Transplant International ISSN 0934-0874

CONGRESS PAPER

Extended right split liver graft for primary transplantation in children and adults*

Vittorio Corno,[1] Michele Colledan,[1] Maria Clara Dezza,[1] Michela Guizzetti,[1] Alessandro Lucianetti,[1] Gregorio Maldini,[1] Domenico Pinelli,[1] Mara Giovanelli,[1] Marco Zambelli,[1] Giuliano Torre[2] and Mario Strazzabosco[3]

1 General Surgery, Liver and Lung Transplantation, Ospedali Riuniti, Largo Barozzi, Bergamo, Italy
2 Pediatrics Ospedali Riuniti, Largo Barozzi, Bergamo, Italy
3 CeLiveR Largo Barozzi, Bergamo, Italy

Keywords
extended right split liver graft, *in situ* split liver, liver transplantation.

Correspondence
Vittorio Corno MD, General Surgery, Liver and Lung Transplantation, Ospedali Riuniti, Largo Barozzi, 1 24128 Bergamo, Italy. Tel.: 0039 035 269390; fax: 0039 035 266898; e-mail: vcorno@ospedaliriuniti.bergamo.it

Received: 31 October 2005
Revision requested: 8 December 2005
Accepted: 17 March 2006

doi:10.1111/j.1432-2277.2006.00323.x

Summary

Skepticism remains about the use of the extended right (ER) split graft (segments I, IV–VIII) for adult liver transplantation. We analyzed the results of primary liver transplantation performed with an ER graft in adult and in pediatric recipients. At our Institution, between October 1997 and June 2005, 32 primary liver transplantations with an ER graft were performed in 22 adult and 10 pediatric recipients. All the splitting procedures were performed *in situ*. Actuarial patient and graft survival among the adult recipients of the ER graft were 100% and 100% at 1 year, and 94% and 94% at 5 years. In the pediatric recipients, patient and graft survival were 90% and 79% both at 1 and 5 years. No hepatic artery thrombosis (HAT) occurred in the adult group, while in the pediatric recipients HAT occurred in two cases. A higher biliary morbidity occurred in the ER graft group when compared with the whole size graft 34% versus 13% ($P = 0.03$). However, this did not affect patient and graft survival. The results of this study may represent a further argument in favor of extensive splitting of all suitable grafts.

Introduction

Several strategies have been employed during the recent years to try to fill the gap between the donors available and the increasing number of liver transplant candidates, such as the use of aged and marginal donors, living related liver transplantation, and split liver transplantation (in which two grafts are obtained from one cadaveric donor) [1,2].

With the conventional split liver technique, the liver is divided along the round ligament, with the smaller part segment II and III or left lateral segment (LLS) transplanted into a child and the larger part segments I, IV–VIII or extended right (ER) graft transplanted into an adult. When this technique has been extensively employed, the use of the LLS graft has almost completely eliminated the mortality of children on the waiting list and the need for adult-to-child living related liver transplantation, with results comparable with those reported following living-related liver transplantation [3–5].

While the use of the LLS from a conventional split has been accepted as a standard of care for pediatric liver transplantation, skepticism still remains about the use of the ER split graft for adult liver transplantation because of concerns that it may provide unfavorable results than whole liver transplantation. ER grafts are therefore considered as marginal by many groups and the procedure has not gained a wide acceptance within the transplantation community [6]. Reviewing data of the European Liver Transplant Registry, Adam *et al.* [7] showed that the risk of mortality after split liver transplantation is similar to the risk of whole liver transplantation in centers that have performed more than 30 procedures.

*This paper was in part presented at the 12th Congress of the European Society for Organ Transplantation (ESOT) in Geneva, Switzerland from October 16–19, 2005.

At our Institution, the 'Ospedali Riuniti di Bergamo', a pediatric liver transplantation program was started in October 1997 followed by an adult liver transplantation program in May 1999. From the beginning of the program we adopted a liberal policy to split the liver from cadaveric donors [8].

We retrospectively reviewed and analyzed the outcome of primary liver transplantations using an ER split graft in children and adults. Furthermore, we compared the results with matched cohorts of pediatric and adult recipients of whole liver grafts, transplanted during the same period of time.

Materials and methods

Between October 1997 and June 2005, we performed 486 liver transplantations in 445 recipients (290 liver transplantations in 256 pediatric recipients and 196 liver transplantations in 189 adult recipients).

Overall the split graft represented 53% of all transplanted grafts. Adult patients received 166 (85%) whole livers, 25 (12.5%) ER grafts (segments I, IV–VIII), four (2%) full left grafts (segments I–IV) and one (0.5%) full right graft (segments V–VIII). In the pediatric recipients 214 (74%) LLSs, 62 (21%) whole livers, 11 (4%) ER and three (1%) full left grafts were transplanted.

Among these recipient populations, we analyzed 22 adults and 10 children who received an ER split liver graft for a primary liver transplant. One pediatric and three adults recipients of an ER split graft for urgent re-transplantation after a primary whole size liver transplantation were excluded from this analysis. We compared the results with cohorts of 48 adult and 13 pediatric patients, matched for age, indications, and United Network for Organ Sharing (UNOS) status, who received a whole liver graft as primary liver transplantation during the same time frame. Both the combined liver + kidney transplantation and a combined liver + double lung transplantation were included in the adult recipients group.

Donor selection

From the beginning we adopted a liberal policy of extensive splitting, with criteria that were already reported [3,8]. Gross-pathological findings at the harvesting operation were the main criteria for organ refusal. Particular care was applied to the evaluation of donor over 50 years of age, but age *per se* was not an exclusion criterion. Pediatric donors were used as well.

Donor surgical technique

All the splitting procedures were performed *in situ* as described by Rogiers *et al.* [9] during a multi-organ harvesting, wearing a 3.5× magnification loupes. In all cases, the left hepatic artery along with the common hepatic artery and celiac axis was kept with the LLS graft. Whole size liver grafts were procured in a standard fashion using the rapid-flush technique.

Recipients selection

During the period of the study in our center, every adult and pediatric patient listed for liver transplantation was considered a potential recipient of an ER split liver graft. Urgency and cause of the underlying liver disease did not influence the allocation of a split liver graft.

Recipient surgical technique

All but one graft were implanted using a bi-caval anastomosis technique; in one adult case a piggy-back technique was employed.

As we always kept the celiac axis with the LLS, in the split groups, the arterial anastomosis had to be performed on the right hepatic artery of the graft. Direct anastomosis, without using an interposition graft, was performed in most of the cases under 3.5× magnification surgical loupes or microscope. In case of difficult anastomosis an Ackland approximation clamp was used.

Statistical analysis

Patient and graft survival were calculated according to the Kaplan–Meier method. Comparisons of continuous measures were assessed by one-way analysis of variance followed by the *t*-test for parametric data. Categorical variables were analyzed by Fisher's exact test. Statistical significance is assumed for $P < 0.05$.

Results

Donors

All the split procedures included in this study were performed *in situ* during a multi-organ retrieval generating 32 ER grafts and 32 LLS grafts. Overall, 21 LLS were kept at our Institution and transplanted into 21 pediatric recipients contemporarily at the transplantation of the right extended grafts. The remaining 11 LLS were shared and shipped to other centers in Italy or in Europe. The characteristic of the donors of the adult and pediatric cohorts of patients receiving an ER graft or a whole size liver graft are reported in Table 1.

In the adult cohorts, no statistical significant differences were found regarding the donors' age, donors' weight, graft weight, intensive care unit (ICU) stay, serum

Table 1. Characteristics of the donors for the adult and pediatric recipients.

	Adult ER split		Adult whole size			Pediatric ER split		Pediatric whole size		
	Median	Range	Median	Range	*P*-value	Median	Range	Median	Range	*P*-value
Age (year)	22	12–61	54	17–79	NS	12	3–55	8	0.8–28	NS
Weight (kg)	65	30–90	70	30–110	NS	45	14–64	25	9–50	0.04
Graft weight (g)	1055	730–1650	1550	720–2400	NS	720	210–1000	610	350–1020	NS
ICU ≥5 days (%)	2	1–12	2	1–13	NS	2	1–10	2	1–8	NS
	5/22 (23%)		11/48 (23%)			2/10 (20%)		3/13 (23%)		
Na^+ ≥155 mEq/l	149	137–166	147	108–169	NS	151	13–498	148	129–179	NS
	4/22 (18%)		6/48 (13%)			3/10 (30%)		3/13 (23%)		
ALT (U/l)	35	6–279	43	5–216	NS	42		39	16–138	NS
Dopamine ≥8γ/kg/min	3/22 (14%)		11/48 (23%)		NS	2/10 (20%)		3/13 (23%)		NS
E or NE	6/22 (27%)		14/48 (29%)		NS	1/10 (10%)		2/13 (15%)		NS
Cardiac arrest	1/22 (5%)		2/48 (4%)		NS	–		1/13 (8%)		NS

E, epinephrine; NE, norepinephrine; ER, extended right; ALT, alanine transaminase.

sodium, serum alanine transaminase (ALT) level, and use of vasopressors.

Between the pediatric cohorts, a statistically significant difference was found regarding the donors' weight ($P = 0.04$) with heavier donors in the group used for the split liver procurement.

In both cohorts of pediatric and adult recipients of an ER split liver graft, donors with either ICU stay longer than 5 days, serum sodium higher then 155 mEq/l, high-dose vasopressors and history of cardiac arrest were not systematically discarded.

Recipients

The characteristics and the indication for transplantation of both cohorts of adult and pediatric recipients of an ER split graft or whole size graft are reported in Tables 2 and 3. Among the cohorts of adult recipients there were no significant differences regarding the recipient's age, Model for End-Stage Liver Disease score, UNOS status, donor–recipient-weight-ratio (DRWR), ischemia time or length of stay in the ICU after transplantation. A statistically significant difference was found with the recipient's weight, the heavier recipients being in the group who received a whole size graft ($P = 0.002$), and in graft-recipient-weight-ratio (GRWR) that was higher in the recipients of a whole size graft ($P = 0.02$).

Operative time was comparable in both adult recipient groups with a median time of 390 min (mean 414 ± 114, range 235–630 min) for the recipients of an ER split graft and a median time of 360 min (mean 390 ± 155, range 210–1170 min) for the recipients of a whole size liver graft (NS).

Among the adult recipients of an ER graft the arterial reconstruction was performed mainly with a direct anastomosis, but in five cases (23%) an interposition arterial homograft from the same donor of the liver graft was used. In three cases, a linear arterial graft (one iliac artery, one splenic artery, and one superior mesenteric artery) was interposed between the right hepatic artery of the graft and the recipient's common hepatic artery; in one case an iliac graft was interposed between the right hepatic artery of the graft and the recipient's right hepatic artery arising from the superior mesenteric artery; in the remaining case an iliac Y graft was sutured to the right hepatic artery and to an accessory branch for segment IV, and was then anastomosed to the infra-renal aorta of the recipient. In the group of recipients of a whole size liver, no interposition grafts were used and the arterial reconstruction was performed with a direct anastomosis.

Biliary reconstruction was mainly performed with a duct-to-duct anastomosis (86% in the recipients of a split graft and 83% in the recipients of a whole size graft). In the remaining 14% and 17% of the adult recipients, a Roux en Y hepatico-jejunostomy was used.

Between the two pediatric cohorts of patients the recipients of an ER split graft had a significantly higher Pediatric (model) for End-Stage Liver Disease (PELD) score. The GRWR was significantly higher and the DRWR significantly lower for them than for the control group. Ischemia time was also longer for the pediatric recipients of an ER graft. Operative time was comparable with a median of 300 min (mean 357 ± 76, range 275–470 min) in the recipients of an ER split graft and a median of 280 min (mean 302 ± 88, range 180–430 min) in the whole size graft group. In both groups, no interposition graft was used and all the arterial reconstructions were performed as a direct anastomosis.

In the pediatric recipients with a right split graft, biliary reconstruction was performed with a Roux en Y hepatico-jejunostomy in 70% of cases, while in the remaining 30%, a duct-to-duct biliary anastomosis was performed. In the group receiving a whole size graft, a bilio-digestive anasto-

Table 2. Indications for liver transplantation in cohorts of adult and pediatric recipients of an extended right split or whole size liver graft.

Indication	Adult split I, IV–VIII ($n = 22$)	Adult whole ($n = 48$)	Pediatric split I, IV–VIII ($n = 10$)	Pediatric whole ($n = 13$)
HCV	7 (32)	14 (30)	–	–
HCC	5 (23)	19 (40)	–	–
HBV	4 (18)	2 (4)	–	–
FHF/SFHF	2 (9)	2 (4)	–	–
Alcohol	–	5 (10)	–	–
Cystic fibrosis	1 (5)*	1 (2)*	1 (10)	1 (8)
Biliary atresia	–	–	4 (40)	4 (31)
Alagille	–	–	–	4 (31)
Crigler–Najjar	–	–	2 (20)	–
Byler's	–	–	–	2 (15)
Wilson	–	–	1 (10)	–
Hepatoblastoma	–	–	1 (10)	–
Glycogenosis	–	–	1 (10)	–
Others	3 (13)	5 (10)	–	2 (15)

HCV, Hepatitis C virus; HCC, Hepatocellular Carcinoma; HBV, Hepatitis B virus; FHF, Fulminant Hepatic Failure; SFHF, Sub Fulminant Hepatic Failure.
The percentage values are given in parenthesis.
*Recipients of a combined liver + double lung transplantation.

Table 3. Characteristics of the adult and pediatric recipients stratified by type of graft.

	Adult ER split		Adult whole size			Pediatric ER split		Pediatric whole size		
	Median	Range	Median	Range	*P*-value	Median	Range	Median	Range	*P*-value
Age (years)	49.9	22.7–62.6	54.8	19.3–65.4	NS	10.2	1–12	7.8	0.9–12.2	NS
Male:female	16:6		39:9			8:2		5:8		
Weight (kg)	63.5	40–82	73	31–108	0.002	30	8–53	24	7–33	NS
MELD score	17	8–30	24	8–31	NS	–				
PELD score	–		–			13	5–33	8	3–22	0.033
UNOS status										
1	2 (9%)		2 (4%)		NS	–		–		
2A	2 (9%)		7 (15%)		NS	1 (10%)		1 (8%)		NS
2B	14 (64%)		30 (62%)		NS	3 (30%)		3 (23%)		NS
3	4 (18%)		9 (19%)		NS	6 (60%)		9 (69%)		NS
DRWR	1	0.6–1.6	1	0.5–1.7	NS	1.75	1.2–2.5	1.1	0.4–3.3	0.001
GRWR	1.7	1.3–3	2.3	1–4.7	0.02	2.6	1.2–5.4	3.6	1.4–7.3	0.004
Ischemia time (h)	8	2.8–12.2	7.2	3–11.1	NS	7.2	5.2–10.8	6	4.2–9.2	0.041
ICU (days)	2	1–169	2	1–31	NS	4	2–7	4	3–8	NS
Combined transplantation										
Liver + kidney	1		1			–		–		
Liver + lungs	1		1			–		–		

MELD, Model for End-Stage Liver Disease; PELD, Pediatric (model) for End-Stage Liver Disease; UNOS, United Network for Organ Sharing; DRWR, Donor–Recipient-Weight-Ratio; GRWR, Graft-Recipient-Weight-Ratio.

mosis was performed in 92% of the recipients, and a duct-to-duct anastomosis was accomplished in 8% of the patients.

Complications

Among the adult recipients of an ER split graft, we did not observe any hepatic artery thrombosis (HAT). In one case, a stenosis of the supra hepatic vena cava anastomosis occurred and was successfully treated by balloon dilation. Another patient developed a subtotal thrombosis of the retro-hepatic vena cava that was managed conservatively by oral anticoagulants.

In the cohort of adult recipients of a whole size graft, one (2%) patient developed HAT on the fifth postoperative day and underwent a successful re-transplantation. In another case, a stenosis of the hepatic artery has been managed by a placement of an expandable stent.

Two pediatric recipients of an ER split graft had HAT. In one case, a 8 kg recipient of a right split graft procured from a 14 kg pediatric donor developed a HAT on the first postoperative day, 2 days the patient underwent a re-transplantation but died of multiple organ failure and brain edema. The other child developed a late HAT and was successfully re-transplanted almost 10 months after the first procedure. Among the pediatric recipients of a whole size graft, no vascular complications occurred.

Overall, among the adult and pediatric recipients of an ER split graft, biliary complications occurred in 11/32 patients (34%), whereas among the recipients of a whole size graft, biliary complications occurred in 8/61 patients (13%); this difference was statistically significant ($P = 0.03$). Among the 11 patients who had biliary complications four required a surgical re-operation; in three cases a conversion to a Roux en Y hepatico-jejunostomy was performed to treat a biliary fistula and two anastomotic stenosis, respectively. In one case, a bile leak from the cut surface of the graft required a direct suture. In the remaining seven recipients of an ER split graft who developed biliary complications, four cases of biliary stenosis were successfully treated by endoscopic retrograde cholangiopancreatography (ERCP) or percutaneous trans-hepatic cholangiography and balloon dilation. One patient with a biliary fistula was treated by placement of naso-biliary tube; another case of biliary fistula was managed by a percutaneous approach and placement of a trans-hepatic biliary drainage. One case of biliary leakage from the cut surface with an intraperitoneal fluid collection underwent an ultrasound-guided drainage.

Among the eight patients who developed biliary complications after liver transplantation with a whole size graft, five required a surgical intervention. A biliary fistula was managed with a conversion to a Roux en Y hepatico-jejunostomy in two cases and with a re-do of the hepatico-jejunostomy in one case. One patient had a biliary stenosis that after an initial attempt of conservative treatment by ERCP and balloon dilation, underwent a conversion to a Roux en Y hepatico-jejunostomy. In a pediatric recipient, a stenosis of bilio-digestive anastomosis was treated with a re-do of the hepatico-jejunostomy. Two cases of anastomotic stenosis were managed conservatively by ERCP, balloon dilation and placement of an endoprosthesis. One case of bile leak and intraperitoneal fluid collection was drained under ultrasound guidance.

Among the adult and pediatric recipients of an ER split graft, two patients had a bile leak from the cut surface, whereas anastomotic biliary complications occurred in 8/22 (36%) of the duct-to-duct biliary reconstructions and in 1/10 (10%) case of Roux en Y hepatico-jejunostomy. This difference, although considerable, was not statistically significant (NS).

Among the 63 duct-to-duct biliary reconstructions (22 ER grafts and 41 whole liver grafts) anastomotic biliary complications occurred in 13 patients (21%); whereas among the 30 Roux en Y hepatico-jejunostomy (10 ER and 20 whole liver grafts) we observed four (13%) anastomotic biliary complications. This difference was not statistically significant (NS).

A statistically significant difference ($P = 0.047$) was found comparing the incidence of anastomotic biliary complications between a duct-to-duct anastomosis in the ER split graft group 8/22 (36%) and a duct-to-duct biliary reconstruction in the whole size graft 5/41 (12%).

Biliary complications, both anastomotic and nonanastomotic, occurred in 9/22 cases (41%) among the adult recipients of ER graft; while in the adult recipients of a whole liver graft biliary complications occurred in 7/48 cases (15%); this difference was statistically significant ($P = 0.03$). The results according to the type of graft used are summarized in Table 4.

Patients and graft survival

Among the 32 recipients (22 adults and 10 children) of an ER graft, 1 year and 5 year patient/graft survival was 97%/94% and 93%/90%, respectively. Whereas among the 61 recipients (48 adults and 13 children) of a whole liver graft, patient/graft survival was 92%/90% both at 1 and 5 years (NS).

In the adult group of recipients of an ER split graft with a median follow up of 832 days (range 131–2023) patient and graft survival was 100% and 100% at 1 year and 94% and 94% at 5 years, respectively. One patient died, of bacterial meningitis and neurological complications, with a functioning graft, 20 months after transplantation. With a median follow up of 594 days (range 148–1996) patient and graft survival is 90% and 88% both at 1 and 5 years among the adult recipients of a whole size graft (Figs 1 and 2). The five deaths were related in one case to a multiple organ failure and brain hemorrhage in the second postoperative week; to an intra-operative cardiac arrest in another case; one patient developed heart failure and subsequently died of cardiac arrest on the 50th postoperative day; another patient died of recurrent sepsis; one patient died of brain metastasis from hepatocellular carcinoma 7 months after transplantation.

Among the pediatric recipients of an ER split graft, with a median follow up of 1156 days (range 217–2128) the actuarial 1 and 5 year patient survival is 90% while 1 and 5 years graft survival is 79% (Figs 1 and 2). Two children were re-transplanted, one of whom died later as a consequence of HAT (see above). In the pediatric group of recipients of a whole size graft, patient and graft survival is 100% both at 1 and 5 years (Figs 1 and 2).

Table 4. Results according to the type of graft used.

	ER Adult	Whole adult	*P*-value	ER pediatric	Whole pediatric	*P*-value	ER adult + pediatric	Whole adult + pediatric	*P*-value
1 year patient/graft survival (%)	100/100	90/88	NS	90/79	100/100	NS	97/94	92/90	NS
5 year patients/graft survival (%)	94/94	90/88	NS	90/79	100/100	NS	94/90	92/90	NS
HAT	0/22 (0%)	1/48 (2%)	NS	2/10 (20%)	0/13	NS	2/32 (6%)	1/61 (2%)	NS
Biliary complications	9/22 (41%)	7/48 (15%)	0.03	2/10 (20%)	1/13 (8%)	NS	11/32 (34%)	8/61 (13%)	0.03

HAT, hepatic artery thrombosis; ER, extended right.

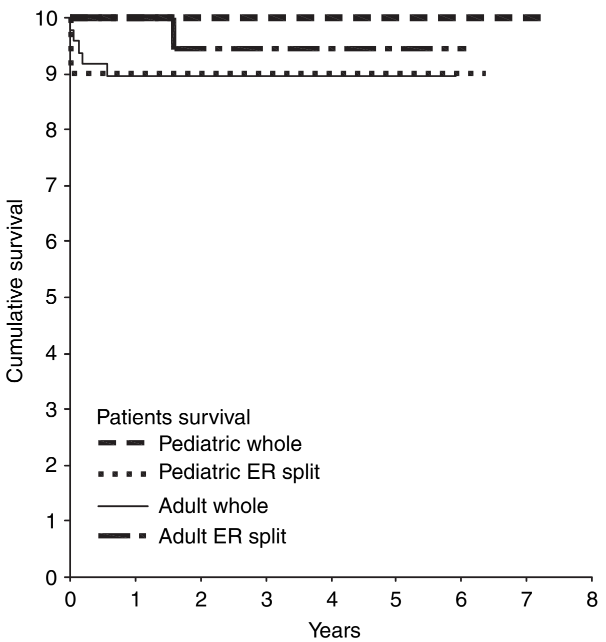

Figure 1 Kaplan–Meier patient survival according to the type of graft. Adult whole versus ER NS; pediatric whole versus ER NS (log rank NS).

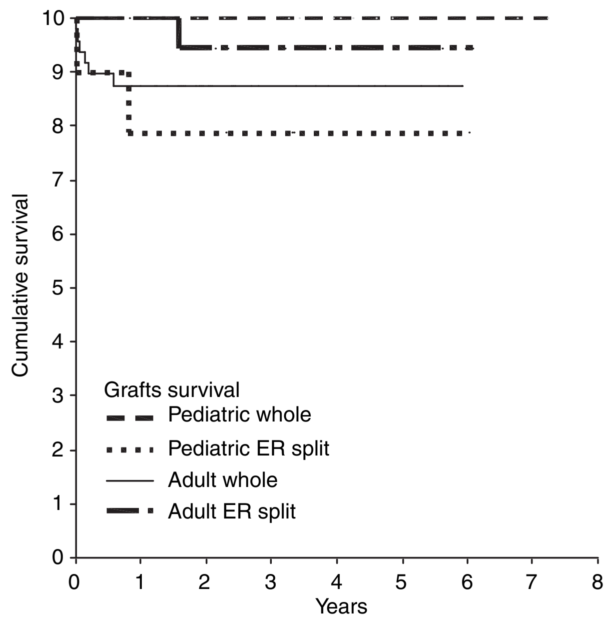

Figure 2 Kaplan–Meier graft actuarial survival according to the type of graft. Adult whole versus ER NS; pediatric whole versus ER NS (log rank NS).

Discussion

The shortage of suitable organ donors has been very problematic especially for pediatric recipients because of the difficulty in finding a size-matched organ. To overcome this problem, Bismuth and Houssin (1984) [10] published the first successful clinical application of a reduced size liver graft by which a portion of a cadaver liver was used for transplantation to a child and the remaining portion was discarded. The reduced size technique was successful when transplanted to small children, but resulted in a shifting of organs from the pool of the adult recipients to that of pediatric recipients.

During the following years, under the increasing pressure of organ shortage, retaining the right part of a cut down liver graft allowing the transplantation of two patients with one donor liver, seemed the natural evolution of the reduced size technique and in 1988 Pichlmayr reported the first clinical use of a split liver technique [11]. The main goal of split liver graft was to supply the pediatric recipients with a small size liver graft without penalizing the adult waiting list. After an initial learning phase, the split liver technique became a well-established procedure for transplantation to pediatric patients with results comparable with those achievable with whole size and living-related liver transplantation [6,7,12–15].

In contrast to the good results in children, the initial patient and graft survivals after transplantation of the ER graft in the adult recipients were inferior to those of whole liver transplants [16,17]. Even if technical improvement with better donor and recipient selection led to more favorable results in the second half of the 1990s, some skepticism still remains about the use of an ER split graft. The procedure is performed mostly by centers with mixed populations of pediatric and adult recipients [15,18,19].

Usually the ER liver lobe accounts for 70–80% of the standard liver volume, which represents 2% of the body weight. Experience gained from the adult living donor liver transplantation, shows that transplantation of the graft with a GRWR ≥1% can achieve results comparable with those with whole organ transplantation [20]. In our series, both in adult and pediatric recipients of an ER graft GRWR was never lower than 1.2% (adult recipients median 1.7 range 1.3–3; pediatric recipients median 2.6, range 1.2–5.4).

No uniformity exists regarding the donor criteria for an *in situ* split liver procurement; the ideal criteria for *in situ* splitting advocated by different centers or organ procurement organizations include: (i) age ≥10 ≤ 35–50; (ii) a stable hemodynamic; (iii) ICU stay ≤2–5 days; (iv) liver function test ≤2–5× normal values; (v) dopamine <15γmcg/kg/min; and (vi) serum sodium <160–170 mmol/l [14,21,22]. In several occasions we went beyond these criteria and this did not appear to have a negative impact on the outcome, thus, a less strict criteria for *in situ* splitting might be used [23].

Regarding the arterial vascular partition we always kept the celiac axis with the LLS. The usefulness and safety of maintaining the celiac axis with the LLS has already been advocated to obviate the need for microsurgical reconstruction of the left hepatic artery [24]. The right hepatic artery is generally larger than the left sided artery and more amenable to vascular reconstruction. In our series, no HAT occurred in the adult recipients of an ER split graft. Among the pediatric recipients we observed two cases of HAT with an incidence of 20% that is rather high. In one case, an early HAT occurred in a 1-year-old child weighting 8 kg who received a right graft from a 3-year-old 14 kg pediatric donor. This was our first split liver transplant with a pediatric graft and the anastomosis was performed with a 3.5× magnification loupes without using a microscope. Our experience has led us to perform the smallest under microscope magnification and with the approximating clamp.

When analyzing the biliary complications altogether, 11/32 (34%) patients had biliary complications in the ER split graft group, versus 8/61 (13%) in the whole graft group ($P = 0.03$). ER grafts provided a higher biliary morbidity, however, this higher incidence of biliary complications did not affect patient and graft survival.

Even though not statistically significant, a considerable difference exists in the incidence of anastomotic biliary complications between duct-to-duct anastomosis and Roux en Y hepatico-jejunostomy 36% vs 10% in the patients who received an ER graft (NS). However, we prefer duct to duct anastomosis when technically possible, as it seems more physiological and allows both endoscopic retrograde and percutaneous access to the bile ducts. In our series, patient and graft survival compared favorably with those of recipients of a whole size graft, and matched perfectly to the most recent results reported in the literature. Patient survivals at 1 year varying between 77 and 100% and graft survivals of 69–100% have been reported both in American and European series [8,14,19,20,25–30]. In our pediatric recipients of an ER split graft, the patient and graft survivals were inferior, without reaching a statistical significance, to those of recipients of a whole size graft. A higher PELD score, longer ischemia time, and technical difficulty in arterial reconstruction of grafts obtained from very small donors may in part explain these results.

In conclusion, our results confirm that use of an ER split graft in both adult and pediatric recipients of a primary liver transplantation, is safe and effective, at a center with a 'high volume' of split liver procedures, at least as the use of a whole size liver graft and did not place the recipients at a higher risk. In spite of a higher incidence of biliary complications, in the ER split graft group, patients and graft survival were not affected and the achieved results were comparable with those of recipients of a whole size liver. Particularly, in the adult population, the results achieved with ER split graft, in terms of patients and graft survival, were even better, although not significantly, than those of a whole size organs. We currently do not ask adult patients for a specific consent to receive a split graft: rather, in the general consent to liver transplantation they are informed of our policy of extensive splitting of the livers and that they may therefore receive either a whole size or a split graft. Patients are informed that use of an ER split graft is burdened with a higher biliary morbidity, but that the expected results regarding patient and graft survival, are not influenced, in the short or long-term, by this choice. In fact, with this type of information, no patient, so far, has been asked to select the type of graft.

We believe that these results may provide a further stimulus for the widespread diffusion of the split liver technique and in favor of considering good quality cadaveric livers as 'paired organs'. We believe that splitting techniques should be an essential part of the training of liver transplant surgeons and the development of extensive splitting programs should be encouraged and supported by the health authorities.

Acknowledgements

We acknowledge Riccardo Bezzo for the essential contribution with data management.

References

1. Gridelli B, Remuzzi G. Strategies for making more organs available for transplantation. *N Engl J Med* 2000; **343**: 404.
2. Colledan M, Andorno E, Valente U, Gridelli B. A new splitting technique for liver grafts. *Lancet* 1999; **353**: 1763.
3. Colledan M, Segalin A, Spada M, Lucianetti A, Corno V, Gridelli B. Liberal policy of split liver for pediatric liver transplantation. A single centre experience. *Transpl Int* 2000; **13**(Suppl. 1): S131.
4. Broering DC, Mueller L, Ganschow R, *et al.* Is there still a need for living-related liver transplantation in children. *Ann Surg* 2001; **234**: 713.
5. Gridelli B, Spada M, Petz W, *et al.* Split-liver transplantation eliminates the need for living-donor liver transplantation in children with end-stage cholestatic liver disease. *Transplantation* 2003; **75**: 1197.
6. Renz JF, Emond JC, Yersiz H, Ascher NL, Busuttil RW. Split-liver transplantation in the United States. Outcomes of a National Survey. *Ann Surg* 2004; **239**: 172.
7. Adam R, Cailliez V, Majno P, *et al.* Normalized intrinsic mortality risk in liver transplantation: European Liver Transplant Registry study. *Lancet* 2000; **356**: 621.
8. Spada M, Gridelli B, Colledan M, *et al.* Extensive use of split liver for pediatric liver transplantation. A single center experience. *Liver Transpl* 2000; **6**: 415.
9. Rogiers X, Malagò M, Habib N, *et al. In situ* splitting of the liver in the heart-beating cadaveric organ donor for transplantation in two recipients. *Transplantation* 1995; **59**: 1081.
10. Bismuth H, Houssin D. Reduced-size orthotopic liver graft in hepatic transplantation in children. *Surgery* 1984; **95**: 367.
11. Pichlmayr R, Ringe B, Gubernatis G, *et al.* Transplantation einer Spender-leber auf zwei Empfänger (Splitting-Transplantation) – Eine neue Methode in der Weiterentwicklung der Lebersegmenttransplantation. *Langenbecks Arch Chir* 1988; **373**: 127.
12. Azoulay D, Astarcioglu I, Bismuth H, *et al.* Split liver transplantation: the Paul Brousse Policy. *Ann Surg* 1996; **224**: 737.
13. Rela M, Vougas V, Muiesan P, *et al.* Split liver transplantation, King's College Hospital experience. *Ann Surg* 1998; **227**: 282.
14. Busuttil RW, Goss JA. Split Liver transplantation. *Ann Surg* 1999; **229**: 313.
15. Revillon Y, Michel JL, Lacaille F, *et al.* Living-related liver transplantation in children: the ''Parisian'' strategy to safely increase organ availability. *J Pediatr Surg* 1999; **34**: 851.
16. Emond JC, Whitington PF, Thistlethwaite JR, *et al.* Transplantation of two patients with one liver. Analysis of a preliminary experience with ''split-liver'' grafting. *Ann Surg* 1990; **212**: 14.
17. Merion RM, Campbell DA. Split-liver transplantation: one plus one doesn't always equal two. *Hepatology* 1991; **14**: 572.
18. Broering DC, Topp S, Schaefer U, *et al.* Split liver transplantation and risk to the adult recipient: analysis using matched pairs. *J Am Coll Surg* 2002; **195**: 648.
19. Washburn K, Halff G, Mieles L, Goldstein R, Goss JA. Split-liver transplantation: results of statewide usage of the right trisegment graft. *Am J Transpl* 2005; **5**: 1652.
20. Marcos A, Fisher R, Ham J, *et al.* Right lobe living donor liver transplantation. *Transplantation* 1999; **68**: 798.
21. Emond JC, Freeman RB, Renz JF, Yersiz H, Rogiers X, Busuttil RW. Optimizing the use of donated cadaver livers: analysis and policy development to increase the application of split-liver transplantation. *Liver Transpl* 2002; **8**: 863.
22. Schlitt HJ. Which liver is splitable? In: Rogiers X, Bismuth H, Busuttil RW, Broering DC, Azoulay D, eds. *Split Liver Transplantation. Theoretical and Practical Aspects.* Darmstadt: Steinkopff Verlag, 2002: 63–66.
23. Spada M, Bertani a, Guizzetti M, *et al.* Can donor selection criteria for split liver transplantation be safely expanded? A multicenter, multivariate analysis. *Transpl Intern* 2005; **18**(Suppl. 1): 20.
24. Kilic M, Seu P, Goss JA. Maintenance of the celiac trunk with the left-sided liver allograft for *in situ* split-liver transplantation. *Transplantation* 2002; **73**: 1252.
25. Goss JA, Yersiz H, Shackleton CE, *et al. In situ* splitting of cadaveric liver for transplantation. *Transplantation* 1997; **64**: 871.
26. Nashan B, Lueck R, Becker T, Schlitt MH, Grannas G, Klempnauer J. Outcome of split liver transplantation using ex-situ or *in situ* splits from cadaver donors. *Joint meeting of the International Liver Transplantation Society, European Liver Transplantation Association and Liver Intensive Care Group of Europe*. 2001: July 11–13.
27. Sauer IM, Pascher A, Steinmüller T, *et al.* Split liver and living donation liver transplantation: the Berlin experience. *Transplant Proc* 2001; **33**: 1459.
28. Maggi U, Rossi G, Reggiani P, *et al.* Graft loss and retransplantation rate after *in situ* liver transplantation. *Joint meeting of the International Liver Transplantation Society, European Liver Transplantation Association and Liver Intensive Care Group of Europe*. 2001: July 11–13.
29. Yersiz H, Renz JF, Farmer DG, Hisatake GM, McDiarmid SV, Busuttil RW. One hundred *in situ* split-liver transplantations. A single center experience. *Ann Surg* 2003; **238**: 496.
30. Merion RM, Rush SH, Dykstra DM, Goodrich N, Freeman RB, Wolfe RA. Predicted lifetimes for adult and pediatric split liver versus adult whole liver transplant recipients. *Am J Transpl* 2004; **4**: 1792.

