# Graft Survival and Segment Discards Among Split-Liver and Reduced-Size Transplantations in the United States From 2008 to 2018

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**Split-liver transplantation has allocation advantages over reduced-size transplantation because of its ability to benefit 2 recipients. However, prioritization of split-liver transplantation relies on the following 3 major assumptions that have never been tested in the United States: similar long-term transplant recipient outcomes, lower incidence of segment discard among split-liver procurements, and discard of segments among reduced-size procurements that would be otherwise "transplantable." We used United Network for Organ Sharing Standard Transplant Analysis and Research data to identify all split-liver (n = 1831) and reduced-size (n = 578) transplantation episodes in the United States between 2008 and 2018. Multivariable Cox proportional hazards modeling was used to compare 7-year all-cause graft loss between cohorts. Secondary analyses included etiology of 30-day all-cause graft loss events as well as the incidence and anatomy of discarded segments. We found no difference in 7-year all-cause graft loss (adjusted hazard ratio [aHR], 1.09; 95% confidence interval [CI], 0.82-1.46) or 30-day all-cause graft loss (aHR, 1.13; 95% CI, 0.70-1.80) between split-liver and reduced-size cohorts. Vascular thrombosis was the most common etiology of 30-day all-cause graft loss for both cohorts (56.4% versus 61.8% of 30-day graft losses; $P = 0.85$). Finally, reduced-size transplantation was associated with a significantly higher incidence of segment discard (50.0% versus 8.7%) that were overwhelmingly right-sided liver segments (93.6% versus 30.3%). Our results support the prioritization of split-liver over reduced-size transplantation whenever technically feasible.**

***Liver Transplantation 28 247–256 2022 AASLD.***
**Received May 31, 2021; accepted August 14, 2021.**

In the setting of an ongoing organ shortage in the United States, children and smaller stature adults with end-stage liver disease are particularly disadvantaged in access to liver transplantation because of graft-to-patient size mismatch.[1-6] Transplantation of partial liver segments via split-liver or reduced-size transplantation is commonly used when whole-liver transplantation is too large for the intended recipient.[7-12] In each case, a portion of the donor liver is transplanted into the recipient, enabling appropriate segment-to-patient size matching. However, split-liver transplantation involves allocation of liver segments to 2 recipients at the time of the organ offer, whereas reduced-size transplantation occurs when a single center procures the whole liver and then reduces it before transplantation, discarding the unused portion and benefiting only a single recipient.[12,13] As such, prioritization of split-liver transplantation over reduced-size transplantation has been advocated to benefit more patients and

*Abbreviations: aHR, adjusted hazard ratio; ALT, alanine aminotransferase; AST, aspartate aminotransferase; BSA, body surface area; CI, confidence interval; HCC, hepatocellular carcinoma; HR, hazard ratio; IQR, interquartile range; MELD, Model for End-Stage Liver Disease; OPO, organ procurement organization; PELD, Pediatric End-Stage Liver Disease; STAR, Standard Transplant Analysis and Research; UNOS, United Network for Organ Sharing.*

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improve access to transplantation among children and smaller stature adults.

However, the assumption of greater benefit to more patients after split-liver transplantation relies on 3 major assumptions that have never been tested in the United States. First, long-term posttransplantation recipient outcomes have never been compared between the practices. Concerns remain that split-liver transplantation outcomes may be inferior to those of reduced-size transplantation given the technical and anatomical challenges of splitting a liver for 2 separate recipients.[14,15] In particular, increased incidence of vascular thrombosis has been associated with short-term graft complications and failure among split-liver transplantation episodes.[16-19] Yet whether vascular thrombosis events and short-term graft loss are more common among split-liver versus reduced-size liver transplantation remain unknown. Second, the incidence of segment discard has never been compared between split-liver and reduced-size transplantation. Should incidence segment discard among split-liver transplantation approach 50%, it would likely result in similar numbers of transplant recipients when compared with reduced-size transplantation. Finally, the anatomy of segment discard has never been analyzed. If reduced-size transplant segment discards are generally left-sided segments from smaller sized donors, these segments might be too small to allocate to another recipient, and split-liver transplantation for that procurement episode would be more challenging.

Therefore, we sought to investigate these questions by analyzing data from the United Network for Organ Sharing (UNOS) between 2008 and 2018. Our objectives were to compare whether either practice was associated with higher long-term all-cause graft loss (a measure of patient outcomes) or a higher incidence of transplantable segment discard (a measure of potential allocation wastefulness). We hypothesized that split-liver transplantation episodes would have higher rates of 30-day graft loss attributed to technical factors but that long-term graft survival would be similar. Furthermore, we hypothesized that split-liver transplantation would have a lower incidence of segment discard but that the anatomy of discarded segments would be similar between practices.

*The data that support the findings of this study are publicly available at the United States Department of Health and Human Services website: https://optn.transplant.hrsa.gov/data/request-data/.*

*John R. Montgomery and Craig S. Brown had full access to all the data in this study and take responsibility for the integrity of the data and the accuracy of the data analysis. John R. Montgomery is supported by the Obesity Surgery Scientist Fellowship Award administered from National Institute of Diabetes and Digestive and Kidney Diseases Grant T32-DK108740. Alexandra Highet is supported by National Center for Advancing Translational Sciences of the National Institutes of Health Grant TL1TR002242. Craig S. Brown is supported by the Ruth L. Kirschstein Postdoctoral Research Fellowship Award administered from National Institute on Drug Abuse Grant F32-DA050416.*

*Additional supporting information may be found in the online version of this article.*



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*DOI 10.1002/lt.26271*

*Potential conflict of interest: Nothing to report.*

# Patients and Methods

## DATA SOURCE

This study represents an analysis of data from the UNOS Standard Transplant Analysis and Research (STAR) file. This file was requested from UNOS and reflected the Organ Procurement and Transplantation Network database as of June 10, 2019, with procurements, transplants, and outcomes added through March 31, 2019. The data contained deidentified patient-level information for transplant recipients and waitlist candidates dating back to October 1, 1987, and is available online on request.[20] This study was determined to be exempt by the Michigan Medicine Institutional Review Board because it contains all deidentified data from a quality improvement registry; informed consent was not required.

## STUDY POPULATION

All adult and pediatric liver procurement events with intention to transplant between January 1, 2008, and December 31, 2018, were identified from the UNOS STAR file. This start date was chosen because of the November 2007 match run rule that defined "split eligibility" among deceased liver donors[21]; the end date was chosen to ensure a minimum of 6 months of follow-up among transplantation episodes. The procurement events were linked with liver transplant recipient data. Episodes were excluded if the liver was not procured with intention to transplant (eg, for

research purposes only). Split-liver transplantation episodes were identified when 2 separate liver segment dispositions were listed in the deceased donor data file. Reduced-size transplantation episodes were identified when partial liver transplantation was performed outside of an identified split-liver transplantation episode. A flow diagram of the study population is shown in Supporting Fig. 1.

## OUTCOMES

The primary outcome was all-cause graft loss between split-liver and reduced-size transplantation episodes, defined as patient death or retransplantation. The secondary outcome among transplant recipients was etiology of graft loss. Upon data exploration, it was discovered that there was extensive data missingness of graft loss etiology after 30 days of transplantation (missingness = 188/270 [69.6%] for graft loss events occurring >30 days from transplantation). Conversely, graft loss within 30 days of transplantation was better recorded (missingness = 57/156 [36.5%] for graft loss events within 30 days of transplantation). Therefore, the decision was made to only report etiology of graft loss within 30 days of transplantation. Graft loss etiologies were categorized as primary nonfunction, vascular thrombosis, acute rejection, and recipient death with a functioning graft. Vascular thrombosis included hepatic artery thrombosis, portal vein thrombosis, hepatic outflow occlusion, and other vascular thrombosis. Acute rejection episodes included cellular and antibody-mediated causes. Death with a functioning graft was determined when the patient died and variables for primary nonfunction, vascular thrombosis, and rejection were all negative and nonmissing.

Secondary outcomes among procurement episodes included incidence, anatomy, and estimated volumes of discarded segments. Incidence of segment discard was computed by assuming that each split-liver and reduced-size procurement event could result in 2 transplantation episodes. Anatomy of discarded segments were classified according to the Couinaud classification system: left lateral (segments 2-3), left lobe (segments 2-4), right lobe (segments 5-8), and right trisegment (segments 4-8).[22] The UNOS STAR files do not contain data on liver segment volume or weight. Therefore, we estimated discarded segment volumes (in cubic centimeters) by multiplying the total estimated liver volume (calculated per the Vauthey formula) by the median proportion of liver that each segment represents (per Abdalla et al.: 16% among left lateral segments, 33% among left lobes, 65% among right lobes, and 82% among right trisegments).[23-25]

## STATISTICAL ANALYSIS

First, temporal trends in split-liver and reduced-size transplantation volume were compared. This was performed using time-series analysis with Newey-West standard errors for coefficients estimated by ordinary least squares regression. The Cumby-Huizinga test was used to test for autocorrelation within cohorts. As no autocorrelation was detected, the resulting analyses reflect linear regression models with robust standard errors. Given the possible clinical interchangeability of split-liver and reduced-size transplantation, the annual volume of each was correlated and the Pearson correlation coefficient ($\rho$) was reported.

Next, time-to-event analyses were performed with Kaplan-Meier curves and Cox proportional hazards modeling. Episodes were censored at time of last follow-up. Kaplan-Meier curves were compared with the log-rank test. Multivariable Cox regression models were created using stepwise backward elimination to estimate the hazard of all-cause graft loss within 7 years of transplantation. The initial, full model included recipient age at transplantation, donor age at procurement, recipient sex, recipient race (Black versus non-Black), donor body surface area (BSA; in meters squared), Pediatric End-Stage Liver Disease (PELD) score or laboratory Model for End-Stage Liver Disease (MELD) score, hepatocellular carcinoma (HCC) exception status, recipient history of portal vein thrombosis, insurance type (private versus other), listing status (1A/1B versus other), retransplant status (retransplant versus first-time transplant), year of transplantation, and blood-type incompatibility (compatible versus incompatible).[26] BSA was calculated using the Du Bois and Du Bois formula.[27] Covariates with the highest $P$ values were sequentially eliminated from the model until all $P$ values were <0.15. The final model included the following covariates: recipient age at transplantation, donor age at procurement, donor BSA, insurance type, retransplant status, and year of transplantation. Cox model standard errors were adjusted to account for clustering of outcomes within centers. Because of potential concerns of increased short-term graft loss among split-liver transplantation episodes, a sensitivity analysis of all-cause graft loss before and after 30 days of transplantation was conducted.

Next, etiologies of graft loss events within 30 days of transplantation were compared between cohorts. To

address the outcome missingness in 57/156 (36.5%) of graft loss episodes within 30 days of transplantation, we elected to perform multiple imputation using a multinomial logistic function with 1000 imputations based on recipient age, donor age, donor BSA, donor terminal aspartate aminotransferase (AST) level, recipient history of portal vein thrombosis, previous transplantation status, status 1A/1B listing, blood-type incompatibility, time to graft loss (in days), and year of transplantation. Proportions with 95% confidence intervals (CIs) were reported and compared with the *F* test. Sensitivity analysis using the complete-case approach was also performed to assess the robustness of our results.[28]

Finally, the incidence of segment discard and anatomy of discarded segments were compared with $\chi^2$ tests. A tornado plot was constructed to display these results. Because of the concerns that donor height and weight would be different between split-liver and reduced-size transplantation episodes (thereby influencing the anatomy and resulting "transplantability" of discarded segments), figures of discarded segment anatomy by donor height and weight were constructed.

Strengthening the Reporting of Observational Studies in Epidemiology guidelines for cohort studies were followed for data and analysis reporting.[29] Continuous data were compared by the nonparametric Wilcoxon rank sum test and presented as medians with interquartile ranges (IQRs); proportional data were compared by $\chi^2$ test or Fisher's exact test when appropriate. A kernel density plot of recipient age at transplantation was used to highlight age distribution differences between split-liver and reduced-size transplantation recipients. A 2-sided $P < 0.05$ was used to indicate statistical significance for all comparisons. Demographic data missingness was minimal and are noted in the Table 1 footnotes. All analyses were conducted using STATA version 15.1 (StataCorp, College Station, TX).

# Results

## CHARACTERISTICS OF SPLIT-LIVER AND REDUCED-SIZE TRANSPLANT EPISODES

In total, 2409 partial liver transplantation episodes were identified between January 1, 2008, and December 31, 2018. Of these, 1831 (76.0%) were split-liver transplantation episodes, and 578 (24.0%) were reduced-size transplantation episodes. The median annual volume of split-liver transplantation was 168 patients (minimum 137, maximum 203; Fig. 1). No temporal trend in annual split-liver transplantation volume was observed (slope +3.1 episodes/year; 95% CI, −1.0 to +7.3 episodes/year). The median annual volume of reduced-size transplantation was 55 patients (minimum 38, maximum 63). There was a small but statistically significant temporal trend toward decreased annual volume of reduced-size transplantation (slope −1.6 episodes/year, 95% CI −3.1 to −0.1 episodes/year). Annual split-liver and reduced-size transplantation volumes were found to have a strong inverse correlation ($\rho = -0.916$; $P < 0.001$).

Donor, recipient, and transplant characteristics are listed in Table 1. Split-liver transplantation donors were older with larger BSAs. Split-liver transplantation recipients were older, had larger BSAs, more likely to receive HCC exception points, and spent more time on the waiting list. Split-liver transplantation recipient age followed a bimodal distribution, whereas reduced-size transplantation recipient age was right skewed (Fig. 2). Reduced-size transplantation recipients were more likely to be status 1A/1B listings and have histories of previous liver transplantation. Split-liver transplantation episodes had shorter cold ischemic times, although this difference was clinically small at a difference in median values of 0.6 hours.

## ALL-CAUSE GRAFT LOSS

Median follow-up was 4.8 years (IQR, 2.0 to 7.7 years). Kaplan-Meier curve estimates of all-cause graft failure among split-liver transplantation episodes was 11.8% at 1 year, 16.6% at 3 years, 19.3% at 5 years, and 22.4% at 7 years (Fig. 3). Among reduced-size transplantation episodes, the estimated incidence of all-cause graft failure was 10.6% at 1 year, 14.9% at 3 years, 17.0% at 5 years, and 20.0% at 7 years. This difference was not statistically significantly different ($P = 0.31$). There was no statistical difference in 7-year all-cause graft loss between split-liver and reduced-size transplantation after adjusting for recipient age, donor age, donor BSA, recipient insurance, retransplant status, and year of transplantation (adjusted hazard ratio [aHR], 1.09; 95% CI, 0.82-1.46; Table 2). On sensitivity analysis, split-liver transplantation was not associated with increased hazards of all-cause graft loss within 30 days of transplantation (aHR, 1.13; 95% CI, 0.70-1.80) or beyond 30 days after transplantation (aHR, 1.08; 95% CI, 0.77-1.51).

**TABLE 1. Donor, Recipient, and Transplantation Characteristics**

| | Split-Liver Transplantation | Reduced-Size Transplantation | *P* Value |
|---|---|---|---|
| Donor characteristics | | | |
| Procurements | 998 | 578 | N/A |
| Age, years | 19 (16-26) | 13 (7-18) | <0.001 |
| Male sex | 669/998 (67.0) | 368/578 (63.7) | 0.18 |
| Body mass index, kg/m$^2$* | 23.1 (20.8-25.5) | 20.2 (17.0-23.5) | <0.001 |
| BSA, m$^2$ | 1.79 (1.64-1.93) | 1.48 (0.91-1.78) | <0.001 |
| Hypertension | 46/993 (4.6) | 26/577 (4.5) | 0.91 |
| Diabetes mellitus | 10/994 (1.0) | 15/577 (2.6) | 0.015 |
| Smoker | 31/990 (3.1) | 8/576 (1.4) | 0.033 |
| Intravenous drug use | 38/988 (3.8) | 13/575 (2.3) | 0.089 |
| Donation after circulatory death | 0/998 (0.0) | 3/578 (0.5) | 0.049 |
| Terminal ALT, IU/L* | 31 (20-54) | 35 (21-65) | 0.005 |
| Terminal AST, IU/L | 43 (27-73) | 48 (28-81) | 0.021 |
| Recipient characteristics | | | |
| Number of recipients | 1831 | 578 | N/A |
| Age, years | 9 (1-56) | 1 (0-4) | <0.001 |
| Male sex | 879/1831 (48.0) | 297/578 (51.4) | 0.16 |
| Race/ethnicity | | | 0.17 |
| White | 987/1831 (53.9) | 315/578 (54.5) | |
| Black | 233/1831 (12.7) | 74/578 (12.8) | |
| Hispanic | 430/1831 (23.5) | 118/578 (20.4) | |
| Asian | 140/1831 (7.6) | 49/578 (8.5) | |
| Other† | 41/1831 (2.2) | 22/578 (3.8) | |
| Body mass index, kg/m$^2$* | 19.5 (16.6-24.8) | 16.9 (15.5-18.7) | <0.001 |
| BSA, m$^2$* | 1.02 (0.44-1.74) | 0.44 (0.34-0.71) | <0.001 |
| Laboratory MELD score | 17 (11-24) | 20 (13-25) | 0.41 |
| PELD score | 13 (–1 to 25) | 16 (3-24) | 0.029 |
| Private insurance | 808/1831 (44.1) | 236/578 (40.8) | 0.16 |
| Status 1A or 1B listing | 380/1831 (20.8) | 210/578 (36.3) | <0.001 |
| HCC exception points | 268/1831 (14.6) | 9/578 (1.6) | <0.001 |
| Previous transplantation | 87/1831 (4.8) | 51/578 (8.8) | <0.001 |
| Previous portal vein thrombosis | 155/1829 (8.5) | 48/578 (8.3) | 0.90 |
| Days on waiting list, days | 94 (26-271) | 42 (11-108) | <0.001 |
| Transplant characteristics | | | |
| Number of transplants | 1831 | 578 | N/A |
| Cold ischemia time, hours* | 6.8 (5.1-8.5) | 7.4 (6.2-9.0) | <0.001 |
| Blood-type incompatible | 44 (2.4) | 35 (6.1) | <0.001 |

NOTE: Data are provided as n, n (%), or median (IQR).
*Missingness <1.0% for split-liver and reduced-size transplantation cohorts.
†Other races include American Indian/Alaska Native, Native Hawaiian or Other Pacific Islander, and multiracial.

## ETIOLOGY OF ALL-CAUSE GRAFT LOSS WITHIN 30 DAYS OF TRANSPLANTATION

A total of 426 all-cause graft loss events were observed during the study period; of these, 156 (33.6%) occurred within 30 days of transplantation. Vascular thrombosis was the most common etiology of all-cause graft loss within 30 days of transplantation, accounting for >50% in both split-liver and reduced-size transplantation cohorts (Table 3). There was no statistically significant difference in etiology of all-cause graft loss within 30 days of transplantation between the cohorts ($P = 0.85$). Sensitivity analysis using a complete-case approach had similar results (Supporting Table 1).

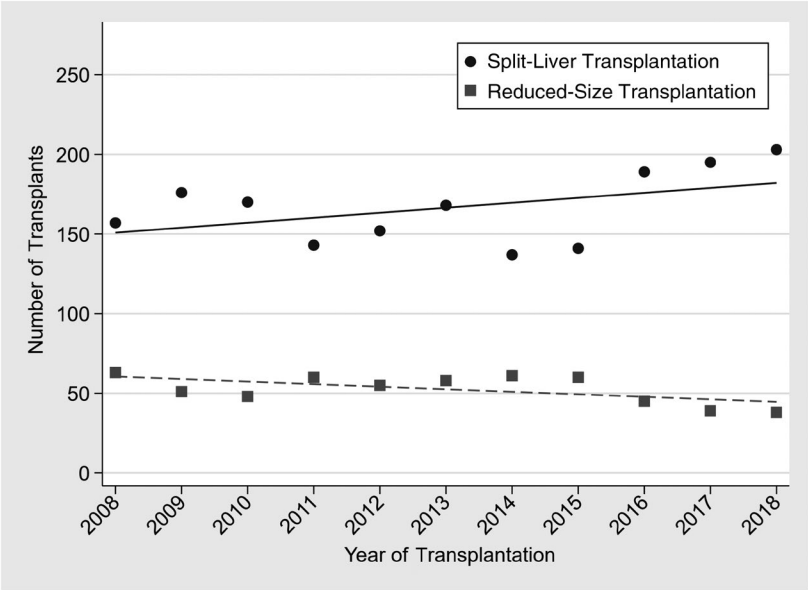


**FIG. 1.** Annual volume of split-liver and reduced-size transplantation episodes in the United States from 2008 to 2018. Dots represent annual number of split-liver and reduced-size transplantation episodes. Lines are the linear fits of these volumes over time. Pairwise correlation ($\rho$) between split-liver and reduced-size liver transplantation by year was −0.916 ($P < 0.001$).

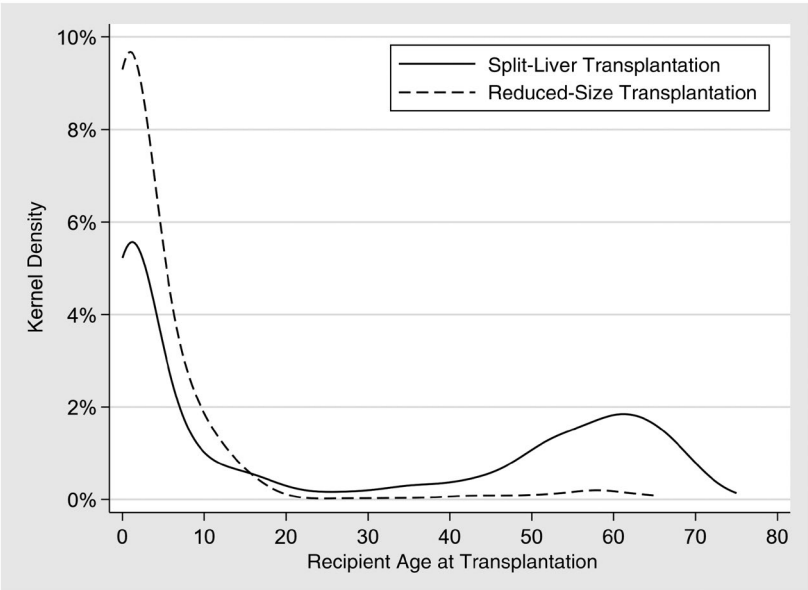


**FIG. 2.** Smoothed kernel density plots of recipient age at transplantation between split-liver and reduced-size transplantation episodes. As shown, recipient age at transplantation among split-liver transplantation episodes (solid line) follows a bimodal distribution, whereas recipient age at transplantation among reduced-size transplantation episodes (dotted line) follows a right-skewed distribution.

## INCIDENCE, ANATOMY, AND VOLUME OF SEGMENT DISCARDS

Of 79,667 liver procurement episodes during the study period, 1003 (1.3%) split-liver and 578 (0.7%) reduced-size procurements were identified. In total, 175/2006 (8.7%) split-liver segments and 578/1156 (50.0%) reduced-size segments were discarded ($P < 0.001$ for comparison). Split-liver discards were usually left-lateral segments (91/175, 52.0%), whereas reduced-size

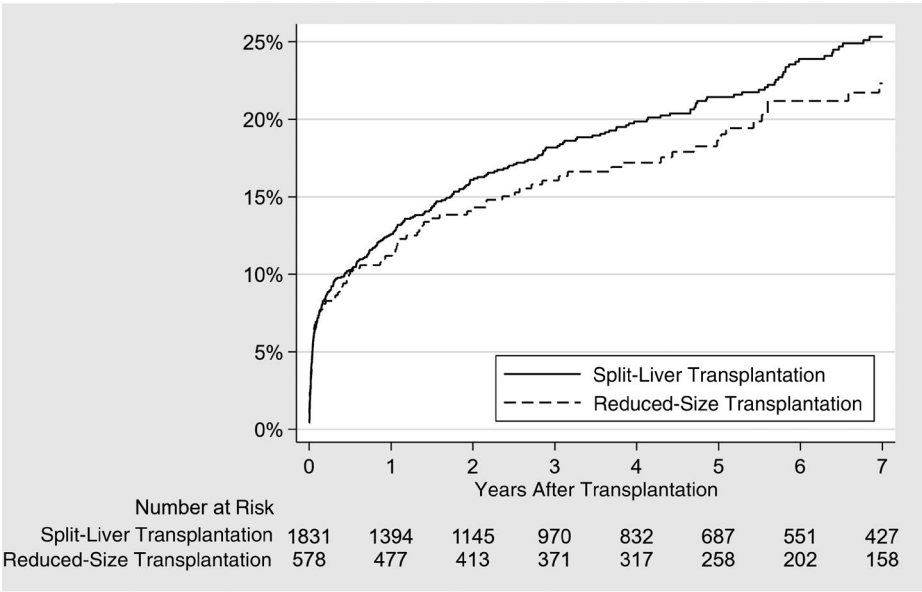


**FIG. 3.** Kaplan-Meier curves of all-cause graft loss between split-liver and reduced-size transplantation episodes. There was no statistical difference between the curves on log-rank test ($P = 0.31$).

**TABLE 2. Cox Proportional Hazards Analysis of All-Cause Graft Loss Between Split-Liver and Reduced-Size Transplantation Episodes in the United States From 2008 to 2018**

| | Univariate Analysis | | Multivariable Analysis | |
|---|---|---|---|---|
| | HR (95% CI) | *P* Value | aHR (95% CI) | *P* Value |
| Split-liver transplantation | 1.12 (0.80-1.58) | 0.50 | 1.09 (0.82-1.46) | 0.55 |
| Recipient age at transplantation, per 5-year increase | 1.02 (1.00-1.04) | 0.10 | 1.02 (1.00-1.04) | 0.035 |
| Donor age at procurement, per 5-year increase | 1.11 (1.05-1.16) | <0.001 | 1.13 (1.08-1.19) | <0.001 |
| Donor BSA, per 0.1 $m^2$ increase | 1.01 (0.98-1.04) | 0.59 | 0.96 (0.93-0.99) | 0.019 |
| Private insurance | 0.85 (0.68-1.06) | 0.15 | 0.79 (0.65-0.96) | 0.020 |
| History of previous liver transplant | 2.04 (1.49-2.79) | <0.001 | 2.18 (1.57-3.03) | <0.001 |
| Year of transplantation, per 1-year increase | 0.97 (0.93-1.01) | 0.10 | 0.96 (0.93-1.00) | 0.042 |

discards were usually right lobe (326/578, 56.4%) or right trisegment (215/578, 37.2%; $P < 0.001$ for comparison; Fig. 4). Volume of reduced-size segment discards were statistically significantly larger than split-liver segment discards (median volumes 745 [IQR, 425-998] $cm^3$ versus 252 [IQR, 199-699] $cm^3$; $P < 0.001$). The anatomies of the discarded segments by donor height and weight are displayed in Supporting Fig. 2. Distribution of donor height and weight appeared similar between the split-liver and reduced-size segment discards.

# Discussion

Between 2008 and 2018, we found no difference in long-term all-cause graft loss between split-liver and reduced-size transplantation episodes. In addition, there was no evidence of increased hazards of all-cause graft loss within 30 days of transplantation among split-liver transplantation episodes. The etiology of all-cause graft loss within 30 days of transplantation was similar between cohorts, with the majority of graft losses being secondary to vascular thrombosis. Finally, reduced-size procurements resulted in a significantly higher incidence of segment discards that were usually right-sided liver segments.

Similar incidences of short-term and long-term all-cause graft loss between split-liver and reduced-size transplantation episodes further underscores the need to prioritize split-liver transplantation over reduced-size transplantation whenever technically feasible. This study demonstrates that reduced-size transplantation overwhelmingly results in discards of right-sided liver

**TABLE 3. Etiology of Graft Loss Within 30 Days of Transplantation Between Split-Liver and Reduced-Size Transplantation Episodes**

| | Split-Liver Transplantation, % | Reduced-Size Transplantation, % | *P* Value |
|---|---|---|---|
| Vascular thrombosis | 56.4 (45.9-66.9) | 61.8 (43.6-79.9) | 0.85 |
| Primary nonfunction | 30.3 (20.4-40.2) | 23.9 (8.2-39.6) | |
| Acute rejection | 7.7 (1.5-13.8) | 5.8 (0.0-15.9) | |
| Death with functioning graft | 5.6 (0.0-11.9) | 8.5 (0.0-19.5) | |

NOTE: Data are presented as proportions with 95% CIs.

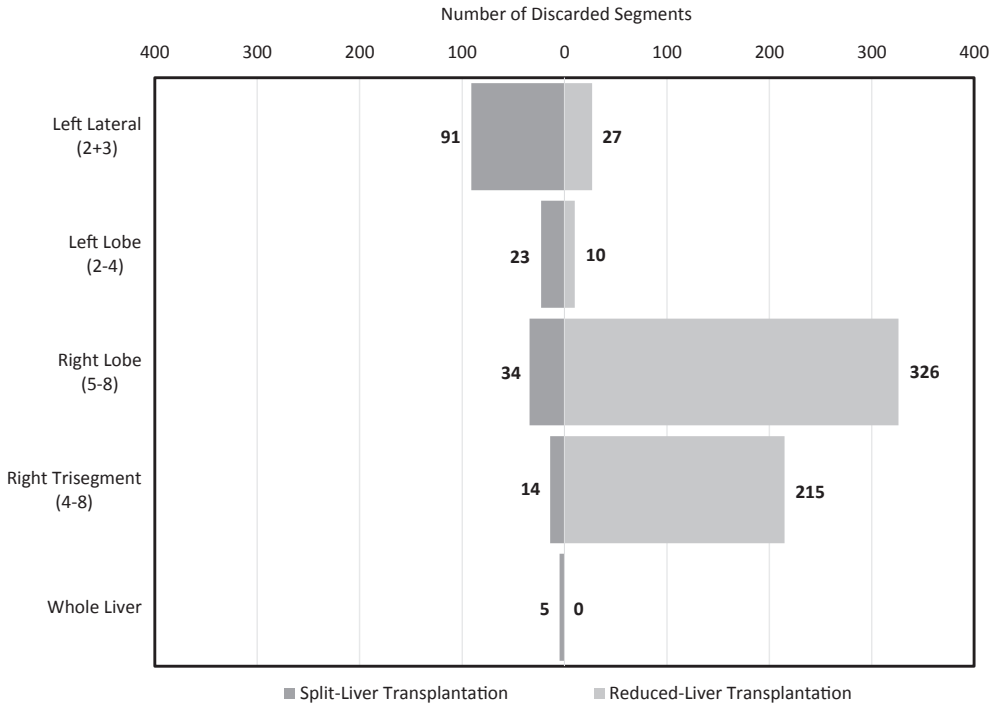


**FIG. 4.** Tornado plot of discarded segment anatomy between split-liver and reduced-size transplantation episodes. The anatomy of discarded segments was statistically significantly different on $\chi^2$ test ($P < 0.001$).

segments (right lobe and right trisegment), which are generally larger and should be usable for transplant into an appropriate-size recipient. Similar donor height and weight distributions among discarded segments further rejects the hypothesis that differential donor size leads to the use of reduced-size over split-liver transplantation on a population level. Finally, the lack of a bimodal distribution among reduced-size transplantation episodes (compared with split-liver transplantation episodes) suggests that reduced-size transplantations occur when a pediatric center is allocated a whole liver that they intend to reduce without consideration of allocation of the residual segment to a second recipient. Taken together, these data suggest that the continued use of reduced-size transplantation when split-liver transplantation is technically feasible represents a potentially wasteful practice.

Although there is national agreement that split-liver transplantation needs to be better used to increase the number of liver transplantations performed annually, there is debate as to the means.[30] Logistical challenges of allocating split-liver segments to different centers has been identified as a major barrier to split-liver transplantation. As such, multiple split-liver allocation variances (region 8, region 2, and a single organ procurement organization [OPO] in region 5) have been attempted to incentivize split-liver transplantation by allocating both segments to the same center.

Proponents maintain that such variances solve logistical problems, encourage centers to perform more split-liver transplantations, and allow for optimal anatomical splitting of the liver for the center's 2 recipients. However, opponents are concerned that these variances disadvantage centers without institutionally affiliated pediatric programs because of the match run rules that favor allocation to pediatric recipients. Furthermore, there is concern that increasing split-liver transplantation among adults will have poorer patient outcomes compared with whole-liver transplantation, and centers will be penalized for these outcomes. Given that split-liver transplantation represents <2% of all liver transplants performed annually, we contend that concerns over disadvantaging individual centers by increasing split-liver transplantation is overstated.[31] The transplant community should prioritize performing the greatest number of transplants to save the greatest number of lives, even if this is at the marginal expense of a small number of transplant centers. We advocate for any split-liver variances that accomplish more split-liver transplantations and prevent the unnecessary wasting of reduced-size transplant discards.

Current transplantation policies require OPOs to exercise equal effort and resources to place each segment of a split-liver procurement; however, there is little accountability among OPOs or transplant centers for converting reduced-size transplantation episodes to split-liver transplantation. Although our analysis suggested a higher potential acuity among reduced-size transplantation recipients (more likely to be status 1A/1B listing, retransplants, and higher PELD scores), these factors alone should not absolve transplant centers or OPOs from their dual responsibility to facilitate placement of the unused segment. In clinical practice, the decision to reduce or split a liver is delegated to the accepting center for the primary recipient. Transplant centers should be required to report their intention to perform reduced-size transplantation at the time of organ offer acceptance, which should trigger the OPO to exercise equal effort and resources to place the unused segment. Ongoing emphasis on creating best practices and standards in split-liver transplantation is needed to facilitate decision making as it relates to the assignment of blood vessels and bile ducts between the 2 allografts and procurement technique. Such standards will help facilitate collaboration between transplant centers and OPOs that may convert more appropriate donors to split-liver transplantation.

In addition to similar short-term and long-term all-cause graft loss between split-liver transplantation and reduced-size transplantation episodes, we found similar etiologies of 30-day graft loss between the practices. Vascular thrombosis was associated with the majority of graft losses within this timeframe. This highlights the increased technical complexity of these procedures and identifies vascular complications as the key challenge to target for improvement in outcomes for split-liver transplantation and reduced-size transplantation. Further analysis of center-level variations in practice may identify best practices to decrease vascular thrombosis events among split-liver transplantation and reduced-size transplantation episodes.

Our study has limitations. First, the etiology of graft loss was missing in 36.6% of graft loss episodes within 30 days of transplantation. Multiple imputation was used to estimate the graft loss etiology, but it is possible that technical causes of graft loss could have been underestimated or overestimated. Even so, the robustness of our results was supported by a sensitivity analysis using a complete-case approach. Second, biliary and vascular anatomic characteristics between split-liver transplantation and reduced-size transplantation episodes are not captured in the UNOS STAR file and therefore cannot be compared. We were not able to compare biliary or vascular anatomy between split-liver transplantation and reduced-size transplantation episodes and cannot say with certainty that all of the reduced-size transplantation donors had anatomies amenable to splitting. However, it is highly unlikely that biliary and vascular anatomies alone would explain the choice to perform reduced-size transplantation in all 578 patients. Third, this study is limited by its retrospective nature and the use of registry data that are prone to residual confounding and misclassification bias. However, these data are the best available to study these rare events on a national basis. Finally, this study does not address the larger proportion of whole-liver transplantations that might be amendable to split-liver transplantation. This potential population of split-liver transplantations must be addressed with future studies to realize a substantial impact on split-liver transplantation use.

In conclusion, 25% of partial liver transplantations are reduced-size transplantation episodes, which leads to the discard of generally right-sided segments that likely could have been used for transplantation to another candidate. Our analysis revealed similar incidences of short-term and long-term all-cause graft loss between split-liver transplantation and reduced-size

transplantation, suggesting that a presumed advantage in outcomes does not support the use of reduced-size transplantation. It is critically important to develop best practices and policies that encourage transplant centers and OPOs to prioritize split-liver transplantation when technically feasible and minimize the use of reduced-size transplantation, thus optimizing the impact of each deceased organ donor.

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