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Case Report

Arterial grafts as a conduit in inflow reconstruction in postoperative hepatic artery thrombosis after orthotopic liver transplantation: a case report

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Abstract: Hepatic artery thrombosis (HAT) and hepatic artery stenosis (HAS) are common complications of orthotopic liver transplantation (OLT) and can lead to hypohepatia or dysfunction of the transplanted liver or death. In these 2 cases, we attempted to achieve hepatic artery patency through the use of interventional thrombolysis and anticoagulation, but the thrombosis was repeated. After several attempts, transplanted liver function continued to deteriorate, which led us to perform emergency hepatic artery reconstruction. We report 2 cases of patients with HAT and HAS after OLT treated surgically by connecting the transplanted liver with the recipient's abdominal aorta by the donor's iliac or splenic artery. The results suggest that this approach could be used to treat emergency cases of HAT and HAS.

Keywords: Orthotopic liver transplantation, thrombosis, stenosis, artery reconstruction

Background

After orthotopic liver transplantation (OLT), complications affecting the hepatic artery may cause ischemia and further result in hypohepatia or dysfunction of the transplanted liver or death of the patient [1]. Hepatic artery thrombosis (HAT) is not only the second main cause of transplantation failure other than primary dysfunction of the transplanted liver, but also the most common complication of OLT. Generally, there are 3 therapeutic options for HAT: revascularization, retransplantation, and observation [2]. With the development and popularization of transcatheter endovascular interventional technique, it has also been applied to the treatment of HAT. Currently, the typical therapies of HAT include surgical revascularization, percutaneous puncture thrombolysis, percutaneous transluminal angioplasty, liver retransplantation, and expectant treatment [3]. Liver retransplantation used to be the only way to treat HAT and similar conditions, but has been associated with high mortality of patients and represents a waste of scarce sources [4]. Through emergency treatment procedures for transplantation, great progress has been made in the treatment of HAT or hepatic artery stenosis (HAS) [5, 6], while revascularization can only be performed when HA diseases are discovered through Doppler ultrasonography in the early stage [7, 8]. We report 2 cases of patients with hepatic cirrhosis or primary liver cancer who suffered early repeated hepatic artery stenosis and thrombosis after liver transplantation. The life span of transplanted livers and patients was successfully prolonged by using allogenic arteries as vascular grafts for reconstruction of blood supply of the hepatic arteries (**Table 1**). These 2 cases provided experience for diagnosis and treatment of HA stenosis and recurrent thrombosis after liver transplantation and provided a new approach for hepatic artery reconstruction with allogenic artery grafts.

Case report

Case 1 is a 44-year-old man with history of hepatitis who underwent piggyback orthotopic liver transplantation on February 24, 2016 because

Table 1. Patients' information in 2 cases

Case Number	Gender	Age (years)	Primary Disease	The Time Interval Between LT and Hepatic Artery Reconstruction (days)	Arterial Graft	The Time of Follow-up (months)
1	Male	44	Liver cirrhosis, primary liver cancer	15	Cryopreserved iliac artery	>17
2	Male	39	Hepatic failure, hepatic encephalopathy	11	Splenic artery	>16

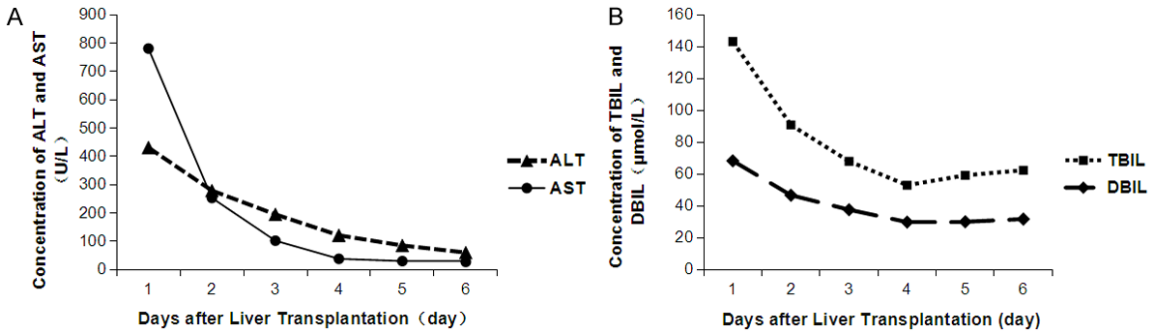

Figure 1. Liver function changes of Case 1 after liver transplantation in the curve. A: Graph shows Case 1 recipient's change of concentration of ALT and AST after liver transplantation along with the time; B: Graph shows Case 1 recipient's change of concentration of TBIL and DBIL after liver transplantation along with the time.

of liver cirrhosis and primary liver cancer. Preoperative computed tomography (CT) showed massive hepatocellular carcinoma with intrahepatic multiple metastases, liver cirrhosis, and multiple small lymph nodes in the bilateral axillae and portal branch obscurity. Preoperative PET-CT didn't show carcinoma with extrahepatic metastases but the patient showed liver dysfunction before the surgery. In liver transplantation, after hepatic hilus detachment, we cut off the hepatic artery at the distal bifurcation of left and right hepatic artery, implanted the donated liver, trimmed the bifurcation of gastroduodenal artery into funnel shape, and made continuous eversion suture to the donor's hepatic artery with 6-0 Prolene suture. After anastomosis, the hepatic artery graft became patency with significant arterial pulse. **Figure 1A** and **1B** are the diagrams on the history of alanine transaminase (ALT), aspartate transaminase (AST), total bilirubin (TBIL) and direct bilirubin (DBIL) during post-operative day (POD) 1-6 after liver transplantation. They show gradually decreased ALT and AST and gradually increased TBIL during POD 4-6 after surgery, which were suspected to be caused by the blood supply insufficiency of biliary tract caused by stenosis, embolism, and other hepatic artery complications. Color Doppler ultrasonography was performed on the transplanted liver at POD 2, and color Doppler power imaging (CDPI) suggested obscure hepatic artery and detectable arterial spectrum. Computed tomography angiography (CTA) and contrast-enhanced computed tomography (CT) at POD 5 suggested no visualization of the common hepatic artery (**Figure 2A**). This led us to perform digital subtraction angiography (DSA) of the hepatic artery at POD 6 which showed no visible hepatic artery, and post-transplantation anastomotic stenosis of hepatic artery and thrombosis (**Figure 2B**). After anastomotic angioplasty of the hepatic artery and stent implantation, angiography was taken for re-examination, which showed anastomosis was slightly narrow and the hepatic artery was patent (**Figure 2C**). In view of the possible recurrence of thrombosis, we continued thrombolytic therapy by using urokinase and aspirin. At POD 7, DSA suggested thrombosis and enlargement of splenic artery after post-transplantation hepatic artery angioplasty and we did second round of hepatic artery thrombolysis. At POD 8, 9 and 13, DSA angiography suggested clear common hepatic artery, proper hepatic artery, left and right hepatic artery, slow blood flow, small artery of left lobe of liver, and fluent stent of common hepatic artery (**Figure 2D**). At POD 7 and 10, color Doppler ultrasonography was performed on the transplanted liver, which showed an obscure hepatic artery. At POD 15, DSA showed post-transplantation celiac trunk thrombosis

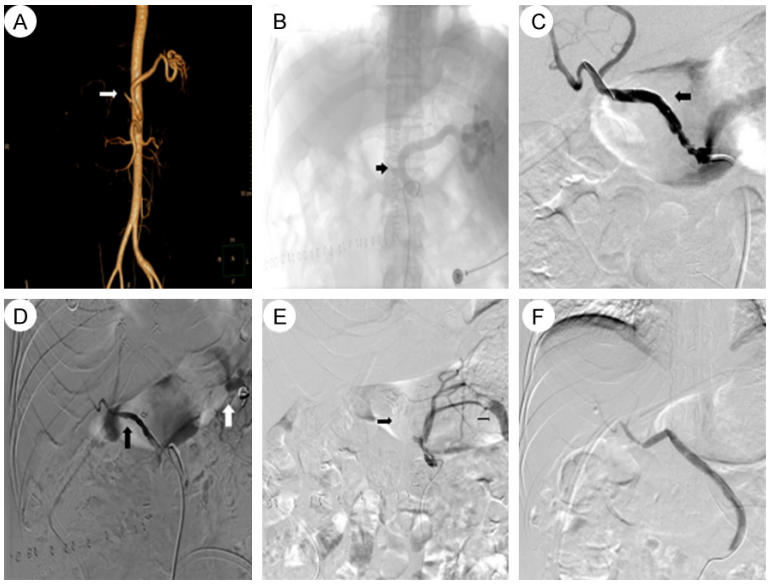

Figure 2. The results of the imaging examination after hepatic transplantation and hepatic artery reconstruction in Case 1. A: CTA at POD showed no visualization of common hepatic artery; B: DSA at POD 6 showed no visible hepatic artery (arrow); C: After anastomotic angioplasty of hepatic artery and stent implantation, DSA showed anastomosis was slightly narrow and hepatic artery was patency (arrow); D: At POD 13, DSA angiography suggested clear common hepatic artery, slow blood flow (black arrow), partial splenic artery embolization (white arrow); E: At POD 15, DSA showed post-transplantation celiac trunk thrombosis and poor outcome of stenting and thrombolysis (thick arrow) and clear splenic artery (thin arrow); F: At POD 11 of hepatic artery reconstruction, DSA angiography suggested no evidence of stenosis in the anastomotic stoma, bypass artery is fluent.

and poor outcome of stenting and thrombolysis were observed, which led us to perform emergency hepatic artery reconstruction (**Figure 2E**).

Hepatic artery reconstruction: We cut off the hepatic artery at the common hepatic artery and took out the visible clots from the hepatic artery. Then we flushed the intrahepatic artery with urokinase 50,000 IU + heparin saline 20 mL and ligated the artery at the division site of the receptor's side. After dissection of the abdominal aorta under the superior mesenteric at the mesenteric root, we occluded the abdominal aorta with an occlusion clamp and then trimmed a 2 cm incision on the abdominal aorta at occlusion site. Cryopreserved allogenic iliac artery were first thawed at 20°C for 30 min and then rapidly rewarmed to 37°C, sutured to the broken site of donor artery with 6-0 Prolene suture. We bluntly dissected the artery at the root of Traitz ligament with hemostatic forceps to create a stoma, passed the anastomosed iliac artery through the stoma to the division site of abdominal aorta, and made end-to-side anastomosis between the iliac artery and the abdominal aorta received a 6-0 Prolene suture. After opening the blood flow, the intraoperative color Doppler ultrasonography suggested satisfactory intrahepatic artery pulse.

After hepatic artery reconstruction, the patient was administered urokinase at 4000 IU/min and 2500 IU of heparin sodium by continuous pump via DSA thrombolysis catheter for 11 days, which was followed by testing the patient's coagulation function and sustained heparinization daily. From POD 1 to POD 3 after hepatic artery revascularization, the level of ALT, AST, TBIL, and DBIL was almost normal; color Doppler ultrasonography suggested that the hepatic arterial trunk and left branch spectrums were detectable. At POD 5, 8, 11, and 14 after hepatic artery reconstruction, DSA angiography suggested no evidence of stenosis in the anastomotic stoma and fine left and right hepatic arteries of the donor with slow hepatic blood perfusion, so we kept the microcatheter for thrombolysis by urokinase (**Figure 2F**). Around at POD 8 after hepatic artery reconstruction, the TBIL were temporarily increased (up to 45.7 μmol/L). Considering the high risk for recurrence of intrahepatic thrombosis, we administered dopamine for blood pressure maintenance by increasing the blood pressure of hepatic artery, in addition to daily administration of urokinase and continuous pump of low molecular heparin. At POD 20 after hepatic artery reconstruction, the liver function fully recovered. At present, the patient has had his hepatic artery constructed at March 10, 2016 for more than 17 months, and remains under follow-up.

Case 2 is a 39-year-old man with history of jaundice hepatitis, hepatitis B, and fatty liver underwent piggyback orthotopic liver transplantation on December 9, 2015 because of acute hepatic failure and hepatic encephalopathy. Preoperative CT showed fatty liver and

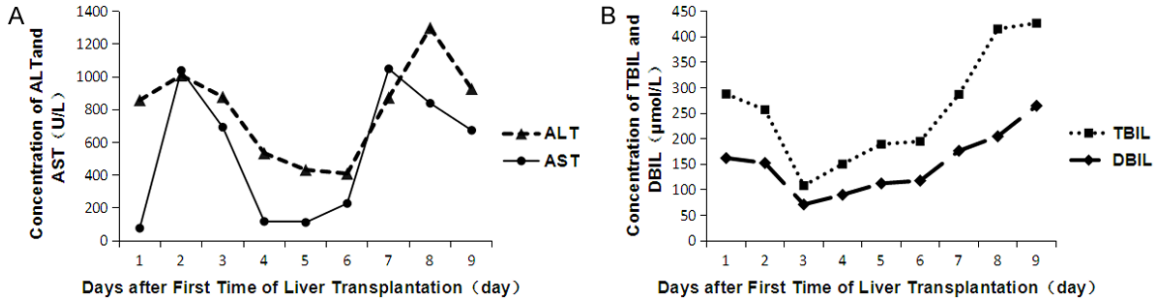

Figure 3. Liver function changes of Case 2 after liver transplantation in the curve. A: Graph shows Case 2 recipient's change of concentration of ALT and AST after first time of liver transplantation along with the time; B: Graph shows Case 2 recipient's change of concentration of TBIL and DBIL after first time of liver transplantation along with the time.

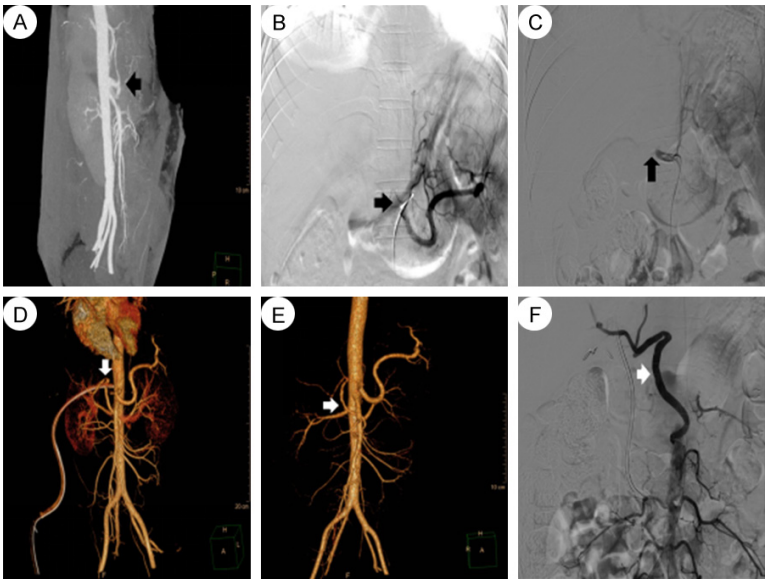

Figure 4. The results of the imaging examination after twice hepatic transplantation and hepatic artery reconstruction in Case 2. A: At POD 3 of first time of liver transplantation, contrast-enhanced CT showed slight stenosis of lumen at the origin of hepatic artery and clear developing of abdominal aorta and celiac trunk (arrow); B: At POD 8 of first time of liver transplantation, DSA showed hepatic artery stenosis with thrombosis (arrow); C: At POD 9 of first time of liver transplantation after the interventional therapy, the hepatic artery wasn't patency (arrow); D: At POD 1 after hepatic artery reconstruction, CTA showed no stenosis of hepatic artery bypass (arrow); E: At POD 4 after hepatic artery reconstruction, CTA showed no stenosis of hepatic artery bypass (arrow); F: At POD 47 after hepatic artery reconstruction, DSA showed no stenosis of hepatic artery bypass (arrow).

a small amount of perihepatic effusion. The patient underwent multiple rounds of preoperative plasmapheresis and hemodialysis because of hepatic dysfunction, poor coagulation function, and hepatic encephalopathy-induced coma. The first time liver transplantation was performed according to classical piggyback liver transplantation. After anastomosis, the hepatic artery became patent with a significant arterial pulse. **Figure 3A** and **3B** show the change of ALT, AST, TBIL, and DBIL during POD 1-9. From POD 2 to POD 5 after surgery, the color Doppler ultrasonography showed that there was a clear lumen and no abnormal filling defect in the hepatic artery. At POD 3, CTA and contrast-enhanced CT showed slight stenosis of lumen at the origin of hepatic artery and clear abdominal aorta and celiac trunk (**Figure 4A**). During POD 6-9, the level of ALT, AST, TBIL, and DBIL continuously increased. At POD 8, the color Doppler ultrasonography of transplanted liver showed no significant hepatic artery ultrasonogram. The DSA at Emergency Department showed hepatic artery stenosis with thrombosis. The thrombolytic therapy was provided by injecting 200,000 IU urokinase with indwelling arterial catheter and by continuous pumping of urokinase at 200,000 IU/min for continuous thrombolytic therapy (**Figure 4B**). But the DSA at POD 9 showed hepatic artery occlusion with thrombosis, the interventional therapy failed to make the hepatic artery patent (**Figure 4C**). As a result, the patient underwent the second allogeneic liver transplantation at POD 11.

The second liver transplantation and hepatic artery reconstruction was performed on De-

cember 20, 2015. After cutting off the transplanted liver graft of the first time, then the second liver graft's suprahepatic and infrahepatic inferior vena cava and portal vein were sutured. Then the abdominal aorta was dissected under superior mesenteric artery at mesenteric root and occluded with an occlusion clamp. A 2 cm incision was trimmed on the abdominal aorta at occlusion site. Since there was no appropriate cryopreserved iliac vessel, the untrimmed donor's splenic artery was used as the bypass graft for hepatic artery bypass. We bluntly dissected the artery at the root of Traitz ligament with hemostatic forceps to create a stoma, let the splenic artery pass through the stoma to the broken site of abdominal aorta, and then made end-to-side anastomosis between the splenic artery and abdominal aorta with 6-0 Prolene suture. After opening the blood flow, color Doppler ultrasonography suggested satisfactory intrahepatic artery pulse.

Color Doppler ultrasonography of transplanted liver on the right postoperative day showed that the reconstructed hepatic artery was clear. CTA and contrast-enhanced CT showed that the hepatic artery bypass was clear (**Figure 4D**). From POD 2 to POD4 after hepatic artery reconstruction, the level of ALT, AST, TBIL, and DBIL gradually decreased. CTA and contrast-enhanced CT showed that the hepatic artery bypass was slightly locally bent and stenosed with clear branches at distal hepatic artery (**Figure 4E**). At POD 19 after hepatic artery reconstruction, the liver function was almost recovered. At POD 26 after reconstruction, the level of transaminase, bilirubin and γ glutamyltranspeptidase (γ-GGT) temporarily increased (ALT 280 U/L, AST 138 U/L, TBIL 59.2 μmol/L, DBIL 25.8 μmol/L, GGT 1096 U/L). CT showed no special change of transplanted liver and hepatic puncture biopsy suggested mild rejection reaction. Then the patient was administered methylprednisolone and larger dose of immunosuppressor for impact treatment. In consideration of the continuous increase of bilirubin, biliary tract disease was suspected. The patient underwent endoscopic retrograde cholangiopancreatography (ERCP) for examination and showed significant stenosis at the biliary anastomotic site. A stent was placed after transcatheter dilatation of stenosis to enhance liver-protecting therapy. At POD 47 after hepatic artery reconstruction, color Doppler ultrasonography suggested a slightly high resistance index of the hepatic artery bypass and DSA showed no sign of stenosis at the anastomotic site of hepatic artery bypass but slow liver blood perfusion (**Figure 4F**). At present, the patient has had his hepatic artery constructed for more than 16 months, and remains under follow-up.

Discussion and conclusions

Over the past few decades, despite the remarkable development of vascular anastomotic techniques, and a few occurrences of vascular complications associated with OLT have been reported. It has been reported that the incidence of vascular complication ranges around 0.8%-20%, with a mortality rate about 11%-20% [9-12]. OLT-associated vascular complications include thrombosis, stenosis, and pseudoangioma of the hepatic artery, stenosis and thrombosis of the portal vein, and thrombosis and thrombosis of the postcava and hepatic arteries [13]. Among these complications, HAT is the most common singularly occurring complication of orthotopic liver transplantation [13]. The incidence of HAT after orthotopic liver transplantation was 1.6%-30% [14-17] while a large sample statistics reported it as 3%-9% [18], but it may cause an early mortality up to 58% after the transplantation [19]. The cause of HAT is still under debate. It is believed that over 20% of HAT is caused by surgical techniques in artery anastomosis, such as arterial diameter mismatch between the donor and receptor, poor donor quality, complex arterial revascularization, or arterial tortuosity [20]. In addition, non-surgical factors also play a role, such as the donor being aged above 60, prolonged cold ischemia time, preservation injury, different blood type between donor and recipient, positive cytomegalovirus in the donor, tendency for hypercoagulation in the recipient's blood, and primary sclerosing cholangitis in the donor or recipient [21-24]. However, the most common cause of HAT is vascular collapse cause by long hepatic arteries, organ rejection, and advanced age of the donor, slow blood flow, narrowed lumen, arterial revascularization, and re-transplantation of liver [25-28]. As another common vascular complication of OLT, the incidence of HAS is between 2%-15% [29-35]. Reports showed [31] that poor surgical techniques, transplant rejection, and crush injury are the risk factors of HAS.

In view of the severity of vascular complications after liver transplantation, early discovery and diagnosis are the key to their treatment [36]. It is reported that about 2.3% of the early acute HTA can be diagnosed from the increased aminotransferase, early biliary fistula, and acute graft dysfunction [37], and the occurrence of HAS is also manifested by increased aminotransferase. However, with the incidence of asymptomatic HAS as high as 20%-27% [38, 39], imaging is required for proper evaluation. Imaging is the most useful method to evaluate the OLT-associated complications, and commonly used methods include color Doppler ultrasonography, CT, CTA, and transcatheter endovascular interventional techniques. Since color Doppler ultrasonography is both sensitive and specific to the detection of hepatic artery thrombosis, it is capable of detecting absent blood flow velocity in hepatic artery and its branches. It is also considered as the gold standard in detecting hepatic artery thrombosis [40]. Some reports also claimed daily routine post-operative ultrasound examinations are helpful to the early detection of hepatic artery thrombosis and stenosis. However, in some cases, post-operative color Doppler ultrasonography may perform poorly or inconclusive in detecting hepatic arterial flow and thus additional imaging methods are required [41]. In Case 1 where the patient suffered from liver cirrhosis, even as albumin was used to reduce the ascetic fluids before surgery, gastrointestinal tract congestion, and severe intestinal tympanites were still found during the procedure. Post-operative color Doppler ultrasonography found poor performance of hepatic arteries, so transcatheter endovascular interventional technique was conducted. For patients with hepatic artery thrombosis and flow absence in the hepatic arteries, the diagnostic accuracy of MR angiography (MRA) is equal to the color Doppler ultrasonography [42], while the diagnostic accuracy of 3-dimensional CT is equal [43] or higher than [44] the color Doppler ultrasonography. 3-dimensional CT can visualize the locations of hepatic artery stenosis [45] which can be treated by percutaneous hepatic angioplasty and surgical procedures [46, 47].

Transcatheter endovascular interventional techniques have been used for treatment of multiple arterial obstructive diseases, especially acute obstruction of coronary arteries. For HAT and HAS, interventional therapy can be used both for diagnosis and for treatment. In addition to confirming the diagnosis, interventional therapy allows endovascular treatment for HAT and HAS at the affected part of hepatic artery. Due to the presence of complicating massive hemorrhage, it was not recommended to conduct interventional therapy for early HAT after OLT [48]. However, with the advancement of interventional techniques, there have been reports [49] that have claimed that interventional thrombolysis is an effective and safe approach for treatment of early HAT after OLT. In Case 1, the blood bilirubin of the patient increased at POD 6. With poor performance of color Doppler ultrasonography in detecting hepatic arteries, interventional therapy was conducted through hepatic arterial thrombolysis and stenting treatment with no occurrence of massive hemorrhage and other complications, which demonstrated the safety of transcatheter endovascular interventional techniques. In Case 2, the patient underwent DSA at POD 8 after the initial liver transplantation and hepatic artery stenosis and thrombosis were shown. Then the flow of hepatic arteries recovered after interventional thrombolysis, which also demonstrated the efficacy of interventional therapy. It is reported [49] that early HAT after OLT may cause extensive thrombosis of the hepatic arterial system. Since a thrombus in the hepatic arterial system may cause increased post-hepatic load, simply improving the techniques of hepatic arterial anastomosis is insufficient for the improvement of hepatic arterial flow, and reduction of post-hepatic load stress needs to be performed concurrently with the treatment of HAT. In Case 1, the patient had a slow hepatic arterial flow before and after hepatic artery bypass grafting, and continous thrombolysis and anticoagulation after intervention not only reduced the risk of thrombosis, but also prevent increased pressure of hepatic arterial system caused by thrombosis so as to further reduce the risk posed by thrombosis.

Re-transplantation of liver is an effective way to treat HAT and HAS, however, the lack of liver donors is a common obstacle for this approach. Thus hepatic artery reconstruction presents a solution to HAT and HAS with which the intervention approach can't deal. There are several reported cases where iliac arteries were used in place of hepatic arteries to perform hepatic

Table 2. Different usage of vascular allograft in studys

Authors	Case Number, n	Origine of Vascular Allografts	Indication of Surgery	Surgery
Mabrut JY et al., 2012 [55]	3	Cryopreserved iliac artery allograft from deceased donors in a tissue bank	Hepatitis B cirrhosis; Acetaminophen-induced acute liver failure; hepatitis C cirrhosis with hepatocellular carcinoma	Liver transplantation
Jashari R et al., 2013 [56]	2506	Cryopreserved arterial allograft from brain death donors and deceased donors in the European Homograft Bank	Infections, critical limb ischemia, congenital cardiac malformations, arterial injury and prosthetic graft thrombosis	Cardiac surgery and vascular surgery
Mourad MM et al., 2014 [57]	10	The donors' iliac arteries from donation after circulatory death donors	–	Arterial reconstruction during liver transplantation
Touma J et al., 2014 [58]	54	Cryopreserved arterial allografts from brain deceased multiple organ donors	Native aortic infection and prosthetic graft infection	Aortic reconstruction
Heng WL et al., 2015 [59]	9	Cryopreserved iliac artery grafts and iliac vein (n=1) graft in tissue bank	Primary sclerosing cholangitis; Liver cirrhosis; Acute liver failure; Hepatitis B flare; Right mycotic internal carotid artery aneurysm	Living-donor liver transplantation; Reconstruction of right internal carotid artery
Ali MA et al., 2015 [60]	65	Cryopreserved arterial grafts	–	Outflow reconstruction in right lobe living donor liver transplantation
Ha TY et al., 2016 [61]	20	Cryopreserved iliac arterial allografts from brain death donors	–	Upper arm hemodialysis vascular access grafts

artery reconstruction in liver transplantation [50-54] with favorable prognosis after transplantation. Here we summarized the reports of cryopreserved arterial grafts in LT and other uses in **Table 2**. However, no report was found by using cryopreserved iliac arteries for hepatic artery bypass grafting in the treatment of post-transplantation HAT and HAS. In Case 1, the patient suffered from repeated thrombosis after interventional thrombolysis and stent implantation. After formation of a thrombus in the celiac trunk, with the intervention approach proven ineffective, an emergency surgery was performed where cryopreserved allogenic iliac arteries were used to conduct hepatic artery reconstruction between the donor's hepatic artery and the recipient's abdominal aorta under the renal artery. In Case 2, the patient suffered from hepatic arterial thrombosis after the initial liver transplantation.

For liver re-transplantation, we performed a novel procedure of hepatic artery bypass grafting between the donor's splenic artery and the receptor's abdominal aorta, which successfully improved the function of the donated liver. Since the iliac and splenic arteries can be procured and easily saved when harvesting the organ, this approach not only provides a new way to use for cryopreserved iliac and splenic arteries, but also presents a new idea for transplant surgeons to treat HAT and HAS in emergency cases and perform hepatic artery revascularization during liver re-transplantation, which can hopefully reduce the need for liver re-transplantation for patients.

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Disclosure of conflict of interest

None.

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References

[1] Vivarelli M, Cucchetti A, La Barba G, Bellusci R, De Vivo A, Nardo B, Cavallari A, Pinna AD. Ischemic arterial complications after liver transplantation in the adult: multivariate anal-

ysis of risk factors. Arch Surg 2004; 139: 1069-1074.
[2] Pareja E, Cortes M, Navarro R, Sanjuan F, Lopez R, Mir J. Vascular complications after orthotopic liver transplantation: hepatic artery thrombosis. Transplant Proc 2010; 42: 2970-2972.
[3] Frongillo F, Lirosi MC, Nure E, Inchingolo R, Bianco G, Silvestrini N, Avolio AW, De Gaetano AM, Cina A, Di Stasi C, Sganga G, Agnes S. Diagnosis and management of hepatic artery complications after liver transplantation. transplantation proceedings 2015; 47: 2150-2155.
[4] Markmann JF, Markowitz JS, Yersiz H, Morrisey M, Farmer DG, Farmer DA, Goss J, Ghobrial R, McDiarmid SV, Stribling R, Martin P, Goldstein LI, Seu P, Shackleton C, Busuttil RW. Long-term survival after retransplantation of the liver. Ann Surg 1997; 226: 408-418, 418-420.
[5] Pinna AD, Smith CV, Furukawa H, Starzl TE, Fung JJ. Urgent revascularization of liver allografts after early hepatic artery thrombosis. Transplantation 1996; 62: 1584-1587.
[6] Cavallari A, Vivarelli M, Bellusci R, Jovine E, Mazziotti A, Rossi C. Treatment of vascular complications following liver transplantation: multidisciplinary approach. Hepatogastroenterology 2001; 48: 179-183.
[7] Dodd GR, Memel DS, Zajko AB, Baron RL, Santaguida LA. Hepatic artery stenosis and thrombosis in transplant recipients: Doppler diagnosis with resistive index and systolic acceleration time. Radiology 1994; 192: 657-661.
[8] Nishida S, Kato T, Levi D, Naveen M, Berney T, Vianna R, Selvaggi G, Buitorago E, Al-Niami A, Nakamura N, Vaidya A, Nery J, Tzakis A. Effect of protocol Doppler ultrasonography and urgent revascularization on early hepatic artery thrombosis after pediatric liver transplantation. Arch Surg 2002; 137: 1279-1283.
[9] Akun E, Yaprak O, Killi R, Balci NC, Tokat Y, Yuzer Y. Vascular complications in hepatic transplantation: single-center experience in 14 years. Transplant Proc 2012; 44: 1368-1372.
[10] Bekker J, Ploem S, de Jong KP. Early hepatic artery thrombosis after liver transplantation: a systematic review of the incidence, outcome and risk factors. Am J Transplant 2009; 9: 746-757.
[11] Abbasoglu O, Levy MF, Vodapally MS, Goldstein RM, Husberg BS, Gonwa TA, Klintmalm GB. Hepatic artery stenosis after liver transplantation--incidence, presentation, treatment, and long term outcome. Transplantation 1997; 63: 250-255.
[12] Saad WE, Davies MG, Sahler L, Lee DE, Patel NC, Kitanosono T, Sasson T, Waldman DL. Hepatic artery stenosis in liver transplant recipients: primary treatment with percutaneous transluminal angioplasty. J Vasc Interv Radiol 2005; 16: 795-805.
[13] Singh AK, Nachiappan AC, Verma HA, Uppot RN, Blake MA, Saini S, Boland GW. Postoperative imaging in liver transplantation: what radiologists should know. Radiographics 2010; 30: 339-351.
[14] Drazan K, Shaked A, Olthoff KM, Imagawa D, Jurim O, Kiai K, Shackelton C, Busuttil R. Etiology and management of symptomatic adult hepatic artery thrombosis after orthotopic liver transplantation (OLT). Am Surg 1996; 62: 237-240.
[15] Shaked A, McDiarmid SV, Harrison RE, Gelebert HA, Colonna JR, Busuttil RW. Hepatic artery thrombosis resulting in gas gangrene of the transplanted liver. Surgery 1992; 111: 462-465.
[16] Hashikura Y, Kawasaki S, Okumura N, Ishikawa S, Matsunami H, Ikegami T, Nakazawa Y, Makuuchi M. Prevention of hepatic artery thrombosis in pediatric liver transplantation. Transplantation 1995; 60: 1109-1112.
[17] Tan KC, Yandza T, de Hemptinne B, Clapuyt P, Claus D, Otte JB. Hepatic artery thrombosis in pediatric liver transplantation. J Pediatr Surg 1988; 23: 927-930.
[18] Stange BJ, Glanemann M, Nuessler NC, Settmacher U, Steinmuller T, Neuhaus P. Hepatic artery thrombosis after adult liver transplantation. Liver Transpl 2003; 9: 612-620.
[19] Singhal A, Stokes K, Sebastian A, Wright HI, Kohli V. Endovascular treatment of hepatic artery thrombosis following liver transplantation. Transpl Int 2010; 23: 245-256.
[20] Bekker J, Ploem S, de Jong KP. Early hepatic artery thrombosis after liver transplantation: a systematic review of the incidence, outcome and risk factors. Am J Transplant 2009; 9: 746-757.
[21] Bekker J, Ploem S, de Jong KP. Early hepatic artery thrombosis after liver transplantation: a systematic review of the incidence, outcome and risk factors. Am J Transplant 2009; 9: 746-757.
[22] Duffy JP, Hong JC, Farmer DG, Ghobrial RM, Yersiz H, Hiatt JR, Busuttil RW. Vascular complications of orthotopic liver transplantation: experience in more than 4,200 patients. J Am Coll Surg 2009; 208: 896-903, 903-905.
[23] Lopez-Andujar R, Moya A, Montalva E, Berenguer M, De Juan M, San JF, Pareja E, Vila JJ, Orbis F, Prieto M, Mir J. Lessons learned from anatomic variants of the hepatic artery in 1,081 transplanted livers. Liver Transpl 2007; 13: 1401-1404.
[24] Oh CK, Pelletier SJ, Sawyer RG, Dacus AR, McCullough CS, Pruett TL, Sanfey HA. Uni- and multi-variate analysis of risk factors for early

and late hepatic artery thrombosis after liver transplantation. Transplantation 2001; 71: 767-772.
[25] Vivarelli M, Cucchetti A, La Barba G, Bellusci R, De Vivo A, Nardo B, Cavallari A, Pinna AD. Ischemic arterial complications after liver transplantation in the adult: multivariate analysis of risk factors. Arch Surg 2004; 139: 1069-1074.
[26] Mourad MM, Liossis C, Gunson BK, Mergental H, Isaac J, Muiesan P, Mirza DF, Perera MT, Bramhall SR. Etiology and management of hepatic artery thrombosis after adult liver transplantation. Liver Transpl 2014; 20: 713-723.
[27] Warner P, Fusai G, Glantzounis GK, Sabin CA, Rolando N, Patch D, Sharma D, Davidson BR, Rolles K, Burroughs AK. Risk factors associated with early hepatic artery thrombosis after orthotopic liver transplantation-univariable and multivariable analysis. Transpl Int 2011; 24: 401-408.
[28] Flint EW, Sumkin JH, Zajko AB, Bowen A. Duplex sonography of hepatic artery thrombosis after liver transplantation. Ajr Am J Roentgenol 1988; 151: 481-483.
[29] Todo S, Makowka L, Tzakis AG, Marsh JJ, Karrer FM, Armany M, Miller C, Tallent MB, Esquivel CO, Gordon RD, Et A. Hepatic artery in liver transplantation. Transplant Proc 1987; 19: 2406-2411.
[30] Wozney P, Zajko AB, Bron KM, Point S, Starzl TE. Vascular complications after liver transplantation: a 5-year experience. Ajr Am J Roentgenol 1986; 147: 657-663.
[31] Abbasoglu O, Levy MF, Vodapally MS, Goldstein RM, Husberg BS, Gonwa TA, Klintmalm GB. Hepatic artery stenosis after liver transplantation--incidence, presentation, treatment, and long term outcome. Transplantation 1997; 63: 250-255.
[32] Denys AL, Qanadli SD, Durand F, Vilgrain V, Farges O, Belghiti J, Lacombe P, Menu Y. Feasibility and effectiveness of using coronary stents in the treatment of hepatic artery stenoses after orthotopic liver transplantation: preliminary report. AJR Am J Roentgenol 2002; 178: 1175-1179.
[33] Kodama Y, Sakuhara Y, Abo D, Shimamura T, Furukawa H, Todo S, Miyasaka K. Percutaneous transluminal angioplasty for hepatic artery stenosis after living donor liver transplantation. Liver Transpl 2006; 12: 465-469.
[34] Lastovickova J, Peregrin J. Percutaneous transluminal angioplasty of hepatic artery stenosis in patients after orthotopic liver transplantation: mid-term results. Cardiovasc Intervent Radiol 2011; 34: 1165-1171.
[35] Maruzzelli L, Miraglia R, Caruso S, Milazzo M, Mamone G, Gruttadauria S, Spada M, Luca A, Gridelli B. Percutaneous endovascular treatment of hepatic artery stenosis in adult and pediatric patients after liver transplantation. Cardiovasc Intervent Radiol 2010; 33: 1111-1119.
[36] Frongillo F, Lirosi MC, Nure E, Inchingolo R, Bianco G, Silvestrini N, Avolio AW, De Gaetano AM, Cina A, Di Stasi C, Sganga G, Agnes S. Diagnosis and management of hepatic artery complications after liver transplantation. Transplant Proc 2015; 47: 2150-2155.
[37] Grodzicki M, Anysz-Grodzicka A, Remiszewski P, Cieslak B, Kotulski M, Kalinowski P, Paluszkiewicz R, Rowinski O, Krawczyk M. Treatment of early hepatic artery thrombosis after liver transplantation. Transplant Proc 2011; 43: 3039-3042.
[38] Da SR, Raphe R, Felicio HC, Rocha MF, Duca WJ, Arroyo PC, Palini GL, Vasquez AM, Miquelin DG, Reis LF, Silva AA, Da SR. Prevalence, treatment, and outcomes of the hepatic artery stenosis after liver transplantation. Transplant Proc 2008; 40: 805-807.
[39] Ueno T, Jones G, Martin A, Ikegami T, Sanchez EQ, Chinnakotla S, Randall HB, Levy MF, Goldstein RM, Klintmalm GB. Clinical outcomes from hepatic artery stenting in liver transplantation. Liver Transpl 2006; 12: 422-427.
[40] Vaidya S, Dighe M, Kolokythas O, Dubinsky T. Liver transplantation: vascular complications. Ultrasound Q 2007; 23: 239-253.
[41] Pareja E, Cortes M, Navarro R, Sanjuan F, Lopez R, Mir J. Vascular complications after orthotopic liver transplantation: hepatic artery thrombosis. Transplant Proc 2010; 42: 2970-2972.
[42] Glockner JF, Forauer AR, Solomon H, Varma CR, Perman WH. Three-dimensional gadolinium-enhanced MR angiography of vascular complications after liver transplantation. AJR Am J Roentgenol 2000; 174: 1447-1453.
[43] Legmann P, Costes V, Tudoret L, Girardot C, Hazebroucq V, Uzan E, Fery-Lemonnier E, Bonnin A. Hepatic artery thrombosis after liver transplantation: diagnosis with spiral CT. AJR Am J Roentgenol 1995; 164: 97-101.
[44] Katyal S, Oliver JR, Buck DG, Federle MP. Detection of vascular complications after liver transplantation: early experience in multislice CT angiography with volume rendering. AJR Am J Roentgenol 2000; 175: 1735-1739.
[45] Quiroga S, Sebastia MC, Margarit C, Castells L, Boye R, Alvarez-Castells A. Complications of orthotopic liver transplantation: spectrum of findings with helical CT. Radiographics 2001; 21: 1085-1102.
[46] Abbasoglu O, Levy MF, Vodapally MS, Goldstein RM, Husberg BS, Gonwa TA, Klintmalm GB.

Hepatic artery stenosis after liver transplantation--incidence, presentation, treatment, and long term outcome. Transplantation 1997; 63: 250-255.
[47] Ohdan H, Tashiro H, Ishiyama K, Ide K, Shishida M, Irei T, Ohira M, Tahara H, Itamoto T, Asahara T. Microsurgical hepatic artery reconstruction during living-donor liver transplantation by using head-mounted surgical binocular system. Transpl Int 2007; 20: 970-973.
[48] Zajko AB, Campbell WL, Bron KM, Schade RR, Koneru B, Van Thiel DH. Diagnostic and interventional radiology in liver transplantation. Gastroenterol Clin North Am 1988; 17: 105-143.
[49] Kim BW, Won JH, Lee BM, Ko BH, Wang HJ, Kim MW. Intraarterial thrombolytic treatment for hepatic artery thrombosis immediately after living donor liver transplantation. Transplant Proc 2006; 38: 3128-3131.
[50] Ma Y, Li Q, Ye ZM, Zhu XF, He XS. Use of arterial conduit for arterial revascularization during liver and multivisceral transplantation. Chin Med J (Engl) 2011; 124: 2986-2989.
[51] Muralidharan V, Imber C, Leelaudomlipi S, Gunson BK, Buckels JA, Mirza DF, Mayer AD, Bramhall SR. Arterial conduits for hepatic artery revascularisation in adult liver transplantation. Transpl Int 2004; 17: 163-168.
[52] Meyer C, Riehm S, Perrot F, Cag M, Nizand G, Audet M, Veillon F, Jaeck D, Wolf P. Donor iliac artery used for arterial reconstruction in liver transplantation. Transplant Proc 2000; 32: 2791.
[53] Muiesan P, Rela M, Nodari F, Melendez HV, Smyrniotis V, Vougas V, Heaton N. Use of infrarenal conduits for arterial revascularization in orthotopic liver transplantation. Liver Transpl Surg 1998; 4: 232-235.
[54] Shaw BJ, Iwatsuki S, Starzl TE. Alternative methods of arterialization of the hepatic graft. Surg Gynecol Obstet 1984; 159: 490-493.
[55] Mabrut JY, Abdullah SS, Rode A, Bourgeot JP, Eljaafari A, Baulieux J, Ducerf C. Cryopreserved iliac artery allograft for primary arterial revascularization in adult liver transplantation. Clin Transplant 2012; 26: E12-E16.
[56] Jashari R, Van Hoeck B, Ngakam R, Goffin Y, Fan Y. Banking of cryopreserved arterial allografts in Europe: 20 years of operation in the European homograft bank (EHB) in Brussels. Cell Tissue Bank 2013; 14: 589-599.
[57] Mourad MM, Liossis C, Gunson BK, Mergental H, Isaac J, Muiesan P, Mirza DF, Perera MT, Bramhall SR. Etiology and management of hepatic artery thrombosis after adult liver transplantation. Liver Transpl 2014; 20: 713-723.
[58] Touma J, Cochennec F, Parisot J, Fialaire Legendre A, Becquemin JP, Desgranges P. In situ reconstruction in native and prosthetic aortic infections using cryopreserved arterial allografts. Eur J Vasc Endovasc Surg 2014; 48: 292-299.
[59] Heng WL, Madhavan K, Wee P, Seck T, Lim YP, Lim CH. Banking of cryopreserved iliac artery and vein homografts: clinical uses in transplantation. Cell Tissue Bank 2015; 16: 235-242.
[60] Ali MA, Yong CC, Eng HL, Wang CC, Lin TL, Li WF, Wang SH, Lin CC, Yap A, Chen CL. Cryopreserved arterial grafts as a conduit in outflow reconstruction in living donor liver transplantation. J Hepatobiliary Pancreat Sci 2015; 22: 498-504.
[61] Ha TY, Kim YH, Chang JW, Park Y, Han Y, Kwon H, Kwon TW, Han DJ, Cho YP, Lee SG. Clinical outcomes of cryopreserved arterial allograft used as a vascular conduit for hemodialysis. J Korean Med Sci 2016; 31: 1266-1272.