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Portal Vein Reconstruction in Pediatric Liver Transplantation From Living Donors

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Objective
The authors analyze the surgical pattern and the underlying rationale for the use of different types of portal vein reconstruction in 110 pediatric patients who underwent partial liver transplantation from living parental donors.

Summary Background Data
In partial liver transplantation, standard end-to-end portal vein anastomosis is often difficult because of either size mismatch between the graft and the recipient portal vein or impaired vein quality of the recipient. Alternative surgical anastomosis techniques are necessary.

Methods
In 110 patients age 3 months to 17 years, four different types of portal vein reconstruction were performed. The portal vein of the liver graft was anastomosed end to end (type I); to the branch patch of the left and right portal vein of the recipient (type II); to the confluence of the recipient superior mesenteric vein and the splenic vein (type III); and to a vein graft interposed between the confluence and the liver graft (type IV). Reconstruction patterns were evaluated by their frequency of use among different age groups of recipients, postoperative portal vein blood flow, and postoperative complication rate.

Results
The portal vein of the liver graft was anastomosed by reconstruction type I in 32%, II in 24%, III in 14%, and IV 29% of the cases. In children <1 year of age, type I could be performed in only 17% of the cases, whereas 37% received type IV reconstruction. Postoperative Doppler ultrasound (mL/min/100 g liver) showed significantly ($p < 0.05$) lower portal blood flow after type II (76.6 ± 8.4) *versus* type I (110 ± 14.3), type III (88 ± 18), and type IV (105 ± 19.5). Portal vein thrombosis occurred in two cases after type II and in one case after type IV anastomosis. Portal stenosis was encountered in one case after type I reconstruction. Pathologic changes of the recipient native portal vein were found in 27 of 35 investigated cases.

Conclusion
In living related partial liver transplantation, portal vein anastomosis to the confluence with or without the use of vein grafts is the optimal alternative to end-to-end reconstruction, especially in small children.

Orthotopic liver transplantation is today the treatment of choice for end-stage liver disease in adults as well as in children. Although the supply of organs for adults is more or less adequate, the size-matched organ availability for pediatric patients is critical. It has been reported that in the United States 25% to 50% of the pediatric candidates for liver transplantation died on the waiting list because of the shortage of organs.[1,2] Alternatives to full-size liver transplantation for children have been recently developed to overcome these limitations. Currently, three alternative concepts are frequently used in specialized liver transplant centers all over the world: reduced-size liver transplantation,[3-6] split-liver transplantation,[7,8] and partial liver transplantation from living donors.[9-12] In all these procedures, a part of the adult donor liver is transplanted to the pediatric recipient. Therefore, despite the difficulties of adequate volume reduction and the age difference, all these techniques also share the problem of size mismatch between the vessels of the adult liver and the recipient.

Portal vein reconstruction is a crucial factor for a successful transplantation because it allows blood flow to the liver graft, ending the ischemic period for the graft as well as the anhepatic period for the recipient. In reports on reduced liver and split-liver transplantation, standard end-to-end portal vein anastomosis and the use of the cadaveric donor's iliac vein and saphenous vein for interposition to the recipient's portal system have been described.[11,13,14]

In Japan, living related transplantation is the only chance to rescue pediatric patients with end-stage liver disease, because we are not allowed to use cadaveric donors. Therefore, the Second Department of Surgery of Kyoto University initiated the program of living related partial liver transplantation in children in June 1990. Aside from the problem of size mismatch of the liver graft portal vein and the recipient portal vein, portal vein reconstruction in living related transplantation is further aggravated by the fact that the quality of the recipient portal vein is often impaired by previous surgery for the underlying liver disease (Kasai's operation). Furthermore, for safety reasons the availability of vascular grafts from the living donor is limited.[15]

In the present study, we describe the surgical pattern for portal vein reconstruction in a series of 110 pediatric patients in partial liver transplantation from living donors. We analyzed each type of portal vein reconstruction with respect to the frequency of use in different age groups, the changes of portal vein blood flow, and the postoperative complication rate.

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Table 1. PREOPERATIVE PROFILE OF THE RECIPIENTS

Number of patients	110
Sex	
Male	33
Female	77
Age (average) (yr)	4.2 (0.3–17)
Body weight (kg)	14.5 (3.1–58)
Graft weight (g)	264 ± 67
Graft weight/recipient body weight ratio (%)	2.6 (0.6–11.2)
Diagnosis (number)	
Biliary atresia	94
Liver cirrhosis	3
Wilson's disease	3
Intrahepatic cholestasis	3
Budd-Chiari syndrome	2
Protoporphyria	1
Fulminant hepatitis	1
Hypertyrosinemia	1
Glycogen storage disease	1
Chronic rejection (retransplantation)	1

PATIENTS AND METHODS

Since June 1990, the Second Department of Surgery, Kyoto University Hospital, has performed a series of 110 cases of partial liver transplantation from living donors on pediatric patients with end-stage liver disease. The operations were performed with informed consent of the parents and were approved by the Ethics Committee of Kyoto University. Table 1 summarizes the recipients' clinical profile. Approximately 86% of the patients suffered from biliary atresia. The operation was performed on 33 boys and 77 girls, ranging in age from 3 months to 17 years (average age, 4.2 years). The liver graft was obtained from the recipient's father (47 cases) or mother (63 cases). The age of the donors ranged from 19 years to 51 years. The donors were selected based on willingness to undergo partial liver donation on an informed consent basis, normal liver function tests, suitable liver volume for the recipient's abdominal cavity, and ABO blood compatibility, as described in detail elsewhere.[16]

The donor and recipient operations were performed according to the principles we reported earlier.[12,15,16] In the donor, left lobectomy or lateral segmentectomy was

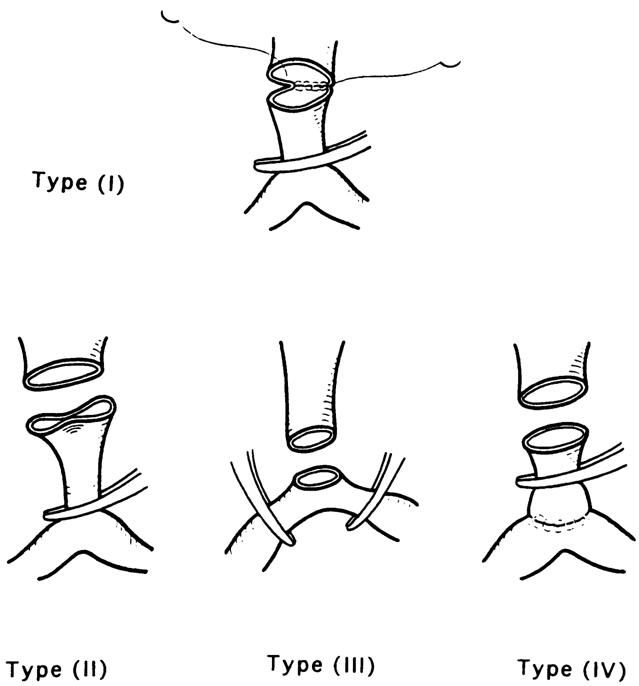

Figure 1. Reconstruction types for portal vein anastomosis. Type I, end-to-end (n = 35); type II, branch patch (n = 27); type III, confluence (n = 16); type IV, vein graft (n = 32).

performed using an ultrasonic scalpel (Cusa 200 CEM; Cavitron, Stanford, CA) and bipolar electric cautery. With this technique, liver resection can be performed without vascular clamping to prevent damage to the graft as well as the remaining liver. In general, the left portal vein, the left biliary duct, and the left hepatic artery were isolated. After clamping the left hepatic vein, the left portal vein was cannulated and the graft was flushed *in situ* with chilled Ringer's solution, followed by cold University of Wisconsin solution.

In the recipient, the liver graft was implanted in an orthotopic manner after hepatectomy of the native liver. The inferior vena cava of the recipient was side-clamped to preserve the blood flow, and hepatic vein anastomosis was performed in end-to-end or end-to-side fashion.

The portal vein reconstruction was performed in four different ways (Fig. 1). Type I was the standard end-to-end anastomosis. In Type II, the graft portal vein was anastomosed to the bifurcation of the recipient right and left portal vein (branch patch). In type III, the allograft portal vein was sutured to the confluence of the recipient superior mesenteric vein and splenic vein. In type IV, a vein graft was interposed between the graft portal vein and the confluence of the recipient superior mesenteric vein and splenic vein. The vein grafts were obtained from the donor. In cases with a maternal donor, the left ovarian vein was harvested. In cases with a paternal donor, the inferior mesenteric vein was used. The vascular grafts were anastomosed to the confluence of the recipient before the liver graft was implanted. The portal vein anastomosis was performed with 7-0 polypropylene (Prolene) running suture without growth factor.

The hepatic artery anastomosis was performed by microsurgical techniques with the help of a microscope (except for the first seven cases, where magnifying glasses were used). Vascular grafts have not been used so far for hepatic vein or hepatic artery reconstruction. The bile duct anastomosis was carried out using Roux-en-Y or an interposed jejunal conduit for bile drainage.

To evaluate portal vein reconstruction, we analyzed the frequency of the different surgical patterns for portal vein reconstruction among our 110 cases. We also investigated the complication rate and the portal vein blood flow after the different types of portal vein reconstruction by Doppler ultrasonography, which we perform routinely before, during, and after surgery. In 35 consecutive cases, we investigated the pathology of the recipient's native portal vein to evaluate the changes in vessel quality due to the underlying disease or to previous operations.

Data are expressed as mean ± standard error of the mean. Statistical analysis was calculated by one-way analysis of variance for differences among groups and by Student's t test, where appropriate. Probability values < 0.05 were regarded as significant.

RESULTS

Survival Rate

The overall survival rate of the 110 cases after partial liver transplantation from a living donor was 86% (in elective cases 91% and in emergency cases 65%).

Portal Vein Reconstruction

For portal vein reconstruction, four different patterns of anastomosis were used, as described in Figure 1 and Table 2. Type I was used for portal vein reconstruction in 36 cases (32%), type II in 27 cases (24%), and type III in 16 cases (14%). In 32 cases (29%), type IV with vascular graft interposition was performed. In one early case, the recipient's infrarenal cava and the recipient's external iliac vein were used for vein grafts.

The average diameter of the liver graft portal vein was 8.2 ± 0.2 mm. The average vessel diameter was 4.9 ± 0.2 mm for the recipient's native portal vein and 7.7 ± 0.3 mm for the harvested vascular grafts (ovarian vein or inferior mesenteric vein).

Table 3 shows the frequency of the different patterns of portal vein reconstruction in relation to the recipient's age and body weight and the native portal vein diameter.

Table 2. PORTAL VEIN RECONSTRUCTION TYPES AND COMPLICATION RATE

Technique	Number (%)	Complications (n)
Type I: end-to-end	35 (32)	Stenosis (1)
Type II: branch patch	27 (24)	Thrombosis (2)
Type III: confluence	16 (14)	—
Type IV: vascular graft	32 (29)	Thrombosis (1)
Donor's ovarian vein	19	
Donor's inferior mesenteric vein	11	
Recipient's infrarenal cava	1	
Recipient's external iliac vein	1	

In children <1 year of age (n = 35), type I portal vein anastomosis could be performed in only 17% of cases, whereas type IV reconstruction was used in 37% of cases. In children >6 years (n = 28), type I anastomosis was done in 53% and type IV in 10% of cases. In children from 1 to 6 years (n = 47), type I reconstruction was performed in 32% and type IV in 31% of cases.

Complications After Portal Vein Reconstruction

Portal vein thrombosis occurred in two cases after type II anastomosis and in one case after type IV reconstruction with a vein graft of the donor's inferior mesenteric vein. Portal vein stenosis occurred in 1 case 6 months after transplantation using type I reconstruction (see Table 2).

Portal Vein Blood Flow

The portal vein blood flow of the 110 recipients was measured routinely by Doppler ultrasonography before, during, and after transplantation. Portal vein blood flow was hepatopetal in 68 cases and hepatofugal in 25 cases; in 8 cases, a to-and-fro pattern was found. In seven cases, Doppler ultrasonography failed to detect portal vein blood flow before surgery.

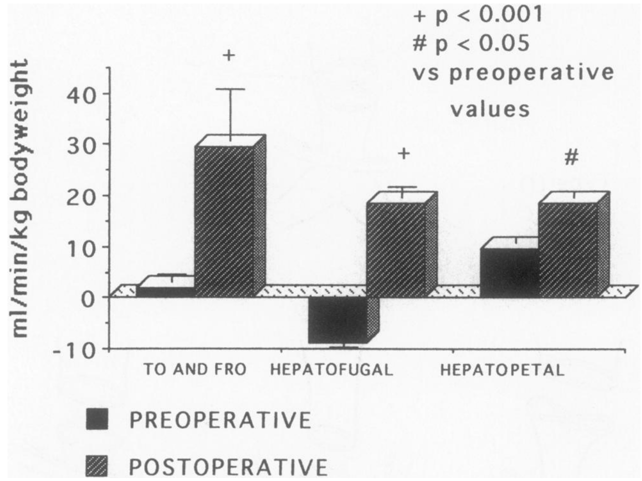

Figure 2. Portal vein blood flow increase after transplantation *versus* preoperative values.

Figure 2 shows portal vein blood flow before and after transplantation, directly after abdominal closure. In all cases, independent of preoperative blood flow direction, the portal vein flow increased after transplantation significantly compared to preoperative values: in cases with to-and-fro blood flow, from ±1.7 ± 1.47 to 29.5 ± 10 mL/min/kg ($p < 0.001$), in cases with hepatofugal flow from −9 ± 2 to 18.5 ± 2.1 mL/min/kg ($p < 0.001$), and in cases with hepatopetal flow from 9.8 ± 1.1 to 18.7 ± 1.2 mL/min/kg ($p < 0.05$).

Figure 3 shows portal vein blood flow after different types of portal vein reconstruction. After type II reconstruction, the portal vein flow was significantly lower (76.6 ± 8.4 mL/min/100 g liver; $p < 0.05$) than type I reconstruction (110 ± 14.3 mL/min/100 g liver). The portal blood flow after type III (88 ± 18 mL/min/100 g liver) and after type IV reconstruction (105 ± 19.5 mL/min/100 g liver) showed no significant differences.

Table 3. PORTAL VEIN DIAMETER AND PORTAL VEIN RECONSTRUCTION WITHIN DIFFERENT AGE GROUPS OF THE RECIPIENTS

	Group I	Group II	Group III
Age (yr)	<1	1–6	>6
Body weight (kg)	6.9 ± 0.5	10.5 ± 0.5	30.0 ± 2.2
Portal vein diameter (mm)	3.8 ± 0.2	4.2 ± 0.2	7.7 ± 0.7
n	35	47	28
Portal vein reconstruction [number (%)]			
Type I: end-to-end	6 (17)	15 (32)	15 (53)
Type II: branch patch	11 (31)	8 (17)	8 (28)
Type III: confluence	5 (14)	9 (19)	2 (7)
Type IV: vein graft	13 (37)	15 (31)	3 (10)

Pathology of the Recipient Portal Vein

The pathology of the recipient portal vein was analyzed in 35 consecutive cases of biliary atresia and Kasai's operation. Table 4 shows that in 80% of the cases (28 patients), the quality of the portal vein was altered. In only 20% of the cases (7 patients) were no remarkable changes of the portal found.

DISCUSSION

Different surgical modalities (reduced liver size, split-liver, and living related liver transplantation) for partial

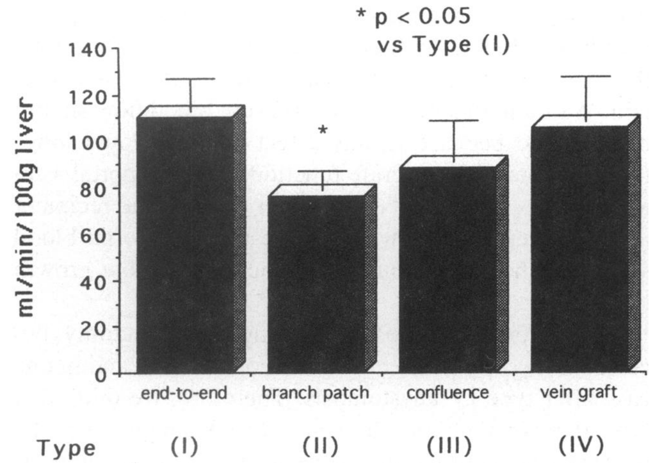

Figure 3. Portal vein blood flow after different types of reconstruction. Type II (branch patch) resulted in significantly (* $p < 0.05$) lower portal vein blood flow than type I (standard end-to-end anastomosis).

liver transplantation from adult donors have been described to overcome the shortage of organs for pediatric patients with end-stage liver disease.[17] One of the problems in partial liver transplantation is the impaired quality and the size difference of the graft vessels that must be anastomosed to the recipient's vascular structures. In regard to portal vein reconstruction, different types of anastomosis have been described in cases where end-to-end anastomosis of the graft portal vein and the recipient portal vein is impossible. Strong et al.[18] prefer to suture the graft portal vein to the bifurcation of the right and left branches of the recipient portal vein. Kalayoglu et al.[19] described the use of venoplasty of the graft portal vein to reduce the diameter of the graft vein. Broelsch et al.[11] and others[13,14] have used vein grafts from the donor's inferior mesenteric vein, saphenous vein, or iliac vein from cadaveric donors. Although the availability of vein grafts in living related liver transplantation is limited, we successfully used the left ovarian vein from maternal or the inferior mesenteric vein from paternal donors in all cases when a vein graft was needed. The recipient's infrarenal vena cava and the recipient's external iliac vein were used in one instance in the early stage of our transplantation program.

In this study, we analyzed the surgical pattern of portal vein reconstruction in a series of 110 partial liver transplantations from living donors performed at our institution. In this series, four different types of portal vein reconstruction were used: the allograft left portal vein was sutured in an end-to-end fashion to the recipient portal vein (type I); to the branch patches of the right and left portal bifurcation (type II); to the confluence of the recipient supramesenteric vein and splenic vein (type III); or to a vein graft interposed between the confluence of the recipient and the graft left portal vein (type IV).

The criteria for the use of each type of portal vein reconstruction were as follows (Table 5). If the recipient portal vein had a soft vessel wall, type I reconstruction was performed if the size was adequate (diameter > 4 mm), and type II reconstruction was done if the portal vein was too small (diameter < 4 mm). If the recipient portal vein was small in diameter and had a sclerotic wall, we performed type III reconstruction when the liver graft's portal vein was long enough to be anastomosed to the confluence. If the liver graft's portal vein was too short, we interposed a vein graft for type IV reconstruction. The factors that influenced our rationale for portal vein reconstruction are summarized in Table 6.

In only 32% of cases could the portal vein be con-

Table 4. PATHOLOGY OF THE NATIVE PORTAL VEIN IN 35 PEDIATRIC RECIPIENTS

Pathology	Number
Diagnosis: biliary atresia	35
Portal vein pathology	
Severe fibrosis	15
Mild fibrosis	4
Intima/wall thickness	9
No remarkable change	7

Table 5. CRITERIA FOR THE USE OF THE DIFFERENT TYPES OF PORTAL VEIN RECONSTRUCTION

	Recipient's Portal Vein		
Type	Diameter (mm)	Wall	Liver Graft's Portal Vein Length
I	>4	Soft	Sufficient
II	<4	Soft	Sufficient
III	<4	Sclerotic	Sufficient
IV	<4	Sclerotic	Short

Table 6. FACTORS THAT INFLUENCE PORTAL VEIN RECONSTRUCTION

Age/body weight of the recipient
Size mismatch
  Liver graft portal vein diameter
  Recipient portal vein diameter
Impaired native portal vein quality by
  Liver disease
  Previous operations

structed in an end-to-end fashion; 29% of cases required a vein graft. In children <1 year of age, type IV reconstruction was common (37% of cases) due to the small diameter of the recipient portal vein. In those cases, the standard end-to-end anastomosis could be performed in only a relatively small number of cases (17%). In general, we found that the frequency of the standard procedure increased with the age of the recipient. Our data show that the surgeon must be prepared to perform vein graft reconstruction more often when the recipient is <6 years old.

Aside from the recipient's age, the impairment of the recipient's portal vein quality is another factor that influences the choice of portal vein reconstruction method. We found pathologic changes of vessel quality in 80% of the 35 consecutive cases we investigated. This can be explained by the fact that in our series, the recipients had undergone an average of 1.9 (range 0–5) previous laparotomies (Kasai's operation or relaparotomies). Furthermore, in biliary atresia patients, portal vein sclerosis caused by cholangitis is common.

In our protocol, Doppler ultrasonography is routinely performed on the recipient before, during, and after liver transplantation. It was found to be helpful for real-time evaluation of the liver graft's blood supply during and after surgery and in the follow-up period. It also enabled us to determine the diameter of the recipient portal vein before surgery. When those data showed a native portal vein diameter of <4 mm, we prepared to harvest a vein graft from the donor. When Doppler sonography showed to-and-fro blood flow or hepatofugal blood flow in the portal trunk, during the operation we closed the spontaneous portosystemic shunts, resulting in hepatopetal blood flow in almost all cases.

Of the four different patterns of portal reconstruction we performed in our series, type II reconstruction showed a significantly lower postoperative portal vein blood flow compared to type I anastomosis; portal blood flow after type III anastomosis and type IV reconstruction showed no significant difference. This observation cannot be explained by different portal vein diameters in the reconstruction groups (mean portal vein diameter: type I, 6.4 ± 2.8 mm; type II, 4.2 ± 1.4 mm; type III, 3.8 ± 0.9 mm; type IV, 3.6 ± 0.9 mm). An alternative explanation could be that the recipient portal veins in reconstruction group type II were more fibrotic and sclerotic than in the other groups, so that anastomosis technique alone may not be responsible for the lower flow rates. Although portal blood flow is also influenced by other factors (*e.g.*, blood volume, portosystemic shunts), we think that anastomosis to the confluence of the superior mesenteric vein and splenic vein with or without the use of vein grafts provides the maximal blood flow to the liver graft due to a wider anastomosis diameter than in type II. On the other hand, no data concerning the optimal or necessary portal vein blood flow for sufficient graft function are available; therefore, the clinical relevance of this finding is uncertain. We think that maximal portal vein blood flow should be achieved because it may affect the short- and long-term outcome of the graft function. A wide portal vein anastomosis may also be important because the recipient and the liver graft grow over time, and the portal blood supply to the graft should be sufficient to allow growth of the liver.

Portal vein thrombosis requiring thrombectomy occurred in two cases after type II reconstruction and in one case after type IV anastomosis. Therefore, we think that type II reconstruction has some disadvantages over the other reconstruction types we performed. During the postoperative follow-up period, we experienced one case of portal vein stenosis in an asymptomatic patient after type I reconstruction. This patient was successfully treated by percutaneous transhepatic balloon dilatation. The data show that the postoperative vascular complication rate, despite the small vessel diameter, is not higher than in adult liver transplantation, where, for example, portal vein thrombosis also occurs in 1% to 2% of cases.[20] On the donor side, no morbidity or mortality was seen from the harvesting of the unilateral ovarian vein in maternal donors or the inferior mesenteric vein in paternal donors.

CONCLUSIONS

From this analysis, we conclude that in living related liver transplantation for pediatric patients, the portal vein often cannot be reconstructed in the standard end-to-end fashion, especially in children <6 years of age. The operative tactic for portal vein reconstruction must be tailored to the recipient. If end-to-end reconstruction is impossible, anastomosis of the portal vein to the confluence of the superior mesenteric vein and the splenic vein, with or without the use of vein grafts, can be a safe alternative.

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