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ORIGINAL ARTICLE

Risk factors of hepatic artery thrombosis in pediatric deceased donor liver transplantation

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Abstract

Purpose Hepatic artery thrombosis (HAT) remains a life-threatening complication in liver transplantation. We aim to investigate the risk factors of HAT in deceased donor pediatric liver transplantation.

Methods 104 recipients from 2014 to 2016 were enrolled; donor and recipient characteristics, surgical variables, graft and recipient survival rate were compared between recipients with or without HAT. Univariate and multivariate analysis were applied to identify the risk factors of HAT.

Results The recipient survival rate was 87.0% and 96.3% at 1 year, and 87.0% and 96.3% at 3 years in HAT and non-HAT groups without significant difference. The graft survival rate was 73.9% and 96.3% at 1 year, and 73.9% and 95.1% at 3 years in HAT and non-HAT groups; significant difference was observed between two groups at both 1 and 3 years. Donor age less than 8.5 months, graft weight less than 190 g and GRWR less than 2.2% were identified as independent risk factors for HAT. Recipients with HAT were associated with higher incidence of post-operative biliary complications.

Conclusions Young donor age and small liver graft are risk factors for HAT in deceased donor pediatric liver transplantation.

Keywords Pediatric liver transplantation · Hepatic artery thrombosis · Acute rejection · Recipient survival

Introduction

Liver transplantation remains the sole treatment for children with acute liver failure and end-stage liver diseases. Over the past decades, the 20-year recipient and graft survival rates have reached 79% and 64%, respectively [1]. However, the graft survival rate is approximately 15% lower than recipient survival rate due to graft failure. Hepatic artery thrombosis (HAT) is one of the most severe complications in pediatric liver transplantation that usually leads to increased morbidity, graft loss, and recipient death [2, 3]. Due to the small size of vessels and complexity of surgical technique, HAT has been reported to occur in 5–18% of children after liver transplantation [4, 5] which is much higher than adult recipients (3–5%) [6, 7].

Different factors, such as graft type, cold ischemia time, acute rejection and arterial anastomosis method, may contribute to the occurrence of HAT [8]. Previous studies mainly focused on the occurrence of HAT in living donor liver transplantation (LDLT) in children [9, 10]. Deceased liver grafts have longer cold ischemia time and more complex organ procurement procedure than living-related grafts. To our knowledge, the risk factors and features of HAT in deceased donor pediatric liver transplantation have not been studied. Understanding the risk factors for HAT is an important step to improve recipient outcomes after pediatric liver transplantation. In this study, we aim to reveal the risk factors for HAT after deceased donor liver transplantation in children.

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Patients and methods

Donor and recipient data

A total number of 421 pediatric liver transplantations were performed in Tianjin First Center Hospital from January 2014 to December 2016. Three-hundred and seventeen recipients who received living-related or split liver transplantation were excluded from the study. ABO incompatible cases were not included in this study. The remaining 104 recipients who received deceased donor whole liver transplantation were included. Donors of donation after brain death (DBD) and donation after circulatory death (DCD) were both applied in our centre. The criteria and practical guidance for determination of brain death in children formulated by brain injury evaluation quality control centre of national health and family planning commission in China and the guidelines for the determination of brain death in children from American Academy of Pediatrics Task Force on brain death in children were used to determine donor brain death [11, 12]. DCD donors were determined as previously reported [13]. None of the organs were procured from executed prisoners. We complied with the rules of China Liver Transplant Registry (CLTR) for organ allocation. The donor and recipient characteristics, surgical aspects, and post-operative complications were recorded. This study was approved by the institutional review board of Tianjin First Center Hospital (Approval Number: 2018N099KY).

Surgical procedure

Deceased donor whole liver transplantation with piggy-back technique was performed in all recipients. The outflow tract was constructed between graft upper vena cava and the common orifice of three recipient hepatic veins. The portal vein was anastomosed with end-to-end technique. The donor liver was re-perfused after portal vein reconstruction. Hepatic artery was anastomosed under surgical loupe or microscope. Hepatojejunostomy was performed for biliary reconstruction. Double-immunosuppressive agents consisting of tacrolimus and steroids were used as our immunosuppressive protocol after transplantation.

Principles for hepatic artery preservation and reconstruction

To prevent HAT, hepatic artery was always handled with special care from organ procurement to reconstruction. During organ procurement, the hepatic artery was perfused from aorta, and the donor livers were preserved in the University of Wisconsin (UW) solution during transportation. Well-trained and experienced surgeons were responsible for the back table procedure, the surrounding tissues of hepatic artery were trimmed softly, and unnecessary traction and manipulation were avoided. We tried to keep adequate tissues around hepatic artery to avoid vascular wall injury. During artery reconstruction, we usually take the coeliac trunk patch at the junction between coeliac trunk and aorta from the donor; as for recipient, the patch at the junction of right and left hepatic artery or the patch at the junction of common hepatic artery and gastroduodenal artery was prepared for patch-to-patch continuous anastomosis. In a few cases, the artery anastomosis was performed between donor coeliac trunk end and recipient proper hepatic artery end in an interrupted manner. Hepatic artery anastomosis was performed under a surgical loupe or microscope. 8-0 or 9-0 prolene sutures were used depending on the diameter of the vessels. If the anastomosis was performed between two artery patches, continuous manner was used, and in case of end-to-end anastomosis, interrupted manner was applied.

Management for HAT

Heparin sodium was applied to all the pediatric recipients in the first week after transplantation. Warfarin was added on the third day after operation and used alone after 1 week. The target value of International Normalized Ratio (INR) was between 1.5 and 2.0. The anti-coagulation treatment normally lasted for 6 months with possible prolongation in patients with vascular complications. Post-operative hepatic artery flow was monitored by Doppler-ultrasound every day in the first post-operative week and every 2 days after 1 week. Once the blood flow of hepatic artery was missing, the patients were subjected to enhanced CT scan or arteriography to confirm the diagnosis. For patients with HAT, we used to perform embolectomy and re-anastomose the hepatic artery immediately. However, this approach only benefits patients in the short term; HAT happens again in some patients after several days. Thus, we currently give conservative treatment by intensifying the anti-coagulation therapy with low molecular weight heparin, warfarin and alprostadil; when HAT occurs, this strategy leads to better revascularization of hepatic artery or the formation of collateral circulation.

Statistical analysis

Normal distribution of variables was tested by Kolmogorov–Smirnov test. The cutoff value for continuous variables was determined by ROC curve. Variables with normal distribution were summarized with mean and standard deviation and compared across groups with two-tailed *t* test. Variables without normal distribution were summarized as median and range, and compared with nonparametric Mann–Whitney

U test. The survival curves of recipients and grafts were created by Kaplan–Meier method and compared by Log Rank test. The risk factors for HAT were first investigated by univariate logistic regression analysis; risk factors with a p value <0.20 were further tested by multivariate logistic regression model. Hosmer–Lemeshow test was used to examine the goodness of fit for the logistic regression model. Results were summarized by p values, odds ratios (ORs) and 95% confidence intervals (CIs). The statistical analysis was completed in SPSS 23.0 (IBM, München, Germany). The difference was considered statistically significant with p values smaller than 0.05.

Results

Donor and recipient characteristics

A total number of 104 deceased donor liver transplantations in children were performed during the study period. Among these recipients, the overall incidence of HAT was 22.1% ($n=23$). The donor and recipient characteristics were compared in recipients with or without HAT (HAT group vs non-HAT group). The donor age in HAT group was significantly younger than non-HAT group ($p=0.005$). No statistical difference was observed with regard to donor weight, gender, donor type and graft weight between the two groups (Table 1).

Among all recipients, there was no statistical difference in age, weight and graft-to-recipient weight ratio (GRWR). The main reason for liver transplantation in children remains biliary atresia in our centre; no statistical difference was seen in disease distribution. The severity of recipient's primary disease reflected by pre-operative level of albumin (ALB), total bilirubin (TBIL), direct bilirubin (DBIL), International Normalized Ratio (INR), Pediatric End-Stage Liver Disease PELD score and Child–Pugh score was similar between the two groups (Table 2).

Table 1 Donor characteristics

	HAT ($n=23$)	Non-HAT ($n=81$)	p value
Age (months)	4.0 (0.1, 60)	13.0 (0.5, 84)	0.005
Weight (kg)	6 (3, 18)	10 (3, 40)	0.057
Gender (female/male)	11/12	39/42	0.978
Graft weight (g)	180 (94, 540)	300 (106, 700)	0.084
Donor type			0.878
Donation after brain death	19	68	
Donation after cardiac death	4	13	

Table 2 Recipient characteristics

	HAT ($n=23$)	Non-HAT ($n=81$)	p value
Age (<8.5 months)	8 (4, 40)	9 (4, 237)	0.612
Weight (<190 g)	8.8 ± 4.0	10.9 ± 8.8	0.280
GRWR (<2.2%)	2.8% ± 1.6%	3.3% ± 1.5%	0.192
Diagnosis			
Biliary atresia	20	69	
Alagille syndrome	0	1	
Graft failure	3	2	
Congenital liver fibrosis	0	5	
Cholangiectasis	0	3	
Caroli's disease	0	1	
Pre-operative blood test			
ALB (g/L)	35.0 ± 5.3	33.4 ± 5.8	0.218
TBIL (μmol/L)	203.0 (8.7, 533.3)	206 (4.7, 608.5)	0.725
DBIL (μmol/L)	108.0 (3.2, 188.0)	93.1 (1.7, 348.0)	0.950
INR	1.2 (0.9, 1.8)	1.3 (0.8, 10.4)	0.067
PELD score	21.8 ± 6.6	25.3 ± 10.9	0.148
Child–Pugh score	7.9 ± 1.8	8.3 ± 1.7	0.390

Intraoperative data

All recipients were operated under the same surgical procedure. The anhepatic phase was significantly longer in HAT group compared with non-HAT group ($p=0.021$). Other intraoperative data, including total operation time, cold ischemia time, time from portal perfusion to artery perfusion and blood loss, were not significantly different between the two groups. Post-operatively, both groups have similar days of intensive care unit (ICU) stay and hospital stay. The peak levels of alanine transaminase (ALT), TBIL and lactic acid were comparable. All patients were followed strictly by our follow-up team. The length of the follow-up period was similar between the two groups (Table 3).

Risk factors for HAT

Potential risk factors (donor features, recipient features, and surgical aspects) were analyzed to reveal the independent risk factors for HAT (Table 4). Univariate logistic regression analysis identified donor age <8.5 months, donor weight <9 kg, graft weight <190 g and GRWR <2.2% as significant risk factors for HAT. These factors together with others with a p value <0.2 (recipient age <8 months, cold ischemia time >6 h, and Time from portal perfusion to artery perfusion >40 min) were further analyzed by multivariate logistic regression analysis. Three independent risk factors were identified: donor age

Table 3 Surgical aspects

	HAT ($n=23$)	Non-HAT ($n=81$)	p value
Operation			
Cold ischemia time (h)	9.0 ± 2.5	8.9 ± 3.6	0.863
Total operation time (min)	545.3 ± 100.9	510.9 ± 84.5	0.102
Anhepatic phase (min)	64.8 ± 29.7	54.5 ± 13.9	0.021
Time from portal perfusion to artery perfusion (min)	46.0 ± 17.8	44.5 ± 17.5	0.729
Blood loss (mL)	300 (200, 1900)	350 (50, 1700)	0.505
ICU stay (days)	4.5 ± 3.7	3.6 ± 1.4	0.068
Hospital stay (days)	36 (10, 206)	28 (12, 123)	0.195
Post-operative blood test			
Peak ALT (U/L)	679 (123, 2722)	378 (84, 6800)	0.125
Peak TBIL (μmol/L)	240.7 ± 140.1	238.7 ± 158.5	0.956
Peak lactic acid (mmol/L)	3.6 (1.5, 11.2)	2.7 (1.1, 9.3)	0.074
	3[a]	11[a]	
Follow-up (months)	38.7 ± 11.8	34.1 ± 10.2	0.064

[a]Missing data

Table 4 Univariate logistic regression analysis for the risk of HAT

Variable	OR	95% CI	p value
Donor features			
Age < 8.5 months	6.204	2.309–16.670	< 0.001
Body weight < 9 kg	3.500	1.373–8.919	0.007
Male donor	1.103	0.401–2.560	0.978
Graft weight < 190 g	4.108	1.606–10.51	0.002
DCD donor	1.101	0.322–3.771	0.878
Recipient features			
Age < 8 months	2.167	0.868–5.411	0.093
Body weight < 6.5 kg	1.878	0.708–4.981	0.201
GRWR < 2.2%	4.845	1.857–12.520	< 0.001
Biliary atresia	0.826	0.239–2.856	0.763
PELD score > 22	1.815	0.722–4.563	0.201
Child score > 10	1.158	0.348–3.856	0.811
Surgical aspects			
Cold ischemia time > 6 h	2.125	0.727–6.213	0.162
Time from portal perfusion to artery perfusion > 40 min	2.476	0.927–6.612	0.065

< 8.5 months (OR = 4.327, $p = 0.004$), graft weight < 190 g (OR = 2.912, $p = 0.027$) and GRWR < 2.2% (OR = 3.714, $p = 0.008$) (Table 5). Unsurprisingly, HAT was strongly associated with post-operative biliary complications (OR = 12.38, 95% CI: 3.3–45.8, $p < 0.001$).

Table 5 Multivariate logistic regression analysis for the risk of HAT

Variable	OR	95% CI	p value
Donor age < 8.5 months	4.327	1.593–11.752	0.004
Donor weight < 9 kg	2.382	0.923–6.150	0.073
Graft weight < 190 g	2.912	1.127–7.527	0.027
GRWR < 2.2%	3.714	1.418–9.726	0.008

Table 6 Outcome of recipients with HAT

Days from transplantation to confirmed HAT	3.91 ± 2.47 days
Days from HAT to hepatic artery repatency	10.72 ± 6.48 days
HAT-related retransplantation	3 cases
HAT-related death	2 cases

Management of HAT

In most cases, HAT was diagnosed within 1 week after transplantation with a mean time of 3.91 ± 2.47 days. The revascularization of hepatic artery or the formation of collateral circulation was achieved within 2 weeks with a mean time of 10.72 ± 6.48 days with our conservative therapy. Three patients were diagnosed with liver abscess and graft failure; re-transplantation was performed at 35, 41 and 42 days, respectively, after the first transplantation. Two patients died 7 days after transplantation due to HAT-induced liver abscess, infection and graft loss (Table 6).

Recipient and graft survival rate

The overall 1- and 3-year recipient and graft survival rates for the 104 patients were 94.2, 94.2, and 91.3%, 90.4%. The mean follow-up time was 38.7 ± 11.8 months and 34.1 ± 10.2 months in HAT group and non-HAT group, respectively. The recipient survival rate was 87.0% and 96.3% at 1 year, and 87.0% and 96.3% at 3 years, in HAT and non-HAT groups. No statistical difference was observed. Two patients in HAT group died of HAT-induced liver abscess and graft failure, one patient died of pulmonary infection 6 months after transplantation. Three patients died in non-HAT group, one due to respiratory failure and epileptic seizure, one due to graft versus host disease (GVHD), and the other one due to severe infection and multi-organ dysfunction syndrome (MODS) (Fig. 1a).

The graft survival rate was 73.9% and 96.3% at 1 year, and 73.9% and 95.1% at 3 years, in HAT and non-HAT groups. The graft survival rate in HAT group was significantly lower than non-HAT group at both 1 and 3 years ($p = 0.001$, $p = 0.003$). Three patients in HAT group underwent re-transplantation due to HAT; one patient in non-HAT

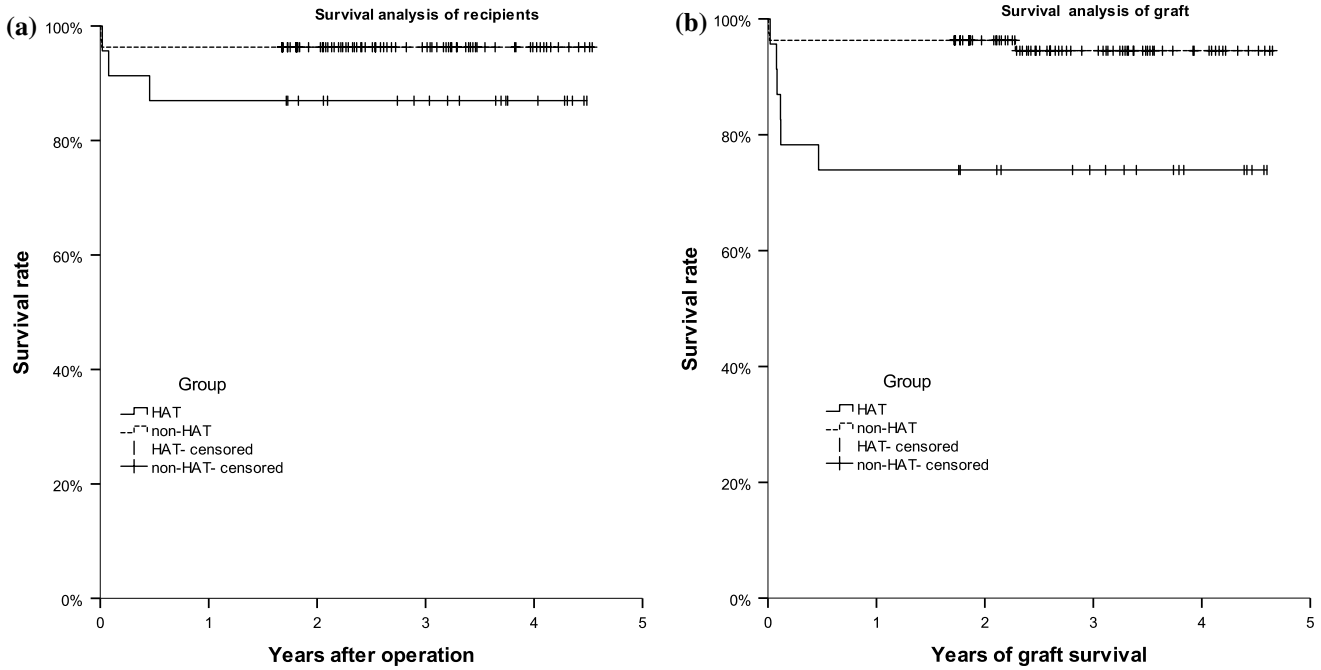

Fig. 1 **a** Survival analysis of recipients in HAT and non-HAT groups, showing the Kaplan–Meier curves of recipient survival. **b** Survival analysis of grafts in HAT and non-HAT groups, showing the Kaplan–Meier curves of graft survival

group underwent re-transplantation 2 years after the first transplantation due to chronic rejection (Fig. 1b).

Discussion

HAT is considered as a severe complication in pediatric liver transplantation. To our knowledge, this study is the first to investigate the risk factors for HAT as well as donor and recipient outcomes in deceased donor liver transplantation in children. We found that donor age < 8.5 months, graft weight < 190 g and GRWR < 2.2% are the independent risk factors for HAT in pediatric liver transplantation. Compromised graft survival rate was seen in patient with HAT. Nevertheless, HAT did not influence the recipient survival rate.

HAT is one of the major complications influencing patient and graft outcomes in liver transplantation [14]. Although the exact mechanism of HAT is still unknown [15], a variety of reasons have been found to be involved in the occurrence of HAT, including: type of artery anastomosis, coagulation status after surgery, viral infection, donor type, cold ischemia time and acute rejection [16–18]. In pediatric recipients, the small size of the organs and arteries is the major difference as compared with adult recipients. Therefore, the incidence of HAT in children has reported to be higher than that in adults [2]. Numerous studies regarding the risk factors and treatment methods for HAT in adults have been published [19–21]. However, relevant research in children, especially in recipients who received deceased donor liver transplantation, is still scarce. In this study, we excluded living donor, split and reduced-size liver transplantations to rule out the influence of graft type. In addition, the technique we used in organ procurement and hepatic artery anastomosis were identical in all patients. In accordance with our hypothesis and previous studies [22, 23], we found that young donor age (donor age < 8.5 months) and small liver graft (graft weight < 190 g, GRWR < 2.2%) act as independent risk factors for HAT in recipients receiving deceased donor liver transplantation. It was reported that young recipient age contributed to the occurrence of HAT [10]. However, our study indicated that young donor age and small donor graft weight rather than young recipient age were associated with HAT in our study population. This may be explained by the difference of organ allocation system in different centers. Previous studies showed that GRWR value less than 1.0–1.5% can be regarded as small-for-size liver graft in children [24, 25]. One study retrospectively analyzed a 20-year experience of living donor pediatric liver transplantation; it reported that a GRWR < 1.1% was an independent risk factor for HAT [26]. As for deceased donor pediatric liver transplantation, our study showed that GRWR < 2.2% was associated with higher incidence of HAT. The difference may attribute to different graft types; well-selected living donor liver grafts are considered to be superior in terms of quality.

Several other factors that we clinically hypothesized to be related to the occurrence of HAT turned out to be irrelevant

in our study. Prolonged cold ischemia time could induce the injury of vascular endothelium and further contribute to vascular complications [7]. Our result was consistent with a recent report showing that longer cold ischemia time did not lead to higher incidence of HAT [27]. The patients with HAT had significantly longer anhepatic phase during operation in our study; the longer anhepatic phase may result from the small size of liver grafts which increased the difficulty of surgery. The average total operation time in HAT group was also 35 min longer than non-HAT group, although not significant. Besides, the donor type (DBD and DCD donors) and severity of the disease (PELD and Child–Pugh score) were not associated with HAT in our study population.

The function of the liver graft relies greatly on the sufficient blood flow of hepatic artery which provides a large proportion of oxygenized blood into the liver [15]. The thrombosis of hepatic artery may lead to hepatic necrosis and ischemic biliary complications; these complications may further lead to irreversible hepatocyte necrosis and severe sepsis which can be life threatening [2]. Thus, the monitoring of hepatic artery flow is crucial for the recipient's post-operative management [28]. Doppler ultrasound was performed daily in the first week and every 2 days from the second week after surgery to detect the early thrombosis and take prompt measures when HAT occurs. In our study, aside from three cases of re-transplantation and two cases of death, the success rate of hepatic artery revascularization and collateral circulation formation was 77.3% with our conservative therapy, higher than previously reported [2]. The liver is able to withstand the occlusion of arterial blood flow through the formation of collateral circulation [29, 30]. The capability of angiogenesis in the whole donor liver of young children is more prominent. Thus, HAT did not influence long-term recipient survival rate.

The relations between HAT and biliary complication have been well recognized due to the sole blood supply of biliary system from hepatic artery [31]. It is not difficult to explain that HAT was associated with biliary complication in our population. Biliary stricture was more frequently seen after HAT; this kind of complication was detected through liver function, Doppler ultrasound, magnetic resonance cholangiopancreatography (MRCP) or percutaneous transhepatic cholangiography.

In spite of the effective prophylactic and therapeutic measures for HAT, it is still unavoidable to mention that HAT resulted in compromised graft survival rate [32, 33]. The 1- and 3-year graft survival rate in patients with HAT was significantly worse than patients without HAT in our study. It is worth noting that all HAT-related graft loss or death happened in one year after transplantation. Thus, HAT mainly influenced the short-term graft survival rate.

In our study, we focused on deceased donor pediatric liver transplantation. It is revealed that donor age < 8.5 months, graft weight < 190 g and GRWR < 2.2% were independent risk factors for HAT. The occurrence of HAT was associated with biliary complications and affected graft survival rate. With appropriate treatment, the recipients in HAT group have achieved similar survival rate with recipients in non-HAT group. Our study contributed to the understanding and management of HAT in deceased donor pediatric liver transplantation. However, more investigations are still needed to find out more effective strategies in preventing and treating HAT.

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Compliance with ethical standards

Conflict of interest All the authors of this manuscript have no conflict of interest to disclose.

Ethical approval All the procedures in studies involving human participants were in accordance with the institutional review board of Tianjin First Center Hospital (Approval Number: 2018N099KY) 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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