ORIGINAL ARTICLE

Portal Vein Thrombosis and Outcomes for Pediatric Liver Transplant Candidates and Recipients in the United States

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The effect of occlusive portal vein thrombosis (PVT) on the mortality of pediatric liver transplant candidates and recipients is poorly defined. Using standard multivariate techniques, we studied the relationship between PVT and waiting-list and posttransplant survival rates with data from the Scientific Registry of Transplant Recipients (September 2001 to December 2007). In all, 5087 liver transplant candidates and 3630 liver transplant recipients were evaluated during the period. PVT was found in 1.4% of the liver transplant candidates (n = 70) and in 3.7% of the liver transplant recipients (n = 136). PVT was not associated with increased wait-list mortality [hazard ratio (HR) = 1.1, 95% confidence interval (CI) = 0.5-2.4, P = 0.77]. Conversely, PVT patients had a significantly lower unadjusted survival rate in the posttransplant period (P = 0.01). PVT was independently associated with increased posttransplant mortality in multivariate models (30-day survival: HR = 2.9, 95% CI = 1.6-5.3, P = 0.001; overall survival: HR = 1.7, 95% CI = 1.1-2.4, P = 0.01). The presence of PVT in pediatric liver candidates was not associated with increased wait-list mortality but was clearly associated with posttransplant mortality, especially in the immediate postoperative period. *Liver Transpl 17:1066-1072, 2011.* © 2011 AASLD.

Portal vein thrombosis (PVT) is a common sequela of chronic liver disease in both adult and pediatric patients.[1-4] Architectural changes in the liver parenchyma secondary to chronic liver disease increase the resistance to the portal vein blood flow and result in venous stasis. A patient's susceptibility to thrombogenesis is increased by acquired or inherited hypercoagulopathies.[2,5,6] Although patients with PVT may present with acute hepatic decompensation, it is more often diagnosed as an incidental finding during the pretransplant radiographic evaluation or during liver transplantation.[1,7] Occlusive PVT leads to severe portal hypertension and significant morbidity related to

ascites, hepatohydrothorax, hypersplenism, or variceal bleeding. Improvements in the prophylactic management of esophageal varices have reduced the risk of bleeding, but these cirrhosis-related complications are particularly difficult to manage in children.[3,5,8-11]

Despite these complications, the natural history of PVT in children is poorly described and is not well understood. The current literature consists primarily of single-center reports, and the reported incidence of PVT has varied widely (as high as 10% in candidates and 16% in recipients).[12,13] Our previous work suggests that PVT is associated with increased mortality in adult liver transplant recipients, but the outcomes

remain less clear for pediatric liver transplant candidates.[14,15] It is critical for us to understand the complex relationship between PVT and survival in both the waiting-list and post–liver transplant pediatric populations. This knowledge could help us to optimize the timing of liver transplantation for children at risk for devastating complications. In short, large multicenter studies or clinical registry data are needed to best understand and care for these complex patients.

Within this context, we studied PVT in pediatric liver transplant candidates and recipients with a national sample derived from data from the Scientific Registry of Transplant Recipients (SRTR). We hypothesized that pediatric patients with PVT would have an increased risk of mortality both on the waiting list and after liver transplantation. In this case, transplant pediatricians might want to consider policies that facilitate early transplantation for these complex patients even while they are still considering the implications of PVT for posttransplant survival.

PATIENTS AND METHODS

Study Population

This study was approved by the University of Michigan Institutional Review Board.

SRTR data were obtained and were based on patient-level data submitted by transplant centers in the United States to the Organ Procurement and Transplantation Network. All liver transplant candidates who were initially wait-listed at an age < 18 years between September 2001 and December 2007 were included in the study cohort.

In the SRTR database, the PVT status is reported at 2 different times: the time of listing (ie, for liver transplant candidates) and the time of transplantation (ie, for transplant recipients). As in our previous works,[13,14,16] the PVT field from the candidate file was used for the purpose of evaluating wait-list mortality. For the analysis involving transplant recipients, the PVT field from the recipient file was used. As previously noted, the PVT fields in the candidate and recipient files frequently did not match. For example, PVT was noted in 70 liver transplant candidates and in 136 liver transplant recipients. This likely occurred for 2 reasons. First, PVT is frequently diagnosed at the time of liver transplantation. Second, even if PVT is diagnosed before transplantation, the data recorded in the candidate history files are rarely updated by transplant centers, except for variables that would change the Model for End-Stage Liver Disease (MELD) or Pediatric End-Stage Liver Disease (PELD) score. If our goal is to make clinical policy recommendations, using data from the recipient files for wait-list outcome measurements would not be clinically valid; therefore, we did not specifically make adjustments when the 2 PVT covariates were not in agreement.

Each candidate was observed until death, and censoring was performed only for the earliest of the following: living donor liver transplantation, the candidate's loss to follow-up, or the end of the observation period (December 31, 2007). If a candidate was removed from the wait list, he was assumed to have died.

PVT in Liver Transplant Candidates

For the purpose of descriptive analysis, the study cohort of candidates was divided into 2 groups: liver transplant candidates with PVT (PVT candidates) and liver transplant candidates without PVT (non-PVT candidates). For all candidates, univariate comparisons were made between the PVT and non-PVT groups. Kaplan-Meier survival curves were created to compare the survival rates of the liver transplant candidates with and without PVT, and the log-rank test was used for statistical comparisons. For the longer term follow-up of candidates with PVT, we did not have an adequate sample size to support a valid model, so time points after this threshold are not displayed on the Kaplan-Meier curve. A Cox regression was used to estimate the covariate-adjusted effect of PVT on wait-list mortality. Each candidate was observed until death, and censoring was performed only for the earliest of the following: living or deceased donor liver transplantation, the candidate's loss to follow-up, or the end of the observation period (December 31, 2007). Each model included an indicator for the PVT status [(1) yes or (0) no] and the following adjustment covariates: race, sex, age, dialysis status, bilirubin, international normalized ratio (INR), albumin, sodium, and a history of malignancy. No covariates were time-dependent, and the inactive time was included in the analysis.

For the Cox time-to-transplant model, patients began their follow-up on the date of their initial placement on the waiting list, and they were followed until the earliest of the following: death, living or deceased donor liver transplantation, their loss to follow-up, or the end of the study. The model adjustment covariates included the following: race, sex, age, dialysis status, bilirubin, INR, albumin, sodium, and a history of hepatoblastoma. No covariates were time-dependent, and the inactive time was included in the analysis.

PVT in Deceased Donor Liver Transplant Recipients

For all recipients, univariate comparisons were made between the PVT and non-PVT groups. Kaplan-Meier survival curves were created to compare the survival rates of the liver transplant recipients with and without PVT, and the log-rank test was used for statistical comparisons. For the longer term follow-up of recipients with PVT, we did not have an adequate sample size to support a valid model, so time points after this threshold are not displayed on the Kaplan-Meier curve.

For the posttransplant mortality model, recipients began their follow-up at the time of liver transplantation (deceased or living). For the model of 30-day survival, the patients were followed until death or the

TABLE 1. Characteristics of Pediatric Liver Transplant Candidates With or Without PVT (n = 5087)

Characteristic	Candidates Without PVT (n = 5017)	Candidates With PVT (n = 70)	P Value
Age (years)*	5 ± 6.0	6 ± 6.3	0.103
Race [n (%)]			0.64
Caucasian	2593 (51.7)	37 (52.9)	
African American	860 (17.1)	10 (14.3)	
Asian	256 (5.1)	2 (2.9)	
Hispanic	1166 (23.2)	19 (27.1)	
Other	142 (2.8)	2 (2.9)	
Sex, female [n (%)]	2559 (51.0)	49 (70.0)	0.002
PELD score at listing*	15.3 ± 13.7	9.9 ± 13.2	0.001
Body mass index (kg/m^2)*	18.1 ± 4.5	18.6 ± 4.1	0.35
Dialysis [n (%)]	137 (2.7)	1 (1.4)	>0.99
Previous liver transplant [n (%)]	535 (10.7)	12 (17.1)	0.082

*The data are presented as means and standard deviations.

end of the observation time (30 days after transplantation). For the model of overall survival, the patients were followed until death or their loss to follow-up (<1% of recipients). No covariates were time-dependent. The final pretransplant values were coded for creatinine, bilirubin, albumin, INR, sodium, and dialysis. In addition to the aforementioned covariates, the posttransplant mortality models also included the following recipient characteristics at the time of transplantation: sex, age, liver disease etiology, living donor status, and donor risk index components (ie, the donor's age, race, and cause of death, the donation after cardiac death status, and the split liver status).

All statistical analyses were performed with SAS 9.3.1 (SAS Institute, Cary, NC).

RESULTS

PVT in Liver Transplant Candidates

The characteristics of the pediatric candidates with and without PVT who were wait-listed for liver transplantation are displayed in Table 1. The prevalence of PVT (reported in the national database) among the 5087 candidates was 1.4% (n = 70). Candidates with PVT were more likely to be female (70.0% versus 51.0%, P = 0.002) and to have a lower PELD/MELD score when they were placed on the transplant list (9.9 ± 13.2 versus 15.3 ± 13.7, P = 0.001). The following factors did not differ significantly between PVT and non-PVT candidates: age, race, body mass index, dialysis status, and previous transplant status. A diagnosis of biliary atresia was not more common among candidates with PVT, and the survival of biliary atresia candidates was not significantly different from the survival of candidates without biliary atresia (P = 0.72).

Kaplan-Meier survival curves were created to compare the survival rates of liver transplant candidates with and without PVT (Fig. 1). The unadjusted survival rate was not significantly lower for liver transplant candidates with PVT (P = 0.797).
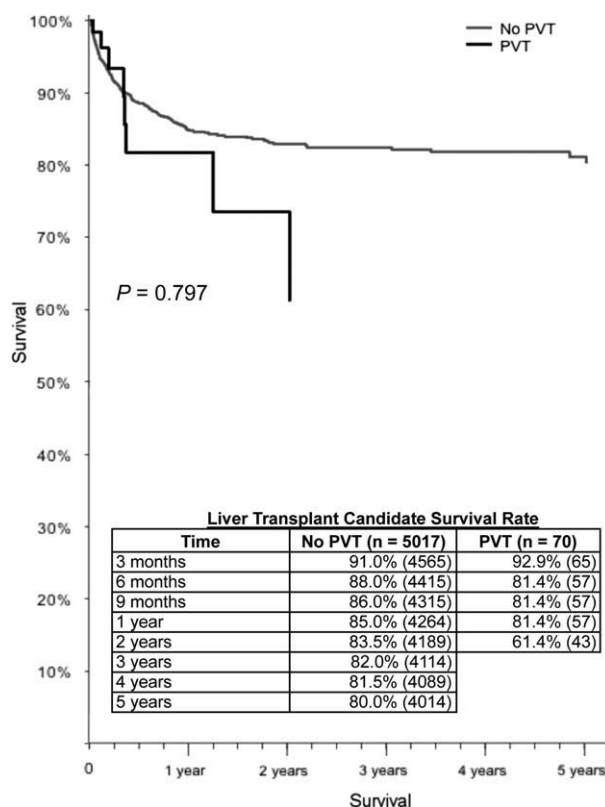

Figure 1. Kaplan-Meier survival curves for wait-listed liver transplant candidates with or without PVT.

We first assessed the relationship between PVT and wait-list mortality with a univariate Cox regression model. PVT was not significantly associated with wait-list mortality [hazard ratio (HR) = 1.1, 95% confidence interval (CI) = 0.5-2.4, P = 0.77]. In an attempt to elucidate the characteristics independently associated with wait-list mortality for all the candidates, we performed a multivariate Cox regression analysis, which is presented in Fig. 2. Once again, PVT was not significantly associated with wait-list mortality by
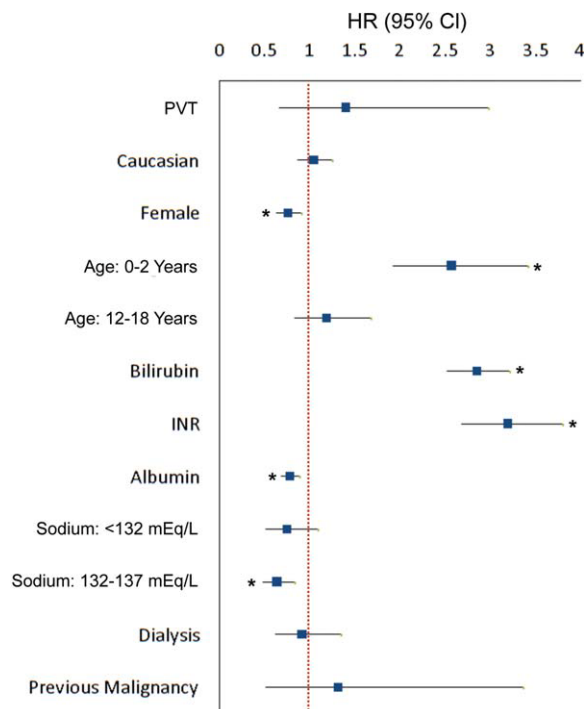
Figure 2. Multivariate Cox regression analysis of wait-list mortality in pediatric liver transplant candidates. PVT was not significantly correlated with the wait-list mortality risk. Female candidates had a decreased mortality risk (HR = 0.8, 95% CI = 0.6-0.9, P = 0.003), and candidates who were 0 to 2 years old had an increased risk (HR = 2.6, 95% CI = 1.9-3.4, P < 0.001).

multivariate analysis (HR = 1.4, 95% CI = 0.7-3.0, P = 0.38). Female sex was associated with a significantly decreased covariate-adjusted mortality risk (HR = 0.8, 95% CI = 0.6-0.9, P = 0.003), whereas candidates who were 2 years of age or younger had an increased mortality risk (HR = 2.6, 95% CI = 1.9-3.4, P < 0.001) in comparison with candidates between the ages of 3 and 11 years. In addition, both bilirubin and INR values were associated with wait-list mortality.

We then investigated the relationship between the reported PVT status and the transplant rate. A covariate-adjusted Cox regression was performed in an effort to determine the candidate characteristics independently associated with the liver transplant rate. PVT was not independently associated with the adjusted liver transplant rate (HR = 0.9, 95% CI = 0.8-1.1, P = 0.35). However, candidates were more likely to receive a transplant if they were female (HR = 1.1, 95% CI = 1.0-1.1, P = 0.001), 2 years old or younger (HR = 1.1, 95% CI = 1.0-1.1, P < 0.001), or 12 to 18 years old (HR = 1.4, 95% CI = 1.3-1.5, P < 0.001; the age reference group consisted of candidates who were 3 to 11 years old). Similarly, candidates with a blood sodium level between 132 and 137 mEq/L had an increased rate of transplantation (HR = 1.2, 95% CI = 1.1-1.2, P < 0.001), whereas a mean sodium level less than 132 mEq/L was not significantly correlated. As expected, the following PELD/MELD

components were significantly associated with the transplant rate: INR (HR = 1.13, 95% CI = 1.06-1.20, P < 0.001), bilirubin (HR = 1.25, 95% CI = 1.23-1.28, P < 0.001), albumin (HR = 0.63, 95% CI = 0.59-0.67, P < 0.001), and dialysis (HR = 1.4, 95% CI = 1.2-1.6, P < 0.001). Race and a previous diagnosis of malignancy were not associated with the transplantation rate.

PVT in Liver Transplant Recipients

The characteristics of pediatric liver transplant recipients with and without PVT and their donors are displayed in Table 2. In all, 3630 patients received a liver transplant, and 3.7% of these patients (n = 136) were reported to have PVT. The graft donor characteristics, such as the donor age, the donor weight, and the donor risk index, were not significantly different between the groups. In addition, the utilization of deceased donor split liver grafts and living donor grafts was similar between the 2 groups. PVT recipients were more likely to be female (64.7% versus 51.1%, P = 0.002). The following recipient characteristics did not differ significantly between the groups: age, race, PELD score at transplant, albumin, sodium, and ascites. PVT was not associated with a diagnosis of biliary atresia, although this assessment was limited by the small sample size. More specifically, 1496 recipients were listed with biliary atresia as the primary diagnosis. Forty of these recipients had PVT, and there were 4 deaths.

Kaplan-Meier survival curves were created to compare the survival rates of the liver transplant recipients with and without PVT (Fig. 3). The unadjusted survival rate was significantly lower in the PVT group across the posttransplant period (P = 0.01). The survival rate was particularly lower in the first few months after transplantation and then continued to trend downward like that of the non-PVT recipients.

We then assessed the implications of PVT for short-term posttransplant survival (30-day survival). PVT was significantly associated with 30-day mortality (HR = 2.9, 95% CI = 1.6-5.3, P = 0.001). Other covariates that were significantly associated with short-term mortality included the following: creatinine (HR = 4.42, 95% CI = 2.8-7.1, P = 0.001), INR (HR = 1.6, 95% CI = 1.1-2.4, P = 0.02), a recipient age of 0 to 2 years versus a recipient age of 3 to 11 years (HR = 1.7, 95% CI = 1.1-2.6, P = 0.014), and donor age (HR = 1.02, 95% CI = 1.01-1.04, P = 0.01). No statistical interactions between PVT and the other covariates (including the age at transplantation) were noted.

A univariate regression was performed to determine the effects of PVT on overall posttransplant mortality. Recipients with PVT showed increased posttransplant mortality (HR = 1.7, 95% CI = 1.2-2.5, P = 0.007). These results were corroborated by a multivariate Cox regression analysis, which revealed that PVT was significantly associated with adjusted posttransplant mortality (HR = 1.6, 95% CI = 1.0-2.4, P = 0.03), as displayed in Fig. 4. The model was adjusted for sex,

TABLE 2. Characteristics of Pediatric Liver Transplant Recipients With or Without PVT and Their Donors (n = 3630)

Characteristic	Recipients Without PVT (n = 3494)	Recipients With PVT (n = 136)	P Value
Donor			
Age (years)*	15 ± 14.7	13 ± 14.1	0.19
Weight (kg)*	42.1 ± 28.8	38.8 ± 28.8	0.19
Graft type [n (%)]			
Deceased donor whole	2135 (61.1)	89 (65.4)	0.31
Deceased donor split	922 (26.4)	36 (26.5)	0.98
Living donor	437 (12.5)	11 (8.1)	0.12
Donor risk index*	2.0 ± 0.6	2.0 ± 0.6	0.58
Cold time (hours)*	7.3 ± 4.0	7.4 ± 2.8	0.56
Recipient			
Age (years)*	5 ± 5.8	4 ± 6.0	0.53
Race [n (%)]			0.35
Caucasian	1825 (52.2)	79 (58.1)	
African American	609 (17.4)	17 (12.5)	
Asian	188 (5.4)	4 (2.9)	
Hispanic	776 (22.2)	30 (22.1)	
Other	96 (2.7)	6 (4.4)	
Sex, female [n (%)]	1784 (51.1)	88 (64.7)	0.002
PELD score at transplant*	15.7 ± 13.8	14.2 ± 12.3	0.21
Albumin (g/dL)*	3.1 ± 0.8	3.0 ± 0.8	0.31
Sodium (mEq/L)*	137.9 ± 5.4	137.8 ± 7.1	0.87
Ascites [n (%)]	1436 (41.1)	64 (47.1)	0.17

*The data are presented as means and standard deviations.

Liver Transplant Recipient Survival Rate

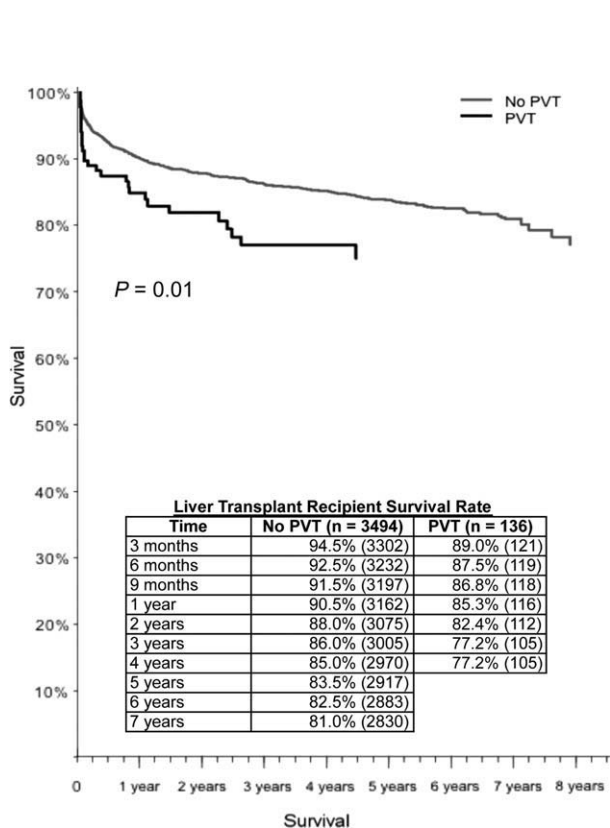| Time	No PVT (n = 3494)	PVT (n = 136)
3 months	94.5% (3302)	89.0% (121)
6 months	92.5% (3232)	87.5% (119)
9 months	91.5% (3197)	86.8% (118)
1 year	90.5% (3162)	85.3% (116)
2 years	88.0% (3075)	82.4% (112)
3 years	86.0% (3005)	77.2% (105)
4 years	85.0% (2970)	77.2% (105)
5 years	83.5% (2917)	
6 years	82.5% (2883)	
7 years	81.0% (2830)	

Figure 3. Kaplan-Meier survival curves for liver transplant recipients with or without PVT.
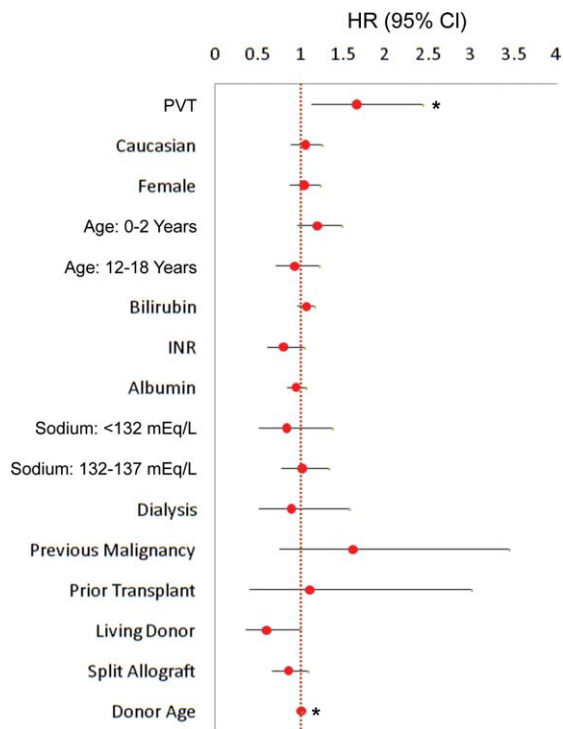

Figure 4. Multivariate Cox regression analysis of posttransplant mortality in pediatric liver transplant recipients. Pediatric liver transplant recipients with PVT had a significantly increased risk of mortality in comparison with recipients without PVT (HR = 1.661, 95% CI = 1.131-2.441, P = 0.01). No other factor was significantly associated with the risk of mortality.

age, race, creatinine, bilirubin, INR, albumin, sodium, dialysis status, graft type, retransplantation status, and a previous diagnosis of malignancy.

DISCUSSION

In this work, we have investigated the relationship between PVT and survival for pediatric liver transplant candidates and recipients. Our hypothesis was that liver transplant candidates and recipients with PVT would have a significantly higher risk of mortality. In fact, we noted a significantly higher rate of posttransplant mortality only in the liver transplant recipients with PVT (3.6%); we did not note a statistically significant relationship between PVT and wait-list mortality. Although this study has several important limitations, it is the largest known study of PVT and pediatric liver transplantation. In this context, these analyses do not specifically support policies facilitating early transplantation for pediatric patients with PVT. This conclusion should be considered within the context of the limitations of this registry-based analysis.

PVT is likely due to a combination of decreased portal venous blood flow (related to cirrhosis, mesenteric venous hypoplasia, or both) and hypercoagulability (eg, acquired protein C and S deficiencies). PVT increases the postoperative risk of death after adult liver transplantation.[14,17] This study shows similar posttransplant survival outcomes and agrees with previous studies of pediatric liver transplant patients.[13] The implications of PVT for the survival of children on the wait list remain less clear. Although we noted a trend toward inferior survival, this trend was not statistically significant. Previous studies of adult liver transplant populations have noted similar findings.[14,16]

When the results of our study are being considered, it is important to understand the limitations of retrospective observational data. The most important limitation of this study is that our ability to truly define the incidence of PVT in the pediatric population with liver diseases is restricted. Only 3.7% of the children who underwent liver transplantation had PVT in our study. Smaller, single-center studies (by our group) have demonstrated much higher rates of PVT in transplant recipients (10%), and this may demonstrate underdetection within the national registry data.[13] A prospective screening study with a large number of centers would be needed for an accurate determination of the incidence of PVT. Another important limitation involves the characterization of PVT (complete or partial). In previous work,[13,16] we assigned a specific definition to PVT so that only cases of occlusive thrombosis of the main portal vein were included. This rigorous definition of PVT is not possible with Organ Procurement and Transplantation Network data; as a result, we are not able to confirm the reliability of the PVT data reported by transplant centers. Clearly, the management of complete PVT is significantly more complex at the time of trans-

plantation. Another limitation involves the lack of data on patients with end-stage liver disease who were never listed for transplantation. Future studies may seek to include these patients because they likely represent a particularly sick cohort of patients. Finally, there are likely associations between biliary atresia and PVT that are not able to be fully understood because of the limitations of this data set. More specifically, pediatric patients with biliary atresia may present with a complex mesenteric venous anatomy. Clearly, the complexity of their clinical scenario is not adequately represented by national registry data. Furthermore, this analysis is limited by the small sample size and event rates for biliary atresia patients with PVT (only 40 recipients and 4 deaths). Additional studies using more robust data sources are needed to better understand the relationships between biliary atresia, PVT and anatomic variations, and outcomes.

Our data suggest that much of the increased risk of postoperative mortality is directly related to the transplant operation. Certainly, there are several options for the surgical management of this complex problem, and it is critical that the mesenteric vascular anatomy be fully understood before transplantation. Because mesenteric venous hypoplasia is common in the setting of biliary atresia, a complete preoperative radiographic workup is particularly important for these patients. Recent studies comparing preoperative assessments of the hepatic and portal vasculature have shown that Doppler ultrasound can be a useful initial screening test and should be followed by computed tomography venography or magnetic resonance venography for definitive operative planning.[18,19] These studies can also help us to recognize important vascular anomalies such as a preduodenal portal vein or the absence of a portal vein.

In summary, PVT is associated with an increase in the postoperative mortality rate, although the relationship between PVT and wait-list mortality remains less clear. Additional work is needed to understand the incidence of this disease, and there should be a particular focus on children who may have PVT but are never listed for transplantation. Although further investigations are needed to delineate the best options for the management of PVT in liver transplant recipients, a careful preoperative diagnosis and planning offer the best opportunities for improvements in postoperative survival outcomes. Finally, although some limitations exist, this work does not seem to support broad-based policy efforts that would facilitate early transplantation for pediatric patients with PVT.

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