Transplant International

Transplant International ISSN 0934-0874

ORIGINAL ARTICLE

Diagnosis and treatment of pediatric patients with late-onset portal vein stenosis after living donor liver transplantation

Youichi Kawano,[1] Koichi Mizuta,[1] Yasuhiko Sugawara,[2] Satoshi Egami,[1] Shuji Hisikawa,[1] Yukihiro Sanada,[1] Takehito Fujiwara,[3] Yasunaru Sakuma,[3] Masanobu Hyodo,[3] Yoshiyuki Yoshida,[4] Yoshikazu Yasuda,[3] Eiji Sugimoto[4] and Hideo Kawarasaki[1]

1 Department of Transplant Surgery, Center for Molecular Medicine, Jichi Medical University, Tochigi, Japan
2 Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan
3 Department of Surgery, Center for Molecular Medicine, Jichi Medical University, Tochigi, Japan
4 Department of Radiology, Center for Molecular Medicine, Jichi Medical University, Tochigi, Japan

Keywords
complication, interventional radiology, living donor liver transplantation, pediatric, portal vein stenosis.

Correspondence
Youichi Kawano MD, Department of Transplant Surgery, Jichi Medical University, 3311-1 Yakushiji, Shimotsuke-shi, Tochigi 329-0498, Japan. Tel.: +81 285 58 7069; fax: +81 285 58 7069; e-mail: y-kawano@jichi.ac.jp

Received: 3 February 2009
Revision requested: 3 March 2009
Accepted: 3 July 2009

doi:10.1111/j.1432-2277.2009.00932.x

Summary

Portal vein stenosis (PVS) after living donor liver transplantation (LDLT) is a serious complication that can lead to graft failure. Few studies of the diagnosis and treatment of late-onset (≥3 months after liver transplantation) PVS have been reported. One hundred thirty-three pediatric (median age 7.6 years, range 1.3–26.8 years) LDLT recipients were studied. The patients were followed by Doppler ultrasound (every 3 months) and multidetector helical computed tomography (once a year). Twelve patients were diagnosed with late-onset PVS 0.5–6.9 years after LDLT. All cases were successfully treated with balloon dilatation. Five cases required multiple treatments. Early diagnosis of late-onset PVS and interventional radiology therapy treatment may prevent graft loss.

Introduction

The first successful living donor liver transplantation (LDLT) in was performed by Strong *et al.* in 1989 [1], and LDLT is now performed worldwide as an alternative to deceased liver transplantation for patients with end-stage liver failure. Late complications after LDLT can occur [2–4]. Among these complications, portal vein stenosis (PVS) is serious and may lead to graft failure. Moreover, delayed diagnosis and treatment of PVS may lead not only to graft failure, but also to hepatopulmonary syndrome or pulmonary hypertension, which makes re-transplantation difficult or impossible [4].

In most patients, PVS is diagnosed using imaging modalities such as ultrasonography (US) [5] and computed tomography (CT) [6], or based on clinical findings, such as symptoms of portal hypertension [7,8], or laboratory data, such as a low platelet count [4]. Interventional radiology (IVR), such as percutaneous transhepatic balloon dilatation, for PVS in pediatric patients after liver transplantation was first described by Raby *et al.* in 1991 [9]. This technique has markedly advanced the treatment of PVS because of its minimal invasiveness, low rate of complications, and high success rates, and good outcomes in LDLT [7,10,11]. Sometimes, however, the portal vein may already be completely occluded when first diagnosed and in this case it is difficult to salvage it using IVR [4,8].

The incidence of portal venous complications is higher in pediatric recipients than in adults [12] attributable to the small diameter of the portal vein, the intrinsically

short graft pedicles, or a size mismatch between the graft portal vein and the recipient's native portal vein. PVS is a complication that can manifest in the immediate perioperative period or even many years after liver transplantation [13], and the incidence of PVS is reported to be 3% after pediatric LDLT [4]. Portal vein thrombosis (PVT) can occur in the early or late stages after liver transplantation. The incidence of PVT is reported to be 4% after pediatric LDLT [4]. Ueda *et al.*[12] reported that portal vein complications that develop within 3 months after liver transplantation have a high mortality rate. Although perioperative portal vein complications are well covered in the literature [7,10,14–18], there are few reports of the diagnosis and treatment of late-onset PVS in pediatric recipients at an outpatient clinic [6,19].

In this study, we retrospectively reviewed our late-onset portal vein-stenotic pediatric LDLT recipients and evaluated the efficacy of our strategy for late-onset PVS in an attempt to diagnose it at an early stage using Doppler US and CT at regular intervals on pediatric LDLT recipients of our outpatient clinic.

Patients and methods

Patients

One hundred thirty-three pediatric LDLT recipients (47 males and 86 females; median age 7.6 years, range: 1.3–26.8 years) at the outpatient clinic, comprising 67 patients (71 transplantations) who had undergone LDLT in our department between May 2001 and September 2005, and 66 patients who had undergone LDLT at other facilities between June 1991 and September 2005, were retrospectively investigated. The median follow-up period of all the patients was 55 months (range 3–174 months). Indications for LDLT in these patients included biliary atresia ($n = 113$); Alagille syndrome ($n = 6$); cryptogenic cirrhosis ($n = 5$); metabolic disorders ($n = 3$); fulminant hepatic failure ($n = 2$); and Byler's disease, hepatoblastoma, cystic fibrosis, and congenital absence of the portal vein ($n = 1$ each).

Surgical technique for PV reconstruction

Our modalities for PV reconstruction were chosen according to the diameter, wall status, and length of the recipient PV and diameter and length of the graft PV. Direct anastomosis of the branch patch, trunk, or branch of the recipient PV and graft PV was performed without adjusting the vein graft to the diameter or length of the vessels when there were no stenotic changes in the recipient PV. When the recipient PV trunk was significantly stenotic, smaller than approximately 5 mm in diameter, the native PV trunk was removed and a vein graft obtained from the donor's ovarian vein, inferior mesenteric vein, middle colic vein, or splenic vein was interposed. Those anastomoses were performed with 6-0 absorbable monofilament sutures in continuous running fashion with growth factor and the method was not changed during this study. On the other hand, detectable portosystemic shunts were ligated until sufficient portal flow to the graft was confirmed by Doppler US during the transplant surgery.

Anticoagulant therapy after LDLT

Anticoagulant therapy after LDLT consisted of prostaglandin E1 (0.01 μg/kg/min) and a protease inhibitor (mesilate gabexate; 1 mg/kg/h) administered intravenously just after the operation for 7 days. Low-molecular heparin (50 units/kg/day) administration was started after confirming that there was no general bleeding tendency on postoperative day 1 or 2 and continued for approximately 14 days. Those anticoagulant drugs were administered according to the anticoagulant therapy after pediatric liver transplantation reported by Hashikura *et al.* [20]. Antithrombin-III concentrates was administered to maintain plasma antithrombin-III levels of at least 80% in plasma. The anticoagulant therapy was discontinued after 14 postoperative days in most patients and then no anticaoagulant agents was administered.

Diagnosis of PVS

Portal vein flow and velocity were monitored by Doppler US (SSD-400^R; ALOKA Co., Tokyo, Japan, once every 3 months) and the portal vein condition, such as patency and degree of stenosis, was monitored by multidetector helical CT (SOMATOM sensation 16^R, SIEMENS AG, Germany) once a year. These imaging studies were also performed when PVS was suspected based on clinical symptoms (abdominal distention, diarrhea, or tarry stools), and complementary to each other depending on the period during which PVS was suspected in the other images.

Portal vein stenosis was diagnosed based on one or more of the following findings: greater than 50% stenosis of the portal vein diameter at the most stenotic point compared with that of the prestenosis main trunk of the portal vein measured by US or CT; aggravated collateral pathways based on multiplanar reconstruction of multidetector helical CT images; portal vein diameter <3 mm with poststenotic dilatation of the intrahepatic portal vein; and mean velocity of <10 cm/s at the umbilical portion of the portal vein on Doppler US. PVS that developed 3 months or more after LDLT was defined as late-onset PVS in our study. We did not change the examination interval of the imaging studies using CT and

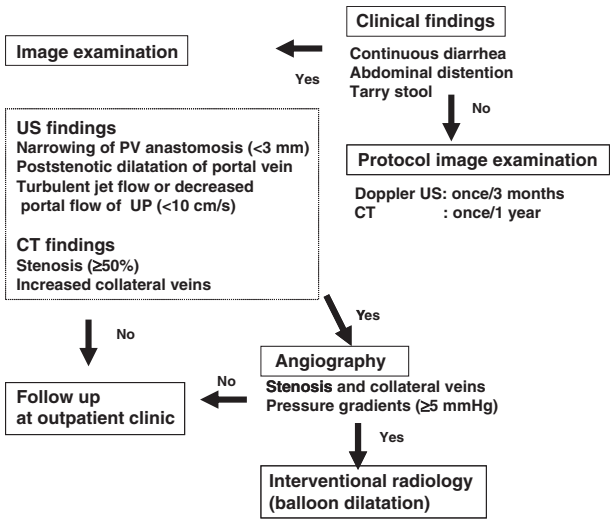

Figure 1 Strategy for late-onset PVS in our outpatient clinic. Angiography and/or balloon dilatation are performed as soon as clinical and image findings suggesting PVS are confirmed. US, ultrasound; PVS, portal vein stenosis.

US, or the criteria of PVS during the study period. Before August 2005, the criteria applied to IVR procedure focused somewhat on the appearance of symptoms of PVS, and the patients diagnosed with PVS based on the above-mentioned findings were followed up as candidates for IVR procedure. After August 2005, the criteria were strictly maintained, even if clinical symptoms did not appear, because repeated IVR was required for recurrent PVS in patients with clinical symptoms. The principal strategy, from diagnosis to IVR procedure of late-onset PVS after August 2005, is summarized in Fig. 1.

Portal vein angiography and IVR procedure

The umbilical portion of the portal vein was approached by direct percutaneous transhepatic puncture guided by US under general anesthesia, and a 6 or 7 Fr. sheath (Supersheath^{R}; Medikit Co., Tokyo, Japan) was inserted. After confirming stenosis of the portal vein and a pressure difference between the pre- and poststenotic lesion in portography, dilatation using a noncompliant balloon (Ultra-Thin Diamond^{R}; Boston Scientific Co., Watertown, MA, USA) was applied to the stenotic lesion. The size of the applied balloon was selected based on the portal vein diameter before the stenosis, i.e., balloon size was 100–125% the diameter of the portal vein. One-minute dilatation was repeated several times with a pressure of 4–12 mmHg until the notch of the stenotic lesion completely disappeared. After confirming successful dilation by portography, the sheath was removed, followed by compression hemostasis for 30 min.

Anticoagulant therapy after IVR for PVS

To prevent thrombus formation during dilatation, an intravenous bolus injection of 50 units/kg unfractionated heparin sodium was administered just before balloon dilatation, followed by additional continuous intravenous administration at 50 units/kg/h. After IVR, low-molecular-weight heparin sodium was administered at a dose of 100 units/kg/day for 3 days, after which the dose was gradually reduced to 50 units/kg/day, and then discontinued 5 days after IVR.

Before August 2005, only unfractionated heparin, not low-molecular-weight heparin sodium, was administered for postoperative anticoagulant therapy, but recently (after August 2005, Cases 10, 11, 12 and the 3rd IVR of Case 9) we changed the unfractionated heparin to low-molecular-weight heparin sodium, as also added warfarin potassium and aspirin to the regimen to prevent recurrent PVS. Warfarin potassium was initiated on the first post-IVR day at a dose of 0.1 mg/kg/day. The dose was then adjusted to maintain the international normalized ratio of prothrombin time between 1.5 and 2.0 [21] for 3 months. Aspirin therapy (2 mg/kg/day) was initiated on the first post-IVR day and continued for 3 months.

Statistical analysis

Values of measured variables were expressed as mean ± standard deviation, and comparisons between paired data were performed using the Wilcoxon signed-rank test using the statistical software DR. SPSS II (SPSS, Chicago, IL, USA). Differences were considered significant at a P-value of <0.05.

Results

Outcome

Among the 133 pediatric LDLT recipients at the outpatient clinic, 12 experienced late-onset PVS (12/133, 9.0%). The characteristics of these patients are summarized in Table 1. The graft types of those patients were the left lateral sector ($n = 9$) and the left liver ($n = 3$). Biliary atresia was the most frequent underlying disease (11 patients, 91.7%). Median age of the patients with late-onset PVS was 4.2 years (1.0–19.8 years). The median interval between LDLT and IVR was 1.5 years (range 0.5–6.9 years).

Portal vein stenosis was confirmed by US and/or CT in all patients with obvious stenosis; among those, decreased portal velocity was detected in six patients, and aggravated collateral pathways were detected in five patients (some patients were included in both groups, Table 1). Nine patients (45%) presented with tarry stool, and

another two patients developed symptoms of either diarrhea or abdominal distention. Since the introduction of our strategy after August 2005, summarized in Fig. 1 (Cases 10, 11, 12), no patient has developed clinical symptoms prior to the diagnosis of late-onset PVS by radiologic findings.

As expected, the two splenectomized patients had particularly high platelet counts (mean ± SD 41.7 ± $10.5 \times 10^4/\mu l$). When these counts were excluded from the evaluation, however, the mean platelet count at the diagnosis of PVS in the remaining 10 patients was $14.0 \pm 3.9 \times 10^4/\mu l$ (normal range in our institution: $13.0–36.9 \times 10^4/\mu l$). None of the 12 patients experienced portal vein thrombus before and after LDLT. Late-onset PVS was observed in two out of seven patients who underwent simultaneous splenectomy at the time of LDLT and in one out of seven patients udnergoing portal vein reconstruction with an interposition graft, but the incidence was not statistically significant.

IVR findings

In these 12 patients, IVR was performed a total of 20 times. Neither bleeding nor other complications associated with IVR were observed in our series. Balloon dilatation was required only once in seven patients, twice in two patients, and three times in three patients. In patients that required repeated balloon dilatation, the median interval between each procedure was 40.5 days (14–839 days, Table 1). Complete occlusion was not encountered in any case, and all PVS patients were successfully treated with IVR, requiring no surgical revision. To date, we have not performed any stent placements, and none of the grafts have failed. All patients were free from clinical signs and recurrence of PVS during our study period with a median follow-up period of 55 months (range 3–174 months).

Portal venous velocity was 17.5 ± 11.1 cm/s pre-IVR and 34.4 ± 14.7 cm/s post-IVR, which indicated a significant increase in portal velocity after IVR ($P < 0.001$). Portal venous velocity decreased below 10 cm/s in six patients. The prestenotic portal venous pressure was 7.2 ± 3.8 mmHg higher than the poststenotic portal venous pressure, but no difference was observed in Cases 7, 8, and 11, in which apparent collateral pathway formation was confirmed in CT findings. The diameter of the stenotic portal vein was 2.4 ± 1.1 mm.

Former PVS patients with anticoagulant therapy including only unfractionated heparin (Cases 1–8, and first and second IVRs of Case 9) frequently developed recurrent PVS, which necessitated repeated balloon dilatation, but after the introduction of combined anticoagulant therapy with low-molecular-weight heparin sodium, warfarin potassium, and aspirin, there were no PVS recurrences (third IVR of Case 9, and Cases 10–12). No adverse effects of the anticoagulant drugs were experienced.

Discussion

One of the major and devastating complications of PVS is PVT. Although, the rates of those complications are not very frequent, they can be serious and lead to graft failure. Buell *et al.* [6] reported that the incidence of PV complications was higher in LDLT compared with that in reduced and split-liver transplantation or in whole liver transplantation from a deceased donor. Therefore, the diagnosis and treatment of those complications is essential after pediatric LDLT.

Late-onset PVS is caused by fibrous and organic thrombus and fibrous hyperplasia of new intima [15]; therefore, to prevent turbulent portal vein blood flow, it is extremely important that the anastomosis is performed meticulously with consistent diameters and without twisting. On the other hand, because risk factors that predispose a patient to portal vein complications include decreased portal vein inflow and the presence of portosystemic shunts before transplantation [22], we also regard pre-existing portosystemic shunts as important factors influencing post-LDLT complications. We can detect pre-existing portosystemic shunts in the recipient by pretransplant CT and US findings. In our patients, detectable portosystemic shunts were ligated until sufficient portal flow to the graft could be confirmed by Doppler US during the transplant surgery. After LDLT, protocol Doppler US was performed at least twice every day for 2 weeks to confirm the direction and amount of portal vein flow. Once PVS occurs, however, prompt diagnosis and treatment without delay is crucial to avoid complete occlusion or subsequent graft failure.

Portal vein anastomosis is technically challenging because the graft portal venous segment is short and necessitates the use of an interposition graft. These grafts significantly increase the risk of portal vein complications [6]. When the recipient PV trunk was significantly stenotic, and approximately smaller than 5 mm in diameter in our pediatric LDLT recipients, the native PV trunk was removed and a vein graft was interposed. The vein graft was obtained from the donor's ovarian vein and inferior mesenteric vein in most procedures. In two procedures, however, we obtained the middle colic vein or splenic vein for use as an interposing vein graft (one case each), because we could not otherwise obtain vessels with an adequate diameter and length to graft to the portal vein in those patients. We carefully observed those donors using a fiberscope and CT. The donors are both doing

Table 1. Patient profiles of late-onset PVS.

No	Age/gender	Indication	Graft type	Days after LT	Image findings	Symptoms	Platelet count ($\times 10^4/mm^2$)	Portal venous velocity (cm/s)		Pressure gradient (mmHg)		Stenosis (mm)	Outcome
								Pre-IVR	Post-IVR	Pre-IVR	Post-IVR		
1	2 Years 2 months/F	Alagille	Lt.lat. sector	184	US:Stenosis, PV velocity↓ CT:Stenosis	Liver dysfunction	15.7	10.3	13.9	–	–	1	Alive
				198	US:Stenosis	None	16.1	16.8	17.4	9	2	–	
				226	US:Stenosis	Tarry stool	8.1	19.1	45.3	6	2	2	
2	2 Years/F	BA	Lt.lat. sector	261	US:PSD, PV velocity↓ CT:Stenosis, Collateral vein	Tarry stool	12.4	6.1	18.7	13	3	2	Alive
				275	US:Stenosis	None	12.8	16.6	39.4	9	3	2	
				1114	US:Stenosis CT:Stenosis, Collateral vein	No symptoms	15.5	13.4	26.6	8	1	2.2	
3	4 Years 3 months/F	BA	Lt.lat. sector	553	US:PSD,PV velocity↓ CT:Stenosis	Tarry stool	10.3	8.9	42.6	5	3	3	Alive
				567	US:PSD, PV velocity↓	Tarry stool	12.4	11.2	34.6	6	4	2	
4	7 Years 7 months/M	BA	Lt.lat. sector	2134	US:PSD CT:Stenosis	Tarry stool	15.3	20.7	37.4	12	2	0.5	Alive
5	1 Year 8 months/F	BA	Lt.lat. sector	284	US:Stenosis, PV velocity↓ CT:Stenosis, Collateral vein	Diarrhea	14.2	9.1	33.7	–	–	0.5	Alive
6	7 Years 5 months/F	BA	Lt.lat. sector	1778	US:PSD, PV velocity↓ CT:Stenosis	Abdominal distention	17.5	6.3	16.1	6	2	3	Alive
				1925	US:Stenosis CT:Stenosis	None	17.2	17.8	18.8	5	2	3	
7	1 Year/M	BA	Lt.lat. sector	742	US:PSD CT:Stenosis, Collateral vein	None	11.8	36.3	52.9	1	0	4	Alive
8	4 Years 2 months/M	BA	Lt.lat. sector	693	US:PSD CT:Stenosis	Tarry stool	9.9	13.8	39.9	1	0	3	Alive
9	8 Years 5 months/F	BA	Lt. liver	518	US:Stenosis, PV velocity↓ CT:Stenosis	Tarry stool	36.9	4.4	16.9	8	1	2	Alive
				571	US:PSD CT:Stenosis	Tarry stool	41.4	24.8	41.1	10	4	4	
				819	US:Stenosis CT:Stenosis	Tarry stool	56.4	13.6	31.8	12	0	2.2	
10	8 Years 1 month/F	BA	Lt. liver	1008	US:Stenosis CT:Stenosis	None	32.2	36.8	54.8	10	5	2	Alive
11	19 Years 9 months/F	BA	Lt. liver	2534	US:PSD CT:Stenosis, Collateral vein	None	9.9	17.3	37	0	0	4	Alive
12	2 Years/M	BA	Lt.lat. sector	357	US:PSD CT:Stenosis	None	9.9	46.2	68.3	8	1	3.9	Alive

LT, liver transplantation; IVR, interventional radiology; BA, biliary atresia; US, ultrasound; PV, portal vein; PSD, poststenotic dilatation; – data not available.

well and there have been no abnormal findings or complications. Late-onset PVS was observed in one out of seven patients undergoing portal vein reconstruction with an interposition graft, but the increase in incidence was not statistically significant.

Although clinical symptoms, such as splenomegaly, liver dysfunction, and tarry stools [4] might be helpful for diagnosing PVS, these symptoms usually develop in the late stage of PVS, at which time IVR might be difficult or impossible. Ueda *et al.* [4] reported that a low platelet count (below the normal range at their admission stage itself) was observed in all patients with late-onset PVS. This was not the case, however, in our study. Platelet count is not helpful in splenectomized recipients and thrombocytopenia may develop after liver transplantation in association with other factors, such as infection [23], rejection [24], and hematologic disorders [25].

Ultrasonography and CT findings might be the most reliable and most sensitive diagnostic tests for the early diagnosis of PVS. Three-dimensional multidetector helical CT is useful for detecting vascular complications after liver transplantation [6,26,27]. Although the procedure requires an experienced technician and sometimes the results are poor because of the patient's general condition, Doppler US examination is also a useful and noninvasive modality for detecting vascular complications [5,28–30]. Indeed, periodic Doppler US and multidetector helical CT in recent procedures have led to the diagnosis of late-onset PVS prior to the development of clinical symptoms or complete portal vein occlusion, allowing us to avoid graft or patient loss attributable to PVS.

Once late-onset PVS has developed, IVR should be performed without delay, as it is essential for a definite diagnosis and effective treatment of PVS [10,15,18]. In our study, before August 2005, although we did not experience complete obstruction and could conduct IVR procedure without surgical treatment in all cases, frequently PVS recurrences were experienced. In consideration of these findings, we concluded that it was necessary to change the criteria for applying the IVR procedure. After August 2005, we changed the principal strategy from diagnosis to IVR procedure of late-onset PVS, summarized in Fig. 1, and did not experience a recurrence of PVS after IVR. This satisfactory result seemed to be enhanced by our strategy for monitoring PVS, which included periodic imaging examinations and adequate diagnostic criteria. On the other hand, one issue requiring caution in our image examinations is radiation exposure by CT. We are well aware of this concern relating to children undergoing radiologic investigations, especially in pediatric liver transplant recipients who will require a life-long follow up. In our department, CT was applied for periodic imaging examination, because CT is readily available, can be performed quickly, obtains sharp images, etc. Because a decade ago, patients undergoing magnetic resonance angiography (MRA) were required to hold their breath and keep quiet for prolonged periods of time during the examination to obtain a clear image, these techniques were difficult to apply in pediatric patients, especially in infants and young children [31]. Recently, with the advent of high-performance gradients, fast magnetic resonance scanning imaging protocols can now be performed with a single breath-hold, even in pediatric patients after liver transplantation [32]. MRA has many advantages over CT angiography, such as noninvasiveness, the lack of a need for iodinated contrast agents, and multiplanar capability, which allows for imaging in coronal, sagittal, or other planes, we advocate the use of this modality for the follow-up of pediatric liver transplant recipients [32,33] and converting CT to MRA for our periodic imaging examination is currently under consideration.

Frequent recurrence of PVS after balloon dilatation is a major problem [18,19,34]. Anticoagulant therapy after IVR for PVS is important for preventing short-term recurrence, but there is currently no established regimen for the prevention of PVT formation after balloon dilatation. In our experience, 16 IVR procedures were conducted in nine patients in the earlier cases (Cases 1–8, and first and second IVRs of Case 9), that is, five patients required more than one balloon dilatation (55.6%). Then, we applied conventional anticoagulant therapy using the three-drug regimen, low-molecular-weight heparin, warfarin, and aspirin, which has proved to be effective for the prevention of recurrent venous thromboembolism [21] and re-occlusion after coronary intervention [35]. The introduction of the anticoagulant regimen abolished the incidence of recurrent PVS in our study and enabled us to manage all of our patients without complications, such as puncture-site bleeding, after the procedure. Although the three-drug anticoagulant therapy may be effective for preventing the recurrence of PVS, it may also be that the early treatment for PVS based on our sequential strategy is effective, because three out of four patients on the anticoagulant therapy underwent balloon dilatation before developing clinical symptoms, such as tarry stool.

Although PVT after liver transplantation is a rare event with a reported incidence between 1% and 4% [4,36–38], it is an agonizing complication that may lead to acute graft failure. Technical complications, a small diameter of the portal vein, history of pre-liver transplantation PVT, surgical shunt operation before liver transplantation, use of cryopreserved vein grafts for portal vein reconstruction, and splenectomy are known risk factors for the development of PVT [15,36]. Clinical symptoms include emerging ascites, variceal bleeding, elevated values on

hepatic function tests, splenomegaly, and lower extremity edema [6,13]. For imaging-based diagnosis, PVT may appear as anechoic and imperceptible on gray-scale on US, as the lack of detectable flow within the portal vein on Doppler US, and as a low-attenuation filling defect with cavernous formation around the thrombus on enhanced CT [38,39]. Treatment of PVT may include mechanical thromboectomy, segmental portal vein resection, percutaneous thrombolysis and stent placement, or balloon angioplasty [13,40,41]. Although, fortunately none of the patients in our experience developed PVT after LDLT, an early diagnosis of PVT before formation of a complete thrombus would be important. Our strategy of periodic imaging examination for liver transplant recipient is expected to be able to detect early-stage PVT, and when partial PVT was diagnosed in our patients, we planned to administer warfarin potassium at a dose of 0.1 mg/kg/day, initially.

The management of recurrent PVS is another problem of IVR. Although successful stent placement for recurrent PVS in liver transplant recipients has been reported [19,31], patient growth and the possibility of future re-transplantation made us reluctant to perform this procedure in our pediatric recipients. Fortunately, we have managed to salvage at-risk grafts by repeated balloon dilation without surgical revision, stent placement, or re-transplantation, but the optimal strategy for recurrent PVS remains to be determined.

Conclusion

Our findings of a 9% incidence of late-onset PVS without complete occlusion and graft loss demonstrate the efficacy of our strategy for diagnosing and treating late-onset PVS using periodic Doppler US and multidetector CT at an outpatient clinic. The optimal treatment for recurrent PVS after IVR, however, remains to be determined.

Authorship

YK, KM and YS: study organization and paper writing. SE, SH, YS, TF, YS, MH and YY: study performing. YY, ES and HK: supervisors.

References

1. Strong RW, Lynch SV, Ong TH, *et al.* Successful liver transplantation from a living donor to her son. *N Engl J Med* 1990; **322**: 1505.
2. Yamanaka J, Lynch SV, Ong TH, *et al.* Surgical complications and long-term outcome in pediatric liver transplantation. *Hepatogastroenterology* 2000; **47**: 1371.
3. Lo CM. Complications and long-term outcome of living liver donors: a survey of 1,508 cases in five Asian centers. *Transplantation* 2003; **75**: S12.
4. Ueda M, Egawa H, Ogawa K, *et al.* Portal vein complications in the long-term course after pediatric living donor liver transplantation. *Transplant Proc* 2005; **37**: 1138.
5. Lee J, Ben-Ami T, Yousefzadeh D, *et al.* Extrahepatic portal vein stenosis in recipients of living-donor allografts: Doppler sonography. *Am J Roentgenol* 1996; **167**: 85.
6. Buell JF, Funaki B, Cronin DC, *et al.* Long-term venous complications after full-size and segmental pediatric liver transplantation. *Ann Surg* 2002; **236**: 658.
7. Cheng YF, Chen CL, Huang TL, *et al.* 3DCT angiography for detection of vascular complications in pediatric liver transplantation. *Liver Transpl* 2004; **10**: 248.
8. Funaki B, Rosenblum JD, Leef JA, *et al.* Portal vein stenosis in children with segmental liver transplants: treatment with percutaneous transhepatic venoplasty. *Am J Roentgenol* 1995; **165**: 161.
9. Raby N, Karani J, Thomas S, *et al.* Stenoses of vascular anastomoses after hepatic transplantation: treatment with balloon angioplasty. *Am J Roentgenol* 1991; **157**: 167.
10. Settmacher U, Nussler NC, Glanemann M, *et al.* Venous complications after orthotopic liver transplantation. *Clin Transplant* 2000; **14**: 235.
11. Funaki B, Rosenblum JD, Leef JA, *et al.* Percutaneous treatment of portal venous stenosis in children and adolescents with segmental hepatic transplants: long-term results. *Radiology* 2000; **215**: 147.
12. Ueda M, Oike F, Kasahara M, *et al.* Portal vein complications in pediatric living donor liver transplantation using left-side grafts. *Am J Transplant* 2008; **8**: 2097.
13. Woo DH, Laberge JM, Gordon RL, *et al.* Management of portal venous complications after liver transplantation. *Tefh Vasc Interv Radiol* 2007; **10**: 233.
14. Cheng YF, Chen YS, Huang TL, *et al.* Interventional radiologic procedures in liver transplantation. *Transpl Int* 2001; **14**: 223.
15. Millis JM, Seaman DS, Piper JB, *et al.* Portal vein thrombosis and stenosis in pediatric liver transplantation. *Transplantation* 1996; **62**: 748.
16. Zajko AB, Sheng R, Bron K, *et al.* Percutaneous transluminal angioplasty of venous anastomotic stenoses complicating liver transplantation: intermediate-term results. *J Vasc Interv Radiol* 1994; **5**: 121.
17. Chardot C, Herrera JM, Debray D, *et al.* Portal vein complications after liver transplantation for biliary atresia. *Liver Transpl Surg* 1997; **3**: 351.
18. Park KB, Choo SW, Do YS, *et al.* Percutaneous angioplasty of portal vein stenosis that complicates liver transplantation: the mid-term therapeutic results. *Korean J Radiol* 2005; **6**: 161.
19. Shibata T, Itoh K, Kubo T, *et al.* Percutaneous transhepatic balloon dilation of portal venous stenosis in patients

with living donor liver transplantation. *Radiology* 2005; **235**: 1078.
20. Hashikura Y, Kawasaki S, Okumura N, *et al.* Prevention of hepatic artery thrombosis in pediatric liver transplantation. *Transplantation* 1995; **60**: 1109.
21. Ridker PM, Goldhaber SZ, Danielson E, *et al.* Long-term, low-intensity warfarin therapy for the prevention of recurrent venous thromboembolism. *N Engl J Med* 2003; **348**: 1425.
22. Lerut J, Tzakis AG, Bron K, *et al.* Complications of venous reconstruction in human orthotopic liver transplantation. *Ann Surg* 1987; **205**: 404.
23. Chang FY, Singh N, Gayowski T, *et al.* Thrombocytopenia in liver transplant recipients: predictors, impact on fungal infections, and role of endogenous thrombopoietin. *Transplantation* 2000; **69**: 70.
24. Chatzipetrou MA, Tsaroucha AK, Weppler D, *et al.* Thrombocytopenia after liver transplantation. *Transplantation* 1999; **67**: 702.
25. Tamura S, Sugawara Y, Matsui Y, *et al.* Thrombotic microangiopathy in living-donor liver transplantation. *Transplantation* 2005; **80**: 169.
26. Katyal S, Oliver JH III, Buck DG, Federle MP. Detection of vascular complications after liver transplantation: early experience in multislice CT angiography with volume rendering. *Am J Roentgenol* 2000; **175**: 1735.
27. Brancatelli G, Katyal S, Federle MP, *et al.* Three-dimensional multislice helical computed tomography with the volume rendering technique in the detection of vascular complications after liver transplantation. *Transplantation* 2002; **73**: 237.
28. Nghiem HV, Tran K, Winter TC III, *et al.* Imaging of complications in liver transplantation. *Radiographics* 1996; **16**: 825.
29. Someda H, Moriyasu F, Fujimoto M, *et al.* Vascular complications in living related liver transplantation detected with intraoperative and postoperative Doppler US. *J Hepatol* 1995; **2**: 623.
30. Tamsel S, Demirpolat G, Killi R, *et al.* Vascular complications after liver transplantation: evaluation with Doppler US. *Abdom Imaging* 2007; **32**: 339.
31. Teo EL, Strouse PJ, Prince MR. Applications of magnetic resonance imaging and magnetic resonance angiography to evaluate the hepatic vasculature in the pediatric patient. *Pediatr Radiol* 1999; **15**: 103.
32. Chu WC, Yeung DT, Lee KH, *et al.* Feasibility of morphologic assessment of vascular and biliary anatomy in pediatric liver transplantation: all-in-one protocol with breath-hold magnetic resonance. *J Pediatr Surg* 2005; **40**: 1605.
33. Stafford-Johnson DB, Hamilton BH, Dong Q, *et al.* Vascular complications of liver transplantation: evaluation with gadolinium-enhanced MR angiography. *Radiology* 1998; **207**: 153.
34. Funaki B, Rosenblum JD, Leef JA, *et al.* Angioplasty treatment of portal vein stenosis in children with segmental liver transplants: mid-term results. *Am J Roentgenol* 1997; **169**: 551.
35. Brouwer MA, van den Bergh PJ, Aengevaeren WR, *et al.* Aspirin plus coumarin versus aspirin alone in the prevention of reocclusion after fibrinolysis for acute myocardial infarction: results of the Antithrombotics in the Prevention of Reocclusion In Coronary Thrombolysis (APRICOT)-2 Trial. *Circulation* 2002; **106**: 659.
36. Lerut J, Tzakis AG, Bron K, *et al.* Complications of venous reconstruction in human orthotopic liver transplantation. *Ann Surg* 1987; **205**: 404.
37. Langnas AN, Marujo W, Stratta RJ, *et al.* Vascular complications after orthotopic liver transplantation. *Am J Surg* 1991; **161**: 76.
38. Berrocal T, Parron M, Alvarez-Luque A, *et al.* Pediatric liver transplantation: a pictorial essay of early and late complications. *Radiographics* 2006; **26**: 1187.
39. Sobhonslidsuk A, Reddy KR. Portal vein thrombosis: a concise review. *Am J Gastroenterol* 2002; **97**: 535.
40. Holbert BL, Campbell WL, Skolnick ML. Evaluation of the transplanted liver and postoperative complications. *Radiol Clin North Am* 1995; **33**: 521.
41. Rossi C, Zambruni A, Ansaloni F, *et al.* Combined mechanical and pharmacologic thrombolysis for portal vein thrombosis in liver-graft recipients and in candidates for liver transplantation. *Transplantation* 2004; **78**: 938.