transection. Segments IV and I are removed as described above. The middle hepatic vein is preserved with the right graft (Fig. 1, A and B).

Postoperative treatment. Postoperative treatment is not essentially different from that for normal liver transplants. High CVPs are

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* Abbreviations: SLT, split (cadaveric) liver transplantation; UNOS, United Network for Organ Sharing.

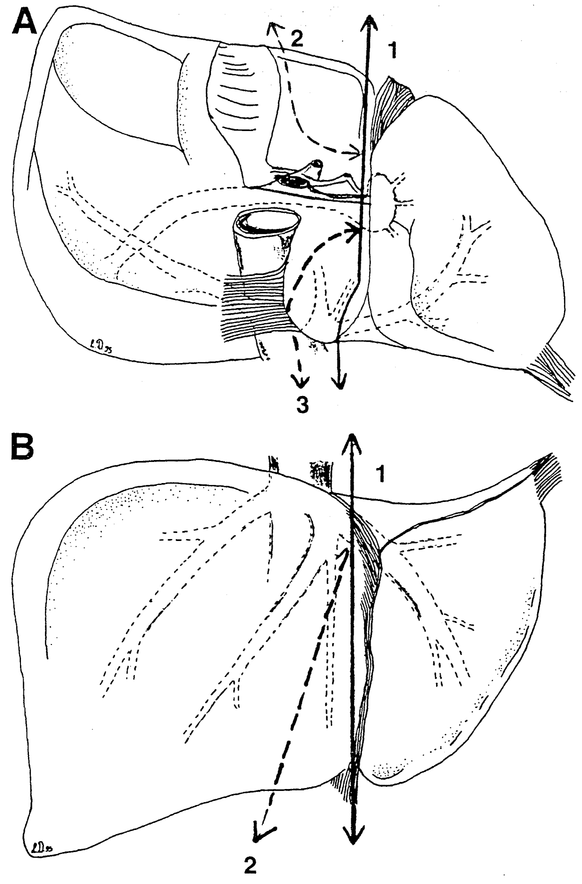

FIGURE 1. (A and B) Lines of transection in the new splitting techniques. The numbers show the sequence of the transections. Transections 2 and 3 are facultative in the in situ technique.

avoided to prevent bleeding from the cut surface. Immunosuppression is maintained at a high normal level to avoid rejection with swelling of the graft. Prophylactic heparin SC, followed by aspirin, is given to prevent arterial thrombosis.

RESULTS

Patient and graft survival rates at 3 months were 89.1% and 76.9% for whole livers, 100% (5/5) and 100% (5/5) for reduced size livers, and 81.2% (13/16) and 75% (12/16) for split livers. One split liver recipient died after 4 months from cytomegalovirus and cryptococcal pneumonia after having been well and at home.

When looking at the split livers, the patient and graft survival rates for right sides of splits were 66.6% (6/9) and 55.5% (5/9). For left sides of splits, survival rates were 100% (7/7) and 100% (Table 1).

Particularly good results were obtained with the new splitting techniques (in situ and ex situ), with graft survival of 9/10 (90%) and patient survival of 9/10 (90%). One recipient of a right ex situ split graft was lost from sepsis after primary poor function of the graft and cardiac complications. (Tables 1 and 2). Particularly, no early or late biliary complications were noted in right or left grafts. Double left bile ducts were present in two of five of the latter group.

In one of the two in situ split livers, segments IV and I had to be removed at the time of transplantation because of

TABLE 1. Results of SLT in Hamburg, Germany, 1994

	n	3 months	
		Patient survival	Graft survival
Classical ex situ	7	5/7	4/7
Right graft	5	3/5	2/5
Left graft	2	2/2	2/2
Modified ex situ	5	4/5	4/5
Right graft	2	1/2	1/2
Left graft	3	3/3	3/3
In situ	4	4/4	4/4
Right graft	2	2/2	2/2
Left graft	2	2/2	2/2

TABLE 2. Complications of SLT

Classical SLT	Modified ex situ SLT	In situ SLT
—Bile duct necrosis[a] —Biloma[a] —Subphrenic abscess[a] —Graft infection —Sepsis	—Primary poor function[b] (cardiac decomp., sepsis), segm. 4 ischemia[a] —Primary poor function[b]	—Portal steal (aux. Tx)

[a] Related to splitting technique.
[b] Possibly related to splitting technique.

ischemia. No postoperative complications occurred, with the exception of a progressive portal steal syndrome after orthotopic auxiliary transplantation for Crigler-Najjar I syndrome. Maximum glutamic oxaloacetic transaminase for the right liver was below 300 U/L for the case where segment IV was not removed. All patients are alive and, with the exception of the child with Crigler-Najjar syndrome (who needed retransplantation after 1 year because of the ischemic damage caused by the portal steal syndrome and possibly chronic rejection), have good liver function.

The systematic application of SLT achieved a gain of eight organs during the 1-year period. The total numbers of liver transplantations in our center could be maintained despite the decreased organ availability. Children and small adults benefited most from the practice of splitting livers.

DISCUSSION

Organ shortage is one of the major challenges of transplantation as the end of the century nears. This is particularly true for lifesaving organs like the liver.

The decrease in organ donation in 1994 motivated us to split every liver of good quality. This resulted in a split graft for 24.2% of our patients with cadaveric transplants. It allowed us to maintain the total number of transplants in spite of the decline in offers and to decrease pediatric waiting list mortality to below 6%.

One of the worries of applying this aggressive splitting program was the possible impact on peritransplant morbidity and mortality.

An analysis of the literature and of personal experience identified bile duct devascularization and prolonged ischemic time as the most important problems in SLT. In addition, it was decided that the resection surface should be kept as small as possible and that the influence of anatomical variations on the splitting technique should be minimized.

The best way to achieve these goals was to use the tech-

nique used for living related liver procurement. By doing so, the line of transection could be pushed as much as possible to the left, thus leaving the hilum of the right liver untouched and providing the smallest resection surface. Dissection of the bile duct bifurcation is completely avoided. From our experience with living related liver transplantation, we knew that two left bile ducts would be obtained in one third of the cases, but this was not believed to be a problem (X. Rogiers, personal communication, ESOT, 1995). As documented in Table 1, the quality of the left graft was not affected by these changes and bile duct complications were completely absent with the new techniques.

Performing this procedure in situ has several additional advantages: (1) a long benching procedure with additional ischemic injury to the graft is avoided; (2) the perfusion of both grafts, after splitting, can be observed in the donor, that is, before transplantation; and (3) perfect hemostasis of the cut sections can be obtained in the donor, benefitting from the donor's coagulation. A precondition for this technique, however, is a donor hospital willing to accept a prolonged organ procurement procedure.

When in situ splitting was not possible, the ex situ technique was used. The same principles were respected: blind transection of the bile duct at a distance from its bifurcation, and primary separation of segments II and III from the rest of the liver. The line of transection was placed half a centimeter to the right of the ligament to avoid a long dissection on the back table and to avoid injury to the hilar vessels of the left lateral lobe. Arteriography and cholangiography on the back table were not performed because this would increase the benching time and cause unnecessary manipulation of the graft. The disadvantage of a long benching procedure remains, however, and, as shown in one of our cases, may lead to primary poor function of both grafts.

An objective comparison of the results of SLT with whole organ transplantation is not possible in this series. The advantage of using the better organs for splitting can be outweighed by the higher incidence of highly urgent patients in this group. The difference in graft and patient loss between right and left grafts was related to the technique in two cases (bile duct necrosis requiring retransplantation, and primary poor function resulting in multiple organ failure and patient death). The results in this series show that systematic splitting leads to effective gain of grafts and can be done with good results.

The total number of SLTs performed was limited by the number of good quality organs available at our center. Splitting a lesser quality liver carries a risk of disastrous primary nonfunction in both recipients. In centers that obtain a larger number of good quality organs, a larger proportion of the transplantations could be performed as split livers.

CONCLUSION

Our experience of 1 year of transplantation demonstrates that SLT can increase the efficacy of graft usage with good survival results. The newer splitting techniques resulted in the disappearance of biliary complications. In situ splitting shows potential for being the superior modality. If these results are confirmed in larger series, splitting livers may become the rule rather than the exception.

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Received 24 August 1995.
Accepted 2 November 1995.