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Transplant & Mechanical Support: Research

Racial Disparities in Coronavirus Disease 2019 Mortality Are Present in Heart Transplant Recipients



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ABSTRACT

BACKGROUND Studies have demonstrated the devastating effects of coronavirus disease 2019 (COVID-19) on vulnerable populations. Although they receive close follow-up, heart transplant recipients represent a particularly vulnerable population, given long-term immunosuppression and comorbid conditions. We sought to investigate the association between race/ethnicity and the probability of death due to COVID-19 in adult heart transplant recipients in the United States.

METHODS Adult isolated heart transplant recipients were identified using the Organ Procurement and Transplantation Network database. Recipients who were described as deceased or lost to follow-up before January 2020 were excluded. Recipients were stratified into 4 cohorts by race/ethnicity. The primary outcome of interest was death due to COVID-19.

RESULTS A total of 22 157 adult recipients were identified. During the course of follow-up, 153 recipients had COVID-19 reported as the primary cause of death. COVID-19 mortality was significantly different between race/ethnicity cohorts (Black, $n = 34$ [0.79%]; Hispanic, $n = 23$ [1.33%]; White, $n = 92$ [0.60%]; other, $n = 4$ [0.44%]; $P = .007$). COVID-19 was listed as a contributing cause of mortality in 0.12% of Black, 0.23% of Hispanic, 0.04% of White, and 0.33% of other recipients ($P = .002$). No significant difference in non-COVID mortality or all-cause mortality was observed. After multivariable adjustment, Black (hazard ratio, 2.78 [1.40-5.52]; $P = .003$) and Hispanic (hazard ratio, 3.92 [1.88-8.16]; $P < .001$) recipients were at higher risk of death due to COVID-19 compared with White recipients.

CONCLUSIONS Compared with White recipients, Black and Hispanic recipients experienced higher rates of COVID-19 mortality after transplantation. These findings suggest that racial/ethnic disparities of COVID-19 mortality in the general population persist in adult heart transplant recipients.

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Across the United States, vulnerable populations have experienced the devastating effects of coronavirus disease 2019 (COVID-19) caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Because of long-term immunosuppression and complex comorbidities, heart transplant recipients are at an increased risk of severe infection and adverse outcomes with COVID-19.¹ Prior studies have demonstrated case-fatality rates in heart transplant recipients up to 25%.²⁻⁴

Racial/ethnic disparities in outcomes among heart transplant recipients have been established previously. An earlier study reported that Black and low socioeconomic status heart transplant recipients have higher rates of death and retransplantation.⁵ The same study found that long-term survival has improved during 21 years for White recipients but not for Black and Hispanic recipients. Additional studies have demonstrated that Black heart transplant recipients are at higher risk of posttransplantation death and that this disparity is

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greatest among recipients who are 18 to 30 years old.^{6,7} The COVID-19 pandemic and coinciding events have shed much-needed light on racial inequities, with recent studies exposing the disproportionate burden of COVID-19 infection, morbidity, and death among racial/ethnic minority groups in the nontransplant population.⁸⁻¹²

The aforementioned work has explored racial/ethnic disparities in posttransplantation outcomes and COVID-19 incidence and mortality, yet how race/ethnicity is associated with one's risk of death due to COVID-19 after heart transplantation has not been described. Although heart transplant recipients are particularly vulnerable to COVID-19, they are also closely monitored by a multidisciplinary team after they receive the transplant.¹³ This close follow-up provides a unique opportunity to employ interventions to combat health and treatment inequities. In this study, we examined the association between race/ethnicity and COVID-19 mortality among adult heart transplant recipients in the United States. We hypothesized that racial/ethnic disparities in deaths due to COVID-19 observed in the general population would persist in heart transplant recipients despite their close follow-up.

PATIENTS AND METHODS

STUDY POPULATION. Adult heart transplant recipients (≥ 18 years old) in the United States were identified using the Organ Procurement and Transplantation Network (OPTN) database. Recipients who died or were lost to follow-up before January 2020 were excluded because they were not at risk of COVID-19 exposure or death. Multiorgan transplant recipients, recipients with a history of prior heart transplant, and patients with inadequate follow-up (< 6 months) were also excluded (Figure 1). All heart transplant recipients with available

follow-up were included, resulting in transplantation dates spanning October 1987 through September 2020.

STUDY DESIGN AND OUTCOMES. Patients were stratified into cohorts by race/ethnicity according to the OPTN database variable ETHCAT that is collected during registration of the transplant candidate. Asian, American Indian/Native American, Native Hawaiian/Pacific Islander, and multiracial patients were combined into an "other" race category because of small sample size. The resulting cohorts were Black, Hispanic, other, and White. Baseline characteristics were extracted from the OPTN database. This study was approved by the Mass General Brigham Institutional Review Board, which provided a waiver of informed consent.

The primary outcome of interest was death due to COVID-19 as reported in the OPTN database under the primary cause of death (COD) variable. Deaths due to COVID-19 reported as free text (COD_OSTXT) were also extracted. Secondary outcomes included non-COVID-19 mortality, COVID-19 as a contributing cause of death, and all-cause mortality.

STATISTICAL ANALYSIS. Continuous data comparisons were performed by the Kruskal-Wallis test, and medians with interquartile ranges were reported. Binary variables were tested by the Fisher exact test, and categorical variable comparisons were performed by the χ^2 test. A 2-sided P value $< .05$ was used to define significance.

Survival analysis was conducted by Cox proportional hazards modeling. Because patients in the United States were not at risk of death due to COVID-19 before January 2020, the follow-up start date was set to January 1, 2020, for all patients receiving transplants on or before that date. Because of variations in follow-up reporting by centers to the OPTN database, follow-up was censored on September 5, 2020 (6 months before the most recently available data). Model building was carried out with a hybrid approach consisting of a univariate screen and inclusion of variables with a P value $< .20$ on univariate Cox regression modeling. In addition, variables with a P value $> .20$ were included in model building if they were identified as potential confounders or related to the outcome in prior literature including available social determinants of health (education level, citizenship status, and health care payer source). These variables were then entered into a backward selection model. In an attempt to account for differential COVID-19 risk by location, COVID-19 death rates by state were calculated by dividing total COVID-19 deaths as reported to the Centers for Disease Control and Prevention on September 30, 2020, by the state's population as reported by the US Census Bureau.^{14,15} States were split into low, mild, moderate, and high risk of COVID-19 death by quartile, and this categorical variable was

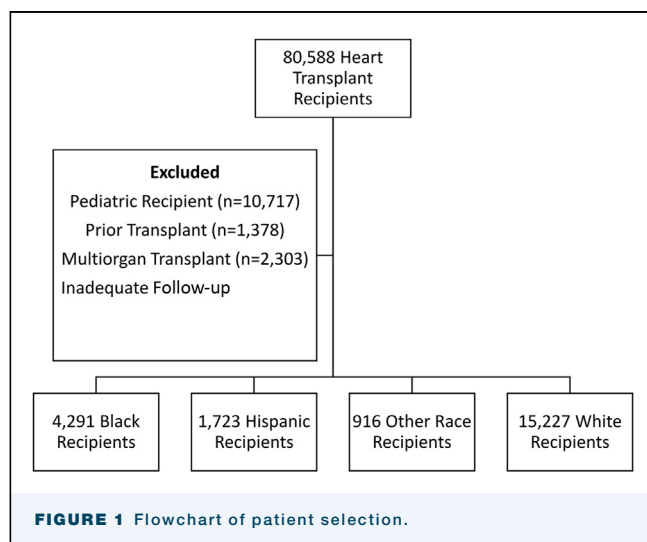


TABLE 1 Demographic and Clinical Characteristics of Heart Transplant Recipients

Variable	White (n = 15 227)	Black (n = 4291)	Hispanic (n = 1723)	Other (n = 916)	P Value
Age, y	56 (47-63)	53 (43-60)	53 (42-60)	54 (44-61)	<.001
Male sex	11 520 (75.7)	2835 (66.1)	1265 (73.4)	705 (77.0)	<.001
Education level					<.001
High school or less	5261 (34.6)	1913 (44.6)	1015 (58.9)	281 (30.7)	
Attended college/technical	3777 (24.8)	1187 (27.7)	326 (18.9)	214 (23.4)	
Associate/bachelor's degree	3077 (20.2)	632 (14.7)	166 (9.6)	215 (23.5)	
Graduate degree	1460 (9.6)	246 (5.7)	50 (2.9)	131 (14.3)	
Missing	1652 (10.8)	313 (7.3)	166 (9.6)	75 (8.2)	
US citizen	15 065 (98.9)	4215 (98.2)	1446 (83.9)	815 (89.0)	<.001
Public insurance	6438 (42.3)	2488 (58.0)	1067 (61.9)	431 (47.1)	<.001
BMI, kg/m ²	26.9 (23.7-30.4)	27.5 (23.9-31.5)	26.5 (23.4-30.0)	24.3 (21.3-28.0)	<.001
History of diabetes	3004 (19.7)	1077 (25.1)	453 (26.3)	256 (27.9)	<.001
Ischemic cardiomyopathy	5122 (33.6)	655 (15.3)	459 (26.6)	279 (30.5)	<.001
History of smoking	6048 (39.7)	1631 (38.0)	616 (35.8)	326 (35.6)	<.001
Creatinine level at time of transplantation, mg/dL	1.1 (0.9-1.4)	1.2 (1.0-1.5)	1.1 (0.8-1.3)	1.1 (0.9-1.4)	<.001
Bilirubin level at time of transplantation, mg/dL	0.7 (0.5-1.1)	0.7 (0.4-1.1)	0.7 (0.5-1.2)	0.7 (0.5-1.2)	<.001
Days on waiting list	87.0 (23.0-258.0)	83.0 (22.0-258.0)	67.0 (19.0-226.0)	54.5 (15.0-189.5)	<.001
On ventilator at transplantation	238 (1.6)	52 (1.2)	19 (1.1)	13 (1.4)	.22
LVAD at transplantation	5154 (33.8)	1820 (42.4)	591 (34.3)	295 (32.2)	<.001
Temporary MCS at transplantation	1673 (11.0)	591 (13.8)	206 (12.0)	121 (13.2)	<.001
Receiving inotropes at transplantation	5780 (38.0)	1722 (40.1)	754 (43.8)	400 (43.7)	<.001
Pretransplantation CO, L/min	4.4 (3.6-5.4)	4.3 (3.5-5.4)	4.0 (3.2-5.0)	3.9 (3.2-4.9)	<.001
Pretransplantation PASP >40 mm Hg	6986 (45.9)	2171 (50.6)	873 (50.7)	430 (46.9)	<.001
Pretransplantation PCWP >12 mm Hg	10 985 (72.1)	3088 (72.0)	1288 (74.8)	644 (70.3)	.06
Pretransplantation TPG >12 mm Hg	4540 (29.8)	1498 (34.9)	516 (29.9)	279 (30.5)	<.001
History of cardiac operation	6586 (50.4)	1747 (43.7)	678 (42.9)	382 (44.9)	<.001
Waiting list status at transplantation					<.001
1A	6890 (45.2)	1931 (45.0)	793 (46.0)	406 (44.3)	
1B	3916 (25.7)	1090 (25.4)	397 (23.0)	243 (26.5)	
Old 2	1446 (9.5)	169 (3.9)	129 (7.5)	74 (8.1)	
1	236 (1.5)	89 (2.1)	25 (1.5)	23 (2.5)	
2	1328 (8.7)	539 (12.6)	187 (10.9)	85 (9.3)	
3	605 (4.0)	224 (5.2)	82 (4.8)	54 (5.9)	
4	628 (4.1)	208 (4.8)	91 (5.3)	24 (2.6)	
5	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
6	147 (1.0)	37 (0.9)	18 (1.0)	7 (0.8)	
Missing	31 (0.2)	4 (0.1)	1 (0.1)	0 (0.0)	
Blood group					<.001
A	6987 (45.9)	1227 (28.6)	634 (36.8)	289 (31.6)	
AB	851 (5.6)	262 (6.1)	57 (3.3)	66 (7.2)	
B	1853 (12.2)	974 (22.7)	196 (11.4)	232 (25.3)	
O	5536 (36.4)	1828 (42.6)	836 (48.5)	329 (35.9)	
Dialysis at follow-up	613 (4.0)	305 (7.1)	59 (3.4)	47 (5.1)	<.001
Corticosteroid use at follow-up	654 (4.3)	278 (6.5)	108 (6.3)	53 (5.8)	<.001
COVID death risk by state					<.001
Low	1826 (12.0)	156 (3.6)	91 (5.3)	67 (7.3)	
Mild	3048 (20.0)	872 (3.6)	91 (5.3)	67 (7.3)	
Moderate	5747 (37.8)	1673 (39.0)	793 (46.0)	460 (50.2)	
High	4602 (30.2)	1589 (37.0)	694 (40.3)	245 (26.8)	

Categorical variables are presented as number (percentage). Continuous variables are presented as median (interquartile range). BMI, body mass index; CO, cardiac output; COVID, coronavirus disease 2019; LVAD, left ventricular assist device; MCS, mechanical circulatory support; PASP, pulmonary artery systolic pressure; PCWP, pulmonary capillary wedge pressure; TPG, transpulmonary gradient.

adjusted for in regression models. Proportionality of hazards was confirmed by Schoenfeld residuals test. The competing risk of non-COVID death was analyzed by Fine-Gray subhazards. Wald test was used to

provide overall P values for categorical variables in regression models. All analyses were performed with Stata 16 statistical software, and GraphPad Prism was used for figure generation.^{16,17}

TABLE 2 Clinical Characteristics of Donors

Variable	White (n = 15 227)	Black (n = 4291)	Hispanic (n = 1723)	Other (n = 916)	P Value
Ischemia time, h	3.2 (2.5-3.8)	3.1 (2.4-3.8)	3.2 (2.4-3.9)	3.2 (2.4-3.9)	.19
Donor age, y	30 (22-40)	30 (23-39)	29 (22-39)	30 (22-40)	.21
History of hypertension	2159 (14.5)	648 (15.3)	220 (13.0)	111 (12.3)	.03
History of myocardial infarction	100 (0.7)	33 (0.8)	10 (0.6)	10 (1.1)	.37
Recipient-donor sex mismatch	3604 (23.7)	1067 (24.9)	510 (29.6)	287 (31.3)	<.001
History of diabetes mellitus	510 (3.4)	126 (3.0)	62 (3.7)	27 (3.0)	.39
History of cancer	199 (1.3)	49 (1.2)	25 (1.5)	15 (1.7)	.53
Smoking history >20 pack-years	2354 (16.0)	538 (12.8)	203 (12.1)	112 (12.4)	<.001
Cocaine use	2848 (20.3)	870 (21.2)	341 (20.8)	136 (15.5)	.001

Categorical variables are presented as number (percentage). Continuous variables are presented as median (interquartile range).

RESULTS

BASILINE CHARACTERISTICS. After exclusion criteria were applied, 22157 heart transplant recipients were identified. Stratification by race/ethnicity resulted in cohorts consisting of 4291 Black, 1723 Hispanic, 916 other, and 15227 White recipients. Baseline characteristics of the recipients are presented in Table 1. The Black cohort had the lowest proportion of male recipients. Hispanic recipients reported lower rates of associate/bachelor’s degree, graduate degree, and US citizenship than the Black, White, and other cohorts. White recipients had the lowest rates of public insurance use and diabetes mellitus but were most likely to have ischemic cardiomyopathy listed as the indication for transplant. Black recipients had the highest rates of pretransplantation durable mechanical circulatory support. Donor characteristics were well balanced between cohorts (Table 2).

UNADJUSTED OUTCOMES. COVID-19 was reported as the primary cause of death in 153 recipients. Rates of death due to COVID-19 were significantly different between Black (n = 34 [0.79%]), Hispanic (n = 23 [1.3%]), White (n = 92 [0.60%]), and other (n = 4 [0.44%]; P = .007) cohorts (Table 3). Most COVID-19 deaths in this study occurred in April and July of 2020 (Figure 2). COVID-19 was reported as a contributing cause of death in 18 recipients (Black, n = 5 [0.12%]; Hispanic, n = 4

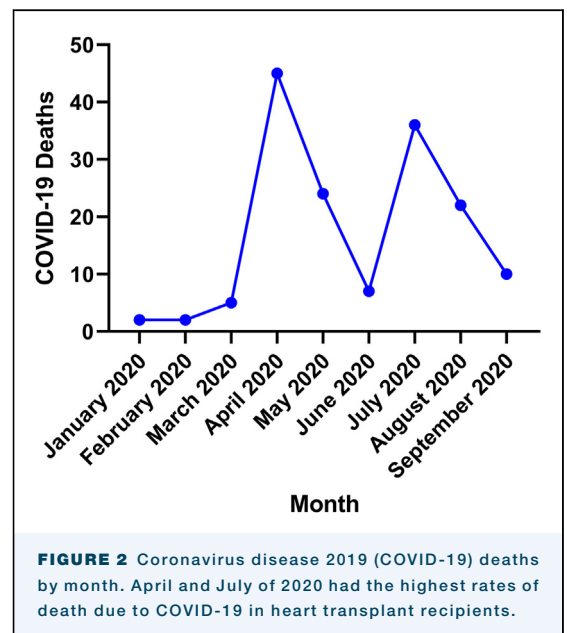
[0.23%]; White, n = 6 [0.04%]; and other, n = 3 [0.33%]; P = .002). No significant difference in non-COVID mortality was observed between Black (n = 251 [5.85%]), Hispanic (n = 85 [4.93%]), White (n = 892 [5.86%]), and other (n = 55 [6.00%]; P = .46) recipients. There was also no significant difference in all-cause (combined non-COVID and COVID) mortality between cohorts (P = .96). Recipients who died of COVID-19 were a median of 9.6 (interquartile range, 5.0-16.1) years after transplantation.

SURVIVAL ANALYSIS. Kaplan-Meier survival estimates are illustrated in Figure 3, in which the log-rank test indicated a significant difference in freedom from death due to COVID-19 between race/ethnicity cohorts (P < .001). The results of univariate and multivariable Cox proportional hazards models are presented in Table 4. Univariable analysis revealed that Black (hazard ratio [HR], 2.07 [1.10-3.92]; P = .02) and Hispanic (HR, 3.91 [1.93-7.92]; P < .001) recipients were at a higher risk for

TABLE 3 Unadjusted Outcomes

	White (n = 15 227)	Black (n = 4291)	Hispanic (n = 1723)	Other (n = 916)	P Value
COVID mortality	92 (0.60)	34 (0.79)	23 (1.33)	4 (0.44)	.007
COVID as contributing cause of death	6 (0.04)	5 (0.12)	4 (0.23)	3 (0.33)	.002
Non-COVID mortality	892 (5.86)	251 (5.85)	85 (4.93)	55 (6.00)	0.46
All-cause mortality	984 (6.46)	285 (6.64)	108 (6.27)	59 (6.44)	.96

Values are reported as number (percentage). COVID, coronavirus disease 2019.



posttransplantation death due to COVID-19 compared with White recipients. This finding persisted (Black: HR, 2.78 [1.40-5.52; $P = .003$]; Hispanic: HR, 3.92 [1.88-8.16; $P < .001$]) after adjustment for characteristics before and after transplantation. Age ≥ 65 years, being on dialysis at most recent follow-up, diabetes mellitus, ischemic cardiomyopathy as an indication for heart transplantation, having a left ventricular assist device before transplantation, taking inotropes before transplantation, and receiving a heart from a donor with >20 pack-year smoking history were all associated with increased risk of death due to COVID-19 during the follow-up period in the multivariable model (all $P < .05$). Fine-Gray modeling was used to account for the competing risk of non-COVID death during the follow-up period. Figure 4 illustrates adjusted cumulative incidence of COVID-19 mortality being the highest in Black and Hispanic recipients, followed by White and other recipients. The increased risk of death due to COVID-19 in Black and Hispanic recipients compared with White recipients observed in the multivariable Cox model persisted after accounting for competing risks (Black: subhazard ratio, 2.84 [1.38-5.82; $P = .004$]; Hispanic: subhazard ratio, 3.98 [1.94-8.20; $P < .001$]; Table 5).

COMMENT

In this analysis of the OPTN database, we showcased that disparities in death due to SARS-CoV-2 infection between racial/ethnic groups observed in the general population are also present among heart transplant recipients. We had several notable findings. First, compared with White race, Black and Hispanic race was associated with higher rates of death due to COVID-19 despite adjusting for available social determinants of health and accounting for the competing risk of non-COVID death. Second, no significant difference in COVID-19 mortality was observed between White and the composite other cohort. Third, we also describe the association of race/ethnicity and COVID-19 mortality among heart transplant recipients across the United States using the OPTN database. Finally, factors associated with death due to COVID-19 (older age, diabetes, and history of ischemic cardiomyopathy) identified in the general population were significant predictors in the heart transplant population.^{18,19} These are in addition to transplant-specific factors (left ventricular assist device at transplantation, inotropes at transplantation, and donor history of smoking >20 pack-years) that reflect the recipient's condition before heart transplantation.

These findings are consistent with the conclusions of previous studies that have analyzed racial disparities in COVID-19 mortality across the United States. Using national-level data, Karmakar and associates⁸ reported

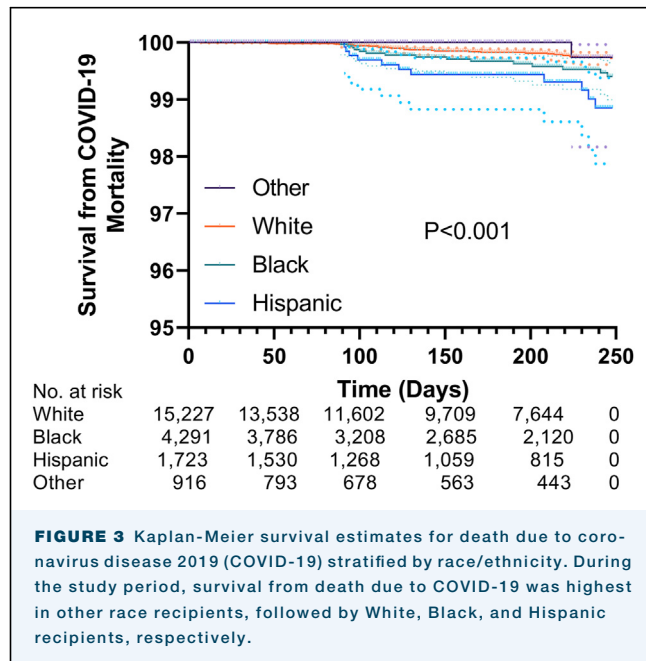
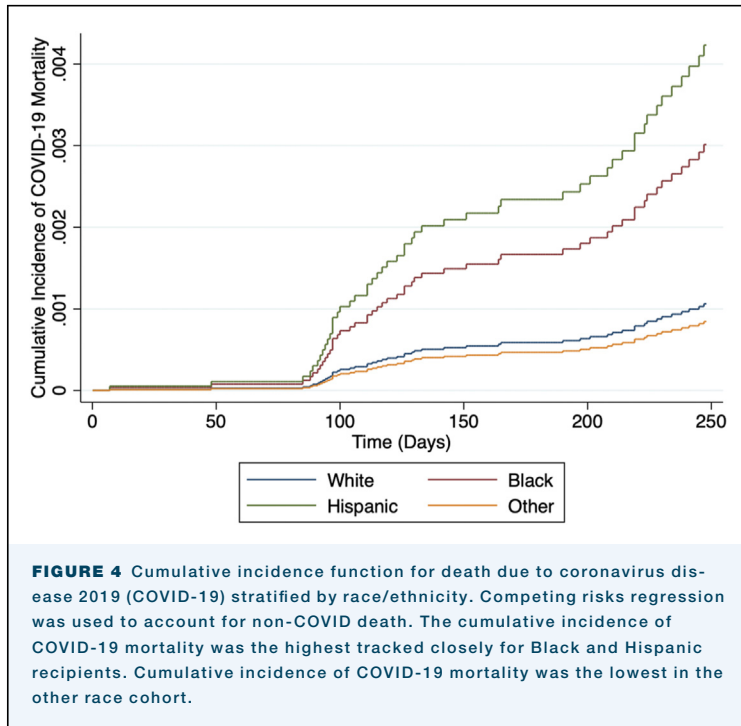


FIGURE 3 Kaplan-Meier survival estimates for death due to coronavirus disease 2019 (COVID-19) stratified by race/ethnicity. During the study period, survival from death due to COVID-19 was highest in other race recipients, followed by White, Black, and Hispanic recipients, respectively.

TABLE 4 Univariate and Multivariable Cox Proportional Hazards Models for COVID Mortality

Variable	Univariate			Multivariable		
	HR	95% CI	P Value	HR	95% CI	P Value
Race/ethnicity			.001			.001
White	1			1		.
Black	2.07	1.10-3.92	.02	2.78	1.40-5.52	.003
Hispanic	3.91	1.93-7.92	<.001	3.92	1.88-8.16	<.001
Other	0.66	0.09-4.88	.61	0.79	0.11-5.84	.82
Age ≥ 65 y	2.99	1.67-5.39	<.001	2.23	1.20-4.14	.01
BMI ≥ 30 kg/m ²	1.34	0.76-2.37	.31			
Dialysis at follow-up	4.79	2.41-9.53	<.001	3.65	1.80-7.37	<.001
Smoking history	1.22	0.71-2.10	.47			
COVID mortality risk by state						.004
Low	1			1		
Mild	0.80	0.26-2.45	.70	1.10	0.29-4.17	.89
Moderate	0.51	0.17-1.48	.21	0.59	0.16-2.19	.43
High	1.79	0.69-4.61	.23	1.79	0.53-5.99	.35
Education			.05			
High-school diploma or less	1					
Attended college/technical school	0.60	0.30-1.21	.16			
Associate/bachelor's degree	0.30	0.10-0.85	.02			
Graduate degree	0.42	0.08-1.32	.12			
US citizenship	0.71	0.17-2.90	.63			
Public health insurance	2.07	1.18-3.63	.01			
Diabetes mellitus	4.10	2.39-7.02	<.001	2.97	1.68-5.24	<.001
Ischemic cardiomyopathy	3.95	2.27-6.89	<.001	3.42	1.86-6.31	<.001
LVAD at transplantation	1.40	0.81-2.41	.22	2.01	1.02-3.96	.04
Inotropes at transplantation	1.49	0.87-2.56	.14	2.30	1.18-4.50	.02
Donor history of smoking ^a	2.40	1.32-4.39	.004	2.48	1.35-4.55	.003

^aMore than 20 pack-years. Variables with missing data in the multivariable model were removed during the backward selection process. BMI, body mass index; COVID, coronavirus disease 2019; HR, hazard ratio; LVAD, left ventricular assist device.



that counties with large populations of racial/ethnic minorities experienced higher rates of death due to COVID-19. This is supported by a second study demonstrating that although only 20% of US counties are disproportionately Black, they accounted for 58% of COVID-19 deaths in the United States.¹¹ Black adults also experience higher rates of serious illness when infected with COVID-19 compared with White adults.⁹

TABLE 5 Fine-Gray Competing Risks Model for COVID Death

Variable	SHR	95% CI	P value
Race/ethnicity			
White	1		<.001
Black	2.84	1.38-5.82	.004
Hispanic	3.98	1.94-8.20	<.001
Other	0.80	0.11-5.86	.82
Age ≥65 y	2.22	1.16-4.26	.02
Dialysis at follow-up	3.40	1.66-6.96	.001
COVID mortality risk by state			
Low	1		
Mild	1.09	0.28-4.17	.91
Moderate	0.58	0.16-2.12	.41
High	1.77	0.53-5.89	.35
Diabetes mellitus	3.00	1.66-5.42	<.001
Ischemic cardiomyopathy	3.41	1.78-6.55	<.001
LVAD at transplantation	1.97	0.99-3.9	.05
Inotropes at transplantation	2.28	1.15-4.51	.02
Donor history of smoking ^a	2.45	1.33-4.54	.004

^aMore than 20 pack-years. COVID, coronavirus disease 2019; LVAD, left ventricular assist device; SHR, subhazard ratio.

A meta-analysis performed by Mackey and colleagues¹⁰ found that Black and Hispanic populations experience higher rates of COVID-19 infection and mortality than White populations do, although there was no difference in case-fatality rate.

As shown by recent studies, the sources of COVID-19 racial/ethnic disparities are multifactorial, involving medical risk factors, social determinants of health, and structural racism. Prior studies have highlighted the impact of social determinants of health on a number of health-related outcomes in the general population.²⁰⁻²² In New York City, the highest rates of hospitalizations and deaths related to COVID-19 were reported in the Bronx, which has the highest proportion of minority residents and households living in poverty and the lowest levels of education attainment.²³ Moreover, increased social vulnerability index has been linked to higher incidence of death due to COVID-19.^{8,24} The social determinants of health available in the OPTN are limited. As more studies demonstrate their importance on patients' health, efforts should be made to better capture them in transplant patients. Before heart transplantation, patients undergo extensive evaluation and may be denied because of lack of social support mechanisms.²⁵ This practice theoretically reduces variability in social determinants of health between heart transplant recipients compared with variability observed among the general population. We hypothesize that the observed disparities in COVID-19 mortality are not ascribed to biologic differences between races, as we recognize that race is a social construct, but rather to additional imbalances in social determinants of health that have not been accounted for. Regardless, it is imperative to detect racial disparities in health outcomes not only to identify vulnerable populations that necessitate close monitoring but also to motivate allocation of resources to confront sources of inequity.

This study has several limitations. First, the incidence of SARS-CoV-2 infection in this population is unknown. These data are not available in the OPTN database, and therefore racial disparities in COVID-19 mortality could be driven by disparities in COVID-19 incidence. However, we believe the disparity in mortality is concerning irrespective of potential differences in COVID-19 exposure or incidence. Second, this is a retrospective study and accordingly has inherent limitations. Third, as mentioned before, key social determinants of health including access to care, social support, and income are not available in the OPTN database, thereby resulting in residual confounding. Fourth, given the number of outcomes, we were unable to include geographic location in the model as this would have resulted in severe overfitting of the model. Fifth, whereas we used follow-up data when available, many covariates were recorded at the time of listing or transplantation and therefore may not represent the patient's status at follow-up.

Finally, this study captures only the first wave of COVID-19 in the United States; it does not include periods when vaccines were available or when variants had emerged. Thus, observed rates of COVID-19 mortality may not reflect current trends.

Unfortunately, our data demonstrate that disparities in COVID-19 mortality exist in heart transplant recipients despite their close follow-up. Black and Hispanic races were associated with higher rates of COVID-19 mortality than White patients after heart transplantation, even after risk adjustment. These findings highlight the need for clinicians and investigations to recognize that minority heart transplant recipients diagnosed with COVID-19 might be at a higher risk of death based on multifactorial risk factors on an individual and societal

level. These data add to an accumulating body of evidence that COVID-19 does not affect all populations equally. Further resources should be allocated to identify and to combat imbalances in social determinants of health and other sources of racial health inequities.

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