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In Situ Splitting of Cadaveric Livers

The Ultimate Expansion of a Limited Donor Pool

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Objective
The authors evaluate the safety, applicability, and effectiveness of a new technique for split-liver transplantation.

Summary Background Data
Split-liver transplantation offers an attractive way to increase the donor pool for cadaveric liver transplantation. The application of this concept has been hampered by inferior patient and graft survivals and higher complication rates. Without supportive data, the concern about increasing biliary leakage and poor initial graft function persisted. The authors focused on the causes of these complications by presenting a new technique to eliminate these problems.

Methods
Liver splitting was performed in the heart-beating cadaveric organ donor, using the technique described for procurement of the left lateral lobe of a live donor. A detailed description of the technique is presented. A retrospective review of the first 14 transplantations resulting from 7 *in situ* splitting procedures was collected. The results were compared with 19 conventional split-liver transplants performed during the same period.

Results
Six-month patient and graft survivals after *in situ* split-liver transplantation were 92.8% and 85.7%, respectively. Biliary complications were absent. Postoperative courses were mostly uneventful and characterized by lower peak transaminase levels compared with standard techniques. Early graft function of extrahepatic organs procured simultaneously was excellent.

Conclusions
In situ split-liver transplantation provides superior results, related mainly to reduction of cold ischemic damage of the grafts and avoidance of biliary complications. *In situ* split-liver transplantation renders graft reduction alone obsolete and opens a donor pool for adults to receive right lobes safely. It allows for long-distance sharing between pediatric and adult liver transplant units because the procedure abolishes *ex situ* benching and prolonged ischemia time and provides two anatomically perfect grafts with hemostasis accomplished.

Organ availability has become a major obstacle to a broader development of liver transplantation. With an increasing number of patients and centers requiring donor organs, the need for augmenting the donor organ pool has become a matter of survival for patients and their centers of choice. Whereas legislation, media network systems, raising public awareness, and procurement agencies cannot meet the growing need for more organs, surgical innovations have contributed increasingly to provide more donor organs (or parts of donor organs) for suitable candidates.[1]

Although hepatocyte transplantation and xenotransplantation may be options in the future, living-donor liver transplantation and split-liver transplantation currently are applicable methods for enlarging the donor organ pool.[2,3]

Split-liver transplantation from cadaveric donors offers an attractive concept because it allows transplantation of two recipients with one liver. Six years ago, the first series of cadaveric split grafts was presented to the American Surgical Association by the University of Chicago group, including 30 transplants in 25 patients.[2] The feasibility and an elaborate concept were presented. However, the patient and graft survivals (60% and 43%, respectively) were inferior to those of full-size orthotopic liver transplantation. In addition, a high incidence of biliary complications (27%) and ischemic necrosis of the median left segment were identified as deleterious problems. In view of the general organ shortage and the increasing need for size reduction to serve pediatric recipients, the method was considered ethically to be acceptable. The recipient in disadvantage, however, remained the adult (right graft) candidate, and the potential benefit to the patient, balancing for the extra risk, was questionable. In addition, a failing right lobe required a rescue retransplantation with a predictably worse outcome.

For several years, publications by others confirmed our findings, hampering the interest in this method of transplantation.[4–9] Under pressure of increasing organ shortage for adult patients, new interest in liver splitting arose in several groups in Europe.

In a retrospective analysis, the European Split Registry reported improved survival, raising new interest in the split procedure.[10] Presentations by the UKE Hamburg[11] and the Hôpital Paul Brousse in Paris (H. Bismuth, personal communication, 1995) reported improved results with split-liver transplants similar to survival rates accomplished in whole-liver transplantation.

Based on our experiences in living-related liver transplantation we were stimulated to perform the splitting procedure in the heart-beating cadaveric donor before preservation of the organ, to avoid extended cold ischemia time and ascertain anatomic integrity of the grafts before implantation.[12] In particular, viability of the median left segment could be confirmed while devascularization of the bile duct could be prevented and hemostasis accomplished. This first success in May 1994 prompted us to continue, and this paper describes the experiences gained from the first series of 14 cases performed in three transplant centers.

Table 1. PATIENT DEMOGRAPHICS

Case No.	Age (yr)	Weight (kg)	D/R Ratio	Diagnosis	UNOS Status
1R	33	46	1.5	ALCI	4
1L	9	40	1.7	CRNA	4
2R	53	75	1.0	SECA	2
2L	3	16	5.0	ACHF	1
3R	37	68	1.1	ALCI	4
3L	0.3	5	15.0	BIAT	4
4R	6	28	1.8	BIAT	4
4L	1.5	6	8.3	PNF	1
5R	56	53	1.6	ALCI	4
5L	54	54	1.6	PBCI	2
6R	41	89	0.7	ACHF	1
6L	4	15	4.2	BIAT	4
7R	40	73	0.8	ALCI	4
7L	10	22	2.7	BIAT	4

ALCI = alcoholic cirrhosis; ACHF = acute hepatic failure; BIAT = biliary atresia; CRNA = Crigler-Najjar disease; PBCI = primary biliary cirrhosis; PNF = primary nonfunction; SECA = secondary malignancy; D/R = donor/recipient; UNOS = United Network for Organ Sharing; UNOS 4 = elective, patient at home; UNOS 2 = patient hospitalized; UNOS 1 = life expectancy less than a few days without transplantation.

PATIENTS AND METHODS

Study Population

This study includes seven *in situ* split-liver procurement performed by the UKE (Hamburg) liver transplant team during 1994 and 1995, including two in cooperation with the teams of Clin. Grosshadern (Munich), and Sahlgrenska Hospital (Gothenburg). This split procurement resulted in 14 transplantations (6 right and 6 left grafts in Hamburg, 1 right graft in Munich, 1 left graft in Gothenburg). One left graft was transplanted in an auxiliary orthotopic position.

Of the 14 recipients of *in situ* split-liver transplantation, three were United Network for Organ Sharing (UNOS) status 1, two were UNOS status 2, and nine were UNOS status 4 (Table 1). Seven grafts were trans-

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planted into adults and seven were transplanted into children. Age and weight ranges were between 0.3 to 56 years and 5 to 89 kg, respectively. Donor/recipient ratios varied from 15 to 0.7.

During the same period, at the UKE Hamburg, 178 liver transplantations were performed, including 9 cadaveric reduced-size (5%) and 20 living-donor liver transplantations (11.2%). Thirty-one split-liver transplantations (17.4%), including 12 *in situ* and 19 *ex situ* procedures, were performed.

Donor Selection

The Donor

Only hemodynamically stable cadaveric multiorgan donors were selected. The donor work-up protocol did not require special invasive or noninvasive examinations. If needed, donor coagulation was corrected.

Medical reasons for a rapid organ procurement (*e.g.*, urgent heart retrieval) were considered to be contraindications for this approach.

The Donor Hospital

Donor hospitals were only required to provide standard surgical facilities allowing for major general surgical procedures. No special equipment was required from the donor hospital. A set with vascular clamps, fine dissecting instruments, clips, and sutures was brought in by the procurement team. No ultrasound dissector was used, with the exception of one case in which it was readily available.

The participation of the donor hospital was always on a voluntary basis requiring the use of their operating room facilities for 1¼ to 2½ extra hours.

Recipient Selection

All recipients had consented to reduced or split-liver transplantation at the time of acceptance, while on the waiting list. When called into the hospital for transplantation they were informed about the details of the procedure and repeated their consent.

Medical management and selection of the patients were performed according to standard medical practice. Three recipients (21.4%) were UNOS status 1, but stable enough to warrant a 2½-hour delay of transplantation. The others were selected so that simultaneous transplantation of two high-risk patients was avoided. Because the size of the left lateral lobe was not predictable, usually two children, one very small and one approximately 10 kg, were called in for preparation. This would allow a very small child with the least chance of obtaining a graft to be transplanted if the left lateral lobe was compatible in size. At the weekly transplant conferences, preformed pairs for split-liver transplantation were determined to speed up decision making at the time of a donor offer.

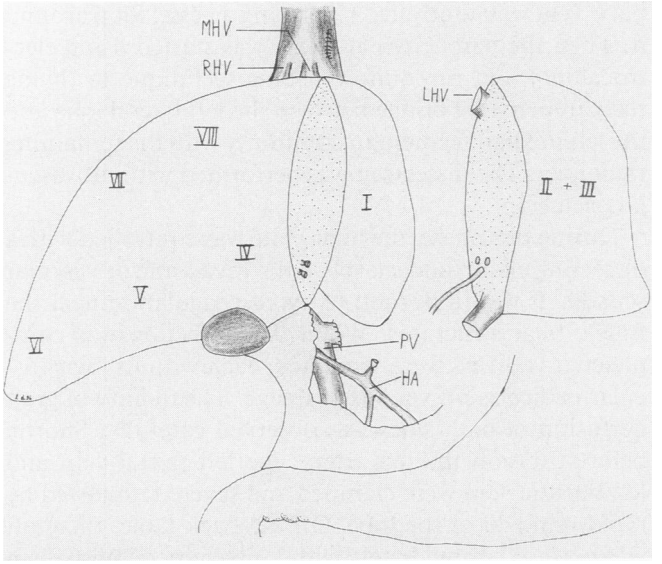

Figure 1. *In situ* splitting procedure.

Surgical Procedures

Donor Procedure

The liver procurement team consisted of one senior surgeon with experience in living-donor liver procurement, one licensed liver procurement surgeon, one resident in training, and one transplant coordinator. The cardiothoracic surgeon was asked to come 1 hour later than usual.

The operation was started with a sternolaparotomy and inspection of the abdominal organs. The infrarenal aorta and vena cava were freed and controlled so that rapid perfusion was possible in case of donor instability.[13] The vascular anatomy and the parenchyma of the liver were evaluated.

The left lateral lobe (segments II and III) was mobilized and prepared identical to a living donor[14,15] (Fig. 1). The left hepatic artery and left portal vein were isolated. The right portion of the hepatoduodenal ligament was left untouched. Attention was paid to save the arterial branch to segment IV whenever possible. The portal branches to segment IV (median left segment) were suture-ligated and transected to allow Rex's recessus to progressively roll over toward the left lateral lobe until the hilar plate was exposed. Frequently, the artery for segment IV runs up at the right edge of the umbilical fissure. The left portal vein branches to the caudate lobe also were suture-ligated and severed. Next, the left he-

patic vein was controlled by placing a vessel loop around it. Then the parenchymal phase was started using electrocautery and mosquito-crushing technique to divide the parenchymal bridge between the left lateral lobe and the left median segment in continuity with the remaining right liver. The dissection was performed without vascular exclusion.

During this phase, the hilar plate was controlled with a dissecting clamp and sharply cut with a knife or vascular scissors. It was important to avoid coagulation near the fragile hilar structures. When the dissection was completed, two livers were separated, each with its own vascular pedicels and venous drainage. The quality of graft perfusion of both sides was observed carefully. Shortly before excision the left artery, the left portal vein and left hepatic vein were clamped and severed, followed by rapid removal of the lobe. On the back table, the graft was perfused immediately with University of Wisconsin solution, first via the portal vein and then by arterial perfusion. Cooled and appropriately wrapped, the graft then was transported to the recipient operating room or long-distance hospital for transplantation into the pediatric recipient. No further benching of this graft was needed, except when vascular interpositions were required.

The vascular and biliary branches of the remaining liver were suture-ligated and hemostasis of the cut section was completed, taking advantage of the donors intact coagulation. From this point, the further procurement was like a routine multiorgan-donor procedure.

Recipient Procedures

Left Graft

The left lateral lobes were transplanted using standard techniques, like in living donor liver transplantation.[14,15] The use of vascular interpositions usually was not necessary.

Right Graft

After procurement, the right graft was benched like a normal full-size liver containing the full length of the hepatic artery, the portal vein, and vena cava. The transplantation was identical to the whole-liver procedure.[16] After portal and arterial revascularization, the perfusion of segment IV was observed carefully. There usually was only a slight cyanotic appearance around the anterior part of this segment, and no further surgery was needed. If hypovascularization of segment IV was distinctly different, it was left in place but a second-look operation through a small laparotomy, after 24 hours, was planned. In one case in which the segment was completely devascularized, segments I and IV were resected, leaving a tissue rim around the bile duct.

RESULTS

Donor Procedure

A total of 12 operations on hemodynamically stable donors were attempted. However, in two cases, the donor liver was not suitable; one donor crashed hemodynamically and in another one, large volume replacement was needed during the procedure, which then was aborted to continue with the procurement of the other organs. Finally, in one small hospital whose staff was performing its first multiorgan donor procurement, the initial plan for *in situ* splitting was abandoned for logistical reasons.

There were no intraoperative problems in all seven cases in which the *in situ* splitting procedure was performed. Both anesthesiology and nursing management were performed by the donor hospital team. The time between beginning the procurement and removal of the left lateral lobe varied from 1¼ hours to 2½ hours. Blood transfusion was needed in some of the donors (maximum, 2 units packed erythrocytes) because of low preoperative hemoglobin levels or increased bleeding caused by coagulopathy.

Fourteen kidneys, two pancreases, and five hearts (no lungs) were procured after the splitting. All organs were transplanted and excellent initial function was demonstrated.

Patient and Graft Survival

Patient and graft survival rates at 6 months are 93% (13/14) and 86% (12/14), respectively (Table 2). The right grafts have a 100% patient and graft survival rate. One left graft was lost at 3 months from progressive inferior vena cava thrombosis, most likely because of protein S deficiency transmitted through the donor liver. This patient died from multiple-organ failure after retransplantation. Another left graft, transplanted in an adult recipient (480 mL for 54 kg), failed after an acute rejection on day 10 and was replaced successfully with a full-size liver. The auxiliary left graft was damaged by portal steal syndrome. Banding of the right portal vein was only partially successful and resulted in retransplantation after 1 year.

Complications

No complications related to the splitting procedure were noted in this series.

Primary function of the grafts was universally excellent, with the exception of the one small-for-size liver. In this case, a 480-mL left lateral lobe was transplanted in a 54-kg patient with primary biliary cirrhosis representing only 44% of the ideal liver volume.[17] After 4 days of co-

Table 2. RESULTS

Case No.	Segments	Patient Status	Graft	Complication	Cold Ischemia Time (min)	Peak AST (U/dL)
1R	1, 4–8	Alive	Okay	No	285	122
1L	2, 3	Alive	Poor	Portal steal	780	192
2R	5–8	Alive	Okay	No	875	1232
2L	2, 3	Alive	Okay	No	550	592
3R	1, 4–8	Alive	Okay	No	740	212
3L	2, 3	Alive	Okay	No	580	576
4R	1, 4–8	Alive	Okay	Protein deficiency	760	181
4L	2, 3	Dead	Loss	Protein deficiency/IVC thrombosis	420	182
5R	1, 4–8	Alive	Okay	No	555	1742
5L	2, 3	Alive	Loss	Insufficient volume/rejection	775	1025
6R	1, 4–8	Alive	Okay	Abscess	670	456
6L	2, 3	Alive	Okay	No	500	803
7R	1, 4–8	Alive	Okay	No	490	148
7L	2, 3	Alive	Okay	Retroperitoneal hemorrhage	420	1080

R = right; L = left; AST = aspartate aminotransferase; IVC = inferior vena cava.

agulation support, the patient's liver function normalized. On day 10, an acute rejection episode caused progressive liver failure and required urgent retransplantation. The median cold ischemia time of all livers was 9.7 hours (range, 4.8–14.6 hours) and thus was comparable to all other liver transplants in our institution.

Vascular complications did not occur. Interpositions were used to prolong the artery in cases receiving only left grafts.

All but one right bile duct were anastomosed in an end-to-end fashion and stented with a T tube. One was drained by hepaticojejunostomy. In four of the six end-to-end cases, T-tube cholangiograms later demonstrated a doubling of the right bile duct or a trifurcation of the bile duct. The left bile ducts were anastomosed uniformly to a Roux-en-Y jejunal loop. A double bile duct was present in two of the seven left lobe cases. In the whole series, not a single bile duct complication occurred during the observation period (follow-up ≥ 6 months).

In most cases, portal reperfusion of segment IV was poor or almost absent at the time of reperfusion. However, the perfusion of this segment improved when the hepatic artery was reconstructed. In several cases, the initially minimal portal perfusion improved during the following days, as documented by Doppler ultrasound. In split case number 2R, segments I and IV were removed after implantation of the right graft because of insufficient vascular perfusion. In all other cases, we were able to maintain segment IV. In split case number 3R, we performed a planned relaparotomy after 24 hours to re-evaluate the vascularization of segment IV, despite low transaminase levels, finding recuperation to normal color of the segment and detectable portal flow on ultrasound. One small abscess at the cut section, easily treated by percutaneous drainage, occurred in case number 6R.

Transplant Efficiency

In 1994 and 1995, 30 patients were served with a split-liver graft at the University of Hamburg (Table 3). Of these, three needed retransplantation within 6 months (1 with another split graft). Thus, 30 patients were served with 17.5 grafts.

If these patients had been transplanted normally, 33 grafts—30 primary and 3 for retransplantation—would have been needed. Thus, the 30 patients currently transplanted with 17.5 livers normally would have needed 33 organs, which is a net gain of 15.5 livers in 2 years.

Table 3. EFFICIENCY OF SPLIT LIVER TRANSPLANTATION (SLTX): HAMBURG, 1994–1995

	N = 30 Patients*	
	30 SLTX	30 Livers
Livers	15	30
Livers retransplanted	2.5	3
Total	17.5	33

* A total of 15.5 livers were gained.

Table 4. LITERATURE REVIEW OF SPLIT LIVER SERIES

Author	Year	n	% HU	Patient Survival (%)	Graft (%)	Biliary Complications (%)	PNF/ PPF (%)	Ischemia (hr)
Emond	1990	18	28	67	50	27	4/—	14.2
Broelsch	1990	30	40	60	43	27	—/—	—
Shaw	1990	10	70	50	50	40	—/—	—
Otte	1990	4	—	50	50	0	0/—	13.9
Houssin	1993	16	56	75	69	25	0/—	12.6
Slooff	1995	15	—	73	67	—	—/—	—
Otte	1995	29	27	71	67	17	3/3?	—
de Ville	1995	98	33	68	62	23.5	5/—	13.7
Bismuth	1995	30	7	93	90	23	—/—	
HH not IS	1996	19	58	63	58	16	0/11	12.6
In situ	1996	14	21	93	86	0	0/0	10.3

HU = high urgency; PNF = primary nonfunction; PPF = primary poor function; HH not IS = Hamburg not *in situ*.

DISCUSSION

Liver transplantation with reduced-size organs has evolved with increasing application into a standard treatment for pediatric recipients since 1985.[1,18–20]

With increasing application of liver transplantation with reduced-size organs, the limited organ supply was shifted to benefit children rather than adult candidates who, in increasing numbers, also were awaiting transplants. In 1988, the first division of a donor organ was reported by Pichlmayr et al., from Hannover, Germany,[21] as an individual approach to transplant a 2-year-old child with biliary atresia and a 63-year-old woman with primary biliary cirrhosis. The first series was presented at the American Surgical Association in 1990 by the University of Chicago group to demonstrate the feasibility and evaluate its broader application.[3] A more efficient use of available organs by splitting a transplant could provide more suitable organs without depending on the expansion of the pool of cadaveric donor organs yet to come. However, this concept has failed to gain wide acceptance until now because of inferior results (Table 4).

One of the reasons for inferior outcome was related to a relatively high number of high-urgency candidates. However, the early Chicago protocol—similar to our current approach—excluded two high-urgency candidates to be transplanted at the same time.

The patient selection followed the immediate need whenever a split procedure became possible. Thus, the patient selection was determined by intensive care unit and team availability rather than by medical urgency criteria exclusively. However, the effect that more organs became available reduced the incidence of urgent candidates per se.

An increased incidence of biliary complications has been recognized as one of the problems of split-liver transplantation since the earliest publications.[2] The bile duct has many anatomic variations that can be missed by the surgeon. In addition, the devascularization of the bile duct during the benching procedure causes leakage or late stenosis.

The impact of the longer ischemic time and benching time has not gained enough attention, although some of the right graft failures in the Chicago experiences were due to primary nonfunctioning grafts possibly caused by long ischemic time. The corresponding lobes (segments II and III) transplanted somewhat earlier into the pediatric recipient functioned reasonably well. It was postulated that for split-liver transplantation, two operating rooms, teams, etc., should be available simultaneously to avoid different and unnecessary prolonged ischemic times.[6] In addition, logistic problems then hampered the further development of split-liver transplantation because many centers would not have the capacity of transplanting two patients simultaneously, including the postoperative intensive care treatment.

Reports of split-liver transplantation series failed to stress the impact of prolonged ischemia time and prolonged benching procedures on the immediate graft function. Long ischemia times alone are known to decrease the initial liver function. In addition, there is evidence that warming up a graft by a few degrees centigrade during the benching procedure will make the tissue more susceptible to reperfusion injury.[22] Therefore, some of the postoperative complications identified as "not related to the splitting procedure" are conceivably caused by poor initial graft function. Finally, there is growing evidence that long ischemic times are correlated

Table 5. COMPARATIVE DATA OF *EX SITU* *VERSUS IN SITU* SPLITTING

	Ex Situ	*In Situ*
Graft survival	58% (11/19)	86% (12/14)
Patient survival	63% (12/19)	93% (13/14)
Cold ischemia time (min)	715 (505–1005)	580 (285–875)
AST max (U/dL)	690 (168–5588)	516 (122–1742)
PRBC (mL/kg)	64.8 (0–666)	47.9 (0–125)
Biliary complications	3	0
PPF/PNF	2/0	0/0

AST = aspartate aminotransfese; PRBC = packed red blood cells; PPF = primary poor function; PNF = primary nonfunction.

with the occurrence of nonanastomotic biliary strictures,[23,24] and that ischemic damage leads to expression of class 2 antigens, resulting in graft rejections.[25]

In situ splitting of the liver uses a technique already established for living-donor liver procurement to perform the splitting of the graft in the heart-beating cadaveric donor. By doing so, the long benching procedure, with its risk of warming of the graft, is avoided. The left lobe can be shipped to the recipient center even before the right lobe is procured, thus minimizing the cold ischemic time and allowing sharing of grafts over longer distances. The reduction of cold ischemia time and benching time has produced a remarkable decrease of ischemic damage both for the left and for the right grafts in our series (Tables 5 and 6).

Our technique of splitting allows procurement of a right graft, including the median left segment, which is anatomically comparable to a normal whole liver of smaller size. Such a graft contains approximately 75% of the total liver volume. The ischemia time and the benching time are not different from a normal liver transplant. The lengths of the artery, portal vein, and bile duct are

Table 6. THE RIGHT GRAFT IN *EX SITU* *VERSUS IN SITU*

	Ex Situ	*In Situ*
Graft survival	50% (5/10)	100% (7/7)
Patient survival	60% (6/10)	100% (7/7)
Cold ischemia time (min)	820 (510–1005)	670 (285–875)
AST max (U/dL)	693 (168–4389)	212 (122–1742)
PRBC (mL/kg)	28.5 (0–198)	47.9 (0–56.6)
Biliary complications	3	0
PPF/PNF	1/0	0/0

AST = aspartate aminotransferase; PRBC = packed red blood cells; PPF = primary poor function; PNF = primary nonfunction.

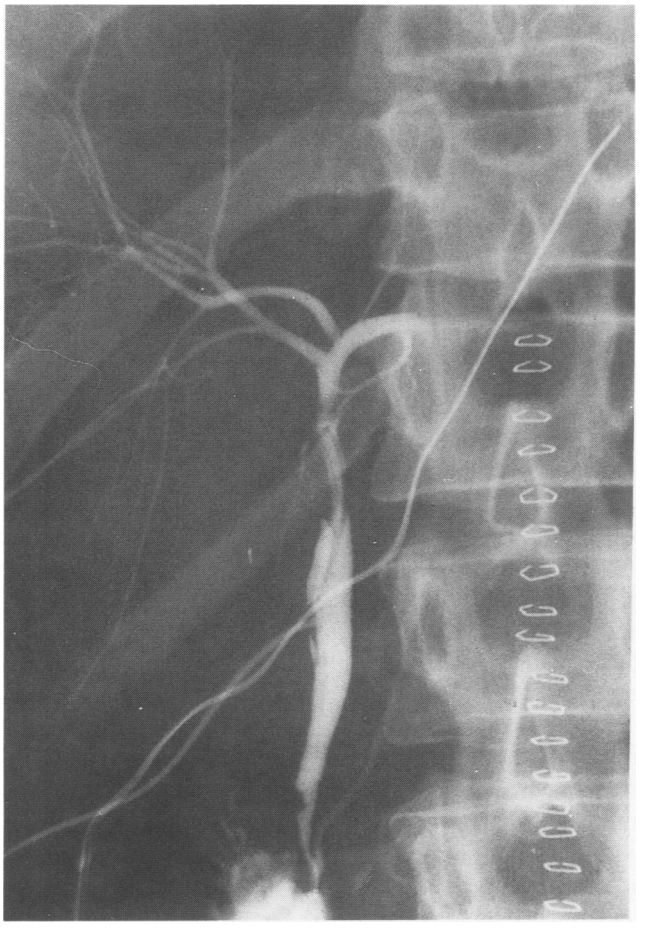

Figure 2. T-tube cholangiogram of right *in situ* split graft.

like those in a normal graft. It only misses its left lateral segment with the left hepatic artery and portal vein and the left hepatic vein. Hemorrhage from the cut section is controlled perfectly and does not present a problem at the time of transplantation because hemostasis in the donor is accomplished with normal coagulation. The implantation does not vary from a routine adult procedure and could be remarkable because no biochemical signs of ischemic damage to this segment were found in the postoperative period of our series. In the one case in which we performed a second-look laparotomy after 24 hours, the perfusion of segment IV had become completely normal, as seen by observation and Doppler ultrasound.

During the preparation of the hilum, the right part of the hepatoduodenal ligament should be left untouched. The lymphatic and nerve tissue between the proper hepatic artery, the right hepatic artery, and the bile duct should remain undissected, resulting in proper vascularization of the latter bile duct. The left bile duct is transected at the level of the interlobar scissure, leaving a relatively long stump of the left hepatic duct proximal to

the bifurcation and avoiding problems with anatomic variants of the bile duct bifurcation (Fig. 2). The vascularization of the bile duct is of crucial importance and needs to be preserved.

The left graft, procured by our technique, does not need further benching at all. It is being transplanted using the standard approach for living-donor liver transplantation. The small and short hepatic artery and portal vein do not present a significant risk of vascular thrombosis when microsurgical techniques are applied. Several series of living-donor liver transplants demonstrated these improvements.[15,26]

Bile duct duplication occurred in approximately one third of the cases. We recently have shown in our living related series that some learning curve was needed to obtain good results with this anastomosis (X. Rogiers, personal communication, 1995).

Because living-donor liver transplantation will soon be part of the professional skills of any pediatric liver transplant surgeon, transplantation of the left cadaveric graft will be safe in the hands of an experienced pediatric team.

The splitting procedure requires 1¼ to 2½ hours from incision of the donor to the point of rapid flush of the other organs via aortic perfusion and subsequent organ retrieval. The procedure can only be performed by an experienced liver surgeon. The other surgeons involved in organ procurement must ensure that this procedure does not harm "their" organs, and explantation can be aborted at any time of hemodynamic instability.

The excellent results with *in situ* splitting renders this procedure acceptable for both pediatric and adult patients. It only requires controlled harvest circumstances and above all, the willingness to split by the surgical teams and the donor hospitals. In the future, it will make graft reduction without splitting ethically unacceptable in the background of continuing organ shortage for children and adults.

CONCLUSION

In situ splitting of the liver provides two organs with optimal quality for liver transplantation. The short ischemic time, absence of a long benching procedure for either lobe, avoidance of bile duct complications, and transplantation of a large right graft are convincing arguments that override the extra efforts during the donor procedure. Splitting the liver with this technique should become accepted practice in "ideal" donors and may, in combination with living-donor liver transplantation, become the ultimate way of expanding the donor pool by surgical innovations.

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Discussion

DR. HENRI BISMUTH (Villejuif, France): I would like first to congratulate Dr. Rogiers and Dr. Broelsch for their innovative procedure of splitting the liver *in situ* for grafting. Indeed, they transpose to the cadaveric donor the technique used for harvesting the left lobe in the living donor, and they show how successful this is. There are three types of liver grafts beside the classical whole liver graft: 1) the reduced-size graft, which makes the graft smaller—it changes the recipient from being an adult to a child but it brings no benefit to the pool of available grafts; 2) The graft from a living donor; and 3) the split-liver graft. Both the latter techniques increase the number of livers available for patients in the waiting list.

I would like to focus on the split liver. In our center, we have developed since January 1995 a policy of systematically considering for splitting all grafts offered to us which appear suitable for this technique. During the last year, we performed 27 split-liver procedures out of 90 transplantations, representing an increase in available grafts of 30%. One-year patient survival rate is 80%, similar to patients transplanted with a whole graft in our center, showing that the increase in the number of grafts was not obtained at an extra cost by the recipients. The authors say that the reduced-size graft has no more indication; even thinking about the great enthusiasm among liver transplant surgeons when this technique was introduced 10 years ago, I totally agree with them.

Dr. Rogiers says that the *in situ* liver splitting technique gives similar results in children as the partial graft coming from a living related donor. I would then ask whether there is any justification for using living donors instead of the split-liver technique in countries where cadaveric donors are available, such as North America and Europe. For even if the risk for the living donor is small, it exists, and by definition, this risk is zero in a cadaveric donor. This is an important ethical point; even if we consider that we may split only 15% of the grafts, these split livers will cover almost all the needs for pediatric liver transplantation.

I thank Dr. Broelsch for giving me the privilege to read his excellent paper before the meeting and to comment on it in front of you.

DR. JEAN EMOND (San Francisco, California): The concept of splitting livers was born in Henri Bismuth's school in Paris and in the Pichlmyr School in Germany nearly 10 years ago. Our initial efforts in Chicago were plagued by technical failures and errors in patient selection. In the present report, we learn of the optimal approach to this appealing therapy with nearly perfect results that could theoretically double the donor supply.

The clear advantage of splitting *in situ* is the reduction of the cold time and the back table preparation, which takes up to 4 hours to make two good grafts, and greater accuracy and safety in dissection. The down side, which was not addressed, is the prolongation of the donor operation, inconveniencing a number of teams, and the performance of a complex dissection under difficult conditions in the whole spectrum of hospitals with operating room teams, which occasionally are indifferent or even hostile to the concept of transplantation.

The relationship between split livers and living donors has been symbiotic. In 1988, the success of a few early cases of split livers gave us confidence that living donors were feasible. Recently, the many lessons of living donors have permitted us to improve split-liver transplants. In San Francisco, all four cases of split livers have resulted in good results without using *in situ* dissection.

So my first question is, what is the added benefit of the *in situ* dissection? Is it possible that the recent improvements reflect the learning curve as much as the change in technique?

The only failure clearly attributed to the graft in your series was an attempt to treat two adults. Are splits going to be limited to adult and child pairs? If this is the case, only 10% of orthotopic liver transplantation candidates are children, so perhaps the benefit of splits will be limited.

In the classical reduced liver, the right lobe is discarded. Are you prepared now to relegate that operation to the museum and offer all right lobes to adults?

Finally, as experience is gained, would you be prepared to mandate splitting of all livers?

DR. CHARLES MILLER (New York, New York): I would just like to briefly capsulize our split data from New York City.

We have done split liver transplants in 11 patients. The first ten were done from five donors using an *ex situ* back table technique, in which we discarded segment 4, as Dr. Broelsch had originally described. The final case was a long distance *in situ* split, where we went to Oklahoma, split the liver, and brought back the right lobe. It worked beautifully, just as Dr. Broelsch described. That patient went home in 10 days.

The most striking difference between our group of patients and Dr. Broelsch's is the amount of very highly urgent patients that we were forced to transplant with this technique. We transplanted 9 of our 11 patients as status 1 or status 2, while I think the majority of his patients were highly elective cases. We did not want to get into that, but we were forced by the clinical reality to move in that direction.

Unfortunately—and I believe because of this—there were four deaths in our series, all in the *ex vivo* split group. Two deaths occurred from primary nonfunction of both grafts from a single liver. It was a damaged liver, we should never have used it, and it killed both recipients within 24 hours of the implantation. It almost killed the transplant team. There was one technical error that caused portal vein thrombosis and graft loss. One other adult, who had waited for a week in the intensive