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ORIGINAL ARTICLE

Endovascular stent placement for venous complications following pediatric liver transplantation: outcomes and indications

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Abstract

Purpose Advances in interventional radiology (IVR) treatment have notably improved the prognosis of hepatic vein (HV) and portal vein (PV) complications following pediatric living donor liver transplantation (LDLT); however, graft failure may develop in refractory cases. Although endovascular stent placement is considered for recurrent stenosis, its indications are controversial.

Methods We enrolled 282 patients who underwent pediatric LDLT in our department from May 2001 to September 2016.

Results 22 (7.8%) HV complications occurred after LDLT. Recurrence was observed in 45.5% of the patients after the initial treatment, and 2 patients (9.1%) underwent endovascular stent placement. The stents were inserted at 8 months and 3.8 years following LDLT, respectively. After stent placement, both patients developed thrombotic obstruction and are currently being considered for re-transplantation. 40 (14.2%) PV complications occurred after LDLT. Recurrence occurred in 27.5% of the patients after the initial treatment, and 4 patients (10.0%) underwent endovascular stent treatment. The stents of all the patients remained patent, with an average patency duration of 41 months.

Conclusion Endovascular stent placement is an effective treatment for intractable PV complications following pediatric LDLT. However, endovascular stent placement for HV complications should be carefully performed because of the risk of intrastent thrombotic occlusion and the possibility of immunological venous injury.

Keywords Interventional radiology · Pediatric living donor liver transplantation · Stent placement · Venous complications

Abbreviations

AMR	Antibody-mediated rejection
AR	Acute rejection
CT	Computed tomography
GV/SLV	Graft volume/standard liver volume
GRWR	Graft to recipient weight ratio
HE	Hematoxylin and eosin
HV	Hepatic vein
HVOO	Hepatic vein outflow obstruction
IVR	Interventional radiology
LDLT	Living donor liver transplantation
OTCD	Ornithine-transcarbamylase deficiency
m/o	Month old
POD	Postoperative day
POM	Postoperative month
PV	Portal vein
SOS	Sinusoidal obstruction syndrome
VOD	Veno-occlusive disease
y/o	Year old

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Introduction

Pediatric living donor liver transplantation (LDLT), which often entails a size mismatch of the graft and blood vessels, has a higher risk of vascular complications than deceased donor liver transplantation (DDLT) [1]. Anastomotic

stenosis and thrombosis of the hepatic vein (HV) and portal vein (PV) may result in graft failure in refractory cases. Although endovascular treatment can be useful for vascular complications after LDLT, the indications for stent placement are controversial [2–4]. Herein, we present the outcomes of stent placement for intractable venous complications after pediatric LDLT in our department and discuss the optimal indications for this treatment.

Materials and methods

Patients

The subjects included 282 patients who underwent pediatric LDLT in our department from May 2001 to September 2016; their characteristics have been retrospectively summarized in Table 1. At the time of LDLT, the 108 males and 174 females had a median weight of 9.8 kg and a median age of 1.4 years. The original diseases included 200 cases of biliary atresia, 17 cases of ornithine-transcarbamylase deficiency (OTCD), 11 cases of graft failure, 11 cases of Alagille syndrome, 6 cases of acute liver failure, and 37 cases involving other diseases. The median observation period was 7.8 years. Approval to conduct this study was obtained from the Ethics Committees of Jichi Medical University (Ethics Committee Approval Case Number 15–106).

Definitions of HV and PV complications

HV and PV stenosis or thrombosis were defined as HV and PV complications. HV and PV complications were identified using blood tests, color-Doppler ultrasonography, and computed tomography (CT) examinations. Interventional radiology (IVR) treatment through the jugular vein, surgical re-anastomosis, surgical thrombectomy, and re-fixation under laparotomy were performed for HV complications, whereas IVR treatment through percutaneous transhepatic PV of the umbilical portion, surgical re-anastomosis, and surgical thrombectomy was performed for PV complications.

Table 1 Demographic data for pediatric liver transplant patients at our department

Period	May 2001–September 2016
Number of cases	282
Gender	Male 108, female 174
Body weight	9.8 kg (2.6–64.9)
Age at LDLT	1.4 years old (0.0–16.5)
Original disease	Biliary atresia, 200; ornithine transcarbamylase deficiency, 17; graft failure, 11; alagille syndrome, 11; acute liver failure, 6; other, 37
ABO-compatibility	Identical, 185; compatible, 48; incompatible, 49
Graft type	Left lateral segment, 197, left lobe, 55; left lobe + S1, 11; S2 mono segment, 13; reduced left lateral segment, 5; S3 mono segment, 1
Observation period	7.8 years (0.0–15.4)

LDLT living donor liver transplantation

Endovascular treatment procedures

Patients with multiple episodes of recurrence, recurrence within several months following the initial treatment, or when IVR treatment was predicted to be impossible at recurrence were defined as intractable cases. Endovascular stent placement was performed for such cases. Endovascular treatment was performed under general anesthesia in the operating room by radiologists.

For HV complications, a right internal jugular vein puncture was performed under ultrasonic guidance, and a sheath was inserted. Next, the guide wire was passed through the stenotic segment, and a catheter was inserted. Angiography was performed, and the HV pressure was measured proximal and distal to the stenosis. Balloon angioplasty was initiated under low pressure, and then higher pressures were used, depending on the pressure gradient and the circumstances of the constriction.

For PV complications, percutaneous transhepatic puncture of the umbilical portion was performed under ultrasound guidance, followed by sheath insertion. Next, a guide wire was passed through the stenosis, a catheter was inserted; portography was performed, and PV pressure was measured proximal and distal to the stenosis. Similar to the HV, the pressure was gradually increased from an initial low pressure.

Endovascular stent placement was performed by the radiologists for both the HV and the PV, in the same manner as balloon angioplasty. A balloon-expandable or self-expanding metallic stent was selected with a diameter based on the non-stenosed vessel diameters proximal and distal to the stenosis. In our institution, we do not use eluting balloon dilatations as an endovascular treatment. A stent of sufficient length to accommodate the stenotic segment was selected, and the position was adjusted to conform to an appropriate shape.

Post-IVR treatment anticoagulation therapy

For anticoagulation therapy after IVR treatment, low molecular weight heparin was administered beginning on postoperative day (POD) 0 at 100 units/kg/day and then gradually decreased until cessation on POD 4. Aspirin was administered starting on POD 1 at 2 mg/kg/day for 3 months after the IVR treatments, and warfarin was administered starting on POD 0 at 0.1 mg/kg/day for 6 months after the IVR treatments. Warfarin was permanently continued in the stent placement cases. The target value for warfarin was a prothrombin time-international normalized ratio of 1.5–2.0 [5].

Histopathological assessment of allografts in recipients with HV complications

We assessed the histopathological features of allografts in recipients with HV complications using hematoxylin–eosin, Azan, C4d and CD34 stains.

Results

HV complications in our department

Figure 1 shows the results of the treatments for HV complications in our department. HV complications after LDLT occurred in 22/282 (7.8%) cases. Surgical treatment was performed at an early period after LDLT, whereas IVR treatment was selected at a late period. For the initial treatment, endovascular balloon dilation was used in 18 patients, re-fixation under laparotomy in 2 patients, surgical thrombectomy in 1 patient, and re-anastomosis in 1 patient.

The recurrence rate after initial treatment was 45.5% (10/22 cases). After the initial IVR treatment, recurrence was observed in 7/18 patients, and re-recurrence occurred in 4/7 patients following re-IVR. One of these 4 patients received a re-transplantation due to graft failure. One patient developed thrombotic occlusion despite stent placement and became a re-transplantation candidate due to graft failure. The remaining 2 patients had subsequent recurrent HV stenosis and did not improve despite IVR treatment. One patient underwent IVR treatment eight times and stent placement twice; however, the patient became a re-transplantation candidate due to thrombotic obstruction. Another case was intractable, and IVR treatment was performed a total of 21 times. In total, 5 patients received a re-transplantation or were candidates for re-transplantation due to HV complications.

Endovascular stent placement was performed in 9.1% of the patients (2/22 patients), and the patency rate after stent placement was 0% (0/2 patients). The two HV stenting cases following LDLT in our department are shown in Table 2. The original diseases were biliary atresia after LDLT and OTCD. The patients received 1 and 8 IVR treatments before the stent placements, and the time to stent placement after LDLT was 8 months and 3.8 years, respectively. The average time from LDLT to stent placement was 2.3 years. The patent periods of the stents were 1.2 years and 1.5 years (the stent-in-stent procedure was performed

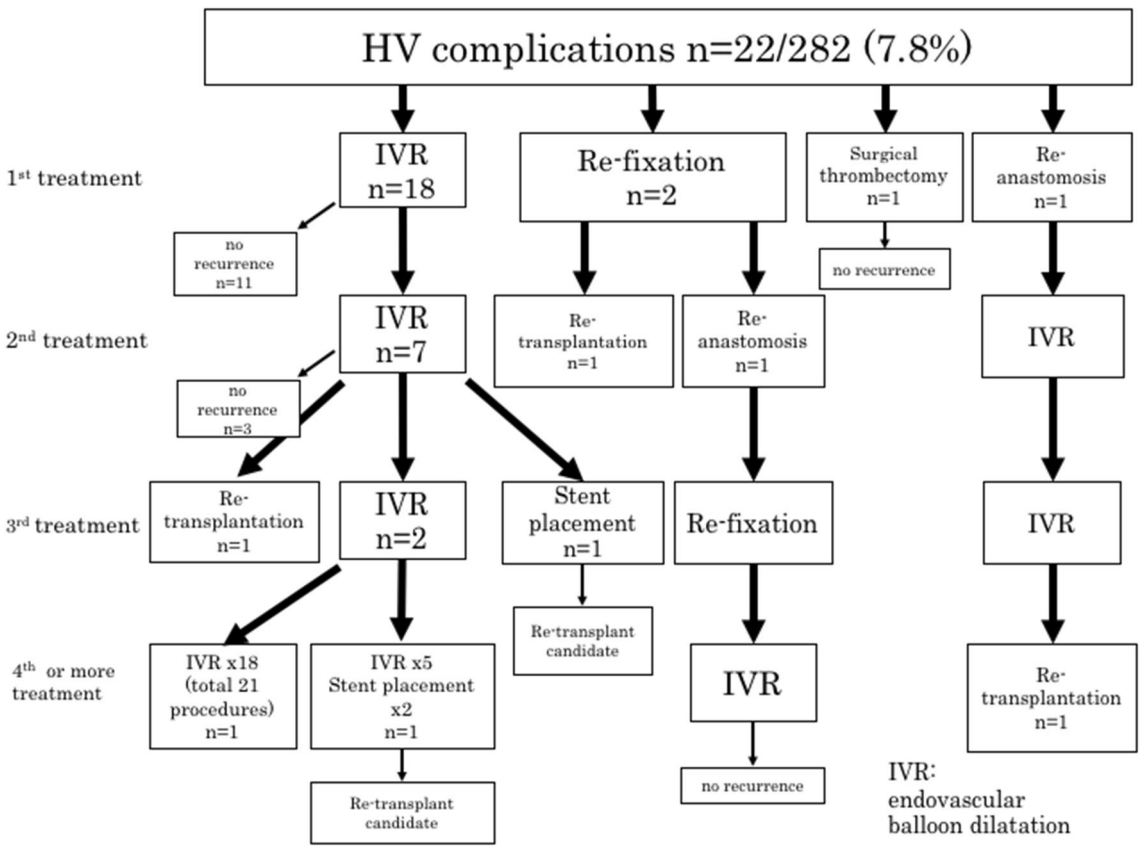

Fig. 1 The outcomes of treatments for HV complications in our department

Table 2 Cases of endovascular stent placement for venous complications

No	Original disease	Age at LDLT	Number of IVR treatment	Contents of IVR treatment	Periods between stent placement and LDLT	Outcomes	Stent patent period
Cases of HV complications							
1	Biliary atresia after LDLT	40 m/o	2	1st: balloon angioplasty 2nd: stent placement	8POM	Graft failure	14 months (thrombosis)
2	OTCD	11 m/o	10	1st–8th: balloon angioplasty 9th, 10th: stent placement	46POM	Graft failure	18 months (thrombosis)
Cases of PV complications							
1	Biliary atresia	7 m/o	3	1st, 2nd: balloon angioplasty 3rd: stent placement	7POM	No recurrence	6 months
	Biliary atresia	7 m/o	3	1st, 2nd: balloon angioplasty 3rd: stent placement	14POM	No recurrence	9 months
3	Biliary atresia	8 m/o	3	1st: thrombectomy 2nd: balloon angioplasty 3rd: stent placement	6POM	No recurrence	80 months
4	Biliary atresia	12 y/o	3	1st: IVR thrombectomy 2nd: balloon angioplasty 3rd: stent placement	35POM	No recurrence	68 months

LDLT living donor liver transplantation, *IVR* interventional radiology, *HV* hepatic vein, *PV* portal vein, *OTCD* ornithine-transcarbamylase deficiency, *m/o* month old, *y/o* year old, *POM* postoperative month

at 8 months). In both cases, graft failure resulted from thrombus occlusion within the stent, resulting in the need for re-transplantation.

Case presentation of intractable HV complication

We present a case of stent placement for HV complication in a 5-year-old boy with OTCD. At the age of 11 months, an ABO blood compatible LDLT was performed, with the father as the donor (graft volume/standard liver volume (GV/SLV): 76.9%, graft to recipient weight ratio (GRWR): 2.7%). HV stenosis was diagnosed 2 months after LDLT, and the patient experienced repeated recurrences, despite IVR treatment. A 10-mm × 25-mm stent (Express LD vascular stent®; Boston Scientific Corporation, Natick, MA, USA) was placed 3.8 years after LDLT following 8 subsequent IVR treatments (Fig. 2a, b). At 8 months following the stent placement (4.5 years after LDLT), ultrasonic examination showed a decrease in the HV blood flow (Fig. 2c). CT examination revealed stenosis distal to the stent. The blood flow improved when an 8-mm × 27-mm stent (Express LD vascular stent®) was placed in the stenosis distal to the previous stent (Fig. 2d). However, at 11 months after re-stent treatment, ultrasonography and enhanced CT showed thrombotic occlusion within the stent, and angiography revealed that only the collateral vessels were patent (Fig. 2e). Attempted thrombus aspiration under endovascular intervention failed. Because graft failure had ensued, the patient became a candidate for re-transplantation, and DDLT registration was pursued.

Histopathological findings in recipients with HV complications

One patient in our intractable HV complication group received a liver transplant twice and experienced graft failure after HV stent placement. The pathological image of the liver removed at the time of the re-transplantation (Fig. 3a–c) and liver biopsy after the re-transplantation (Fig. 3d–h) both confirmed the diagnosis of veno-occlusive disease (VOD) and sinusoidal obstruction syndrome (SOS). We thought that this case of VOD/SOS developed due to acute rejection (AR).

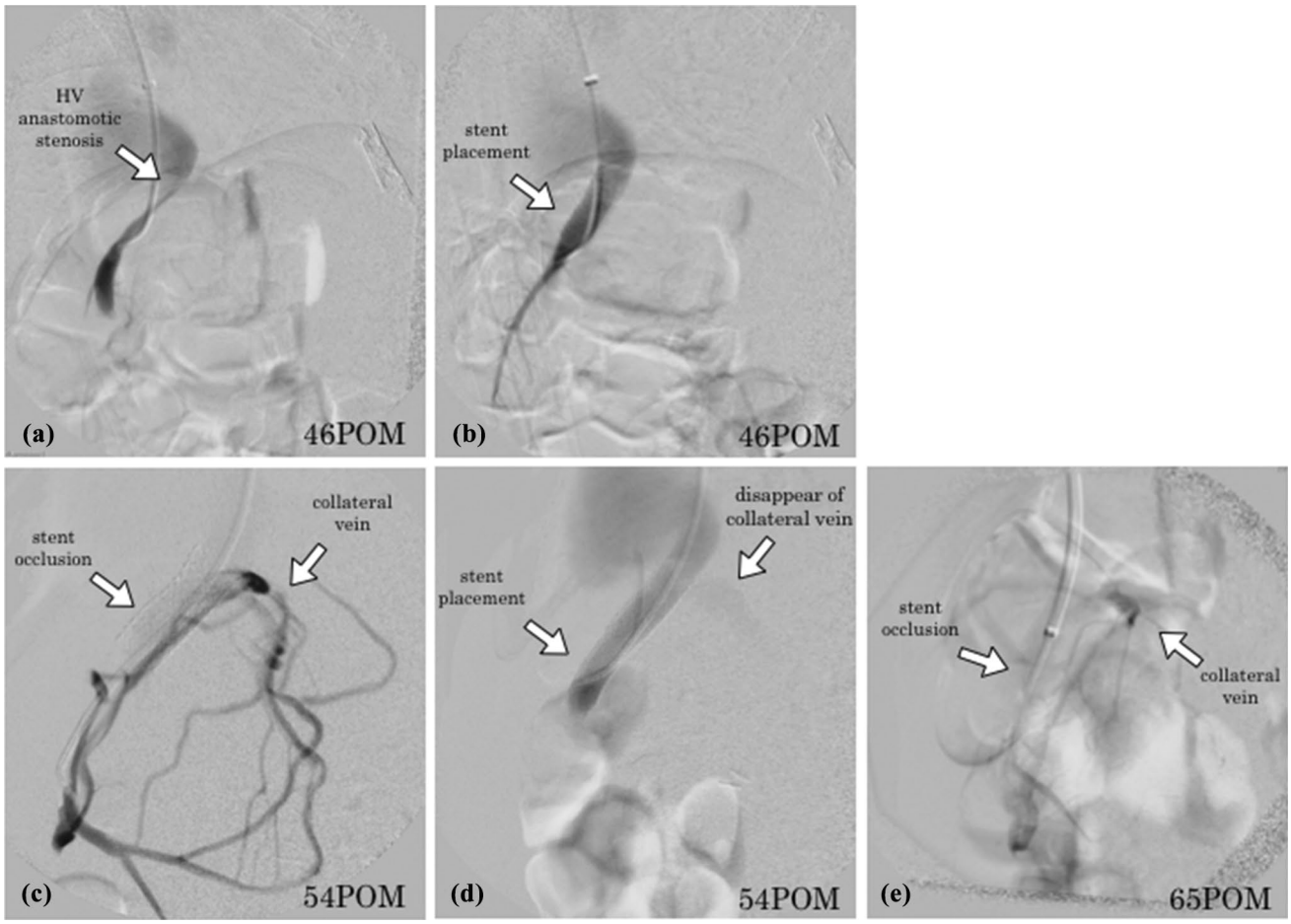

Fig. 2 A case of endovascular stent placement for HV complication. At the ninth IVR treatment (46 POM), anastomotic stenosis was found through intrahepatic angiography (**a**) to be refractory, and a stent was placed in the stenosis (**b**). In the tenth IVR, at 8 months after stent placement, stent obstruction was observed in the intrastent angiography **c**. A stent was placed on the distal side of the stent **d**. 11 months later, stent obstruction and development of collateral vein were observed in the intrastent angiography **e**. We could not perform effective treatment for the patient, and he became a re-transplantation candidate

Another patient with intractable HV complications showed positive HLA donor-specific antibodies (Luminex single-antigen assays). The pathological image of the liver biopsy before HV stenting (Fig. 4a–d) and liver biopsy after HV stenting (Fig. 4e–h) also showed CD34 expression in portal microvascular endothelial cells.

PV complications in our department

Figure 5 shows the results of treatments for PV complications in our department. PV complications after LDLT occurred in 40/282 (14.2%) cases. Surgical treatment was performed in an early period after LDLT, whereas IVR treatment was selected in a late period. For the initial treatment, endovascular balloon dilation was used in 38 patients, surgical thrombectomy in 1 patient, and surgical re-anastomosis in 1 patient.

The recurrence rate after the initial treatment was 27.5% (11/40 cases). One patient treated with surgical thrombectomy subsequently experienced recurrence, and a single IVR treatment was performed. However, a stent placement was performed in the patient following relapse, and there was no subsequent recurrence. Recurrence was observed in 8/38 patients receiving IVR treatment. Five of these eight patients experienced recurrence following re-IVR treatment. Two patients received further IVR treatment, whereas endovascular stent treatment was performed in 3 patients; no subsequent recurrences were observed for either of these latter two groups. Only one patient received a re-transplantation due to PV thrombosis; however, this patient died due to sepsis after re-transplantation.

Endovascular stent treatment was performed in 10.0% of the patients (4/40), and the patency rate of the stents was 100% (4/4 cases). The maximum number of IVR treatments performed in one case was 4. In our department, 4 patients

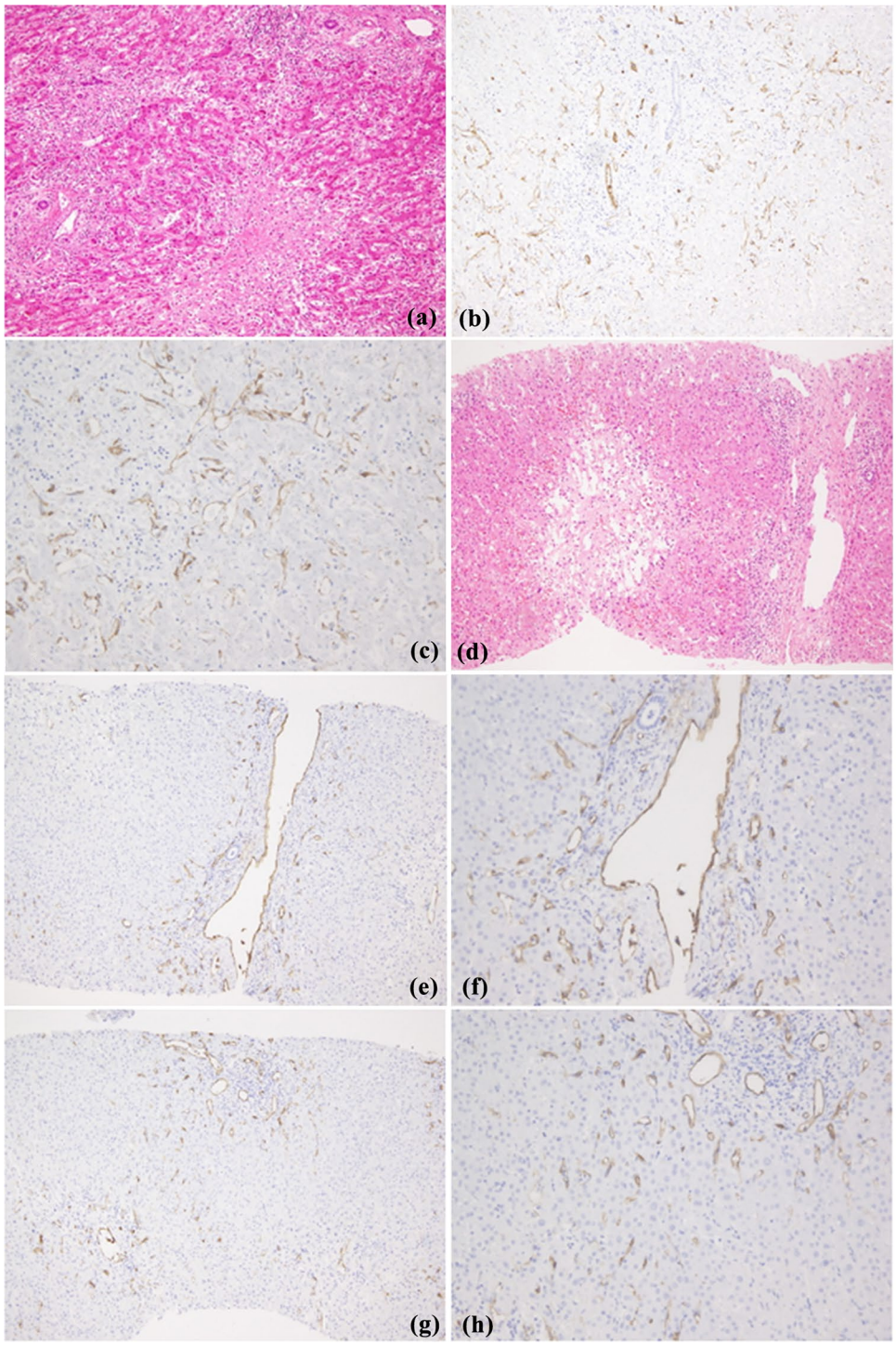

Fig. 3 Hematoxylin and eosin (HE) staining; fibrinoid necrosis suggesting outflow blockage/VOD is observed in centrilobular region (100×; **a**). CD34 immunostaining; CD34 expression is diffusely seen in portal microvascular endothelial cells and sinusoidal endothelial cells (100×; **b**/200×; **c**). HE staining; hepatocyte dropout suggesting outflow blockage/VOD is observed in the centrilobular region (100×; **d**). CD34 immunostaining; CD34 expression is predominantly seen in portal microvascular endothelial cells with extension into inlet venules and periportal sinusoids (100×; **e**/200×; **f**). CD34 expression in portal microvascular endothelial cells extends to the midzonal and centrizonal areas, suggesting sinusoidal capillarization (100×; **g**/200×; **h**)

underwent PV stent placement following LDLT, as shown in Table 2. The original disease in all patients was biliary atresia. In 3 of the 4 patients, IVR treatment was performed twice before the stent placement. One patient underwent a surgical thrombectomy and IVR treatment. The stent placement times following LDLT were 7 months, 14 months, 6 months, and 3 years, with an average of 16 months. Warfarin is permanently administered in the patients with stents, and all these stents remained patent. The patency periods of the stents were 6 months, 9 months, 6.7 years and 5.7 years, respectively, with an average of 41 months.

Cases of intractable PV complications

We present a case of stent placement for PV complication in a 15-year-old female with biliary atresia. At the age of

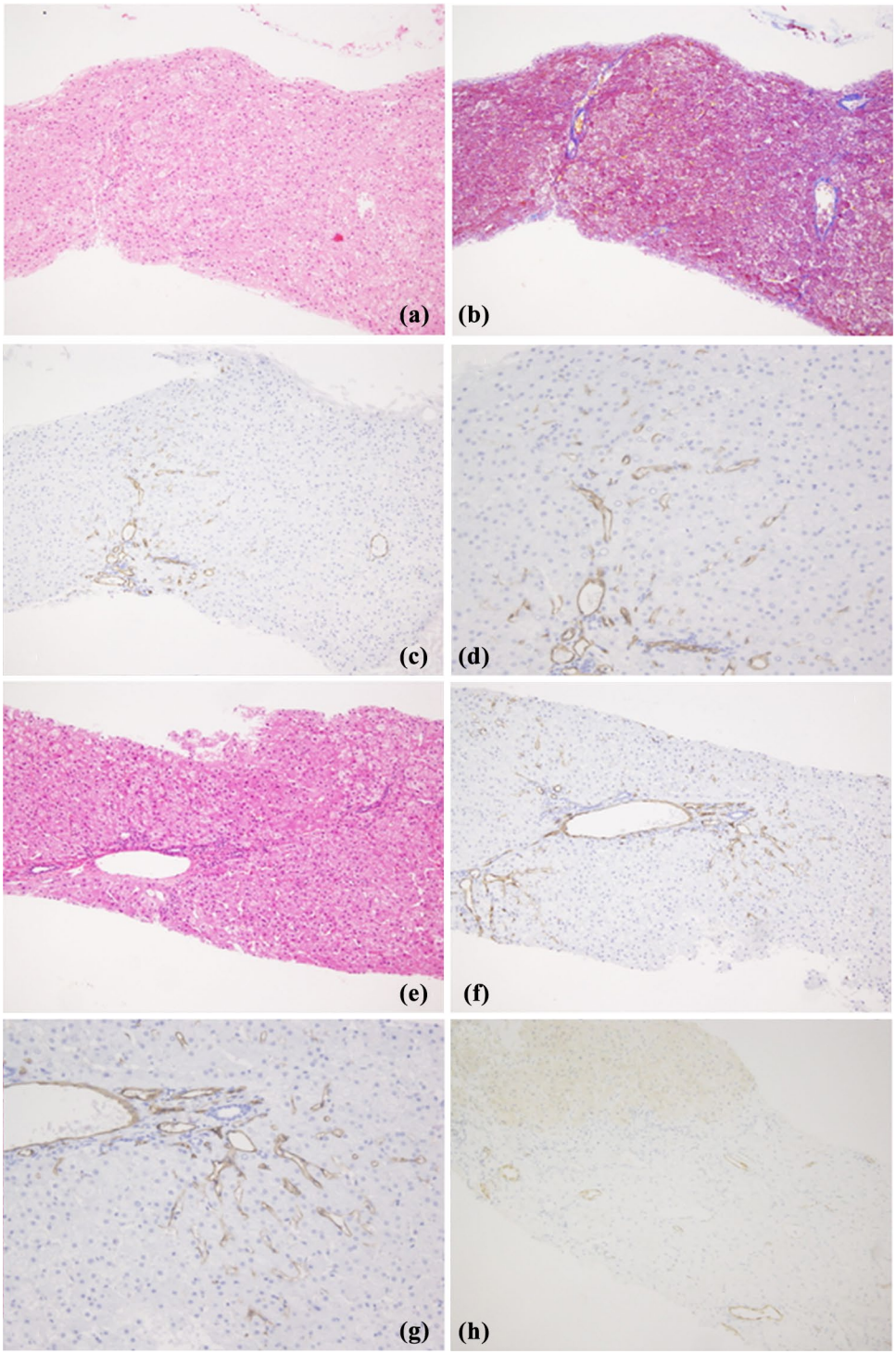

Fig. 4 HE staining (100×; **a**). Azan staining (100×; **b**). CD34 immunostaining; CD34 expression is predominantly seen in portal microvascular endothelial cells with extension into inlet venules and periportal sinusoids (100×; **c**/200×; **d**). HE staining (100×; **e**). CD34 immunostaining; CD34 expression is predominantly seen in portal microvascular endothelial cells with extension into inlet venules and periportal sinusoids (100**x**; **f**/200×; **g**). C4d staining; clear deposits can be observed in more than half of the portal veins (**h**)

12 years, an ABO blood identical LDLT was performed, with the mother as the donor (GV/SLV 38.4%, GRWR 0.9%). At 2 months after the LDLT, IVR treatment was performed for PV stenosis. Due to frequent recurrences, a 10-mm × 25-mm stent (Express LD vascular stent®) was placed 3 years after the LDLT (Fig. 6a–d. At 3.8 years and 5.9 years after the LDLT, balloon-occluded transfemoral obliteration was performed on the portosystemic shunt between the right ovarian vein and the superior mesenteric vein, after which blood flow improved. PV complications did not occur for 5.7 years after the stent placement.

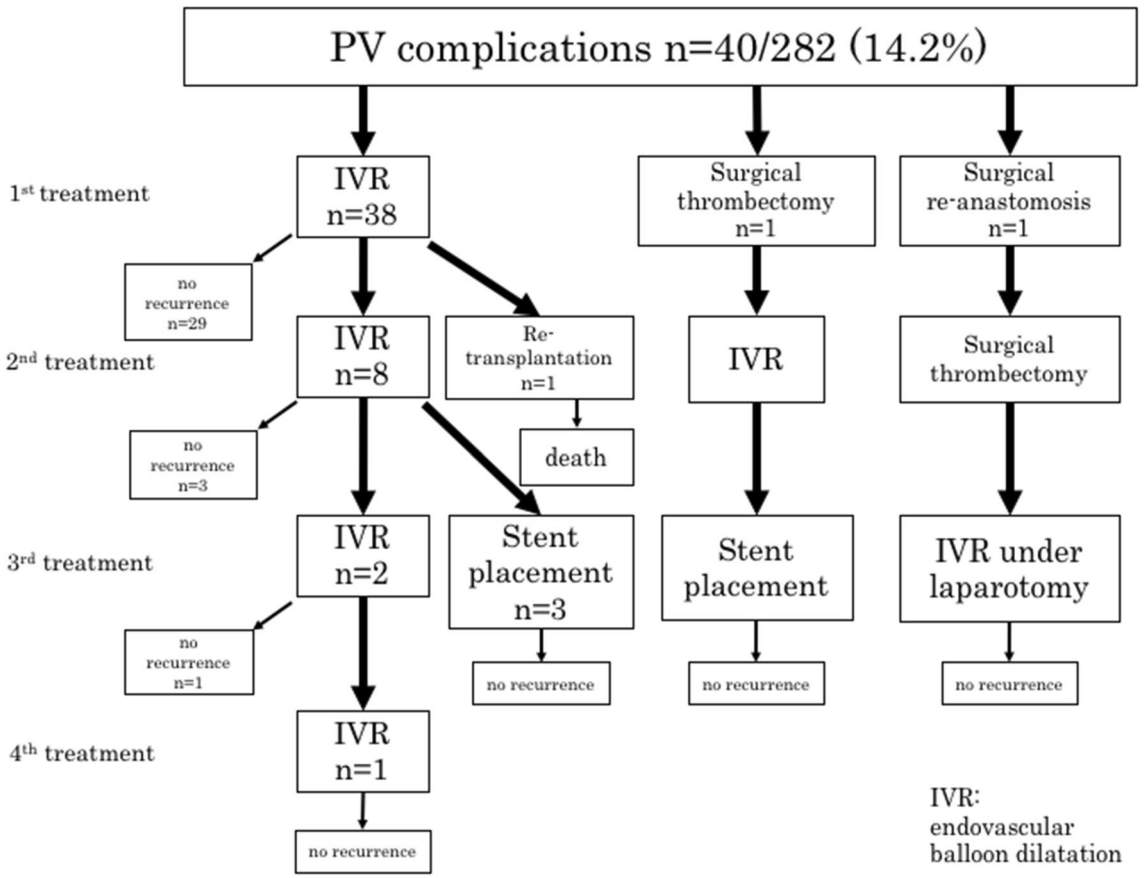

Fig. 5 The outcomes of treatments for PV complications in our department

Discussion

Endovascular balloon angioplasty has been considered effective for both HV and PV complications after pediatric LDLT [2–4]; however, the evaluation was inconclusive for endovascular stent placement. Choi JW et al. and Kitajima T et al. reported on the efficacy and safety of endovascular balloon dilation and stent placement for hepatic venous outflow obstruction (HVOO) after pediatric and adult LDLT [6, 7]. Cheng et al. [7] reported the effectiveness of endovascular stent treatment for PV stenosis and occlusion in adults and children. The patency rate of the stent was 90.9% over an average observation period of 12 months. PV occlusion with cavernous transformation of more than one year was considered a risk factor for treatment failure. Many reports have demonstrated the effectiveness of endovascular stent treatment for venous complications following transplantation (Table 3) [6, 8–12]. In contrast, other studies have expressed concerns regarding the side effects of stent treatment [2–4]. These side effects include the hyperplasia of the intimal membrane, a size mismatch, and interference at the time of re-transplantation, as well as the paucity of long-term stent outcomes, and the possibility of stent migration.

In our department, the incidence of PV complications after pediatric LDLT was 14.2%, which was higher than the incidence of HV complications (7.8%). The rate of re-transplantation and candidate re-transplantation due to HV complications was 22.7% (5/22 cases), whereas the re-transplantation rate due to PV complications was 2.5% (1/40). Although the incidence of HV complications was low, the outcomes were poor. Among the patients who underwent IVR treatment as a first-line treatment, 18 patients had HV complications and 38 experienced PV complications. In total, 77.8% (14/18) of the patients with HV complications and 89.5% (34/38) of the patients with PV complications were treatable with IVR treatment alone. The IVR treatment results for both HV and PV complications were generally considered to be good. The average time to stent placement for HV complications was 2.3 years, whereas the mean patency period of the stent was 1.3 years, and the ultimate patency rate of the stent was 0% (0/2 cases). These patients became candidates for re-transplantation. In contrast, the mean time to stent placement for PV complications was 11 months, with a mean patency period of the stent of 3.3 years and an ultimate patency rate of the stent of 100% (4/4 cases).

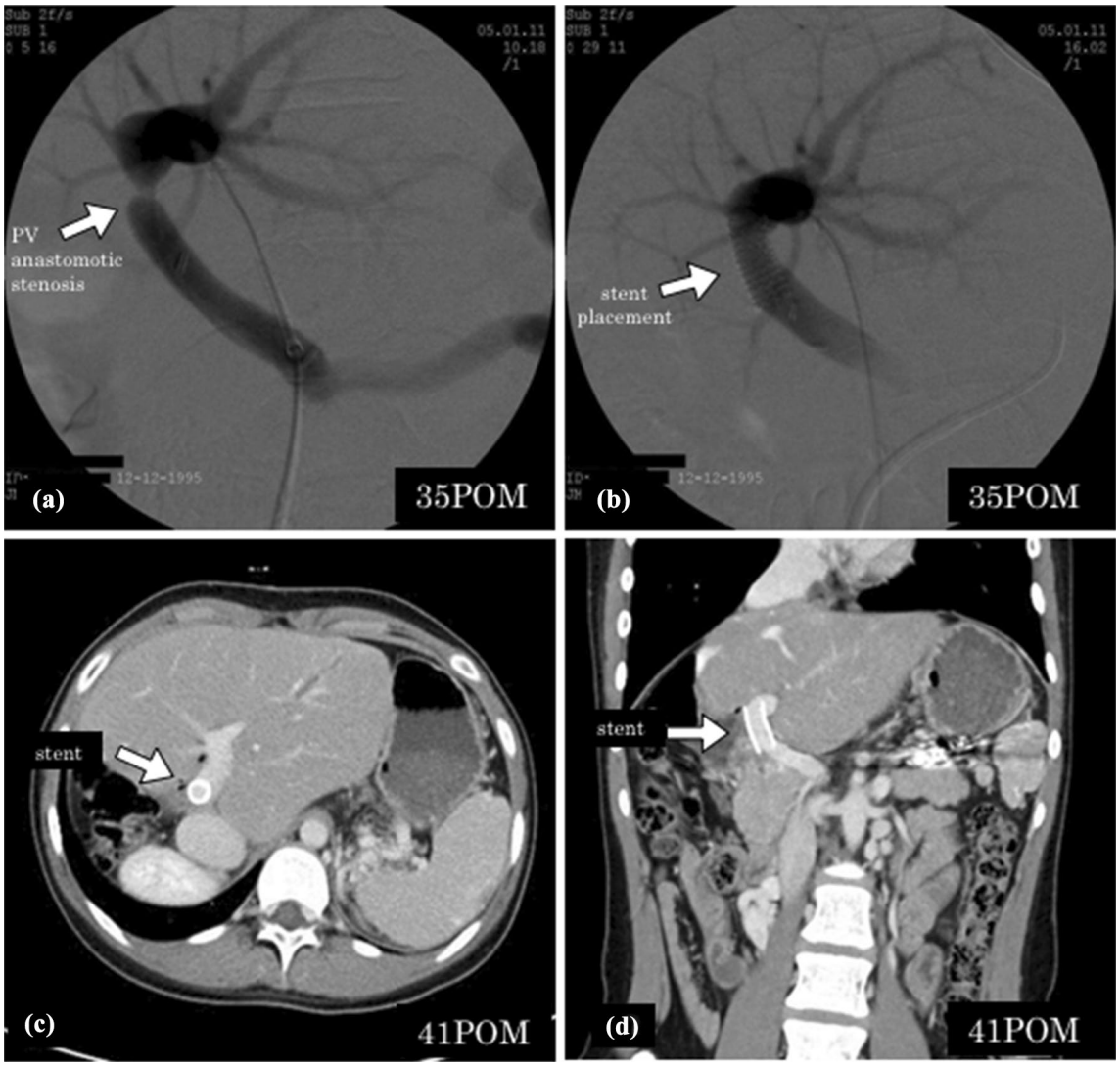

Fig. 6 A case of endovascular stent placement for PV complication. At the third IVR treatment (35 POM), anastomotic stenosis was found through portography (**a**) to be refractory, and a stent was placed in the stenosis (**b**). CT imaging taken 6 months after the stent placement showed patency of the stent (**c**, **d**).

Table 3 Outcomes of endovascular stent placement for venous complications following pediatric liver transplantation

Institutions	Hepatic vein complications	Portal vein complications
Japan Kyoto University [9–11]	Incidence rate, 9.4% Stent placement rate, 12.5% Patency rate, 66.7%	Incidence rate, 8.2% Stent placement rate, 4.7% Patency rate, 50.0%
Korea Seoul National University [6]	Incidence rate, 11.8% Stent placement rate, 44.4% Patency rate, 100%	–
Taiwan Kaohsiung Chang Gung Memorial Hospital [8]	–	Incidence rate, 3.4% Stent placement rate, 68.8% Patency rate, 90.9%
Japan National Center for Child Health and Development [12]	Incidence rate, 1.0% Stent placement rate, 33.3% Patency rate, 100%	–
Our institution	Incidence rate, 7.8% Stent placement rate, 9.1% Patency rate, 0%	Incidence rate, 14.2% Stent placement rate, 10.0% Patency rate, 100%

We believe that the cause of PV stenosis may be anastomosing a small sclerotic vein of the recipient to the donor portal vein or not using an appropriate graft, etc. Based on the results of our cases, stent treatment for PV complication is considered to be effective. On the other hand, we think that the main cause of HV stenosis may be twisting/torsion or kinking at the anastomosis to the inferior vena cava. In fact, there were many cases that were treated with IVR alone. There are many reports that stent treatment is effective for anastomotic stricture. However, we believe that HV stenosis cannot be explained by technical problems alone. VOD and SOS which exhibit the same symptoms as HV complications have also been reported [13]. Although VOD/SOS after liver transplantation is rare, it has been suggested that it may be caused by drugs such as azathioprine, AR, or antibody-mediated rejection (AMR) [14–16]. VOD/SOS cases show CD34 expression in the parenchyma (sinusoidal endothelium), and "sinusoidal capillarization" has been reported as a pathological condition of VOD/SOS [17–19]. One patient with refractory HV complication was pathologically diagnosed with VOD/SOS. We also believe that another patient might be diagnosed with VOD/SOS; however, the patient did not completely meet the criteria of AMR [20]. When a liver transplant patient has HVOO, we should consider the possibility of not only anastomotic stricture but also VOD/SOS developing by AR and/or AMR. Thus, pathological diagnosis by liver biopsy is necessary.

In conclusion, endovascular stent placement is effective for PV complications following pediatric LDLT. However, endovascular stent placement for HV complications should be carefully performed because of the risk of intrastent thrombotic occlusion and the possibility of immunological venous injury. Further studies of our treatments and the accumulation of prospective experience are necessary.

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Compliance with ethical standards

Conflict of interest No commercial organizations. The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional committee (the Ethics Committees of Jichi Medical University (Ethics Committee Approval Case Number 15-106)) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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