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Low volume is associated with worse patient outcomes for pediatric liver transplant centers☆

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Abstract

Background: An inverse association between hospital procedure volume and postoperative mortality has been demonstrated for a variety of pediatric surgical procedures. The objective of our study was to determine whether such an association exists for pediatric liver transplantation.

Methods: We performed a retrospective analysis of pediatric liver transplant procedures included in the Scientific Registry of Transplant Recipients over a 7.5-year time period from July 1, 2000, through December 31, 2007. Pediatric liver transplant centers were divided into three volume categories (high, middle, low) based on absolute annual volume. Mean 1-year patient survival rates and aggregate 1-year observed-to-expected (O:E) patient death ratios were calculated for each hospital volume category and then compared using ordered logistic regression and chi square analyses.

Results: High-volume pediatric liver transplant centers achieved significantly lower aggregate 1-year O:E patient death ratios than low-volume centers. When freestanding children's hospitals (FCH), children's hospitals within adult hospitals (CAH), and other centers (OC) were considered separately, we found that a significant volume-outcomes association existed among OC centers but not among FCH or CAH centers. Low-volume OC centers, which represent 41.6% of all pediatric liver transplant centers and perform 10% of all pediatric liver transplantation, had the least favorable aggregate 1-year O:E patient death ratio of all groups.

Conclusions: We demonstrate that a significant center volume-outcomes relationship exists among OC pediatric liver transplant centers but not among FCH or CAH centers. These findings support the possible institution of minimum annual procedure volume requirements for OC pediatric liver transplant centers.

An inverse association between hospital procedure volume and postoperative patient mortality has been demonstrated for a wide variety of complex adult surgical procedures [1-7]. A volume-outcomes relationship has also been found for several pediatric surgical procedures, including pediatric cardiac surgery, pyloromyotomy, appendectomy, and inguinal hernia [1,8-11]. Currently, pediatric cardiac surgery

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is the only procedure type that is subject to minimum annual hospital volume requirements by the Agency for Healthcare Research and Quality [12-14].

The relationship between hospital volume and patient outcomes after pediatric liver transplantation is not currently known. Studies of adult liver transplantation have produced conflicting results. Earlier analyses have suggested that high-volume adult liver transplant centers achieved lower postoperative mortality rates than low-volume centers, but more recent analyses have failed to demonstrate any significant association between adult liver transplant center volume and recipient outcomes [6,15-21]. The objective our study was to determine whether such a relationship exists for pediatric liver transplantation.

1. Methods

We utilized publicly available liver transplant program-specific data reports collected by the Organ Procurement and Transplantation Network and provided by the Scientific Registry of Transplant Recipients (SRTR). The SRTR Program-Specific Reports contain information on procedure volume, recipient and donor characteristics, and graft and patient outcomes. Expected survival is modeled by Cox regression analyses, with adjustments for a number of different recipient- and donor-specific variables [20]. These regression models are used to construct 1-month and 1-year observed-to-expected recipient death ratios, which are published on-line by the SRTR at 6-month intervals [29,30,32].

All pediatric liver transplant procedures (both cadaveric and living-donor) performed in the United States from July 1, 2000, through December 31, 2007, were included for retrospective analysis. Center volume and center-specific patient outcomes were collected using data from the following SRTR program-specific data reports: January 2004 report = transplants performed from July 1, 2000, through December 31, 2002; July 2006 report = transplants performed from January 1, 2003 through June 30, 2005; and January 2009 report = transplants performed from July 1, 2005 through December 31, 2007 [21-23]. Pediatric recipients were defined as those patients aged < 18 years. Only single-organ transplant procedures were included. Our study was approved by the institutional review board at Duke University Medical Center.

We calculated the total number of pediatric liver transplant procedures performed at each center in the United States over the 7.5-year study period. Center volume categories were defined in such a way that approximately one third of all pediatric liver transplant recipients would be contained within each category. In this manner, the following 3 center volume groups were constructed: low volume centers (≤7 procedures per year), medium volume (8-15 procedures per year), and high-volume (≥16 procedures per year). This methodology for defining hospital procedure is designed to maximize the potential for meaningful statistical analysis and has been used frequently in the hospital volume-outcomes literature [24-28].

Pediatric liver transplant centers were divided into three categories based on their designation by the National Association of Children's Hospitals and Related Institutions: freestanding children's hospitals (FCH), children's hospitals within adult hospitals (CAH), and other centers (OC) [35]. Dependent variables in our analysis included center type and hospital volume (low, medium, and high). Outcome variables included the number of pediatric liver transplant centers and pediatric liver recipients, unadjusted 1-year patient survival rates, and aggregate 1-year observed-to-expected (O:E) patient death ratios. Unadjusted patient survival rates for each hospital volume group were calculated by dividing the total number of patients surviving at 1 year by the total number of recipients for the period. In order to determine the aggregate 1-year O:E patient-death ratios for each center volume group, we divided the sum of the number of observed deaths at centers within that volume group by the sum of the number of expected patient deaths at those centers. The number of expected patient deaths for each center is derived from a risk-adjustment model developed and validated by the SRTR. Covariates used in SRTR modeling of expected outcomes were identical in identical in the first 2 reporting periods that were used in our analysis (donor age, graft ischemia time, recipient age, race, diagnosis, creatinine, preoperative hospitalization, preoperative comorbidities), although the weight given to each of these variables did differ between periods. Period 3 covariates were similar to those used in earlier time periods excepting the addition of recipient ABO type, inclusion of extended donor criteria or deceased donor status, differentiation between whole or partial graft implantation, and presence of recipient history of ascites or hepatocellular carcinoma). The addition of these covariates to the SRTR risk-adjustment model for expected patient outcomes was validated by use on prior cohorts of data (2003-2006) in order to establish their stability across time periods [29-31]. For the earliest 2.5-year time period in our study, the number of 1-year observed and expected patient deaths was not made publicly available by the SRTR. We therefore derived these values from the observed and expected patient survival rates that were provided by the SRTR.

Linear regression and analysis of variance were used to compare unadjusted 1-year survival rates between groups. χ^2 Analyses were used to compare the aggregate 1-year O:E patient deaths ratios. P values were considered significant at $P < .05$. Statistical analyses were performed using Stata/SE version 9.2 (StataCorp LP, College Station, Tex).

2. Results

A total of 3216 pediatric liver transplant procedures performed at 89 transplant centers in the United States over a 7.5-year period were included in our analysis. Twenty of

Table 1 Aggregate pediatric transplant center volume for 2000-2007

	Low-volume centers (≤7 procedures/y)			High-volume centers (≥16 procedures/y)		
	Mean annual volume	No. (%) of centers	No. (%) of patients	Mean annual volume	No. (%) of centers	No. (%) of patients
FCH	4.03	9 (10.1%)	272 (8.5%)	19.5	3 (3.4%)	438 (13.6%)
CAH	2.57	23 (25.8%)	444 (13.8%)	20.9	3 (3.4%)	471 (14.6%)
OC	1.14	37 (41.6%)	316 (9.8%)	22.7	1 (1.1%)	170 (5.3%)
All centers	2.09	69 (77.5%)	1032 (32.1%)	20.6	7 (7.9%)	1079 (33.6%)

these centers (22.5%) were freestanding children's hospitals (FCH), 28 centers (31.5%) were children's hospitals within adult hospitals (CAH), and 41 (46.1%) were other centers (OC). The distribution of patients among the different hospital volume categories is shown in Table 1. Of note, 41.6% of all United States centers performing pediatric liver transplantation were low-volume OC centers, with this group accounting for nearly 10% of all pediatric liver transplant procedures performed during our study period.

For all pediatric liver transplant centers in this study, aggregate one-year O:E patient death ratios were significantly lower for high volume centers (0.77) than for low-volume centers (1.23, $P = 0.027$; see Table 2). Similarly, within the OC category, high volume centers has significantly lower aggregate O:E ratios than high volume centers (0.50 vs 1.41, $P = 0.033$). Conversely, no significant difference could be demonstrated in the aggregate 1-year O:E ratios for low-volume vs high-volume centers in the FCH or CAH categories. One-year unadjusted patient survival rates after pediatric liver transplantation did not differ significantly between high- and low-volume centers regardless of center type (Fig. 1).

Fig. 2 depicts the geographical location of centers that remained active in pediatric liver transplantation in the most recent program-specific data reports provided by the SRTR. The figure demonstrates that many of the OC centers that perform pediatric liver transplant procedures are geographically proximate to FCH or CAH centers.

3. Discussion

In this study, we have demonstrated that a center volume-outcomes relationship exists for pediatric liver transplantation in the United States, most likely owing to the relatively poor outcomes achieved by adult transplant centers that perform this procedure in pediatric patients. On subanalysis, a volume-outcomes relationship could not be demonstrated among FCH or CAH pediatric liver transplant centers. These results suggest the potential need for policies that restrict the performance of pediatric liver transplantation to either children's hospitals or to adult transplant centers that perform a relatively high volume of pediatric procedures.

Prior studies have found a strong volume-outcomes relationships for a number of procedures. The most extensively studied and well-documented volume-outcomes relationship exists for pediatric cardiac surgery, resulting in the development of policies designed to direct patients needing these procedures away from low-volume centers in an effort to improve the mortality associated with pediatric cardiac surgery [32]. Other pediatric surgical procedures have also been shown to exhibit a volume-outcomes effect. For example, Safford et al [11] demonstrated that patients undergoing surgical repair of hypertrophic pyloric stenosis at low-volume centers were 1.6 times more likely to suffer complications than patients undergoing this procedure at high-volume centers [33]. Similar findings have also been demonstrated for pediatric appendectomy or inguinal hernia repair [34-36].

Although we demonstrate a volume-outcomes relationship for pediatric liver transplantation, we also show that this volume-outcomes relationship does not necessarily exist for all the center types that we analyzed. Specifically, we found an inverse relationship between center volume and mortality for OC centers but not for FCH or CAH centers. A number of factors may potentially mitigate the effect of procedure volume on patient outcomes at FCH and CAH centers, including greater access to multidisciplinary teams of

Table 2 Pediatric liver transplant recipient 1-year outcomes by stratified by volume

	Low-volume centers (≤7 procedures/y)		High-volume centers (≥16 procedures/y)		*P* (high- vs low-volume centers)
	No. (%) of survivors	Aggregate O:E ratio	No. (%) survivors	Aggregate O:E ratio	
FCH	241 (88.4%)	1.02	382 (87.2%)	0.82	.57
CAH	378 (85.2%)	1.22	423 (89.8%)	.83	.21
OC	254 (8.7%)	1.41	154 (9.5%)	.50	.03
All centers	873 (84.7%)	1.23	959 (88.9%)	.77	.03

*P values derived from χ^2 analysis comparing aggregate O:E ratios of high-volume with low-volume centers in each category.

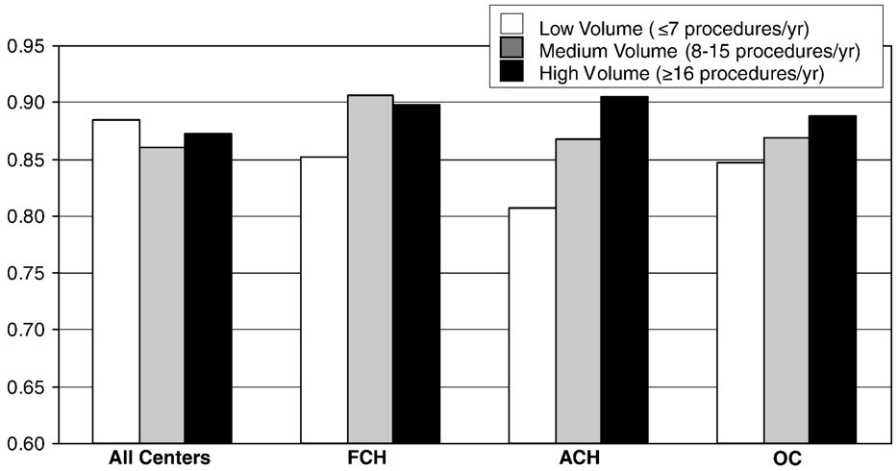

Fig. 1 Pediatric liver transplant recipient 1-year unadjusted patient survival stratified by center volume.

pediatric subspecialists, a larger percentage of fellowship-trained pediatric surgeons, and more experience with performing complex non-transplant hepatobiliary procedures in children [37,38]. Unfortunately, most of the studies that have examined the relationship between center volume and patient outcomes for pediatric procedures have not compared children's to non-children's centers [8-11,36,37].

Our finding of a significant volume-outcomes relationship for pediatric liver transplantation among non-children's (OC) hospitals supports the development of a referral policy that direct patients needing this procedure to children's hospitals or to high-volume non-children's hospitals. Such a policy would affect the approximately 10% of all pediatric liver transplant patients who currently undergo this procedure in low-volume non-children's centers, and appears to be feasible given that many of the existing low-volume OC centers are geographically proximate to FCH, CAH or high-volume OC centers (as is demonstrated for New York City, Chicago, and Houston in Fig. 2).

Our study has several potential limitations. First, our methodology for constructing center volume categories is somewhat arbitrary. We treated center volume as a trichotomous categorical variable (as opposed to using a greater number of categories or treating center volume as a

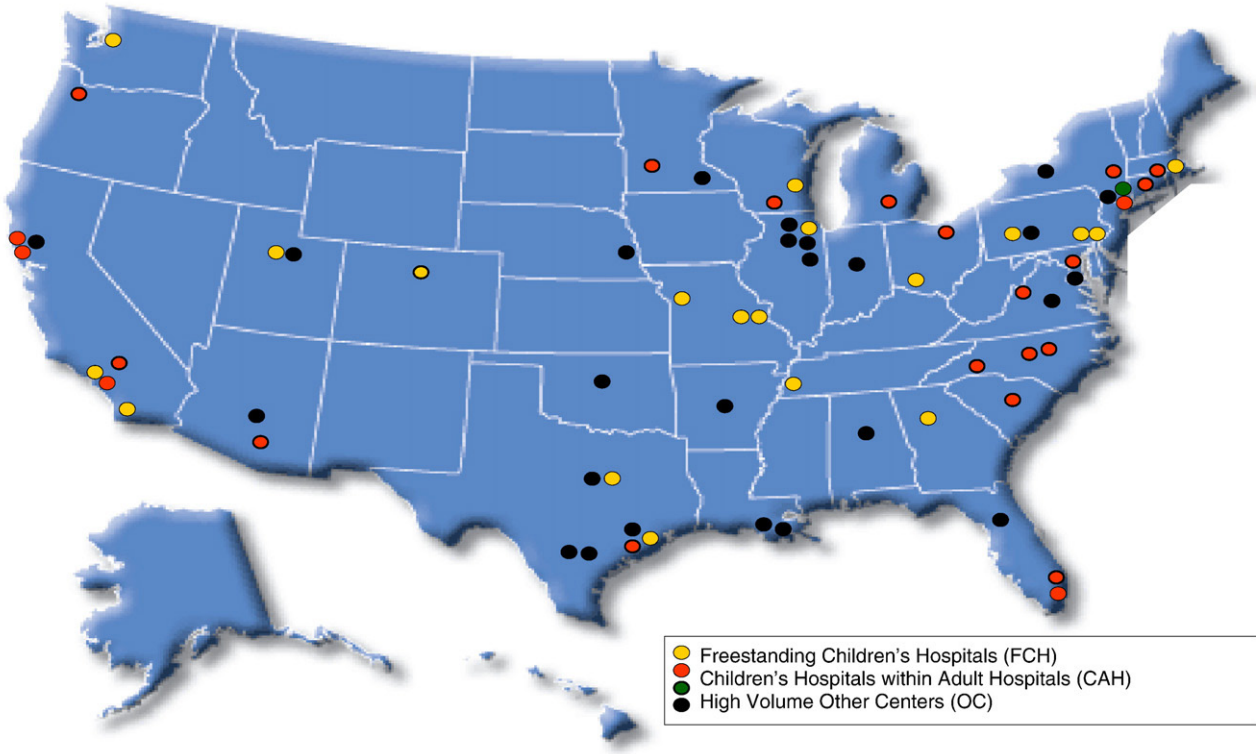

Fig. 2 Geographic distribution of pediatric liver transplant centers in the United States, 2005 to 2007.

continuous variable) in an attempt to increase our ability to detect volume-based differences in post-transplant. Because pediatric liver transplantation is a relatively uncommon surgical procedure, we could not easily design our analysis to identify the best volume level for use in potential volume-based referral policies. Second, we rely on publicly available 1-year expected death estimates provided by the SRTR. In using this data as a proxy for risk-adjusted patient outcomes, we are assuming that the methodology used by the SRTR when constructing these death estimates represents the best possible risk adjustment [30,32]. Third, we cannot fully predict the consequences of our summation of aggregate expected patient deaths over three different reporting periods.

Despite these limitations, we have found that a volume-outcomes relationship exists for pediatric liver transplantation at non-children's hospitals but not at free-standing children's hospitals or children's hospitals within adult hospitals. We therefore conclude that annual procedure volume may serve as a valid indicator of center quality for pediatric liver transplantation among non-children's hospitals. Efforts by low-volume nonfreestanding children's centers to increase their annual volume of this procedure may help those centers to improve their outcomes. Alternatively, policy initiatives which divert pediatric patients needing this procedure to freestanding or attached children's hospitals, or to high-volume centers without children's hospitals, may also be warranted.

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