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Variation in Racial Disparities in Liver Transplant Outcomes Across Transplant Centers in the United States

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Abstract

Little is known about the role that transplant centers may play in perpetuating racial disparities after liver transplantation, which are unexplained by patient-level factors. We examined variation in between-center and within-center disparities among 34,114 Black and White liver transplant recipients in the United States from 2010 to 2017 using Scientific Registry of Transplant Recipient (SRTR) data. We used Cox proportional hazards models to calculate transplant center-specific Black–White hazard ratios and hierarchical survival analysis to examine potential effect modification of the race–survival association by transplant center characteristics, including transplant volume, proportion of Black patients, SRTR quality rating, and region. Models were sequentially adjusted for clinical, socioeconomic, and center characteristics. After adjustment, Black patients experienced 1.11 excess deaths after liver transplant per 100 person-years compared with White patients (95% confidence interval [CI], 0.65-1.56), corresponding to a 21% increased mortality risk (95% CI, 1.12-1.31). Although there was substantial variation in this disparity across transplant centers, there was no evidence of effect modification by transplant center volume, proportion of minority patients seen, quality rating, or region. We found significant racial disparities in survival after transplant, with substantial variation in this disparity across transplant centers that was not explained by selected center characteristics. This is the first study to directly evaluate the role transplant centers play in racial disparities in transplant outcomes. Further assessment of the qualitative factors that may drive disparities, such as selection processes and follow-up care, is needed to create effective center-level interventions to address health inequity.

Liver transplantation is the only potentially curative treatment for end-stage liver disease, which kills approximately 50,000 people in the United States each year.(1) Black patients have lower graft function,(2) inferior graft survival,(3) and worse overall survival(4) after liver

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transplantation than White patients. This disparity has remained consistent over time[5] and persists after controlling for patient-level factors, such as socioeconomic status[6] and clinical covariates.[2] Improving outcomes for these patients, who are already less likely to be on a waiting list for transplant,[7,8] is critical to ensuring equitable benefit from liver transplantation.

Little is known about the role that transplant centers may play in perpetuating or mitigating racial disparities in liver transplant outcomes. The idea that transplant centers may play a role in racial disparities is particularly plausible because of the documented importance of center-level factors to liver transplant outcomes in general.[9,10] Understanding the role of transplant centers in outcome disparities is important because centers have strong incentives to improve patient survival[11] and provide the majority of posttransplant acute care[12]; high-disparity transplant centers are therefore ideal venues for interventions to reduce racial disparities in liver transplant outcomes. Targeted interventions could be developed by identifying specific centers or types of centers with exacerbated racial disparities. Furthermore, understanding the role of transplant centers in racial disparities may provide insight into the mechanisms underlying these disparities, which are currently unexplained by patient-level factors.

The objective of this study was to explore the role of the transplant center in survival disparities among Black liver transplant recipients. First, we described differences in transplant center characteristics between Black and non-Hispanic White transplant recipients (between-hospital disparity) and estimated variation in racial disparities across transplant centers (within-hospital disparity). Next, we assessed whether differences in racial disparity between transplant centers arose from potential effect modification by transplant center characteristics. To do so, we used data from the Scientific Registry of Transplant Recipients (SRTR) on Black and White liver transplant recipients in the United States from 2010 to 2017.

Patients and Methods

DATA SOURCES AND POPULATION

Data on liver transplant recipients were obtained from SRTR, a population-based registry of all solid organ transplant candidates, donors, and recipients in the United States. We included 40,776 adult (age ≥ 18) patients who were non-Hispanic Black or White and received a deceased donor liver transplant between January 1, 2010, and December 31, 2017. Patients were excluded if they received a simultaneous transplant of another organ (n = 3746), had a prior liver transplant (n = 1690), had acute liver failure (n = 1189), or had acute alcoholic hepatitis (n = 134).

VARIABLES

Race was reported by medical providers and dichotomized to non-Hispanic Black or White. Our primary outcome of interest was time to graft failure or death. Survival time was calculated as the time between receipt of transplant and date of death or graft failure,

whichever occurred first, and divided by 365.25 to give the survival time in years. Patients were censored at loss to follow-up or the end of the study period (December 31, 2018).

To explore whether racial disparities in outcomes arose from differential prevalence of important center characteristics or from the differential effect of given center characteristics by race, we selected 4 potential center characteristics of interest. Center characteristics were selected by reviewing the literature on factors associated with transplant outcomes and factors associated with racial disparities in other surgical outcomes. Transplant volume was defined as the number of adult liver transplants performed by the center in the year that the recipient received his or her transplant and was classified into tertiles by year (labeled low-volume, medium-volume, and high-volume centers). The proportion of Black patients was defined as the percentage of Black adult liver transplants performed by the center in the year that the recipient received his or her transplant, classified into tertiles (labeled low-volume, medium-volume, and high-volume centers). Transplant center quality was defined using the SRTR 5-tier system for observed outcomes. Briefly, tiers are assigned based on the hazard ratio (HR) distribution of observed graft and patient survival in the first year after transplant compared with expected posttransplant survival, with tier 5 representing the best performance. Geographic region of the transplant center was assigned according to the US Census regions (Northeast, Midwest, South, and West). All time-varying center characteristics, including transplant volume, proportion of minority patients, and center quality, were assigned by year of transplant to account for variation over time.

Clinical covariates included age, year of transplant, sex, Model for End-Stage Liver Disease (MELD) score at transplant (a measure of disease severity), underlying cause of disease, presence of hepatocellular carcinoma (HCC), recipient medical condition at transplant, body mass index (BMI), donor risk index (DRI), portal vein thrombosis (PVT), diabetes mellitus, and dialysis at transplant. Underlying cause of disease was categorized as hepatitis C, alcoholic liver disease, nonalcoholic steatohepatitis (NASH), and other. Candidate medical condition at transplant was categorized as the following: in the intensive care unit (ICU), hospitalized but not in the ICU, or not hospitalized. The DRI is a validated score used to estimate the risk of graft failure based on donor characteristics, including donor age, race, cause of death, cold ischemic time, height, whether the donation was after circulatory death, and whether the graft was a split or partial graft. Socioeconomic covariates included educational attainment, zip code–level income, and insurance type. Educational attainment of the patient at the time of listing was categorized as less than high school, high school diploma, some college, and associate’s degree or higher. Insurance type was assigned based on the primary payer for the transplant (categorized as public, private, or other).

STATISTICAL ANALYSIS

We described clinical, demographic, and transplant center characteristics of our population both overall and by race. To characterize center-level variation in racial disparities, we used Cox proportional hazards models to calculate center-specific Black–White HRs for centers that had transplanted at least 1 Black patient between 2007 and 2017, adjusted for clinical and socioeconomic characteristics.

We used hierarchical additive survival analysis to estimate the absolute survival difference between Black and White patients and hierarchical Cox proportional hazards models to estimate the relative HR during the entire time period. Models were hierarchical to account for potential clustering of outcomes within transplant centers, where patients treated in the same transplant center may have more similar outcomes to each other than to patients treated elsewhere. We sequentially adjusted models by including clinical, socioeconomic, and center characteristics, as described previously. Missing values were imputed for the 21% of patients missing at least 1 covariate through chained random forests and predictive mean matching using the miss-Ranger package. The presence of effect modification of race by transplant center characteristics was assessed through both statistical significance (P for interaction <0.05) and clinical significance (magnitude of difference between the associations). We also used hierarchical additive survival analysis and Cox proportional hazards modeling to estimate the association of center characteristics with survival separately for both White and Black patients.

We performed a supplementary analysis to further characterize center-level variation in racial disparities. Using center-specific HRs, we classified centers into tertiles of disparity (low, medium, and high). We estimated Kaplan-Meier curves for Black and White patients at centers in each tertile to visualize survival differences within and between tertiles. All analyses were performed in R 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria).

Results

STUDY POPULATION

We identified 33,997 Black and White patients who received a liver transplant at 128 US centers between January 1, 2010, and December 31, 2017. The median follow-up time was 3.5 years (interquartile range, 1.8-5.9). Demographic and transplant center characteristics, stratified by race, are provided in Table 1. Approximately 10% (n = 3617) of transplant recipients in this time period were Black, whereas 90% were White (n = 30,380). The mean age of transplant recipients at listing was 55.3 years, with a mean MELD at transplant of 20.9. The majority of transplant recipients were men (67.9%), although a higher proportion of Black recipients than White recipients were women (39.3% versus 31.3%). Black patients were more likely to have a high school education or less (48.4% versus 42.0%), lower annual household income in the zip code ($53,200 versus $64,400), and public insurance (51.2% versus 41.5%) than White patients. Underlying cause of disease etiology also varied by race, with Black patients being more likely to have hepatitis C (51.5% versus 37.7%), but less likely to have alcohol-associated liver disease (7.0% versus 18.5%) or NASH (5.1% versus 17.2%) than White patients; Black patients were also less likely to have PVT (8.8% versus 13.5%). Medical condition at transplant, recipient BMI, dialysis, and DRI did not vary substantially by race.

RACIAL DIFFERENCES IN TRANSPLANT CENTER CHARACTERISTICS

As expected, the majority of transplant recipients (65.9%) received a transplant at a high-volume transplant center; this proportion did not vary substantially by race. The majority of

Black patients received a transplant at a transplant center in the highest tertile of minority patients (62.8%), whereas only 29.0% of White patients received a transplant at these centers. Black transplant recipients were more likely than White patients to receive care at a tier 1 (8.0% versus 7.0%) or tier 2 (28.7% versus 24.2%) center, and less likely to receive care at a tier 4 (21.4% versus 25.2%) or tier 5 (12.1% versus 13.8%) center. More than half of Black patients received their liver transplant in the South (54.0%) compared with 41.9% of White patients.

VARIATION IN RACIAL DISPARITIES IN SURVIVAL BY TRANSPLANT CENTER

During the study period, there were 861 "events" (deaths or graft failures) among Black patients (23.8%) and 5,840 events among White patients (19.2%). Figure 1 displays center-specific Black–White HRs, adjusted for clinical and socioeconomic variables. Although there is substantial variation from center to center in terms of HRs and confidence intervals (CIs), the majority of the centers have an HR above 1, indicating worse outcomes among their Black patients.

Table 2 presents sequentially adjusted results from both additive and Cox proportional hazards models estimating the magnitude of racial disparities in survival. Unadjusted, Black patients had 1.23 excess deaths per 100 person-years (PYs) compared with White patients (95% CI, 0.78-1.66); this corresponded to a 24% higher hazard of poor outcomes after liver transplant (95% CI, 1.13-1.37). There was no statistically significant interaction between any of the center characteristics considered and race. In low-volume centers, there were 1.16 excess deaths among Black patients per 100 PYs (95% CI, −0.32-2.64) and 1.43 per 100 PYs in high-volume centers (95% CI, 0.89-1.97). Survival differences were larger in centers that treated a low proportion of minority patients (1.49 per 100 PYs; 95% CI, −0.18-3.16) or a high proportion of minority patients (1.21 per 100 PYs; 95% CI, 0.63-1.79) compared with those with a medium proportion of minority patients (1.06 per 100 PYs; 95% CI, 0.31-1.81). Black–White survival differences were highest among the lowest rated transplant centers (tier 1 difference, 1.83; 95% CI, 0.25-3.41; tier 2 difference, 1.79; 95% CI, 0.92-2.66) and similar between tiers 3 (1.06; 95% CI, 0.28-1.84), 4 (0.69; 95% CI, −0.20-1.58), and 5 (0.86; 95% CI, −0.31-0.20). Differences were highest in the Northeast (1.54 per 100 PYs; 95% CI, 0.54-2.54), similar in the Midwest (1.17; 95% CI, 0.18-2.16) and the Southeast (1.15; 95% CI, 0.56-1.74), and lowest in the West (0.80; 95% CI, −0.70-2.29). The overall association between race and survival was slightly increased after adjustment for clinical factors alone (excess deaths among Black patients: 1.34 per 100 PYs [95% CI, 0.90-1.78]; HR, 1.27 [95% CI, 1.16-1.38]), but was attenuated after further adjustment for socioeconomic and center-level characteristics (excess deaths among Black patients: 1.11 per 100 PYs [95% CI, 0.65-1.56]; HR, 1.21 [95% CI, 1.12-1.31]). There was no statistically significant interaction between race and any of the center characteristics after adjustment for covariates. Patterns of associations stratified by center characteristics were similar in both the unadjusted and adjusted results.

Table 3 presents the association of center characteristics with survival, stratified by race, and adjusted for clinical, socioeconomic, and center-level characteristics. None of our prespecified center-level characteristics were meaningfully or statistically significantly

associated with survival among Black or White liver transplant recipients after adjustment for patient-level and other center-level factors.

SUPPLEMENTARY ANALYSES

Figure 2 provides Kaplan-Meier curves for Black and White transplant recipients at low-disparity, medium-disparity, and high-disparity centers. In low-disparity centers, White patients had worse outcomes than White patients at medium-disparity or high-disparity centers. Outcomes among White transplant recipients were better, whereas outcomes among Black transplant recipients were worse, with higher center-level disparities.

Discussion

In this analysis of Black and White liver transplant recipients in the United States, we sought to quantify racial disparities in survival and determine whether differential distribution or effects of transplant center characteristics explained disparities. We found significant racial disparities in survival after transplant, with substantial variation in this disparity across transplant centers. Disparities remained consistent regardless of transplant center volume, proportion of minority patients seen, quality rating, or region. The magnitude of center-level variation in racial disparities indicates that racial disparities may be influenced by transplant centers; however, this variation is not explained by our center characteristics selected a priori. This is the first study to directly evaluate the role transplant centers play in racial disparities in transplant outcomes.

Our findings are consistent with previous studies that have demonstrated persistent racial disparities in liver transplant outcomes. Several studies using SRTR data[6,13,14] have identified racial disparities in overall survival after liver transplantation. These disparities were present before the development of the current MELD-based allocation system and have persisted into the MELD era.[5] In a recent study that linked University HealthSystem Consortium and SRTR data sources, Black liver transplant recipients were seen in lower quality centers and had higher risk of both graft failure and death after transplant than White recipients after controlling for recipient and donor characteristics, geographic region, donor service area, and individual hospital effects.[2] Our findings are consistent with those of this previous study; however, we did not seek to control for individual center effects but instead identify potential sources of between-center variation.

In contrast with previous studies, we did not find a significant association between transplant center volume, quality rating, and outcomes among either Black or White liver transplant recipients. Axelrod et al. previously found that recipients at low-volume centers had 30% higher odds of mortality in the first year after liver transplant compared with high-volume centers.[9] However, this study used data from 1996 to 2000. It is possible that during the past 20 years, care has improved substantially at low-volume centers, thus eliminating the disparity. Ozhathil et al.[15] found that high-volume centers tended to use lower quality donor livers but achieve better allograft and patient survival for high-risk patients compared with low-volume centers. They attributed these findings to greater levels of expertise in these centers. Our finding that effect of center volume did not appear to differ among White and

Black patients after controlling for patient risk profile may have obscured potential subgroup differences among high-risk patients.

We did not observe a significant association between SRTR quality rating and outcomes among White or Black patients. This is in contrast to a previous study by Wey et al.,[16] who demonstrated a 7% decreased risk of mortality among liver transplant recipients for each additional quality tier. The study by Wey et al. assigned patients to a tier at the time of listing, whereas we assigned patients to a tier according to their year of transplant; this may account for our difference in results. Furthermore, tiers are assessed on the basis of 1-year survival, whereas we examined longer term outcomes. It is possible that if we looked solely at 1-year outcomes we would have observed an association between quality rating and survival. However, this rating system has been the subject of substantial controversy in the field, partially because of its focus on the arbitrary endpoints of 1-year survival.[17,18] It is possible that other measures of quality of care—such as process measures—may be more relevant to both survival and racial disparities than those currently in use in the transplant community.

Although racial disparities in transplant outcomes did not vary by our measured center characteristics, there were still centers with exacerbated racial disparities in survival. One potential explanation for this finding is that the center-level factors that matter for racial disparities are not those that we assessed. We selected our factors a priori based on previously published studies in the liver transplant literature and in the broader field of health services research, but we were limited to those that could be derived from available national surveillance data. Accurately measuring potentially important factors, such as candidate selection processes, structural center-level practices, and the accessibility and quality of follow-up care, may require more nuance than is typically found in administrative data sets such as the SRTR. Future research in this area should consider incorporating additional data sources as well as conducting qualitative analysis of high-disparity and low-disparity centers to generate new hypotheses to explore these and other factors that may be important for racial disparities.

Notably, centers with low racial disparities in survival did not necessarily have better outcomes for their Black patients than centers with high racial disparities. Instead, White patients at low-disparity centers had worse outcomes than White patients at high-disparity centers. This finding highlights the importance of understanding center-level drivers of racial disparities when thinking about potential interventions. The goal of such interventions is not for Black and White patients to have equally poor outcomes, so recommending practices from low-disparity centers to high-disparity centers may be inappropriate. Critical assessment of the mechanisms underlying disparities is the first step to designing interventions that truly address racial inequity in transplant outcomes. In addition, this assessment should be informed by both the magnitude of disparity and the underlying outcome rates in each population.[19] We provide both relative and absolute measures of racial disparity in this study to facilitate this assessment.

The results of our study must be interpreted in the context of its limitations. We chose to restrict our study to non-Hispanic Black and White patients, which limits the generalizability

of our findings. We did so because Black patients are at highest risk for poor outcomes after liver transplant, whereas Hispanic and Asian patients have survival rates that are better than or comparable with White patients.[4] However, it is possible that disparities for these populations exist in specific transplant center contexts. Future studies may wish to specifically examine the effects of transplant center factors for these patient populations. Another potential limitation of our findings is the measurement of center-level characteristics. In addition to the limitations of administrative data discussed previously, we may have induced measurement error by assigning center characteristics by the year of transplant. It is possible that center characteristics at precisely the time of transplant are important. However, we would not expect center characteristics to vary too substantially during the course of 1 year. In addition, we would not expect errors in attribution by time to be differential by race. Selection bias may also occur from differences in transplant center selection processes, which cannot be measured using current waitlist data. There may be unmeasured confounding affecting our results. Differences between transplant centers may be explained by unmeasured clinical factors (ie, underlying chronic conditions), social support, or neighborhood environment. Measures of socioeconomic data in SRTR are limited to education, which may be poorly reported, and zip code–level income. There is no measure of individual-level wealth or income, which may impact the influence of race on transplant outcomes. Finally, differences in racial disparities between individual transplant centers may vary over time or be attributed to random variation; we do not have sufficient data to evaluate statistical significance or time trends.

In conclusion, the magnitude of racial disparity in liver transplant outcomes varied across transplant centers, but was not affected by transplant volume, proportion of minority patients served, quality rating, or region. Further assessment of qualitative factors that may drive disparities, such as selection processes and follow-up care, is needed to create effective center-level interventions to address health inequity.

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Abbreviations:

BMI	body mass index
CI	confidence interval
DRI	donor risk index
HCC	hepatocellular carcinoma
HR	hazard ratio
ICU	intensive care unit
MELD	Model for End-Stage Liver Disease
NASH	nonalcoholic steatohepatitis

PVT	portal vein thrombosis
PY	person-year
SD	standard deviation
SRTR	Scientific Registry of Transplant Recipients

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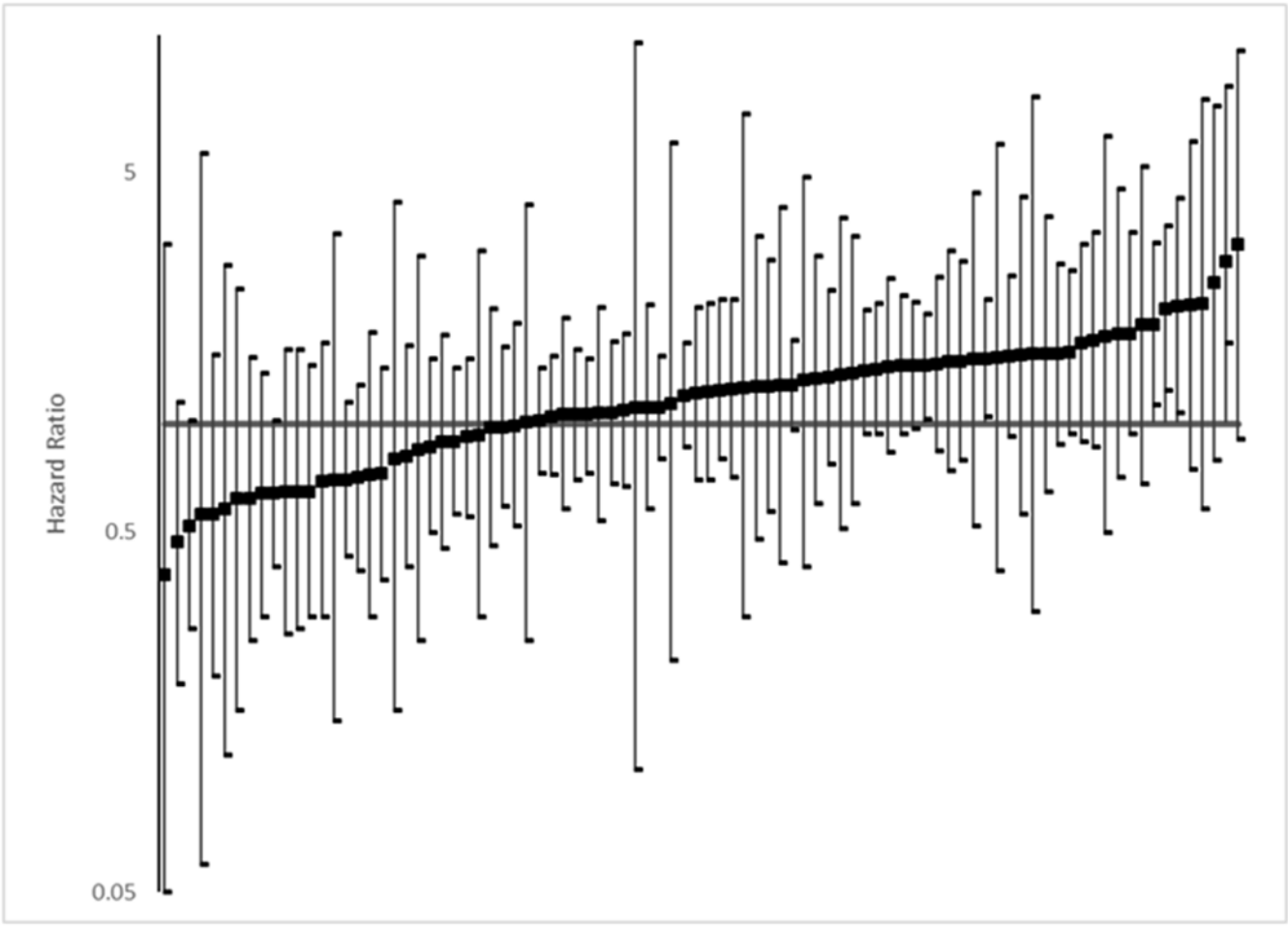

FIG. 1.
Center-specific Black–White HRs adjusted for clinical and socioeconomic variables.

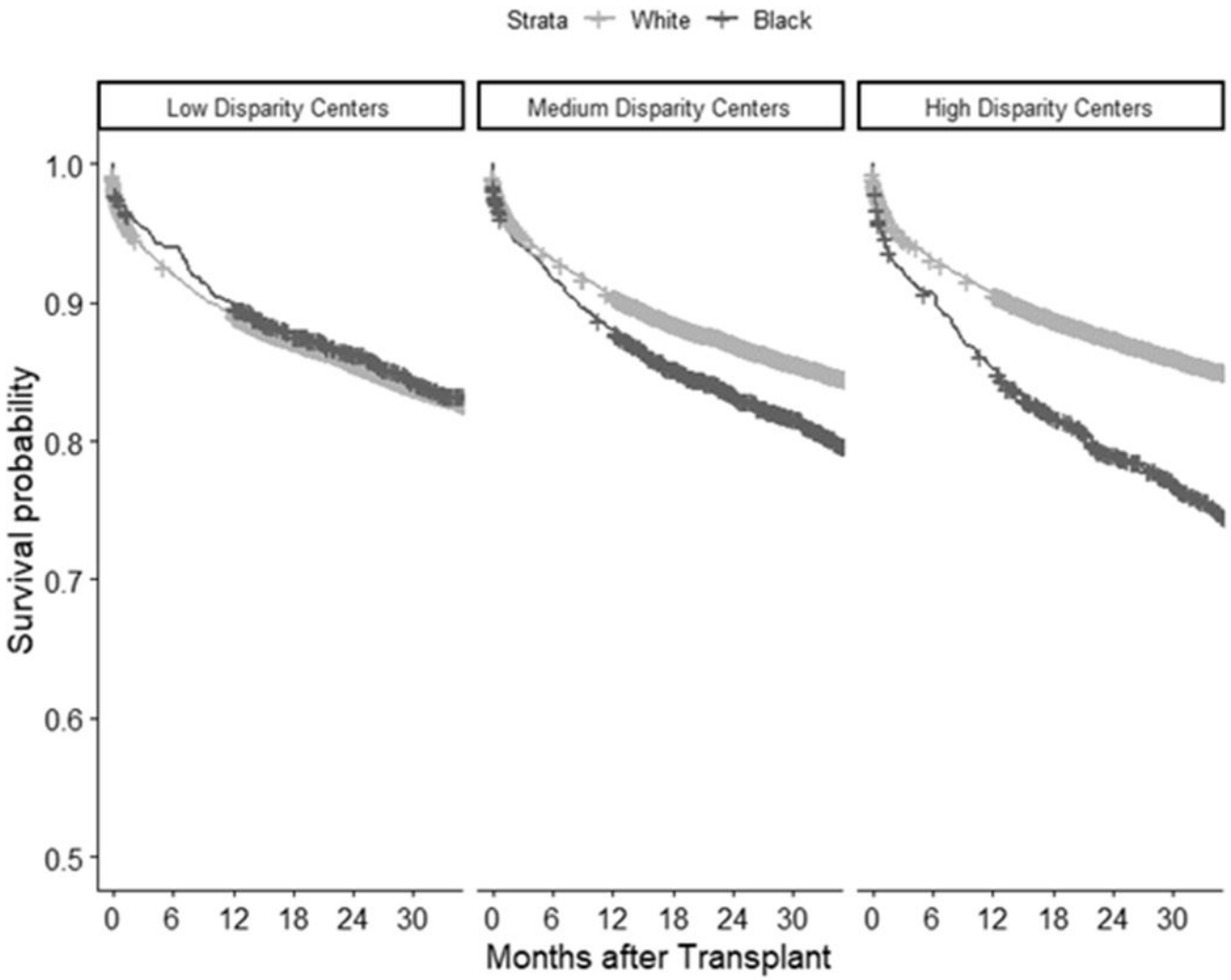

FIG. 2.

Kaplan-Meier curves for Black and White transplant recipients at low-disparity, medium-disparity, and high-disparity centers.

Table 1.

Demographic, clinical, and center-level characteristics of non-Hispanic black and white liver transplant recipients in the United States, 2010 – 2017, Scientific Registry of Transplant Recipients.

	Overall (N = 33,997)	Black (N = 3,617)	White (N = 30,080)	p-value
Center Characteristics				
Transplant volume (N, %)				0.01
Low	2,708 (8.0%)	334 (9.2%)	2,374 (7.8%)	
Medium	8,873 (26.1%)	895 (24.7%)	7,978 (26.3%)	
High	22,416 (65.9%)	2,388 (66.0%)	20,028 (65.9%)	
Proportion of minority patients at center (N, %)				<0.001
Low	9,070 (26.7%)	209 (5.8%)	8,861 (29.2%)	
Medium	13,834 (40.7%)	1,137 (31.4%)	12,697 (41.8%)	
High	11,093 (32.6%)	2,271 (62.8%)	8,822 (29.0%)	
SRTR tier (N, %)				<0.001
1	2,413 (7.1%)	289 (8.0%)	2,124 (7.0%)	
2	8,395 (24.7%)	1,037 (28.7%)	7,358 (24.2%)	
3	9,954 (29.3%)	1,062 (29.4%)	8,892 (29.3%)	
4	8,441 (24.8%)	775 (21.4%)	7,666 (25.2%)	
5	4,636 (13.6%)	439 (12.1%)	4,197 (13.8%)	
Missing	158 (0.5%)	15 (0.4%)	143 (0.5%)	
Geographic region (N, %)				<0.001
Northeast	5,956 (17.5%)	744 (20.6%)	5,212 (17.2%)	
Midwest	8,511 (25.0%)	655 (18.1%)	7,852 (25.9%)	
South	14,673 (43.2%)	1,954 (54.0%)	12,719 (41.9%)	
West	4,854 (14.3%)	263 (7.3%)	4,591 (15.1%)	
Patient Characteristics				
Age (mean, SD)	55.3 (9.9)	53.7 (11.3)	55.5 (9.8)	< 0.001
Sex (N, %)				<0.001
Male	23,077 (67.9%)	2,196 (60.7%)	20,881 (68.7%)	
Female	10,920 (32.1%)	1,421 (39.3%)	9,499 (31.3%)	
Educational attainment (N, %)				<0.001
High school or less	14,498 (42.6%)	1,749 (48.4%)	12,749 (42.0%)	
Some college	8,572 (25.2%)	918 (25.4%)	7,654 (25.2%)	
Associate degree or higher	8,912 (26.2%)	687 (19.0%)	8,225 (27.1%)	
Unknown	2,015 (5.9%)	263 (7.3%)	1,752 (5.8%)	
Annual household income in zip code	63,200 (24,900)	53,200 (22,900)	64,400 (24,900)	<0.001
Mean (SD)	63,200 (24,900)	53,200 (22,900)	64,400 (24,900)	
Missing (N, %)	3,787 (11.1%)	252 (7.0%)	3,535 (11.6%)	
Primary payer (N, %)				<0.001
Private	19,219 (56.5%)	1,741 (48.1%)	17,478 (57.5%)	

	Overall (N = 33,997)	Black (N = 3,617)	White (N = 30,080)	p-value
Public	14,454 (42.5%)	1,852 (51.2%)	12,602 (41.5%)	
Other	324 (1.0%)	24 (0.7%)	300 (1.0%)	
MELD[1] at transplant (mean, SD)	20.9 (10.0)	21.5 (10.6)	20.9 (9.9)	<0.001
Underlying cause of disease (N, %)				<0.001
ETOH[2]	10,551 (17.3%)	442 (7.0%)	10,109 (18.5%)	
Hepatitis C	23,875 (39.2%)	3,240 (51.5%)	20,635 (37.7%)	
NASH[3]	9,720 (15.9%)	319 (5.1%)	9,401 (17.2%)	
Other	16,835 (27.6%)	2,290 (36.4%)	14,545 (26.6%)	
HCC[4] (N, %)				0.03
Yes	54,446 (89.3%)	5,519 (87.7%)	48,928 (89.5%)	
No	6,534 (10.7%)	772 (12.3%)	5,762 (10.5%)	
Medical condition at transplant (N, %)				0.05
In ICU[5]	3,485 (10.3%)	399 (11.0%)	3,086 (10.2%)	
Hospitalized, not in ICU	6,259 (18.4%)	699 (19.3%)	5,560 (18.3%)	
Not hospitalized	24,253 (71.3%)	2,519 (69.6%)	21,734 (71.5%)	
Recipient BMI[6]				0.05
Mean (SD)	28.9 (6.7)	28.7 (7.3)	28.9 (6.6)	
Missing (N, %)	104 (0.3%)	12 (0.3%)	92 (0.3%)	
On dialysis (N, %)				0.02
Yes	2,898 (8.5%)	272 (7.5%)	2,626 (8.6%)	
No	31,099 (91.5%)	3,345 (92.5%)	27,754 (91.4%)	
Portal vein thrombosis (N, %)				<0.001
Yes	4,412 (13.0%)	320 (8.8%)	4,092 (13.5%)	
No	29,585 (87.0%)	3,297 (91.2%)	26,288 (86.5%)	
Donor risk index (mean, SD)				0.18
Mean (SD)	1.17 (1.0)	1.19 (0.8)	1.17 (1.0)	
Missing (N, %)	1,662 (4.9%)	81 (2.2%)	1,581 (5.2%)	

[1] Model for End-Stage Liver Disease

[2] Alcohol-associated liver disease

[3] Non-alcoholic steatohepatitis

[4] Hepatocellular carcinoma

[5] Intensive care unit

[6] Body mass index

Table 2.

Hierarchical additive hazards model and Cox proportional hazards model regressions for the association of race and survival, stratified by center-level characteristics, 2010 - 2017.

	Unadjusted		Clinical[1]		Clinical + Socioeconomic[2]		Clinical + Socioeconomic + Center[3]	
	Survival Difference per 100,000 PY (95% CI)	**Hazard Ratio (95% CI)**	**Survival Difference per 100,000 PY (95% CI)**	**Hazard Ratio (95% CI)**	**Survival Difference per 100,000 PY (95% CI)**	**Hazard Ratio (95% CI)**	**Survival Difference per 100,000 PY (95% CI)**	**Hazard Ratio (95% CI)**
Overall	3.30 (2.07, 4.53)	1.24 (1.13, 1.37)	3.68 (2.47, 4.89)	1.27 (1.16, 1.38)	3.25 (2.03, 4.47)	1.23 (1.12, 1.34)	3.07 (1.82, 4.32)	1.21 (1.12, 1.31)
Transplant volume								
Low	2.31 (−1.79, 6.41)	1.16 (0.89, 1.50)	3.47 (−0.61, 7.55)	1.22 (0.96, 1.55)	2.87 (−1.21, 6.95)	1.18 (0.93, 1.49)	2.58 (−1.52, 6.68)	1.14 (0.90, 1.46)
Medium	2.44 (0.05, 4.83)	1.18 (1.01, 1.37)	2.27 (−0.04, 4.54)	1.16 (1.00, 1.35)	1.70 (−0.57, 3.97)	1.12 (0.96, 1.30)	1.45 (−0.84, 3.74)	1.09 (0.94, 1.28)
High	3.75 (2.22, 5.28)	1.28 (1.14, 1.44)	4.22 (2.72, 5.72)	1.31 (1.18, 1.46)	3.86 (2.36, 5.36)	1.28 (1.15, 1.43)	3.74 (2.22, 5.26)	1.27 (1.15, 1.39)
Proportion of black patients at center								
Low	4.64 (−0.52, 9.79)	1.36 (1.02, 1.80)	4.08 (−0.51, 8.67)	1.30 (0.95, 1.78)	3.69 (−0.90, 8.28)	1.27 (0.93, 1.73)	3.62 (−0.97, 8.21)	1.26 (0.92, 1.72)
Medium	2.63 (0.47, 4.79)	1.20 (1.05, 1.37)	3.11 (1.03, 5.19)	1.22 (1.07, 1.39)	2.70 (0.60, 4.80)	1.19 (1.04, 1.36)	2.79 (0.69, 4.89)	1.19 (1.04, 1.37)
High	3.41 (1.79, 5.03)	1.25 (1.12, 1.39)	3.66 (2.06, 5.26)	1.26 (1.14, 1.39)	3.17 (1.56, 4.78)	1.22 (1.11, 1.35)	3.16 (1.55, 4.77)	1.22 (1.09, 1.34)
SRTR tier								
1	5.00 (0.67, 9.33)	1.37 (1.14, 1.65)	4.75 (0.44, 9.06)	1.34 (1.11, 1.62)	4.77 (0.42, 9.12)	1.33 (1.11, 1.60)	4.67 (0.32, 9.02)	1.32 (1.09, 1.58)
2	4.97 (2.58, 7.36)	1.35 (1.14, 1.61)	4.99 (2.60, 7.38)	1.35 (1.14, 1.61)	4.58 (2.19, 6.97)	1.31 (1.10, 1.57)	4.44 (2.03, 6.85)	1.30 (1.09, 1.54)
3	2.75 (0.61, 4.89)	1.21 (1.06, 1.37)	3.05 (0.89, 5.21)	1.22 (1.07, 1.38)	2.64 (0.48, 4.80)	1.19 (1.04, 1.35)	2.49 (0.31, 4.67)	1.17 (1.03, 1.33)
4	2.00 (−0.43, 4.43)	1.15 (0.98, 1.34)	2.41 (−0.02, 4.84)	1.16 (1.00, 1.36)	2.02 (−0.41, 4.54)	1.13 (0.97, 1.32)	1.73 (−0.72, 4.18)	1.11 (0.95, 1.29)
5	2.36 (−0.84, 5.55)	1.18 (0.93, 1.50)	3.27 (0.08, 6.46)	1.25 (1.01, 1.56)	2.84 (−0.38, 6.04)	1.22 (0.98, 1.52)	2,61 (−0.62, 5.84)	1.20 (0.97, 1.49)
Geographic region								
Northeast	4.16 (1.40, 6.92)	1.29 (1.13, 1.49)	4.06 (1.30, 6.82)	1.26 (1.09, 1.46)	3.72 (0.96, 6.48)	1.23 (1.06, 1.43)	3.62 (0.84, 6.40)	1.22 (1.06, 1.41)
Midwest	3.15 (0.07, 6.23)	1.23 (1.03, 1.47)	2.88 (1.36, 5.62)	1.20 (1.01, 1.42)	2.32 (−0.42, 5.06)	1.15 (0.97, 1.37)	2.18 (−0.58, 4.94)	1.14 (0.95, 1.36)
South	2.98 (1.33, 4.64)	1.22 (1.07, 1.40)	3.70 (2.07, 5.33)	1.28 (1.13, 1.45)	3.38 (1.74, 5.02)	1.25 (1.10, 1.42)	3.28 (1.62, 4.94)	1.24 (1.11, 1.39)
West	2.62 (−0.17, 6.89)	1.20 (0.95, 1.52)	2.50 (−1.62, 6.62)	1.18 (0.96, 1.45)	2.23 (−1.89, 6.35)	1.15 (0.94, 1.42)	2.14 (−1.98, 6.26)	1.14 (0.93, 1.41)

[1]Adjusted for age, year of transplant, sex, MELD at transplant, underlying cause of disease, recipient medical condition at transplant, body mass index (BMI), donor risk index (DRI), portal vein thrombosis (PVT), history of diabetes, and dialysis at transplant.

[2] Adjusted for age, year of transplant, sex, MELD at transplant, underlying cause of disease, recipient medical condition at transplant, body mass index (BMI), donor risk index (DRI), portal vein thrombosis (PVT), history of diabetes, dialysis at transplant, educational attainment, zip-code income, and primary payer.

[3] Adjusted for age, year of transplant, sex, MELD at transplant, underlying cause of disease, recipient medical condition at transplant, body mass index (BMI), donor risk index (DRI), portal vein thrombosis (PVT), history of diabetes, dialysis at transplant, educational attainment, zip-code income, primary payer, and center-level characteristics.

Table 3.

Adjusted[1] hierarchical additive hazards model for the association of center-level characteristics and survival, stratified by recipient race, 2010 - 2017.

Center-Level Characteristics	Within-White Survival Difference per 100,000 PY	Within-Black Survival Difference per 100,000 PY	Within-White Hazard Ratio	Within-Black Hazard Ratio
Transplant volume				
Low	0.81 (−0.61, 2.23)	−0.36 (−4.47, 3.76)	1.06 (0.94, 1.19)	0.96 (0.75, 1.24)
Medium	−0.36 (−1.19, 0.46)	−2.65 (−5.24, −0.06)	0.98 (0.90, 1.06)	0.83 (0.71, 1.00)
High (Ref)	Ref	Ref	Ref	Ref
Proportion of minority patients at center (N, %)				
Low (Ref)	Ref	Ref	Ref	Ref
Medium	−0.05 (−0.92, 0.82)	−0.89 (−5.85, 4.07)	1.00 (0.93, 1.08)	0.95 (0.66, 1.37)
High	0.12 (−0.89, 1.13)	−0.34 (−5.12, 4.44)	1.01 (0.93, 1.10)	0.98 (0.69, 1.37)
SRTR tier (N, %)				
1	0.47 (−1.14, 2.07)	2.54 (−2.61, 7.69)	1.04 (0.91, 1.18)	1.14 (0.87, 1.49)
2	0.80 (−0.38, 1.98)	2.63 (−1.21, 6.47)	1.06 (0.95, 1.18)	1.15 (0.86, 1.54)
3	0.47 (−0.56, 1.71)	0.50 (−3.21, 4.20)	1.04 (0.95, 1.15)	1.02 (0.80, 1.30)
4	0.42 (−0.71, 1.54)	−0.44 (−4.30, 3.42)	1.03 (0.93, 1.14)	0.95 (0.72, 1.26)
5 (Ref)	Ref	Ref	Ref	Ref
Geographic region (N, %)				
Northeast (Ref)	Ref	Ref	Ref	Ref
Midwest	−0.27 (−1.45, 0.90)	−1.59 (−5.31, 2.13)	0.98 (0.88, 1.08)	0.91 (0.75, 1.11)
South	−0.68 (−1.75, 0.38)	−1.24 (−4.28, 1.80)	0.95 (0.86, 1.04)	0.97 (0.80, 1.17)
West	−1.91 (−3.23, −0.59)	−3.64 (−8.46, 1.18)	0.87 (0.75, 1.01)	0.82 (0.68, 0.98)

[1]Adjusted for age, year of transplant, sex, MELD at transplant, underlying cause of disease, recipient medical condition at transplant, body mass index (BMI), donor risk index (DRI), portal vein thrombosis (PVT), history of diabetes, dialysis at transplant, educational attainment, zip-code income, primary payer, and center-level characteristics.