ORIGINAL ARTICLE

Impact of Center Volume on Outcomes of Increased-Risk Liver Transplants

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The use of high-risk donor livers, which is reflective of the gross national shortage of organs available for transplantation, has gained momentum. Despite the demand, many marginal livers are discarded annually. We evaluated the impact of center volume on survival outcomes associated with liver transplantation using high–donor risk index (DRI) allografts. We queried the Scientific Registry of Transplant Recipients database for deceased donor liver transplants (n = 31,576) performed between 2002 and 2008 for patients who were 18 years old or older, and we excluded partial and multiple liver transplants. A high-DRI cohort (n = 15,668), which was composed of patients receiving grafts with DRIs > 1.90, was analyzed separately. Transplant centers (n = 102) were categorized into tertiles by their annual procedure volumes: high-volume centers (HVCs; 78-215 cases per year), medium-volume centers (MVCs; 49-77 cases per year), and low-volume centers (LVCs; 5-48 cases per year). The endpoints were allograft survival and recipient survival. In comparison with their lower volume counterparts, HVCs used donors with higher mean DRIs (2.07 for HVCs, 2.01 for MVCs, and 1.91 for LVCs), more donors who were 60 years old or older (18.02% for HVCs, 16.85% for MVCs, and 12.39% for LVCs), more donors who died after a stroke (46.52% for HVCs, 43.71% for MVCs, and 43.36% for LVCs), and more donation after cardiac death organs (5.04% for HVCs, 4.45% for MVCs, and 3.51% for LVCs, all *P* values < 0.001). Multivariate risk-adjusted frailty models showed that increased procedure volume at a transplant center led to decreased risks of allograft failure [hazard ratio (HR) = 0.93, 95% confidence interval (CI) = 0.89-0.98, *P* = 0.002] and recipient death (HR = 0.90, 95% CI = 0.83-0.97, *P* = 0.004) for high-DRI liver transplants. In conclusion, HVCs more frequently used higher DRI livers and achieved better risk-adjusted allograft and recipient survival. A greater understanding of the outcomes of transplantation with high-DRI livers may improve their utilization, the postoperative outcomes, and future allocation practices.***Liver Transpl 17:1191-1199, 2011.***

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Although the field of orthotopic liver transplantation (OLT) is less than 4 decades old, astounding progress has been made over the years. For nearly a decade, the death rate for wait-listed candidates and the overall size of the national wait list have decreased.[1] However, there continues to be a large mismatch between the number of available organs and the number of people who require transplantation; nearly 2000 patients die on the wait list every year. In recognition of this crisis, transplant centers across the nation have expanded their criteria for deceased donor allografts, and they have argued that the merits of earlier transplantation with higher risk organs outweigh the risks associated with staying on the waiting list.[2] As a result, high-risk allografts, which have previously been called marginal

Abbreviations: CI, confidence interval; CVA, cerebrovascular accident; DCD, donation after cardiac death; DRI, donor risk index; HR, hazard ratio; HVC, high-volume center; LVC, low-volume center; MELD, Model for End-Stage Liver Disease; MVC, medium-volume center; OLT, orthotopic liver transplantation; OPTN, Organ Procurement and Transplantation Network; SD, standard deviation; SRTR, Scientific Registry of Transplant Recipients.

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or compromised organs, have become an important part of the donor organ supply.[3-6]

The relationship between the procedure volume and hospital outcomes has been validated across numerous surgical procedures.[7-11] Except for a small sample, the volume-outcome relationship previously has not been rigorously applied to liver transplantation.[12-16] Volume may or may not be an important marker for outcomes of liver transplantation, but it continues to be used as a benchmark by funding agencies, insurance companies, and the Centers for Medicare and Medicaid Services. Establishing whether volume has a role in liver transplantation is paramount for guiding policy decisions and for determining important factors for care before and after liver transplantation.

The ideal liver donor is defined as follows: a donor less than 40 years old who died after head trauma, who did not have significant steatosis, chronic liver lesions, or other transmissible diseases, and whose donation occurred after brain death.[17] In 2006, Feng et al.[18] advanced our understanding of donor suitability with a donor risk index (DRI) encompassing 7 statistically significant donor characteristics: an age $\geq$ 40 years, a split or partial graft, donation after cardiac death (DCD) status, African American race, a cerebrovascular accident (CVA) as the cause of death, other causes of death, and a shorter stature. The DRI also incorporates regional organ sharing and cold ischemia times, but it does not include the degree of steatosis or vasopressor administration. In the transplantation community, the DRI has become established as a standardized and objective criterion for quantifying liver allograft risk.[18]

In this study, we evaluated the significance of annual procedure volumes for survival trends in OLT patients, and we specifically examined the use of high-DRI allografts. Because of the poor survival outcomes with these organs, we aimed (1) to determine whether a center experience effect might mitigate the poor results and (2) to add to our knowledge of the use of these high-DRI organs. We hypothesized that high transplant center volumes are associated with the use of higher DRI allografts and can be correlated with better posttransplant outcomes.

PATIENTS AND METHODS

Data

All observations were submitted by members of the Organ Procurement and Transplantation Network (OPTN), which is managed by the United Network for Organ Sharing, and were compiled by the Scientific Registry of Transplant Recipients (SRTR). OPTN is a private, nonprofit entity that maintains the national waiting list and provides standardized organ allocation policies for the nation. SRTR is a nationwide database that was established in 1987 and that facilitates the analysis and advancement of organ transplantation.

Cohort

We retrospectively queried the SRTR database for all deceased donor liver transplants performed between January 1, 2002 and December 31, 2008. The end date was limited by the data sets available at the time of the analysis. We included only adult recipients (18 years old or older) and excluded those who received partial liver transplants (reduced liver, living donor, or split liver transplants) or multiple liver transplants. Procedures involving partial liver transplants were excluded from the analysis of differences in organ allocation between these groups and the majority of patients with chronic liver disease awaiting liver transplantation, as previously described.[12]

Treatment Groups

The cohort was sorted by time (the year of procurement) and location (the medical center at which each recipient underwent transplantation). Encrypted hospital identifiers were used to determine the number of OLT procedures performed at each institution. Annual center-specific procedure volumes were evaluated for each year from 2002 to 2008. Transplant centers that performed fewer than 5 procedures per year were excluded from our analysis in an effort to reduce confounding variables. The transplant centers were subsequently ranked in the order of their annual case volumes. All observations were evenly sorted into tertiles and were categorized into the following volume groups: high-volume centers (HVCs; the upper third of the observations), medium-volume centers (MVCs; the middle third of the observations), and low-volume centers (LVCs; the lower third of the observations). Because the center-specific procedure volumes varied from year to year,[10,19] the center rank and, subsequently, the tertile group designation were recalculated for each studied year.

Variables

The following donor demographics were collected: the donor's age (years), sex, ethnicity (Caucasian, African American, or all other minorities), cause of death (anoxia, CVA, head trauma, or other), and DCD status; the region and year of transplantation; the cold ischemia time (hours); and the DRI. In addition, the following recipient demographics were collected: the recipient's age (years), sex, ethnicity (Caucasian, African American, or all other minorities), time on the waiting list (days), hemodialysis treatment and subjective functional status before OLT, ascites status, and Model for End-Stage Liver Disease (MELD) score and the region and year of transplantation. Nominal variables included the following: the sex, the ethnicity, the donor's cause of death, the DCD status, the recipient's ascites status, and the recipient's hemodialysis treatment and subjective functional status before OLT. Ordinal variables included the year and region of transplantation. Continuous variables included the following: the age, the recipient's time on the waiting

list, the cold ischemia time, the recipient's MELD score, and the DRI. MELD scores were calculated for each recipient with the United Network for Organ Sharing modification of the formulary.[20] The DRI was calculated for each donor as previously described.[18] Because no standard definition yet exists for high-risk liver donors, our study used a working definition that dichotomized the DRI spectrum at the median of 1.90; allografts with DRIs > 1.90 were called high-DRI livers and were considered proxies for high-risk livers.

Analysis

Nominal and ordinal categorical variables were tested for statistical significance, which was defined as $P < 0.05$, with Pearson and Mantel-Haenszel chi-square tests, respectively. For continuous variables, means, medians, variances, and standard deviations (SDs) were calculated. Trends were assessed with the Cochran-Armitage trend test, and variations in the central tendencies of continuous variables between the center volume groups were evaluated with a Kruskal-Wallis nonparametric analysis of variance because they did not follow normal distributions.

We performed a univariate analysis of all categorical variables with the log-rank test of equality across strata to evaluate the variables for significance as predictors of the endpoints, which were defined as allograft survival and recipient survival. Causes of allograft failures and recipient deaths were not reliably known from the database. Clinically relevant categorical variables that were considered for multivariate model construction were visualized as Kaplan-Meier curves so that we could evaluate them for statistical significance. Variables included in the DRI[18] and MELD calculations[20] were previously shown to be significant and were excluded from the univariate analysis. A power analysis was also conducted to ensure that the conclusions were not heavily biased in favor of rejection of the null hypothesis because of the large sample size. This analysis (8% of the sample size) ensured that the results were relevant and accurate.

For continuous parameters, a univariate Cox proportional hazards regression was performed to evaluate their inclusion in the multivariate model. Parameters with $P < 0.2$ were included in the covariate selection process. Functional forms of the covariates were assessed with estimated hazard functions, survival functions, and cumulative martingale residuals. Interactions between covariates were also tested. The proportional hazards assumption was evaluated by the graphic log-minus-log method test for Schoenfeld residuals and included time-dependent covariates in the Cox model. Continuous variables in violation of proportional hazards assumptions were dichotomized by their median cutoff points. The Cox model construction included all qualified predictors except for the hospital volume. Covariates were determined by a combination of stepwise regression, Akaike information criteria, and the best subset selection. Because the DRI criteria include the donor's age, ethnicity, cause of death, DCD status, and height (cm), the cold ischemia time (hours), and the regional disparity between the donor and recipient, these factors were omitted from the Cox regression model to avoid collinearity. A frailty model was chosen for our multivariate analysis because of its utility in accommodating center cluster effects.[21] Our frailty model included a category for center volume as a covariate and accounted for the changing relationship between a center's volume and outcomes over time. This risk-adjusted model accounted for donor (DRI), recipient (age, ethnicity, dialysis and functional status at the time of transplantation, and MELD score), and transplant center characteristics (procedure volume) as well as interactions between covariates that were found to be statistically significant (age and functional status only), clinically relevant, and not in violation of proportional hazards assumptions. Only observations for allografts with DRIs > 1.90 were included in our multivariate analysis.

The following categorical and continuous variables were found to be clinically and statistically significant in the univariate analysis and were included in the construction of the frailty model of predictors for allograft failure: the recipient's age, ethnicity, hemodialysis status before transplantation, MELD score, and functional status at the time of transplantation; the DRI; and the interaction between the age and the functional status. The DRI and the recipient's functional status at the time of transplantation were found to violate proportional hazards assumptions. Therefore, the DRI was dichotomized at 2.27 (the median for the high-DRI cohort), and the recipient's functional status was treated as a function of time to meet proportional hazards assumptions and was included in the multivariate model. Lastly, the hospital volume was included as a covariate in our model.

The following variables were found to be clinically and statistically significant in the univariate analysis and were included in the frailty model for deaths of recipients receiving high-DRI transplants: the recipient's age, ethnicity, hemodialysis status before transplantation, MELD score, and functional status at the time of transplantation; the DRI; and the interaction between the age and the functional status. The MELD score and the recipient's functional status at the time of transplantation were found to violate proportional hazards assumptions. The MELD score was dichotomized at >18 (the median for the high-DRI cohort), the recipient's functional status was once again treated as a function of time, and the hospital volume was included as a covariate.

Each covariate in the frailty model was judged as a predictor of allograft or recipient survival with maximum likelihood estimates of the hazard ratios (HRs) and 95% confidence intervals (CIs). SAS 9.2 (SAS Institute, Inc., Cary, NC) and Stata 11 (StataCorp LP, College Station, TX) were used in the analysis.

This study was reviewed by the institutional review board of the University of Massachusetts Medical School and was deemed appropriate for exemption

TABLE 1. Liver Transplants According to the Center Volume for 2002-2008 ($P < 0.001$)

	Transplant Centers per Year		Total Cases		Cases per Transplant Center per Year	
	Range	%	n	%	Median (Mean)	Range
HVCs	7-24	21.84	10,242	32.44	102 (107.25)	78-215
MVCs	18-33	32.10	10,713	33.93	64 (62.74)	49-77
LVCs	39-67	46.06	10,621	33.64	31 (30.66)	5-48
Total	92-102	100	31,576	100*	—	—

*The percentages listed in this column do not add up to precisely 100 because of rounding.

from institutional review board oversight because no personal identifiers were used in the data sets.

RESULTS

Cohort Description

The SRTR database was searched for deceased donor liver transplants between 2002 and 2008 (n = 31,576). The number of deceased donor liver transplants has increased over time, with 3847 cases in 2002 and as many as 4926 cases in 2006. Ninety-two to 102 transplant centers actively contributed data to OPTN during the studied time period. Transplant centers were sorted into HVCs (10,242 cases or 32.44% of the cohort and 21.84% of the centers), MVCs (10,713 cases or 33.93% of the cohort and 32.10% of the centers), and LVCs (10,621 cases or 33.64% of the cohort and 46.06% of the centers, $P < 0.001$). Table 1 presents the average procedure volumes for each center volume group and the ranges for the year-to-year variations from 2002 to 2008. Our results show that in comparison with their LVC counterparts, the HVCs performed on average 3 times more transplants annually, but they endured greater variations in the annual totals between years. Regional trends suggest that the largest data contributions came from region 3 (5189 transplants or 16.43% of the cases) and region 5 (4324 transplants or 13.69% of the cases), whereas the smallest contributions came from region 1 (880 transplants or 2.79% of the cases) and region 6 (1071 transplants or 3.39% of the cases).

Donor and Recipient Demographics

Table 2 displays the donor and recipient demographics for all patients who received a liver transplant between 2002 and 2008. The majority of the donors for the evaluated deceased donor liver transplants were male (59.53%). The ethnic profile consisted of Caucasians (69.45%), African Americans (15.20%), and all other minorities (15.36%, $P < 0.001$). The majority of the donors were 40 years old or older (70.58%), and only 15.73% were 60 years old or older ($P < 0.001$). The primary cause of death was CVA (44.51%), and the average cold ischemia time was 7 hours. The median DRI was 1.90 (mean DRI = 1.99). The majority of the recipients were also male (68.19%) and Caucasian (73.47%). The median recipient age was 54 years, and the median MELD score was 18.

Donor and Recipient Demographics for the Volume Groups

Table 3 outlines the demographics of each tertile for transplants involving allografts with DRIs > 1.90. The following donor characteristics were found to be statistically different between the center volume groups: the median age ($P < 0.05$), ethnicity ($P < 0.001$), cause of death ($P < 0.001$), and DRI ($P < 0.05$). The following clinically relevant recipient characteristics were found to be statistically different between the center volume groups: the median age ($P < 0.05$), ethnicity ($P = 0.007$), ascites status ($P < 0.001$), and functional status before transplantation ($P < 0.001$).

An evaluation of the DRI characteristics showed that in comparison with their lower volume counterparts, HVCs used proportionally greater quantities of high-DRI allografts across multiple donor characteristics: donors who were 60 years old or older (32.31% for HVCs, 33.63% for MVCs, and 28.65% for LVCs), African Americans (16.27% for HVCs, 17.02% for MVCs, and 16.33% for LVCs), and donors who died because of CVAs (62.13% for HVCs, 62.62% for MVCs, and 65.06% for LVCs; all $P < 0.001$). Furthermore, the mean DRI values (2.40 for HVCs, 2.38 for MVCs, and 2.28 for LVCs, $P < 0.05$) and the DRI variances (0.16 for HVCs, 0.15 for MVCs, and 0.10 for LVCs, $P < 0.05$) also correlated with increasing center volume.

Multivariate Allograft Survival Outcomes

Our findings demonstrated that greater hospital volume correlated with an allograft survival benefit (HR = 0.93, 95% CI = 0.89-0.98, $P = 0.002$; Table 4). To better understand the implications of these findings, we evaluated the 1-, 3-, and 5-year survival probabilities with Kaplan-Meier curves (Fig. 1). Our results reflect an unadjusted allograft survival advantage for high-DRI liver transplantation at HVCs versus MVCs and LVCs, and this advantage is independent of the time course (Table 5).

TABLE 2. Donor and Recipient Demographics for All Liver Transplants (n = 31,576)

Demographic Variable	HVCs (n = 10,242)	MVCs (n = 10,713)	LVCs (n = 10,621)	*P* Value
Female recipients [n (%)]	3285 (32.07)	3448 (32.19)	3311 (31.17)	0.223
Female donors [n (%)]	4186 (40.87)	4326 (40.38)	4266 (40.17)	0.569
Recipient ethnicity [n (%)]				0.003
Caucasian	7528 (73.50)	7992 (74.60)	7680 (72.31)	
African American	861 (8.41)	898 (8.38)	975 (9.18)	
Other*	1853 (18.09)	1823 (17.02)	1966 (18.51)	
Donor ethnicity [n (%)]				<0.001
Caucasian	6993 (68.28)	7603 (70.97)	7332 (69.03)	
African American	1589 (15.51)	1656 (15.46)	1553 (14.62)	
Other*	1660 (16.21)	1454 (13.57)	1736 (16.34)	
Median recipient age (years)†	54.3	54.1	53.6	<0.05
Donor age				
40-59 years [n (%)]	5978 (58.37)	5895 (55.03)	5447 (51.29)	<0.001
≥60 years [n (%)]	1846 (18.02)	1805 (16.85)	1316 (12.39)	<0.001
Median (years)	45	43	41	<0.05
Median wait-list time (days)	55	79	92	<0.05
Median cold ischemia time (hours)	7.0	7.0	7.0	>0.05
Causes of donor death [n (%)]				<0.001
Anoxia	1573 (15.36)	1523 (14.22)	1397 (13.15)	
CVA	4765 (46.52)	4683 (43.71)	4605 (43.36)	
Head trauma	3665 (35.78)	4148 (38.72)	4370 (41.14)	
Other	239 (2.33)	359 (3.35)	249 (2.34)	
DCD [n (%)]	516 (5.04)	477 (4.45)	373 (3.51)	<0.001
Recipient hemodialysis status before transplantation [n (%)]	229 (2.24)	185 (1.73)	261 (2.46)	0.002
Recipient functional status before transplantation [n (%)]‡				<0.001
Fine	4975 (57.03)	5155 (59.75)	5205 (60.50)	
Bad	2378 (27.26)	2105 (24.40)	2301 (26.75)	
Very bad	1371 (15.72)	1367 (15.85)	1097 (12.75)	
Recipient MELD score				<0.05
Median (mean)	17.0 (19.10)	19.0 (20.27)	19.0 (20.40)	
Variance (SD)	74.88 (8.65)	78.12 (8.84)	82.88 (9.10)	
DRI				<0.05
Median (mean)	1.97 (2.07)	1.90 (2.01)	1.82 (1.91)	
Variance (SD)	0.24 (0.49)	0.23 (0.48)	0.16 (0.41)	

NOTE: Some percentages do not add up to 100 because of rounding.
*Hispanics, Asians, and others.
†Recipients were 18 years old or older.
‡The functional status was not available for all recipients (percentages are based on the number of recipients for whom this information was available).

Multivariate Recipient Survival Outcomes

Our findings demonstrate that the hospital volume correlates with a recipient survival benefit (HR = 0.90, 95% CI = 0.83-0.97, $P = 0.004$; Table 6). To better understand the implications of these findings, we evaluated the 1-, 3-, and 5-year survival probabilities with Kaplan-Meier curves (Fig. 2). Our results reflect an unadjusted recipient survival advantage for high-DRI liver transplantation at HVCs versus MVCs and LVCs, and this advantage is independent of the time course (Table 7).

DISCUSSION

In this study of the SRTR database, we explored the impact of the center volume on transplant outcomes. The use of high-risk liver donors, which was represented by high DRIs, was found to increase with the transplant center procedure volume. The risk-adjusted analysis predicted that higher center volumes would lead to greater allograft and recipient survival when donor allografts with higher risk profiles (DRI > 1.90) were examined independently.

The number of patients currently awaiting definitive treatment for liver failure markedly exceeds the number of available organs.[22] The use of high-DRI livers is advocated, despite their association with increased morbidity and mortality rates, to reduce the potential loss of wait-list candidates. Unfortunately, the application of expanded criteria liver allografts remains a novel and undefined concept. Therefore, because of regional heterogeneity in the landscape of national

TABLE 3. Donor and Recipient Demographics for Liver Transplants With DRIs > 1.90 (n = 15,668)

Demographic Variable	HVCs (n = 5711)	MVCs (n = 5364)	LVCs (n = 4593)	*P* Value
Female recipients [n (%)]	1947 (34.09)	1815 (33.84)	1525 (33.20)	0.628
Female donors [n (%)]	2901 (50.80)	2847 (53.08)	2505 (54.54)	<0.001
Recipient ethnicity [n (%)]				0.007
Caucasian	4217 (73.84)	3961 (73.84)	3294 (71.72)	
African American	444 (7.77)	457 (8.52)	444 (9.67)	
Other*	1050 (18.39)	946 (17.64)	855 (18.62)	
Donor ethnicity [n (%)]				<0.001
Caucasian	3887 (68.06)	3817 (71.16)	3165 (68.91)	
African American	929 (16.27)	913 (17.02)	750 (16.33)	
Other*	895 (15.67)	634 (11.82)	678 (14.76)	
Median recipient age (years)†	54.9	54.8	54.0	<0.05
Donor age				
40-59 years [n (%)]	3866 (67.69)	3560 (66.37)	3299 (71.35)	0.314
≥60 years [n (%)]	1845 (32.31)	1804 (33.63)	1316 (28.65)	<0.001
Median (years)	55.0	55.0	54.0	<0.05
Median wait-list time (days)	56	83	90	<0.05
Median cold ischemia time (hours)	7.4	7.9	7.5	>0.05
Causes of donor death [n (%)]				<0.001
Anoxia	667 (11.68)	581 (10.83)	397 (8.64)	
CVA	3548 (62.13)	3359 (62.62)	2988 (65.06)	
Head trauma	1352 (23.67)	1202 (22.41)	1086 (23.64)	
Other	144 (2.52)	222 (4.14)	122 (2.66)	
DCD [n (%)]	514 (9.00)	476 (8.87)	371 (8.08)	0.212
Recipient hemodialysis status before transplantation [n (%)]	122 (2.14)	96 (1.79)	108 (2.35)	0.185
Recipient functional status before transplantation [n (%)]‡				<0.001
Fine	2827 (59.07)	2565 (59.60)	2272 (58.83)	
Bad	1397 (29.19)	1035 (24.05)	1002 (25.95)	
Very bad	562 (11.74)	704 (16.36)	588 (15.23)	
Recipient MELD score				<0.05
Median (mean)	17 (18.58)	18 (20.01)	18 (20.13)	
Variance (SD)	71.97 (8.48)	76.16 (8.73)	81.70 (9.04)	
DRI				<0.05
Median (mean)	2.31 (2.40)	2.30 (2.38)	2.21 (2.28)	
Variance (SD)	0.16 (0.40)	0.15 (0.39)	0.10 (0.32)	

NOTE: Some percentages do not add up to 100 because of rounding.
*Hispanics, Asians, and others.
†Recipients were 18 years old or older.
‡The functional status was not available for all recipients (percentages are based on the number of recipients for whom this information was available).

scarcity, allocation policies for high-DRI allografts have largely been transplant center–specific and have been calibrated on the basis of predicted recipient benefits, projected reductions in wait-list mortality, and parity.[23,24] Previous allocation policies advocated the use of any organ for the sickest patients; however, recent evidence has clarified that the DRI and MELD scores are independent factors for graft failure,[25] and higher DRI livers are more appropriate for recipients with elevated MELD scores.[26] It is imperative, therefore, that the evaluation and improvement of allocation practices, especially for high-risk donor allografts, be an ongoing process.

As our understanding of donor organ utilization has become more defined, DRI has proven to be a valuable tool that allows physicians to quantitatively evaluate donor organs. Despite the existing criteria for higher risk cadaveric kidney allografts, the DRI calculation system is inherently more informative and appropriate for the transplant surgeon because of its flexibility. The results of our study confirm the findings of Feng et al.[18]: the DRI as a continuous variable is an independent risk factor for allograft failure. Moreover, a higher DRI was found to be an independent risk factor for recipient death (HR = 1.26, 95% CI = 1.13-1.40, $P < 0.001$). In contrast, however, factors outside the DRI calculation system, such as the recipient's age, functional status, and hemodialysis status before transplantation, are also important to allograft and recipient survival. Furthermore, Feng et al. showed that allograft survival is indirectly proportional to the DRI as a continuous variable when it is adjusted for

TABLE 4. Frailty Model for Predictors of Allograft Failure for Deceased Donor Liver Transplants With DRIs > 1.90 (n = 11,783)

Variable	HR	95% CI	*P* Value
Recipient age (years)	1.00	0.99-1.001	0.18
Recipient race	0.95	0.91-1.00	0.05
Recipient hemodialysis status before transplantation	1.48	1.18-1.84	0.001
MELD score	1.00	1.00-1.01	0.066
Recipient functional status	0.80	0.76-1.08	0.28
DRI > 2.27	1.29	1.20-1.39	<0.001
Interaction between the recipient age (years) and the recipient functional status	1.00	1.00-1.01	0.002
Annual center volume	0.93	0.89-0.98	0.002

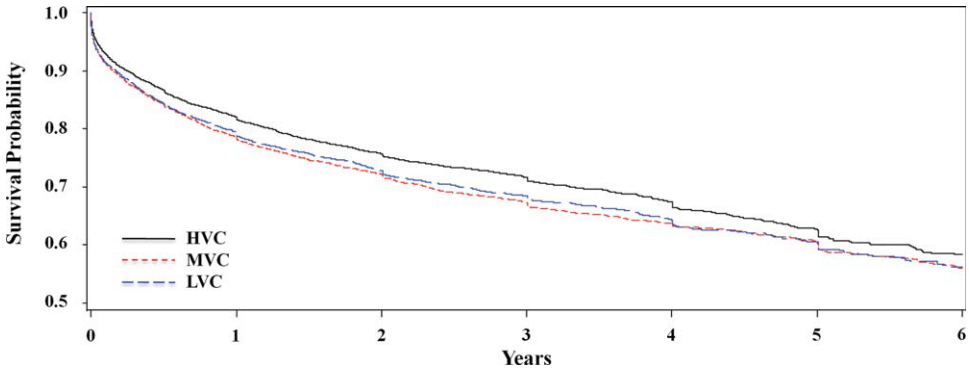

Figure 1. Allograft survival according to the center volume for liver transplants with DRIs > 1.90 ($P < 0.001$).

TABLE 5. Allograft Survival According to the Center Volume for Liver Transplants With DRIs > 1.90

	Survival (%)		
	1 Year	3 Years	5 Years
LVCs	79.4	68.4	60.3
MVCs	78.6	67.2	60.6
HVCs	82.1	71.4	62.6

time. In the absence of standardized benchmarks, we used the median DRI (1.90) of our cohort as a cutoff for evaluating outcomes of high-risk liver transplants. The median DRI was used to efficiently separate the transplant population according to risk profiles. Previous studies have simply categorized livers with DRIs > 2.0 as high-risk organs.[27,28]

The effects and benefits of transplant center procedure volume in liver transplantation have been well described previously.[13,16] Our study is the first to address center volume with respect to donor characteristics and higher DRI allografts. The survival benefits associated with center volume were not geographically dependent. The types of organs used by these centers and the selection of appropriate recipients must be carefully considered. Our results show that HVCs are using donors with high-DRI organs; conversely, the median MELD scores and the waiting times for recipients are also lower at HVCs. This suggests that high-risk livers may be more efficiently used by HVCs. With respect to the selection of appropriate donors and wait-listed candidates, experience and judgment likely come from a combination of procedure volume, resource allocation, and interphysician collaboration. The survival curves (Figs. 1 and 2) do appear to cross over time, and this suggests that the survival advantage of surgical expertise in the immediate perioperative period may decline over time. Additional research is necessary to understand the full implications of the presented trends.

Several limitations must be considered. Because this is a retrospective study, it has the constraints associated with the variables collected in the SRTR database. For example, data on steatosis or the causes of allograft failure were not available and thus could not be included in our analysis. Furthermore, standards may vary significantly from center to center or between regions. We tried to control for this by examining the results within regions. All centers that performed deceased donor liver transplantation and contributed data to the SRTR database during the evaluated time period were used in our study. We excluded all centers that performed fewer than 5 liver transplants per year to reduce the statistical variability and to ensure that the volume groups were appropriately represented. Although we felt that our cutoff (the median DRI) was appropriate for the purposes of

TABLE 6. Frailty Model for Predictors of Recipient Death for Deceased Donor Liver Transplants With DRIs > 1.90 (n = 11,783)

Variable	HR	95% CI	*P* Value
Recipient age (years)	1.00	0.99-1.00	0.38
Recipient race	0.97	0.92-1.03	0.32
Recipient hemodialysis status before transplantation	1.62	1.27-2.07	<0.001
DRI	1.26	1.13-1.40	<0.001
Recipient functional status	0.69	0.55-0.86	0.001
MELD score > 18	1.17	1.07-1.28	<0.001
Interaction between the recipient age (years) and the recipient functional status	1.01	1.00-1.02	<0.001
Annual center volume	0.90	0.83-0.97	0.004

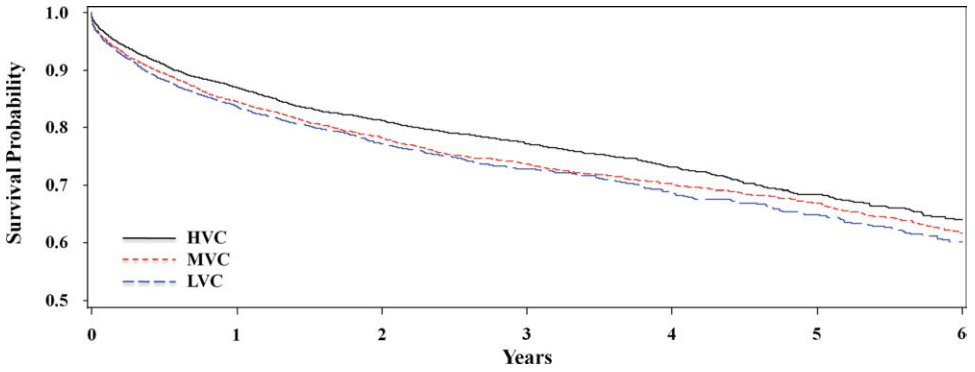

Figure 2. Recipient survival according to the center volume for liver transplants with DRIs > 1.90 ($P < 0.001$).

TABLE 7. Recipient Survival According to the Center Volume for Liver Transplants With DRIs > 1.90

	Survival (%)		
	1 Year	3 Years	5 Years
LVCs	83.6	72.8	64.7
MVCs	84.5	73.6	66.8
HVCs	86.9	77.2	68.3

our evaluation, we also performed analyses with the DRI value of 2.27 to test the results further. It is likely that future studies will choose to define higher risk liver allografts with quantitative criteria more explicit than DRI > 1.90.

To the best of our knowledge, this is the first study correlating the survival benefits associated with the center-specific annual procedure volume and the donor characteristics (specifically the DRI). The large sample size, the demographic uniformity of the study groups, the number of examined covariates, and the risk-adjusted multivariate analysis are the strengths of this registry analysis. Because of the growing size of the national transplant wait list, the critical annual shortfall of available organs, the unfortunate discarding of underused livers, and the subsequent loss of untreated recipients, it remains imperative that every available organ be used to its full potential and that the outcomes of transplantation with these organs continue to be understood and evaluated.

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