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Is there value in volume? An assessment of liver transplant practices in the United States since the inception of MELD

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A R T I C L E I N F O

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A B S T R A C T

Background: Liver transplantation has increased in volume and provides substantial survival benefit. However, there remains a need for value-based assessment of this costly procedure.
Methods: Model for end stage liver disease era adult recipients were identified using United Network for Organ Sharing Standard Transplant Analysis file data ($n = 75{,}988$) and compared across time periods (period A: February 2002 to January 2007; B: February 2007 to January 2013; C: February 2013 to January 2019). Liver centers were divided into volume tertiles for each period (small, medium, large). Value for the index transplant episode was defined as percentage graft survival ≥1 year divided by mean post-transplant duration of stay.
Results: All centers increased value over time due to ubiquitous improvement in 1-year graft survival. However, large centers demonstrated the most significant value change (large +17% vs small +7.0%, $P < .001$) due to a −8.5% reduction in large centers duration of stay from period A to C, while small centers duration of stay remained unchanged (−0.1%). Large centers delivered higher value despite more complex care: older recipients (54.8 ± 10.3 vs 53.0 ± 11.4 years $P < .001$), fewer model for end stage liver disease exceptions (34.0% vs 38.2%, $P < .001$), higher rates of candidate portal vein thrombosis (10.1% vs 8.5%, $P < .001$) and prior abdominal surgery (43.4% vs 37.4%, $P < .001$), and more marginal donor utilization (donor risk index 1.45 ± 0.38 vs 1.36 ± 0.33, $P < .001$). Mahalanobis metric matching demonstrated that compared with small centers, large centers progressively shortened recipient duration of stay per transplant in each period (A: −0.36 days, $P = .437$; B: −2.14 days, $P < .001$; C: −2.49 days, $P < .001$).
Conclusion: There is value in liver transplant volume. Adoption of value-based practices from large centers may allow optimization of health care delivery for this costly procedure.
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Introduction

Liver transplantation (LT) continues to be the only definitive treatment for end-stage liver disease. During the past decade, LT volume in the United States has increased over 45% from approximately 6,300 in 2009 to 9,236 in 2021.[1,2] Concordant with this, it is projected that LT costs will increase by an annualized rate of growth of 4% during the next 20 years.[3] As the liver transplant waitlist continues to grow,[1] and new technologies emerge that enable greater graft utilization[4,5] albeit with the potential for substantial added costs, interrogation of value-based practices is paramount in order to create a system that promotes maximal use and sustainability of this life-saving treatment.

Value, in its most colloquial context, is the exchange of goods and services for costs. In health care, value is defined much the same, with health outcomes as “goods and services” and hospital dollars spent as “costs.”[6,7] Multiple stakeholders, patients, providers, payors, and healthcare institutions, thus

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play a pivotal role in achieving value-based care. Indeed, value-based care allows for prioritization of quality outcomes for patients, while achieving cost containment for providers and payors, and delivering a holistic approach to medicine for health care institutions.[5] Assessments of value-based care have largely focused on optimizing medical decision making through value comparisons between different treatment choices, for example in end-stage renal disease (dialysis versus kidney transplantation),[8] orthopedic surgery (joint replacement versus nonoperative management),[9] and hepatobiliary surgery (laparoscopic versus robotic surgery).[10] Few studies, however, have examined specific factors contributing to high-value care for a specific treatment modality,[11] and even fewer are specific to liver transplantation.[12]

In this study, the association between LT volume and its effect on delivering high-value LT care during the index hospitalization was explored. To this end, temporal trends in LT volume, outcomes, and value for all LT centers in the United States during a 17-year period was examined. Finally, a critical assessment of the effect of center LT volume on value-based care was undertaken by comparing outcomes relative to costs (ie, resource utilization) of small- to large-volume centers.

Methods

Data source

This study analyzed the United Network for Organ Sharing Standard Transplant Analysis files, which contain data on all donors, waitlisted candidates, and recipients of solid organ transplantation in the United States. Periodic follow-up (including, but not limited to, graft function and mortality) were reported to the Organ Procurement and Transplantation Network by transplant centers. The information was linked with matched data from the Social Security Death Master File. This study was deemed exempt by the UT Southwestern Institutional Review Board.

Study population

All liver transplant recipients in the United States from February 1, 2002, through February 1, 2019, were identified (n = 111,639). Pediatric patients <18 years old at the time of transplant, fulminant (status 1) transplants, retransplants, multiorgan transplants, living donor recipients, and recipients lost to follow-up were excluded from analysis (n = 32,821, 29.4%). Recipients that died during their transplant hospitalization were also excluded (n = 2,830, 2.5%), as inclusion of these patients would artificially lower the mean hospital duration of stay. To assess temporal trends, transplanted patients were further stratified by time periods: February 1, 2002 to January 31, 2007 (period A), February 1, 2007 to January 31, 2013 (period B), and February 1, 2013 to January 31, 2019 (period C).

Patient characteristics

The following recipient characteristics were obtained for analysis: age, sex, body mass index, model for end stage liver disease (MELD) score at transplant, liver graft Donor Risk Index, exception status listing, race, insurance type, need for life support, presence of hepatocellular carcinoma, history of previous abdominal surgery, and presence of portal vein thrombosis. These characteristics were identified by survey of post-transplant outcomes from Scientific Registry of Transplant Recipients Risk Adjusted Model documentation.

Center size classification

An a priori decision was made to divide liver transplant centers into tertiles (small, medium, large) by volume based upon the cumulative number of transplants completed at each center during each analysis period. Tertiles were recalculated for each study period.

Value definition

Value in liver transplantation was calculated for each study period as the percent graft survival ≥1 year divided by the mean duration of stay in days for the index transplant surgery episode.[6,12–14]

Statistical analysis

The statistical analyses were performed using Stata 16/MP4 (StataCorp LP, College Station, TX). Patient characteristics were described using mean (standard deviation) for continuous variables and frequencies for categorical variables. Comparison by univariate analysis were made using 2 independent sample t tests with unequal variances for continuous variables and the χ^2 test for categorical variables as appropriate. Differences in recipient characteristics, transplant volume, and transplant value were compared temporally from period to period.

Mahalanobis metric matching analysis

To assess the effect of transplant center volume on value, nearest-neighbor Mahalanobis metric matching with a bias-correction term (https://www.stata.com/manuals/teteffectsnnmatch.pdf) was used to account for confounding while comparing 1-year graft survival rates and transplant hospitalization duration of stays among the treatment group (patients transplanted at small volume centers) and the control group (patients transplanted at large volume centers). Small center recipients (n = 4,875) were matched to large-center recipients (n = 4,632). Previously mentioned patient characteristics were used as covariates in the analysis. In addition to P values, standardized mean differences were used to assess differences between covariates (univariate).[15,16]

Results

During the 17-year study period, 75,988 adult liver transplant recipients were identified and met inclusion criteria. Recipient demographics for the entire cohort are described in Table I. Overall, 1-year graft survival was 90.4%, with a mean transplant-episode hospitalization duration of stay of 13.3 ± 10.8 days.

Temporal trends in volume and value

The number of transplant centers and overall transplant volume increased over time: period A: 112 liver transplant centers, 18,162 transplants; period B: 124 transplant centers, 25,763 transplants; period C: 134 transplant centers, 32,063 transplants (Table II). All centers increased value over time due to ubiquitous improvement in 1-year graft survival (period A: 86%; period B: 90%; period C: 92%; Figure 1). The most significant value increase over time was seen in large centers compared with small centers (+17.0% large vs +7.0% small, P < .001), due to a −8.5% reduction in hospital duration of stay at large centers from period A to C (13.6 ± 10.9 days period A to 12.4 ± 10.3 days period C, P < .001). In comparison, small centers did not demonstrate a significant difference in

Table I
Transplant and recipient demographic characteristics of small and large volume centers over periods A, B, and C

	Overall (*N* = 75,988)	Small (*n* = 5,038)	Large (*n* = 49,674)	
Age, mean (SD)	54.58 (10.3)	53.03 (11.4)	54.79 (10.3)	.001
Donor Risk Index, mean (SD)	1.42 (0.37)	1.36 (0.33)	1.45 (0.38)	.001
BMI, mean (SD)	28.56 (5.7)	28.31 (5.5)	28.58 (5.7)	.001
MELD at transplant, mean (SD)	21.26 (10.4)	21.50 (10.7)	20.94 (10.2)	.001
Male, *n* (%)	51,355 (67.6)	3,564 (70.7)	33,205 (66.8)	.001
HCC, *n* (%)	9,348 (12.3)	660 (13.1)	5,788 (11.7)	.002
Exception, *n* (%)	26,276 (34.6)	1,922 (38.2)	16,890 (34.0)	.001
MELD period, *n* (%)				.001
Period A: 2002–2007	18,162 (23.7)	1,348 (26.8)	11,998 (24.2)	
Period B: 2007–2013	25,763 (34.0)	1,691 (33.6)	16,836 (33.9)	
Period C: 2013–2019	32,063 (42.3)	1,999 (39.7)	20,840 (42.0)	
Race, *n* (%)				.001
White	54,938 (72.3)	3,530 (70.1)	36,521 (73.5)	
Black	6,863 (9.0)	467 (9.3)	4,453 (9.0)	
Hispanic	9,816 (12.9)	694 (13.8)	5,861 (11.8)	
Other	4,371 (5.8)	347 (6.9)	2,839 (5.7)	
Insurance type, *n* (%)				.001
Private	43,386 (57.1)	2,453 (48.7)	29,938 (60.3)	
Public	30,709 (40.4)	2,416 (48.0)	18,462 (37.2)	
Other	1,893 (2.5)	169 (3.4)	1,274 (2.6)	
Life support, *n* (%)	4,419 (5.8)	266 (5.3)	2,768 (5.6)	.387
Portal vein thrombosis, *n* (%)	7,581 (10.0)	427 (8.5)	4,995 (10.1)	.001
Previous abdominal surgery, *n* (%)	32,157 (42.3)	1,883 (37.4)	21,563 (43.4)	.001
Duration of stay, mean (SD)	13.27 (10.8)	14.67 (11.6)	12.75 (10.5)	.001
1-year graft survival, n (%)	68,681 (90.4)	4566 (90.6)	44738 (90.1)	.198

BMI = body mass index; *MELD* = model for end stage liver disease; *HCC* = hepatocellular carcinoma; *SD* = standard deviation.

Table II
Center size stratification and transplant volume in **A.** Period A (2002-2007), **B.** Period B (2007-2013), and **C.** Period C (2013-2019).

A.	Centers	Transplants	
	N	total	Per center per year, mean (SD)
Small	38	1,348	7.1 (1.5)
Medium	37	4,816	26.0 (5.6)
Large	37	11,998	64.9 (6.6)
B.	**Centers**	**Transplants**	
	N	total	Per center per year, mean (SD)
Small	42	1,691	6.7 (1.4)
Medium	41	7,236	29.4 (0.5)
Large	41	16,836	68.4 (1.5)
C.	**Centers**	**Transplants**	
	N	total	Per center per year, mean (SD)
Small	45	1,999	7.4 (2.1)
Medium	45	9,224	34.2 (4.8)
Large	44	20,840	78.9 (7.9)

SD, standard deviation.

duration of stay between periods A and C (+0.59%, 14.5 ± 11.5 days period A to 14.6 ± 11.9 days period C, $P = .836$).

Characteristics of transplant recipients from small and large centers

Large centers delivered higher value compared with small centers despite providing more complex care, as demonstrated by transplanting candidates who were older (54.8 ± 10.3 vs 53.0 ± 11.4 years old, $P < .001$), with fewer MELD exceptions (34.0% vs 38.2%, $P < .001$), with higher rates of both portal vein thrombosis (10.1% vs 8.5%, $P < .001$), prior abdominal surgery (43.4% vs 37.4%, $P < .001$), and with utilization of more marginal grafts (Donor Risk Index 1.45 ± 0.38 vs 1.36 ± 0.33, $P < .001$). Recipient and transplant characteristics are further demonstrated in Table I.

Mahalanobis metric matched value analysis

Recipient age, body mass index, MELD at transplant, male sex, hepatocellular carcinoma diagnosis, exception status, race, insurance type, previous portal vein thrombosis or abdominal surgery, donor risk index (DRI), and transplant period were identified as potentially confounding covariates in assessing value differences between small and large centers (Table I). The comparability between matched cohorts were greatly improved as evidenced by *P* value testing (all $P \geq .05$) and standardized mean differences (all standardized mean differences ≤0.1; Table III).[15,16]

Mahalanobis metric matching of transplanted recipients from small centers and large centers demonstrated that, compared with small centers, large centers delivered higher value care. Transplant hospitalizations at large volume centers were overall shorter than those occurring at small centers (12.9 days large vs 14.6 days small, $P < .001$). Furthermore, small and large centers did not show significant differences in overall 1-year graft survival rates (90.7% small vs 90.4% large, $P = .598$). This finding evolved temporally, as large centers progressively shortened recipient duration of stay per index transplant episode in each period (A: −0.36 days, $P = .437$; B: −2.14 days, $P < .001$; C: −2.49 days, $P < .001$) while maintaining similar graft outcomes (Table IV).

Value followed volume, as centers which increased size classification between periods (small to medium or medium to large) demonstrated +2.1% higher rates of 1-year graft survival ($P = .008$) and a −7.4% decrease in mean duration of stay ($P = .006$), resulting in a +11.0% increase in value ($P < .001$). Conversely, centers which decreased size classification between periods (medium to small or large to medium) did not show significant changes in duration of stay (−0.36%, $P = .930$), 1-year graft survival rate (+2.8%, $P = .163$), or overall value delivery (+3.5%, $P = .542$).

Discussion

In liver transplantation, high-value care depends on the interplay between patient outcomes and resource utilization. We have

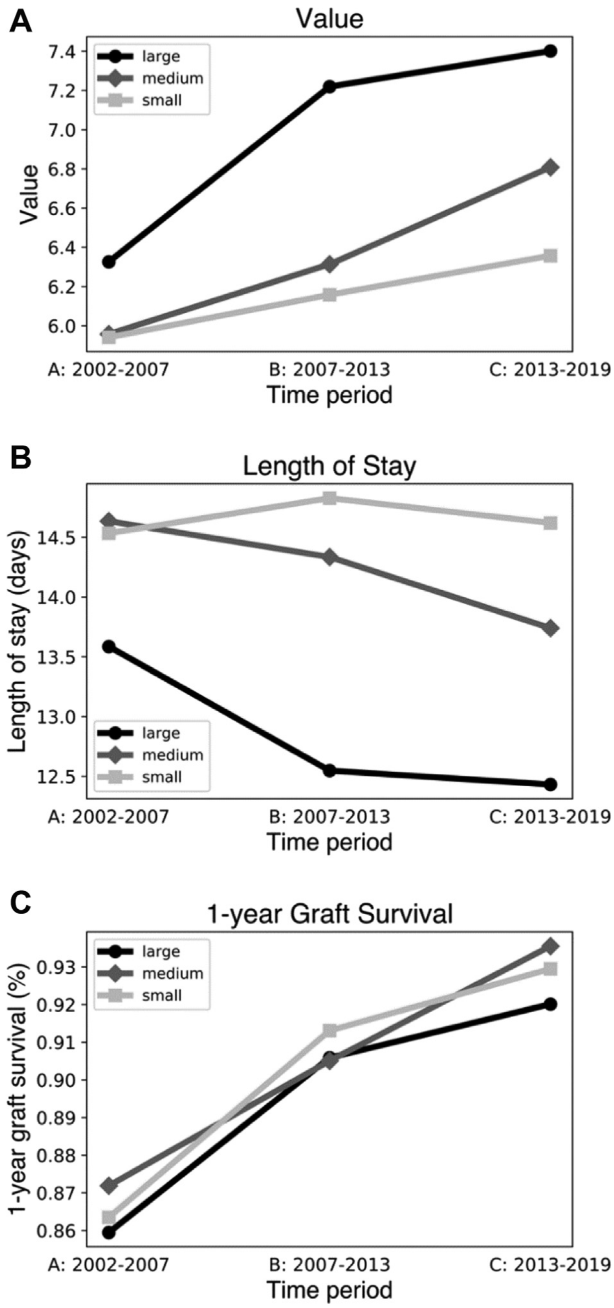

Figure 1. Temporal trends in transplant episode (A) value, (B) length of stay, and (C) 1-year graft survival at small, medium, and large volume centers.

demonstrated for the first time an association between center volume and health care value in liver transplantation. Specifically, despite large volume centers transplanting donor and recipient profiles with significantly greater risk (higher DRI, older patients, fewer MELD exception points), they were able to deliver similar outcomes (1-year graft survival) with lower resource utilization (index transplant hospitalization duration of stay).

Liver transplantation is a complex, interdisciplinary therapy that occurs in multiple phases from referral, to transplant, and through postprocedural care. This, in conjunction with the limited economic data available to assess care delivery throughout these different phases has made defining value challenging. A few studies have attempted analyses of value in the context of solid organ transplantation, and while they have described value in terms of improvement in outcomes per cost, they are limited by inconsistency in definitions and a focus on assessing metrics for care-quality, rather than care-value.[12,17,18] In this study, we used objective surrogates for outcome and cost during the index transplant hospitalization to define value during this phase of LT. In terms of outcome, a focus was placed on evaluating 1-year graft survival, a well-known metric currently used to report program specific outcomes.[12] With regards to costs, hospital duration of stay for the transplant episode was used as this has been shown to correlate with costs in prior studies.[13,14] Applying these definitions to determine value during LT serves as a critical starting point for understanding how center characteristics may influence the delivery of care.

Although this study only assessed value during the index transplantation episode, this work can serve as a framework for defining and understanding value through both the referral and posttransplant phases of care. Further detailed study of these stages of care, and associated quality and cost metrics, are of great importance to elucidating drivers of comprehensive value in LT. In the referral stage, time to evaluation, waitlist time, and waitlist deaths should be included as quality outcomes and pretransplant hospitalizations should be incorporated in determining overall costs. In the posttransplant phase, quality outcomes should consider time to recovery, posttransplant quality of life, ability to return to work/activities of daily living, and posttransplant-complications such as rejection or infections, while posttransplant cost metrics should include readmission episodes. Ideally, if available, actual cost and charge data from representative populations would be highly beneficial. Summing these ratios across the phases of transplant could serve as a construct to more comprehensively evaluate value in liver transplantation.

Irwin et al. are among the few to assess the concept of value in solid organ transplantation.[12] Using data from a single large commercial health plan, they observed significant variations in total cost of transplant among centers with a maintenance of 1-year patient and graft survival. In a separate report, Washburn et al evaluated drivers for liver transplant resource utilization and noted an association between disease severity, namely MELD, and transplant duration of stay (a previously established surrogate for cost).[13,19] Building on this finding, it has been suggested that while MELD may in part predict transplant costs, center-specific characteristics, as well as best practices in the transplant and posttransplant phases of care, may be central to reducing costs.[19,20]

Our assessment of value in LT thus suggests that while similar excellent outcomes can be achieved at centers with varying volume, large volume centers are able to deliver care with decreased resource utilization. In contrast, in many types of complex surgery, such as vascular surgery,[21] cardiac surgery,[22] hepatopancreatobiliary surgery,[23] clear volume-outcome relationships have been noted. Indeed, liver transplantation's ubiquitous and continual improvement in survival outcomes during the 17-year study period regardless of center volume may be due to the persistent regulatory oversight in transplantation that mandates continuous programmatic monitoring, reporting, and meeting of outcome standards. Notably, our study further revealed, through tracking of specific centers that changed size classification from one period to the next, that centers which increased in size classification demonstrated higher subsequent value, while those that decreased in size classification maintained their prior level of value delivery. This suggests that value-based best practices can evolve from experience as a larger volume center, and importantly, can be retained if the inciting volume is later reduced, potentially representing institutional memory and further highlighting the potential of a learned response. Future studies that help delineate the number of liver transplants which allow a center to realize these benefits are thus critical.

Table III
Mahalanobis metric matching cohorts of liver transplant recipients at small and large centers

	Small ($n = 4875$)	Large ($n = 4632$)		SMD
Age, mean (SD)	53.21 (11.2)	53.54 (10.6)	.135	0.031
Donor Risk Index, mean (SD)	1.37 (0.3)	1.37 (0.3)	.520	0.013
BMI, mean (SD)	28.31 (5.4)	28.28 (5.1)	.782	−0.006
MELD at transplant, mean (SD)	21.52 (10.6)	21.35 (10.3)	.451	−0.015
Male sex, *n* (%)	3,449 (70.7)	3,266 (70.5)	.798	−0.005
HCC, *n* (%)	630 (12.9)	599 (12.9)	.990	0.0003
Exception, *n* (%)	1,848 (37.9)	1,733 (37.4)	.619	−0.010
MELD period, *n* (%)			.999	0.0004
Period A: 2002–2007	1,291 (26.5)	1,225 (26.4)		
Period B: 2007–2013	1,625 (33.3)	1,546 (33.4)		
Period C: 2013–2019	1,959 (40.2)	1,861 (40.2)		
Race, *n* (%)			.977	-0.008
White	3,434 (70.4)	3,282 (70.9)		
Black	455 (9.3)	426 (9.2)		
Hispanic	658 (13.5)	615 (13.3)		
Other	328 (6.7)	309 (6.7)		
Insurance type, *n* (%)			.916	-0.006
Private	2,410 (49.4)	2,308 (49.8)		
Public	2,311 (47.4)	2,176 (47.0)		
Other	154 (3.2)	148 (3.2)		
Life support, *n* (%)	253 (5.2)	258 (5.6)	.411	0.017
Portal vein thrombosis, *n* (%)	416 (8.5)	405 (8.7)	.715	0.007
Previous abdominal surgery, *n* (%)	1,842 (37.8)	1,765 (38.1)	.748	0.007
Duration of stay, mean (SD)	14.64 (11.6)	12.87 (10.7)	.001	-
1-year graft survival, n (%)	4420 (90.7)	4185 (90.3)	.598	-

BMI, body mass index; *HCC* = hepatocellular carcinoma; *MELD*, model for end stage liver disease; *SD*, standard deviation; *SMD* = standardized mean differences.

Table IV
Temporal changes in transplant hospitalization duration of stay and 1-year graft survival rates in Mahalanobis metric matched cohorts

Duration of stay (days)				
	Small, mean (SD)	Large, mean (SD)	Difference	*P* value
Period A	14.42 (11.4)	14.07 (11.6)	0.36	.437
Period B	14.82 (11.3)	12.69 (10.7)	2.14	.001
Period C	14.60 (11.9)	12.11 (9.8)	2.49	.001
1-year graft survival (%)				
	Small	Large	Difference	
Period A	86.57	86.39	0.18	.896
Period B	91.28	90.40	0.89	.387
Period C	92.84	92.78	0.06	.944

SD, standard deviation.

Indeed, while the findings in this study suggest lower resource utilization as volume scales, there is still room for improvement at both small and large centers alike. Identifying center specific practices, such as effective enhanced recovery (ERAS) pathways and early extubation protocols,[24,25] and broadly implementing these are important measures that may enable higher-value care delivery. More specifically, though the national median transplant duration of stay for our cohort of large volume centers was 9 days, our group has shown that implementation of an ERAS pathway for LT recipients at our institution decreased median hospital duration of stays to 5 days.[24] Not only were index hospitalizations shorter, actual realized costs per case were also significantly decreased, without significant change in 1-year graft survival. Other studies have shown similar success in decreasing LT resource utilization with ERAS programs.[26,27] Wider sharing and application of such practices is imperative to delivering optimal value in liver transplantation.

The analysis presented in this report is derived from a large registry database, and as such, has inherent limitations. This study proposes a novel definition for value measurement during the index hospitalization for liver transplant that utilizes available objective data to quantify value. Although this metric requires validation through further study, it can serve as an initial framework to be expanded on as more clinical and economic data are curated. In assessing existence of a volume-value relationship in LT, there may be residual confounding of recipient, donor, and transplant characteristics that were unable to be controlled for in our Mahalanobis metric analysis due to data unavailability. Finally, during our study period, multiple Organ Procurement and Transplantation Network policy changes resulted in changes in organ allocation guidelines.[28] Although it was not possible to control for each policy update, the specific dates of our study period, beginning in 2002 with the inception of the MELD/pediatric end-stage liver disease era, and ending in 2019, prior to the implementation of the acuity circle allocation policy and the SARS-CoV-19 pandemic, helped mitigate these changes.

In summary, there is value in liver transplant volume. As cost-containment becomes paramount, it is imperative that value-based best practices from large centers are identified and broadly implemented. Failure to do so may result in centralization of care, further limiting access for patients in need of liver transplantation.

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Conflict of interest/Disclosures

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