



# The influence of equitable access policies and socioeconomic factors on post-liver transplant survival

Dora C Huang<sup>a</sup>, Zachary P Fricker<sup>b</sup>, Saleh Alqahtani<sup>c</sup>, Hani Tamim<sup>d</sup>, Behnam Saberi<sup>b</sup>, Alan Bonder<sup>b,\*</sup>

<sup>a</sup> Department of Internal Medicine, Beth Israel Deaconess Medical Center, 330 Brookline Ave, Boston, MA 02215, United States

<sup>b</sup> Division of Gastroenterology and Hepatology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, United States

<sup>c</sup> Division of Gastroenterology and Hepatology, Johns Hopkins University School of Medicine, Baltimore, MD, United States

<sup>d</sup> Department of Internal Medicine, American University of Beirut, Beirut, Lebanon

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## ABSTRACT

**Background:** Survival following liver transplant (LT) is influenced by a variety of factors, including donor risk factors and recipient disease burden and co-morbidities. It is difficult to separate these effects from those of socioeconomic factors, such as income or insurance. The United Network for Organ Sharing (UNOS) created equitable access policies, such as Share 35, to ensure that organs are distributed to individuals with greatest medical need; however, the effect of Share 35 on disparities in post-LT survival is not clear. This study aimed to (1) characterize associations between post-transplant survival and race and ethnicity, income, insurance, and citizenship status, when adjusted for other clinical and demographic factors that may influence survival, and (2) determine if the direction of associations changed after Share 35.

**Methods:** A retrospective, cohort study of adult LT recipients ( $n = 83,254$ ) from the UNOS database from 2005 to 2019 was conducted. Kaplan-Meier survival graphs and stepwise multivariate cox-regression analyses were performed to characterize the effects of socioeconomic status on post-LT survival, adjusted for recipient and donor characteristics, across the time period and after Share 35.

**Findings:** Male sex (HR: 0.93 (95% CI: 0.90–0.96)), private insurance (0.91 (0.88–0.94)), income (0.82 (0.79–0.85)), U.S. citizenship, and Asian (0.81 (0.75–0.88)) or Hispanic (0.82 (0.79–0.86)) race and ethnicity were associated with higher post-transplant survival, after adjustment for clinical and demographic factors (Table 3). These associations were found across the entire time period studied and many persisted after the implementation of Share 35 in 2013 (Table 3; male sex (0.84 (0.79–0.90)), private insurance (0.94 (0.89–1.00)), income (0.82 (0.77–0.89)), and Asian (0.87 (0.73–1.02)) or Hispanic (0.88 (0.81–0.96)) race and ethnicity).

**Interpretation:** Recipients' socioeconomic factors at time of transplant may impact long-term post-transplant survival, and a single policy may not significantly alter these structural health inequalities.

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## 1. Introduction

Lower socioeconomic status and minority race and ethnicity have been associated with poorer health outcomes, likely related to unequal distribution of and access to healthcare resources [1]. These

disparities manifest in the field of liver transplantation via differences in waitlist mortality, transplantation rate, and outcomes after transplantation [2–6].

In post-transplantation outcomes, for instance, African Americans and individuals with public insurance have been found to have lower survival and poorer outcomes post-transplant, as compared to white or Hispanic Americans and those with private insurance, respectively [2,5]. Lower incomes and public insurance have been associated with poorer transplant outcomes, as well [2,7–9]. However, it remains difficult to disentangle these socioeconomic factors from other factors that may influence post-transplant survival, such as access to care, etiology of liver disease, presence of hepatocellular carcinoma, other medical co-morbidities, or donor factors [10,11].

**Abbreviations:** DDLT, deceased donor living transplant; DM, diabetes mellitus; DRI, donor risk index; HCC, hepatocellular carcinoma; HCV, hepatitis c virus; HE, hepatic encephalopathy; IRB, institutional review board; IQR, interquartile range; LT, liver transplant; MELD, Model for End-Stage Liver Disease; NAFLD, Non-alcoholic fatty liver disease; OPTN, Organ Procurement and Transplantation Network; STAR, Standard Transplant Analysis and Research; UNOS, United Network for Organ Sharing

\* Corresponding author.

E-mail address: [abonder@bidmc.harvard.edu](mailto:abonder@bidmc.harvard.edu) (A. Bonder).

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## Research in context

### *Evidence before this study*

We searched Google Scholar and PubMed for articles published between January 1, 1993 and October 1, 2020, the latter with the following search strategy: "liver transplantation"[mesh] OR "liver transplantation"[tiab] OR "liver transplant"[tiab]) AND ("socioeconomic factors"[mesh] OR "socioeconomic"[tiab] OR "healthcare disparities"[mesh] OR "disparit\*" [tiab] OR "race"[tiab] OR "ethnic\*" [tiab] OR "gender"[tiab]). Review of the articles was notable for observed disparities in waitlist survival, wait time, and post-transplant outcomes, when studied by geography, age, sex, race and ethnicity, income, and insurance across different time periods, though analyses were limited by ability to control for other factors that may also influence post-transplant survival. Two studies looked specifically at the impact of Share 35 policy on access to liver transplantation and recipient survival among specific racial and ethnic populations.

### *Added value of this study*

We adjusted for over 20 clinical and demographic factors that could influence post-transplant survival to better assess associations between socioeconomic variables and post-transplant survival. We considered these associations before and after the Share 35 policy to consider if this policy would significantly impact the direction of these associations. We found that higher post-transplant survival was associated with male sex, private insurance, income, U.S. citizenship, and Asian or Hispanic race and ethnicity, a pattern that continued after Share 35 for the majority of these factors.

### *Implications of all the available evidence*

Our data adds to existing research on socioeconomic disparities in post-liver transplantation survival and health outcomes, and acknowledges that pre-existing structural health disparities will require focused and dedicated policy changes. Future studies are recommended to determine the individual impact of other socioeconomic factors, such as health literacy, residency, and education level, and direct policy changes to ensure equitable outcomes following liver transplantation.

socioeconomic factors: (1) race and ethnicity, (2) income, (3) insurance, and (4) citizenship status.

## 2. Methods

We conducted a retrospective, cohort study, utilizing data from the United Network for Organ Sharing (UNOS)/ OPTN Standard Transplant Analysis and Research (STAR) system. The UNOS/OPTN STAR database contains demographic and clinical information on organ donation and transplant events in the United States from October 1987. Because UNOS is a publicly available de-identified patient-level database, institutional review board (IRB) approval was not required.

We included first-time, adult recipients of deceased-donor liver transplants (LT) from January 2005 to December 2019. The following recipients were excluded: pediatric, living-donor LTs. This time period was chosen to reflect the post-MELD era. Data was divided into two time periods, defined as Era 1, from January 2005 to December 2013, and Era 2, from January 2014 to December 2019. The dividing year of 2013 was selected as a surrogate for the Share 35 policy, implemented in 2013. Recipients with missing data for the income variable were excluded.

The exposures of interest were insurance, income, United States (U.S.) citizenship, and race and ethnicity. Public insurance included Medicaid, Department of Veterans Affairs, or other government-related coverage. Income was defined as presence of income. Race and ethnicity were classified into the following five categories, as represented in the UNOS database: (1) White, (2) Hispanic, (3) African American or Black, (4) Asian, (5) Other. Covariates were age, sex, race and ethnicity, insurance, income, and citizenship status, etiology of liver disease, presence of hepatocellular carcinoma (HCC), ABO blood group, mortality, and associated medical history including diabetes mellitus (DM), ascites, and hepatic encephalopathy (HE), as well as wait-time, MELD score, Donor Risk Index (DRI), and age of donor (Table 1). Etiologies of liver disease were classified into the following five categories: (1) Hepatitis C virus (HCV), (2) Alcoholic liver disease, (3) Non-alcoholic fatty liver disease (NAFLD), (4) Hepatitis B virus, (5) Other etiologies.

The primary outcome was overall survival of post-transplant patients. Follow up was assessed from the time of liver transplantation to the last day of follow up.

### 2.1. Statistical analyses

Statistical testing was performed using STATA software package (version 16.1; StataCorp). Categorical variables were presented as number and percent. Continuous variables were reported by mean and standard deviation. Associations among categorical variables were assessed using Chi-square testing. Comparisons between continuous variables were performed using *T*-tests. Survival analysis was performed using Kaplan-Meier methods. Forward stepwise multivariate cox regression analyses were completed to identify significant predictors of survival, adjusted for recipient and donor characteristics, during the following time periods: (1) 2005–2019, (2) 2005–2013, and (3) 2014–2019, where p-value for entry into the model was set at 0.05, and a p-value of 0.05 was also set for removal from the model. In this stepwise model, the most statistically significant variable, out of the clinically and statistically significant, was entered first into the model, followed by the next most significant, until no other variables were found to be statistically significant.

To assess the effect modification of socioeconomic variables (e.g. insurance, income, and race) on the association between time period and survival, we carried out stratified analyses according to these variables. For each strata of these variables (such as public insurance), the above multivariate analyses were carried out separately. Comparison between all these models was completed to assess if there were any potential effect modifications in the results.

To ensure organs were allocated based on greatest medical need, the Organ Procurement and Transplantation Network (OPTN) implemented equitable access policies for transplantation, such as Model for End-stage Liver Disease (MELD) scores in 2002 and Share 35 in 2013 [12]. Through Share 35, organs would be offered to regional candidates with MELD  $\geq 35$  before local candidates with MELD  $< 35$ , in order to decrease wait time and waitlist mortality for patients with greater MELD scores. Since these policies were implemented, studies have worked to determine if these allocation schemes have changed geographic, racial and ethnic, and sex-based disparities in transplant access and outcomes [3,6,13]. For example, Darden et al. found that previous racial and ethnic disparities in transplant rates and waiting times resolved after Share 35; however, other studies observed persistent disparities after standardized use of MELD scores, with female sex, ethnic minorities, and older age associated with lower likelihood of receiving transplant [6,13–17].

Thus, we had two main objectives: (1) to characterize associations between individual socioeconomic factors and post-transplant survival, while adjusting for other factors associated with post-transplant survival, and (2) to determine if the pattern of associations changed after Share 35. We considered the following four

**Table 1**  
Baseline demographic and clinical characteristics of the study population.

Characteristic	2005–2019 N = 83,254
Age (year) (mean ± SD)	55.47 ± 9.94
Male sex (%)	56,441 (67.8)
Race or ethnicity (%)†	
White	59,311 (71.2)
African American or Black	7447 (8.9)
Hispanic	11,771 (14.1)
Asian	3564 (4.3)
Other	1161 (1.4)
Public insurance (%)	34,513 (41.5)
No income (%)	61,176 (73.5)
Without United States citizenship (%)	746 (0.9)
Era 1 (2005 - 2013) (%)	44,436 (53.4)
Etiology of liver disease	
Hepatitis C (%)	33,923 (40.8)
Alcoholic liver disease (%)	16,838 (20.2)
Non-alcoholic fatty liver disease (%)	11,130 (13.4)
Hepatitis B (%)	2879 (3.5)
Other (%)	18,484 (22.2)
Hepatocellular carcinoma (%)	28,695 (34.5)
ABO blood group, recipient	
A	30,509 (36.7)
B	11,225 (13.5)
AB	4165 (5.0)
O	37,355 (44.9)
Diabetes (%)	22,881 (27.5)
Death (%)	21,470 (25.8)
Spontaneous bacterial peritonitis (%)	6351 (7.6)
Transjugular intrahepatic portosystemic shunt (%)	9060 (10.9)
Ascites (%)	62,665 (75.3)
Hepatic encephalopathy (%)	51,833 (62.3)
Male sex, donor (%)	49,985 (60.0)
Race or ethnicity, donor†	
White	54,611 (65.6)
African American or Black	14,499 (17.4)
Hispanic	10,783 (13.0)
Asian	1994 (2.4)
Other	1367 (1.6)
ABO blood group, donor	
A	31,455 (37.8)
B	10,144 (12.2)
AB	2680 (3.2)
O	38,975 (46.8)
Wait time (days) (median, IQR)	96 (20–290)
Age (mean ± SD)	55.5 ± 9.9
Body mass index (mean ± SD)	29.0 ± 5.7
Weight (kg) (mean ± SD)	85.0 ± 19.7
Height (cm) (mean ± SD)	172.1 ± 10.2
Length of stay (median, IQR)	10.0 (7.0–16.0)
MELD Score (mean ± SD)	21.9 ± 10.0
Donor Risk Index (mean ± SD)	1.61 ± 0.69
Cold ischemia time (mean ± SD)	6.5 ± 2.8
MELD Exception Score (mean ± SD)	27.0 ± 7.4
Serum creatinine (mg/dL) (median, IQR)	1.1 (0.8–1.7)
Serum INR (mean ± SD)	1.87 ± 0.94
Serum bilirubin (mg/dL) (median, IQR)	3.5 (1.6–9.3)
Serum albumin (g/dL) (mean ± SD)	3.10 ± 0.73
Serum sodium (mEq/L) (mean ± SD)	135.9 ± 5.2
Age, donor (year) (mean ± SD)	41.5 ± 16.5
Body mass index, donor (mean ± SD)	27.7 ± 6.4
Weight (kg) (mean ± SD)	81.7 ± 20.4
Height (cm) (mean ± SD)	171.5 ± 10.6

Results were presented by hazard ratio (HR) and 95% confidence interval (CI). Statistical significance was defined at  $\alpha = 0.05$ .

The study adheres to the RECORD guidelines, as reflected on the EQUATOR website [18].

## 2.2. Role of funding sources

No funding sources were involved in this study.

## 3. Results

### 3.1. Characteristics of the study population

83,254 transplant recipients from the UNOS/OPTN STAR database from January 2005 to December 2019 were included. Median follow up time was 3.9 years (range: 0–15.4, interquartile range (IQR): 1.2–7.6). Baseline demographic and clinical characteristics of the study population are shown in [Table 1](#).

### 3.2. Characteristics of the study population by era

Demographics and clinical characteristics of the study populations were compared across eras, Era 1 representing pre-Share 35 and Era 2 representing Share 35, as noted in [Table 2](#). Median follow up time was 7.1 years (IQR: 3.6–10.0) for the pre-Share 35 era and 2.0 years (IQR 1.0–3.7) for the Share 35 era. When analyzed by era, 44,436 (53.4%) transplant recipients were included in Era 1 (2005–2013).

Significant differences were noted between the pre-Share 35 and Share 35 eras, when comparing age, sex, race and ethnicity, insurance, income, and citizenship status ([Table 2](#)).

In particular, while recipients were predominantly white in both the pre-Share 35 and Share 35 eras, there was a higher proportion of white individuals in the pre-Share 35 era. A higher proportion of African American or Black individuals received a transplant in the pre-Share 35 era, as compared to the Share 35 era, whereas a lower proportion of Hispanic individuals were noted in the pre-Share 35 era, as compared to the Share 35 era.

A higher percentage of recipients in the pre-Share 35 era, as compared to the Share 35 era, did not have income but had public (versus private) insurance. More individuals held U.S. citizenship in the Share 35 period, as compared to the pre-Share 35 period.

### 3.3. Outcomes

Overall survival across the entire time period is shown in [Fig. 1](#). When analyzed by era, the Share 35 period was found to have higher five-year post-transplant survival, as compared to the pre-Share 35 era ([Fig. 2](#)). Private, as compared to public, insurance was associated with higher survival at one-, five-, and ten-years post-transplant ([Fig. 3](#)). Income, as compared to no income, was associated with higher survival at one-, five-, and ten-years post-transplant ([Fig. 4](#)). African American or Black race or ethnicity was associated with the lower post-transplant survival, whereas Asian race or ethnicity had the highest post-transplant survival ([Fig. 5](#)).

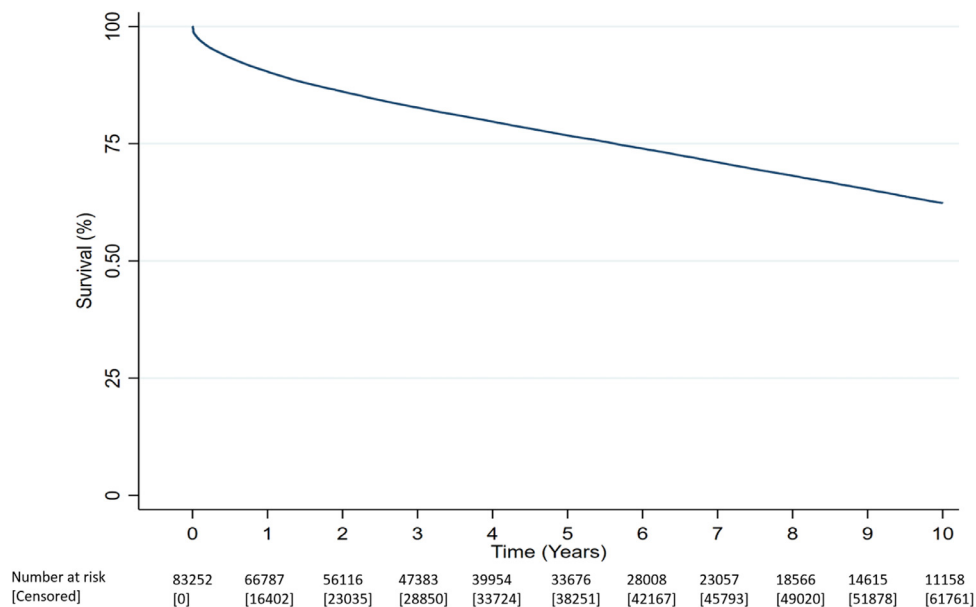
The results of the multivariate Cox regression analysis are displayed in [Table 3](#). The following analyses included adjustment for other demographic and clinical characteristics, listed in [Table 1](#). Overall, male sex, private insurance and income were associated with higher post-transplant survival (HR < 1.0). Many of these associations remained in analyses including only pre-Share 35 or Share 35 recipients ([Table 3](#)). Compared to white recipients, Hispanic and Asian recipients had higher post-transplant survival, whereas African American or Black patients had lower post-transplant survival. The same associations of higher post-transplant survival with Hispanic and Asian races and lower post-transplant survival with African American or Black race held across the pre-Share 35 and Share 35 eras, when analyzed independently ([Table 3](#)).

Non-U.S. citizenship was associated with lower post-transplant survival when analyzed across the entire time period 2005 to 2019 and 2005 to 2013. It was not found to be significant from 2014 to 2019.

Overall, when analyzed by etiology of liver disease, all etiologies, including alcoholic liver disease, NAFLD, Hepatitis B, and other were associated with higher post-transplant survival when compared to the reference group of HCV ([Table 1](#)). Lower post-transplant survival

**Table 2**  
Selected demographic and clinical characteristics of the study population by time period.

Characteristic	Era 1: 2005–2013 N = 44,436	Era 2: 2014–2019 N = 38,818	p-value
Age (year) (mean ± SD)	54.8 ± 9.4	56.2 ± 10.5	< 0.0001
Male sex (%)	30,567 (68.8)	25,874 (66.7)	< 0.0001
Race or ethnicity (%)			< 0.0001
White	31,758 (71.5)	27,553 (71.0)	
African American or Black	4179 (9.4)	3268 (8.4)	
Hispanic	5990 (13.5)	5781 (14.9)	
Asian	1996 (4.5)	1568 (4.0)	
Other	513 (1.2)	648 (1.7)	
Public insurance (%)	16,975 (38.2)	17,538 (45.2)	< 0.0001
No income (%)	33,004 (74.3)	28,172 (72.6)	< 0.0001
Without United States citizenship (%)	343 (0.8)	403 (1.0)	< 0.0001
Etiology of liver disease			< 0.0001
Hepatitis C (%)	21,458 (48.3)	12,465 (32.1)	
Alcoholic liver disease (%)	6795 (15.3)	10,043 (25.9)	
Non-alcoholic fatty liver disease (%)	3925 (8.8)	7205 (18.6)	
Hepatitis B (%)	1752 (3.9)	1127 (2.9)	
Other (%)	10,506 (23.6)	7978 (20.6)	
Hepatocellular carcinoma (%)	15,053 (33.9)	13,642 (35.1)	0.0001
ABO blood group, recipient			0.19
A	16,330 (36.8)	14,179 (36.5)	
B	5896 (13.3)	5329 (13.7)	
AB	2258 (5.1)	1907 (4.9)	
O	19,952 (44.9)	17,403 (44.8)	
Diabetes (%)	11,249 (25.3)	11,632 (30.0)	< 0.0001
Death (%)	16,599 (37.4)	4871 (12.6)	< 0.0001
Ascites (%)	34,164 (76.9)	28,501 (73.4)	< 0.0001
Hepatic encephalopathy (%)	28,119 (63.3)	23,714 (61.1)	< 0.0001
Wait time (days) (median, IQR)	88.0 (21.0–275.0)	107.0 (19.0–305.0)	0.69
Length of stay (median, IQR)	10.0 (7.0–16.0)	10.0 (7.0–16.0)	0.26
MELD Score (mean ± SD)	21.2 ± 9.6	22.7 ± 10.4	< 0.0001
Donor Risk Index (mean ± SD)	1.64 ± 0.71	1.58 ± 0.67*	< 0.0001
MELD Exception Score (mean ± SD)	25.9 ± 7.3	28.3 ± 7.4*	< 0.0001
Serum creatinine (mg/dL) (median, IQR)	1.1 (0.8–1.7)	1.1 (0.8–1.8)	
Serum bilirubin (mg/dL) (median, IQR)	3.6 (1.7–8.8)	3.5 (1.5–10.0)	
Age, donor (year) (mean ± SD)	41.6 ± 16.9	41.3 ± 16.1	0.03



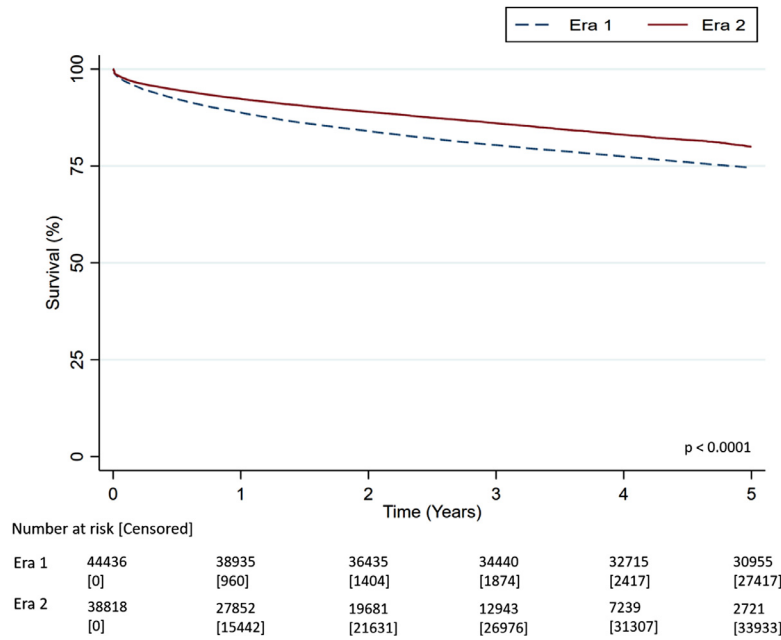
**Fig. 1.** Kaplan Meier curve displaying the overall survival of the study population.

was also associated with history of HCC, DM, or HE, as well as greater MELD score or DRI (Table 3).

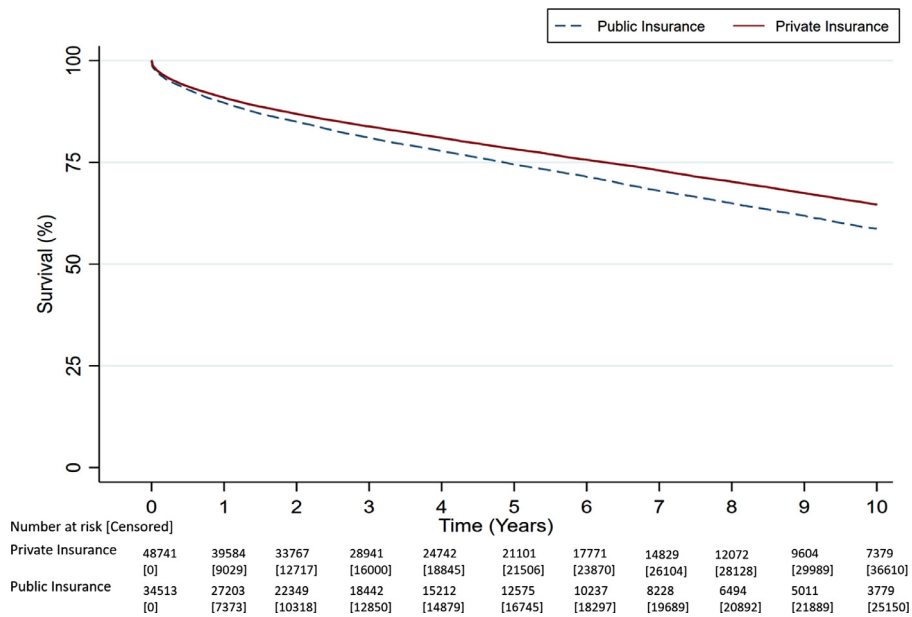
When assessed for effect modification, associations between era and survival were comparable between the different strata of each of the socioeconomic variables alone; in fact, the Share 35 era was associated with higher post-transplant survival, no matter the variable studied (Table 4).

#### 4. Discussion

Our findings build upon previous work focusing on the impact of socioeconomic factors on liver transplantation, by specifically considering income, insurance, citizenship status, and race and ethnicity when adjusting for other factors related to post-liver transplant survival. This study expands upon these



**Fig. 2.** Kaplan Meier curve demonstrating survival when analyzed by pre-Share 35 (Era 1) versus Share 35 (Era 2) period. The Share 35 period was found to have higher five-year post-transplant survival.



**Fig. 3.** Kaplan Meier curve demonstrating survival when analyzed by private versus public insurance. Private insurance was associated with higher survival at one-, five-, and ten-years post-transplant.

findings by studying changes in associations after the Share 35 policy [2,11].

Overall, statistically significant differences in the composition of the study populations were found by era. Private insurance and income were found to be associated with higher post-transplant survival over a ten-year time period, consistent with present-day understanding of the influence of socioeconomic factors on health outcomes [1]. In fact, even when adjusted for demographic factors and medical co-morbidities, male sex, private insurance, income, U.S. citizenship, and certain race and ethnicities were associated with higher post-transplant survival. Of note, the direction of many of these associations did not change after the implementation of Share 35.

The differences in patient composition observed between Era 1 (2005–2013, pre-Share 35) and Era 2 (2014–2019, Share 35) likely

reflect ongoing changes in national demographics, clinical practice, and evolving health policies.

Male sex was found to be associated with higher post-transplant survival, even after adjustment for demographic and clinical characteristics. Previous research has described persistent sex disparities in liver transplant allocation, even when adjusted for geography, with one study suggesting that MELD scores may inaccurately quantify disease burden in women [6,19]. Male and female recipients may enter transplant with different disease burdens and medical co-morbidities, likely influencing their chance of post-transplant survival. In considering post-transplant outcomes, studies have remained conflicted: One study found that male sex was associated with higher post-transplant HCC recurrence risk; however, another review found no sex-based disparity with post-transplant HCC recurrence risk, though did conclude



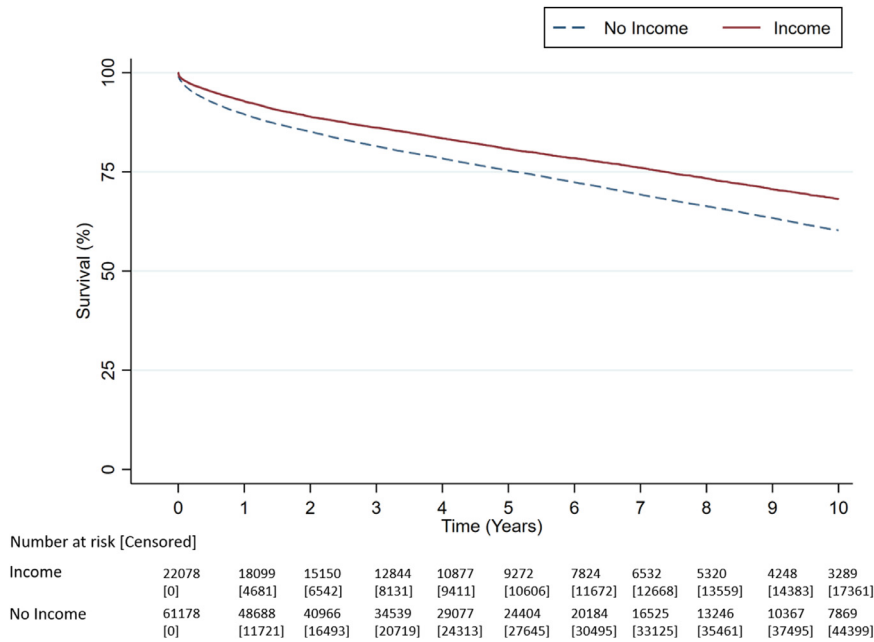


Fig. 4. Kaplan Meier curve demonstrating survival when analyzed by income versus no income. Income was associated with higher survival at one-, five-, and ten-years post-transplant.

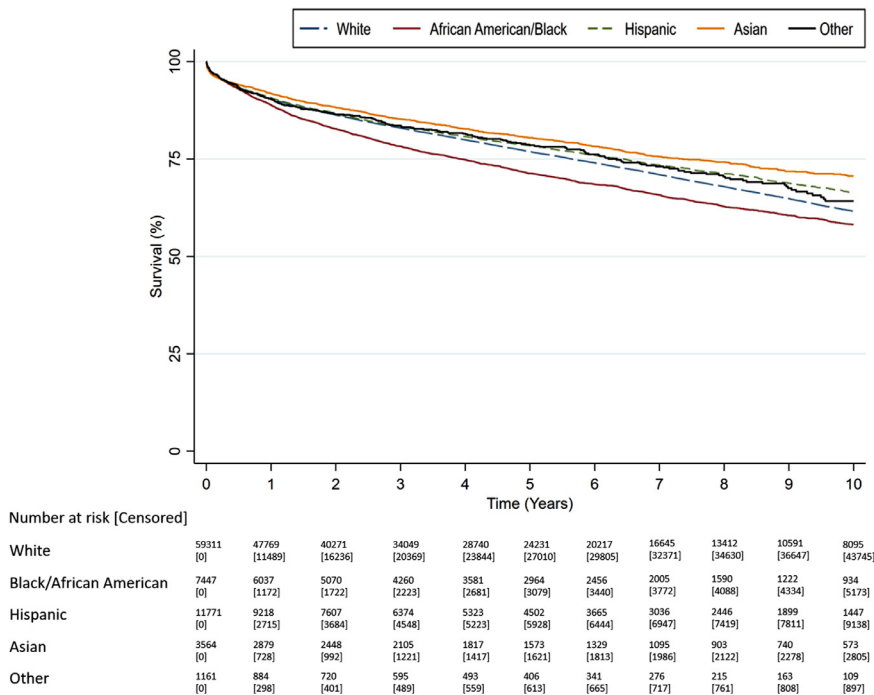


Fig. 5. Kaplan Meier curve demonstrating survival when analyzed by race and/or ethnicity. African American or Black race or ethnicity was associated with lower post-transplant survival, and Asian race or ethnicity was associated with the highest post-transplant survival.

that women recipients were at higher risk of chronic kidney disease and at higher risk of poorer outcomes if transplanted for HCV [20,21].

The evolving composition of race and ethnicity across eras, with a lower proportion of white recipients and higher proportion of Hispanic recipients in the second era, likely reflects changing national demographics, and mirrors previous research that found higher proportions of African American or Black and Hispanic individuals in the Share 35 cohort [13,22].

From 2005 to 2019, African American or Black recipients experienced a significantly higher risk of post-transplant mortality by approximately 16%, or decreased survival as compared to white

recipients, even after adjustment for demographic and clinical characteristics. The decreased survival was observed before and after Share 35, with an additional mortality risk of 15% in the pre-Share 35 cohort and 21% in the Share 35 cohort, as compared to white recipients. These results parallel previous work that found increased hazard of post-transplant mortality among African Americans across different liver disease etiologies, though potentially mitigated by tumor presentation and other treatment related factors [5,23–25].

Conversely, from 2005 to 2019, Asian and Hispanic race and ethnic groups were found to have higher post-transplant survival, with an approximate 20% hazard reduction in mortality, an observation that persisted through the Share 35 era, when adjusted for clinical

**Table 3**  
Associations between post-transplant mortality and demographic and clinical characteristics.

Variable	2005–2019 Hazard Ratio (95% CI)	2005–2013 Hazard Ratio (95% CI)	2014–2019 Hazard Ratio (95% CI)
Era 2, 2014–2019	0.71 (0.68–0.73)	..	..
Male sex	0.93 (0.90–0.96)	0.96 (0.93–0.99)	0.84 (0.79–0.90)
Race			
White	Reference	Reference	Reference
African American or Black	1.17 (1.11–1.22)	1.15 (1.10–1.21)	1.22 (1.11–1.34)
Hispanic	0.82 (0.79–0.86)	0.80 (0.77–0.84)	0.88 (0.81–0.96)
Asian	0.81 (0.75–0.88)	0.79 (0.72–0.86)	0.87 (0.73–1.02)
Private insurance	0.91 (0.88–0.94)	0.90 (0.87–0.93)	0.94 (0.89–1.00)
Income	0.82 (0.79–0.85)	0.82 (0.79–0.85)	0.82 (0.77–0.89)
Without U.S. citizenship	1.22 (1.01–1.47)	1.36 (1.06–1.74)	1.09 (0.81–1.46)
Etiology			
Hepatitis C	Reference	Reference	Reference
Alcoholic liver disease	0.82 (0.79–0.86)	0.80 (0.77–0.84)	0.91 (0.84–0.99)
Non-alcoholic fatty liver disease	0.82 (0.78–0.86)	0.75 (0.71–0.80)	1.03 (0.95–1.13)
Hepatitis B	0.69 (0.63–0.75)	0.65 (0.59–0.72)	0.88 (0.72–1.07)
Other	0.86 (0.83–0.89)	0.81 (0.77–0.84)	1.11 (1.02–1.21)
Hepatocellular carcinoma	1.20 (1.16–1.25)	1.21 (1.17–1.26)	1.19 (1.11–1.28)
Diabetes Mellitus	1.27 (1.23–1.31)	1.29 (1.24–1.33)	1.22 (1.15–1.30)
Hepatic encephalopathy	1.05 (1.02–1.08)	1.04 (1.01–1.08)	1.06 (0.99–1.13)
Age, Recipient	1.14 (1.12–1.16)	1.16 (1.14–1.18)	1.10 (1.07–1.14)
Length of stay	1.22 (1.21–1.23)	1.21 (1.20–1.23)	1.23 (1.21–1.24)
MELD	1.04 (1.03–1.05)	1.03 (1.02–1.04)	1.05 (1.03–1.06)
Donor Risk Index	1.11 (1.07–1.14)	1.10 (1.07–1.14)	1.12 (1.05–1.20)
Age, Donor	1.04 (1.03–1.06)	1.06 (1.04–1.07)	1.00 (0.97–1.03)

\*Models were adjusted for the demographic and clinical characteristics noted in Table 1.

**Table 4**

Stepwise multivariate cox-proportional hazard analyses for associations between the two eras and mortality for different socioeconomic variables.

Variable	Hazard Ratio (95% CI)
Public insurance	0.682 (0.648–0.718)
Private insurance	0.729 (0.695–0.765)
No income	0.696 (0.669–0.724)
Income	0.734 (0.680–0.793)
White	0.705 (0.677–0.735)
African American or Black	0.691 (0.622–0.768)
Hispanic	0.700 (0.635–0.770)
Asian	0.724 (0.603–0.869)
Other	0.879 (0.656–1.178)

\*Era 1 was used as reference.

and demographic characteristics. This challenges an earlier study by Zhang (2017) that specifically studied Asian populations and the effect of Share 35 policy and did not find an 18-month survival difference between Asian and white recipients [13]. However, among Hispanics, our findings mirror a previous study that concluded that Hispanics, as compared to non-Hispanic whites, have similar or better post-liver transplant outcomes [26].

Of note, a previous study postulated that differences in transplantation by race and ethnicity may be mitigated by ABO-nonidentical liver transplant [27]. While an attempt to adjust for a greater number of clinical and demographic variables was made in this study, including ABO match, it is likely that there are additional variables unaccounted for that contribute to this disparity found by race and ethnicity, including other disease-related co-morbidities.

From 2005 to 2019, private, as compared to public, insurance was associated with survival benefit, even after adjustment for demographic and clinical characteristics. The same association was seen before and after Share 35. This corresponds with research that suggests that private insurance is associated with higher post-transplant survival, whether independently or in combination with other socioeconomic factors [2,16,28]. Studies have also found that public insurance is associated with worse pre-transplant, waitlist outcomes, though mitigated by geographic location [7,8]. However, in considering regional sharing policies such as Share 35, a previous study by

Schwartz et al. raised concern that these policies may disincentivize patients with public insurance to expand their geographic range for transplant, given a finding of increased waiting list deaths [7]. It is likely that, even with the adjustments made here, private insurance stands as a surrogate for a host of variables that are not found in UNOS, such as medication access, work and housing stability, reliable transportation, or access to experimental therapies [29].

The higher proportion of recipients without income in Era 1 may reflect the changing U.S. economy [30,31].

From 2005 to 2019, presence of income, as compared to no income, was associated with higher post-transplant survival. The association was observed during the pre-Share 35 and Share 35 eras. This finding adds to ongoing discussion regarding the influence of income on liver transplant: One study found that neighborhood income does not influence the outcome of liver transplant, though others have suggested that higher income (as compared to lower income, rather than no income, as studied here) protects against post-transplant and pre-transplant waiting list mortality and increases incidence of liver transplant [2,7,9].

From 2005 to 2019, U.S. citizenship was associated with higher post-transplant survival. The association was observed in the pre-Share 35 era as well. This may reflect the additional barriers to transplant, such as understanding of the healthcare system and structural social supports, that non-U.S. citizen recipients can encounter, in addition to varying levels of disease severity [32].

In terms of etiology of liver disease, the pre-Share 35 era contained a higher proportion of HCV than the Share 35 era, potentially secondary to advancements in HCV disease therapies [33]. There were more individuals with HCC in the Share 35 era than the pre-Share 35 era, as well, potentially due to the change in MELD exception policies. A higher proportion of NAFLD and alcoholic liver disease was observed in the Share 35 period as compared to the pre-Share 35 period, as well, likely reflective of changing medical co-morbidities, such as increasing prevalence of metabolic syndrome.

From 2005 to 2019 and in the pre-Share 35 period, all etiologies of liver disease, as compared to Hepatitis C, were associated with increased post-transplant survival, likely consistent with advances in HCV treatment in the Share 35 period. These advances in HCV therapy, including direct anti-viral therapies, may have contributed to the lower frequency of ascites and encephalopathy seen in the Share 35

period. When compared across eras, the “other” category of disease etiology was associated with higher post-transplant survival in the pre-Share 35 era but lower post-transplant survival in the Share 35 era, when compared to the reference group of HCV, again likely reflective of evolving HCV therapies.

In terms of medical co-morbidities, a higher proportion of patients were recorded as having ascites or HE in the pre-Share 35 era as compared to the Share 35 era, potentially due to advancements in treatment or earlier recognition of chronic liver disease. A higher proportion of individuals with hepatocellular carcinoma were noted in the Share 35 era though, possibly reflective of time needed to develop end-stage liver disease, in the setting of higher HCV prevalence in the earlier era, as well as the limitation in exception points after Share 35.

Overall, the lower number of deaths observed in the Share 35 era was likely reflective of advancements in recognition and both medical and surgical management of liver disease, including HCV, and transplantation. The lower post-transplant survival found to be associated with HCC, DM, HE, MELD score, and DRI was also expected, given the influence of medical co-morbidities on health outcomes.

While unlikely that a single policy would make a uniquely significant impact, it is interesting to note that this study did not find a change in the protective benefits of income or Hispanic or Asian race and ethnicity after the implementation of Share 35. In fact, it is notable that despite transplanting recipients with higher MELD scores, as was the effect of Share 35, post-transplant survival rates improved, likely with contribution from improvements in clinical management overtime as well, as discussed elsewhere. This adds to previous research on the impact of Share 35, which had conversely found that there was no survival difference between Asian and white recipients after Share 35 and that Share 35 did not improve access to liver transplantation [13,17]. Of note, Share 35 was created to address disparities in liver transplant allocation, while our study considers its association with post-transplant outcomes.

There are several limitations in this study, reflective of retrospective analysis involving a large national database. Inconsistency in the collection and coding of variables can contribute to inaccuracy in results and conclusions. In UNOS, race and ethnicity are self-reported, and races with decreased representation were combined as “other,” which can contribute to reporting and misclassification bias. Income was sorted by presence or absence at time of transplant, though variation by amount likely affects post-transplant outcome. Non-U.S. citizenship also encompassed both unauthorized immigrants and non-U.S. residents (e.g. individuals who may have travelled to the U.S. specifically for transplantation), and socioeconomic characteristics likely differ between these groups. Additionally, mortality was grouped by all-cause, removing further analysis of cause or potential association with socioeconomic status. In analysis, data was considered as a national cohort, rather than sorted geographically or by transplant center, which precludes analysis of region or center-specific associations. Use of a well-studied, large national database, however, increases the generalizability of our findings.

Through an analysis of almost 15 years of UNOS data, we found that male sex, private insurance, income, U.S. citizenship, and Asian or Hispanic race and ethnicity were protective towards post-transplant survival, even when adjusted for demographic factors and medical co-morbidities. This association persisted not only across the time period studied but also after the implementation of Share 35 for male sex, income, private insurance, and Asian or Hispanic race and ethnicity. These results suggest that socioeconomic factors at time of transplant may impact long-term post-transplant survival, and a single policy may not significantly alter these structural health inequalities.

Post-transplant survival is complex. A great deal of work remains in better understanding the individual impact of socioeconomic factors, including the inter-relationship between these variables and other variables not considered here, such as health literacy,

geography, or education level. Future work can consider the impact of these clinical characteristics when solely examined within one race and/or ethnicity, and should consider how other equitable access policies may have uniquely affected pre- and post-transplant outcomes, as separate from concurrent changes in health care and health policy.

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None

#### Data sharing statement

The data that support the findings of this study are openly available in the UNOS database at <https://unos.org/data/>.

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#### Declaration of Competing Interest

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