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Community-level social vulnerability and individual socioeconomic status on liver transplant referral outcome

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Abstract

Background: Recent endeavors emphasize the importance of understanding early barriers to liver transplantation (LT) by consistently collecting data on patient demographics, socioeconomic factors, and geographic social deprivation indices.

Methods: In this retrospective single-center cohort study of 1657 adults referred for LT evaluation, we assessed the association between community-level vulnerability and individual socioeconomic status measures on the rate of waitlisting and transplantation. Patients' addresses were linked to Social Vulnerability Index (SVI) at the census tract–level to characterize community-level vulnerability. Descriptive statistics were used to describe patient characteristics. Multivariable cause-specific HRs were used to assess the association between community-level vulnerability, individual measures of the socioeconomic status, and LT evaluation outcomes (waitlist and transplantation).

Results: Among the 1657 patients referred for LT during the study period, 54% were waitlisted and 26% underwent LT. A 0.1 increase in overall SVI correlated with an 8% lower rate of waitlisting (HR 0.92, 95% CI 0.87–0.96, $p < 0.001$), with socioeconomic status, household characteristics, housing type and transportation, and racial and ethnic minority status domains contributing significantly to this association. Patients residing in more vulnerable communities experienced a 6% lower rate of transplantation (HR 0.94, 95% CI 0.91– 0.98, $p = 0.007$), with socioeconomic status and household characteristic domain of SVI significantly contributing to this association. At the individual level, both government insurance and

Abbreviations. CDC WONDER, Center for Disease Control WONDER Wide-ranging Online Data for Epidemiology Research; ESLD, end-stage liver disease; LT, liver transplantation; MELD, model for end-stage liver disease; SES, socioeconomic status; SVI, Social Vulnerability Index; UNOS, United Network for Organ Sharing; US, United States.

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employment status were associated with lower rates of waitlisting and transplantation. There was no association with mortality prior to waitlisting or mortality while on the waitlist.

Conclusion: Our findings indicate that both individual and community measures of the socioeconomic status (overall SVI) are associated with LT evaluation outcomes. Furthermore, we identified individual measures of neighborhood deprivation associated with both waitlisting and transplantation.

INTRODUCTION

Liver transplantation (LT) is the only lifesaving procedure available for patients with end-stage liver disease (ESLD). To receive a transplant, patients must be referred to a transplant center, evaluated for transplant, and registered on the United Network for Organ Sharing (UNOS) waitlist. Socioeconomic and demographic disparities affecting access to LT have been well studied after waitlisting stage. Prior to the model for end-stage liver disease (MELD) implementation, Black patients have been shown to be underrepresented on the waitlist, have more advanced disease at waitlisting, and are more likely to die while awaiting LT.[1] After MELD implementation, transplant rates for Black patients improved, but they remained 10% less likely than White patients to undergo transplantation.[2]

The role of socioeconomic status (SES) as a barrier to waitlisting is not well understood, partly because transplant centers capture a variable number of individual measures of SES on their referred patients. A potential solution to address the often absent or limited SES data might be area-based socioeconomic measures using geocoding of residential data.[3] These community measures characterize the neighborhoods in which individuals live in, which contains both the social and material characteristics that are relevant for health,[4] and can be geocoded to a patient's address.[5] In this study, we used the US Centers for Disease Control and Prevention Social Vulnerability Index (SVI), which is a composite measure of social vulnerability (overall SVI). Prior research has demonstrated that increasing community vulnerability has been associated with lower odds of receiving a living donor kidney transplant[6] and lower odds of waitlisting and death during LT evaluation.[7]

There has been a growing call to standardize patient socioeconomic data and geographic social deprivation indices[8] to gain a better understanding of the early barriers to LT. One such tool that can be useful in identifying specific social risk factors that patients being evaluated for LT might encounter is SVI, which comprises several social determinants of health indicators from multiple domains. Thus, our study aimed to assess the association between overall SVI and its domains, individual measures of SES, and LT referral outcomes (waitlist and transplantation). Our hypothesis was that both community-level vulnerability and individual measures of SES would affect waitlisting and transplantation, independent of disease severity, as reflected by the MELD score, disease etiology, and HCC status.

METHODS

Study design

We conducted a retrospective study in full compliance with the Declaration of Helsinki, and it was approved by the institutional review board at the University of California San Francisco (UCSF) (IRB #20-32625). The study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[9] We retrospectively reviewed medical records of patients referred for LT evaluation at UCSF to evaluate the association between community-level vulnerability, individual measures of SES, and LT evaluation (waitlist and transplant).

We used the Centers for Disease Control and Prevention's SVI to establish a relative ranking of social vulnerability for each census level through the 2014 to 2018 American Community Survey 5-year estimates. By using ArcGis Pro, we matched patient home addresses to their census tract–level information and then paired census tract–level SVI with each patient's census tract. Theme-specific percentile rankings were created using fifteen individual census-level variables, which were grouped and summed into 4 thematic domains.[10] These domains include socioeconomic status (SES), household characteristics, racial and ethnic minority status, and housing type and transportation. SES domain comprises 4 census-level indicators: living below poverty line, no high school diploma, unemployed, and median income. On the other hand, household characteristics domain comprises census-level indicators centered around single-parent household, individuals under the age of 17 years or over the age of 65 years, and individuals with disability. Housing type and transportation domain

comprises census-level indicators about housing security and access to transportation. Racial and ethnic minority status domain comprises racial and ethnic minority status as well as proportion of individuals over the age of 5 years who speak English "less than well".[11] These domains describe patients' neighborhoods, identifying components of their community that might be contributing to their health outcomes.

The overall SVI, or composite community-level vulnerability, is the sum of each of the four domains.[10–12] SVI measurements range from 0 to 1, with higher values indicating greater community-level vulnerability. To account for the negligible mean difference between waitlisted and denied groups (< 0.10), we standardized SVI by calculating a 0.10 increase in overall and 4 domains of SVI.

Study population

A total of 1657 adult patients (18 years and older), who were referred for LT evaluation between January 1, 2013 and December 31, 2015, were evaluated. Since the average time from referral to transplantation at our center is 5 years, all data were extracted on September 30, 2021.

Outcomes and exposures

Our primary outcome of interest was rate of waitlisting, and our secondary outcome of interest was rate of transplantation. Main exposure variables consisted of individual measures of SES and community-level vulnerability. Individual measures of SES include individual insurance types (Private, Medicaid, or Medicare) and employment status (unemployed, disabled, retired, or working). Community-level vulnerability was defined using SVI, which was used as a continuous variable (Fig. 1).

Statistical analysis

Descriptive and bivariate analyses

Frequencies and percentages were used to report categorial data. Medians and first-third quartiles (Q1–Q3) were used to report continuous data. We compared variables between groups using Pearson chi-square and Wilcoxon signed-rank test for categorical and continuous variables, respectively.

Cause-specific HR models

We used cause-specific HR to assess the impact of main exposure variables and covariates on waitlisting and transplantation. Our base model covariates included age at referral (y), sex, HCC status (yes/no), disease etiology (alcohol-associated liver disease, NAFLD/ NASH, chronic HBV, chronic HCV, cholestatic liver disease, and others), and MELD score at referral – all variables known to be associated with waitlisting and transplantation.

Race, a social construct, through structural racism can affect both individual measures of SES (employment and insurance type) and community-level vulnerability (SVI). As such, we treated race and ethnicity as confounders between individual measures of SES, community-level vulnerability, and LT evaluation outcome (waitlist and transplantation). Patient's race, as captured by electronic health record (EHR), was obtained and consisted of 3 categorical variables [White, Black, and others (American Indian, Asian, and Pacific Islander patients)].

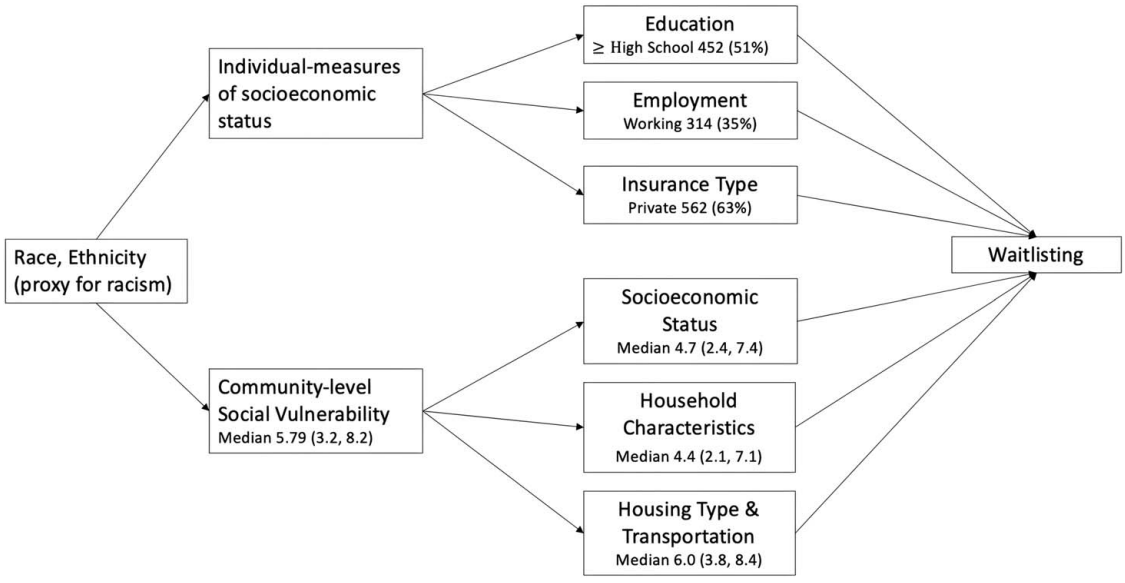

FIGURE 1 Conceptual framework.

Patient's ethnicity, as captured in EHR record, was categorized as Hispanic/Latinx and not Hispanic/Latinx patients.

Our 2 final multivariable cause-specific HR models examined the effects of community-level vulnerability (SVI) and individual measures of SES (insurance type and employment status) on waitlisting and transplantation. We also assessed for cause-specific HR for mortality, including death before waitlist (for patients who were referred but died prior to waitlisting) and waitlist mortality (for patients who were waitlisted but died prior to transplantation). We censored patients at the date of last follow-up or the end of study period (9/2021). All models were adjusted age, sex, MELD at referral, HCC Status, disease etiology, race, and ethnicity.

Pearson correlation matrices showed no severe collinearity issues between community-level vulnerability (SVI), race/ethnicity, and individual measures of SES (insurance type and employment) (coefficients were all less than 0.8).

Missing data

The data available for statistical analysis differed substantially between those denied and those waitlisted, and there were substantial amounts of missing values among those denied in the predictor variables we wanted to include in our statistical models. Given the high proportion of missing data for education type (61.6%), especially in those who were denied, we opted to exclude this variable from our models to not bias our outcome. Sample characteristics of participants were compared between those with or without missing data, where the missing data group was defined as those missing values for any variables included in the multivariable models with $>5\%$ missing (race and ethnicity, employment status, and MELD at referral). Given the significant differences between these 2 groups (Supplemental Table 1, http://links.lww.com/HC9/A335), we concluded that the data are not missing at random and analyzed the missing/unknown categories for these variables in the multivariable models. Sensitivity analyses models were performed using complete case analysis and multiple imputation.

Multiple imputations with 10 imputed data sets using a multiple chained equations approach were used to fill in missing values for race and ethnicity (7.2%), employment (8.7%), and MELD at referral (15.5%). These variables along with waitlisting, age, sex, SVI, HCC status, insurance type, and disease etiology were included in the imputation model.

Results are presented as HR and 95% CI. Hypothesis tests were two sided, and the significance threshold was set to 0.05. Data were analyzed using standard statistical software package, STATA version 17 (Stata Corp, College Station, TX).

RESULTS

Patient characteristics

During the study period, 1657 patients were referred for LT, of whom 54.0% were waitlisted: the median age was 58 (Q1–Q3 52 – 64) years, 67.4% were male, 50.7% were non-Hispanic White patients, 87.2% had English as their preferred language, 50.5% had high school or beyond education, 35.1% were employed, and 62.8% had private insurance. In terms of disease variables, 47.0% had chronic hepatitis C (HCV), 46.0% had HCC, and the median MELD at referral was 14 (Q1–Q3 10 – 19). Community-level vulnerability differed by LT evaluation outcome (waitlist), with the median overall SVI of 5.79 (Q1–Q3 3.21 – 8.16) for waitlisted patients. The median SES ($p<0.001$), household characteristics ($p = 0.001$), and housing type and transportation ($p=0.006$) domains of SVI were all significantly lower for waitlisted patients (Table 1) compared to denied patients.

Of the patients referred for LT, 1244 (75.1%) proceeded to evaluation, 1191 (71.9%) reached patient selection committee, 895 (54.0%) were waitlisted, and ultimately, 433 (26.1%) underwent transplantation. The primary reasons patients were referred but not evaluated included difficulty contacting the patient and inadequate financial or insurance clearance. From the evaluation stage to the patient selection committee, the proportion of patients with unknown/missing education decreased by 7.6% (from 17.8% to 10.2%), while the proportion with unknown/missing insurance type declined by 4.6% (from 7.7% to 3.1%). Furthermore, the proportion of patients with unknown/missing employment status reduced by 7.7% (from 14.7% to 7.0%). Between patient selection and waitlisting, the largest reductions in proportion were observed in patients with less than high school education (a 25% decrease from 98.8% to 73.8%), those with Medicaid insurance (a 22.1% decrease from 60.0% to 37.9%), and patients with disability employment status (a 23.0% reduction from 71.3% to 48.2%) (Fig. 2).

Predictors of waitlisting and receipt of LT

Community-level vulnerability and individual measures of SES (insurance type, employment status) were assessed as predictors of waitlisting using multivariable cause-specific HR models adjusting for base covariates (age, sex, MELD at referral, HCC status, and disease etiology), race, and ethnicity (Table 2). We found that patients residing in more vulnerable communities had an 8% lower rate of waitlisting per 0.1 U increase in overall SVI (HR 0.92, 95% CI 0.87–0.96, $p < .001$). In terms of SVI domains, a 0.1 U increase in SES domain (HR 0.92, 95% CI 0.89 – 0.96, $P <0.001$), household characteristics domain (HR 0.94, 95% CI 0.91 – 0.98; $p = 0.007$), housing type and transportation domain

TABLE 1 Patient characteristics by referral outcome (deny versus waitlist) (N = 1657)

Characteristic	N (%) Deny 762 (46.0)	Waitlist 895 (54.0)	*p*
Patient variables			
Age at referral, median (1st–3rd quartile), years	58 (52, 63)	58 (52, 64)	0.68
Sex	—	—	0.17
Male	490 (64.2)	602 (67.4)	—
Female	273 (35.8)	292 (32.6)	—
Race and Ethnicity	—	—	—
Non-Hispanic White patients	356 (46.7)	454 (50.7)	—
Non-Hispanic other[a]	65 (8.5)	132 (14.8)	—
Non-Hispanic Black patients	34 (4.5)	45 (5.0)	—
Hispanic/Latinx patients	194 (25.5)	257 (28.7)	—
Missing/Unknown	113 (14.8)	7 (0.8)	—
Individual socioeconomic status measures			
Primary Language	—	—	0.52
English	673 (88.3)	780 (87.2)	—
Spanish	50 (6.6)	59 (6.6)	—
Chinese/Mandarin	11 (1.4)	20 (2.2)	—
Other[b]	25 (3.3)	35 (3.9)	—
Missing/Unknown	3 (0.4)	1 (0.1)	—
Education	—	—	**< 0.001**
< High School	147 (19.3)	413 (46.1)	—
≥ High School	146 (19.1)	452 (50.5)	—
Missing/Unknown	469 (61.6)	30 (3.4)	—
Employment	—	—	**< 0.001**
Working	142 (18.6)	314 (35.1)	—
Unemployed	166 (21.8)	174 (19.4)	—
Disabled	146 (19.2)	136 (15.2)	—
Retired	170 (22.3)	266 (29.7)	—
Missing/Unknown	138 (18.1)	5 (0.6)	—
Characteristic	**N (%) Deny 762 (46.0%)**	**Waitlist 895 (54.0%)**	***p*-value**
Insurance type	—	—	**< 0.001**
Private	268 (35.2)	562 (62.8)	—
Medicare	223 (29.3)	204 (22.8)	—
Medicaid	208 (27.3)	127 (14.2)	—
Missing/Unknown	63 (8.3)	2 (0.2)	—
Community-level vulnerability			
Overall SVI, median (1st-3rd quartiles)	6.6 (4.2, 8.7)	5.79 (3.21, 8.16)	**< 0.001**
Socioeconomic Status domain	5.72 (3.29, 8.04)	4.73 (2.38, 7.38)	**< 0.001**
Household characteristics domain	5.14 (2.71, 7.67)	4.40 (2.05, 7.06)	**0.0001**
Housing Type & transportation domain	6.83 (4.26, 8.80)	6.03 (3.81, 8.42)	**0.0006**
Racial & ethnic minority status domain	7.89 (6.20, 8.92)	7.90 (6.21, 8.86)	0.72
Liver disease factors			
Etiology	—	—	**< 0.001**
NASH/NAFLD	100 (13.1)	100 (11.2)	—
Alcohol-associated liver disease (ALD)	176 (23.1)	180 (20.1)	—
HBV	26 (3.4)	77 (8.6)	—
HCV	341 (44.8)	421 (47.0)	—
Primary biliary cholangitis (PBC)/ Primary sclerosing cholangitis (PSC)	17 (2.2)	50 (5.6)	—
Other[c]	52 (6.8)	66 (7.4)	—
Missing/Unknown	50 (6.6)	1 (0.1)	—
MELD Score at Referral, median (1st-3rd quartiles)	13 (10, 18)	14 (10, 19)	**0.01**
MELD Score at Referral	—	—	**< 0.001**
< 15	299 (39.2)	449 (50.2)	—
15–29	188 (24.7)	415 (46.4)	—
30–35	9 (1.2)	21 (2.4)	—
> 35	12 (1.6)	7 (0.8)	—
Unknown/missing	254 (33.3)	3 (0.3)	—
HCC Status (Y/N)	—	—	**< 0.001**
Yes	105 (13.8)	412 (46.0)	—
No	657 (86.2)	483 (54.0)	—

Notes: p values are from Pearson chi-squared and Wilcoxon rank sum tests for categorical and continuous variables, respectively.
[a]Non-Hispanic Other race: American Indian, Asian, and Pacific Islander patients.
[b]Other language: Korean, Vietnamese, Japanese, Thai, Burmese, Cambodian, Laotian, Philippines, Punjabi, Hindi.
[c]Other etiology = polycystic liver disease (PLD), Caroli, Cryptogenic, cystic fibrosis (CF), autoimmune hepatitis (AIH).

(HR 0.94, 95% CI 0.90 – 0.97, $p = 0.001$), and racial and ethnic minority status domain (HR 0.94, 95% CI 0.89 – 0.99, $p = 0.04$) were associated with lower rate of waitlisting. For individual measures of SES, both insurance type and employment status were associated with waitlisting. Patients with Medicaid (HR = 0.50, 95% CI 0.34 – 0.73, $p < 0.001$) or Medicare insurance (HR 0.68, 95% CI 0.50 – 0.91, $p = 0.01$) had lower rates of

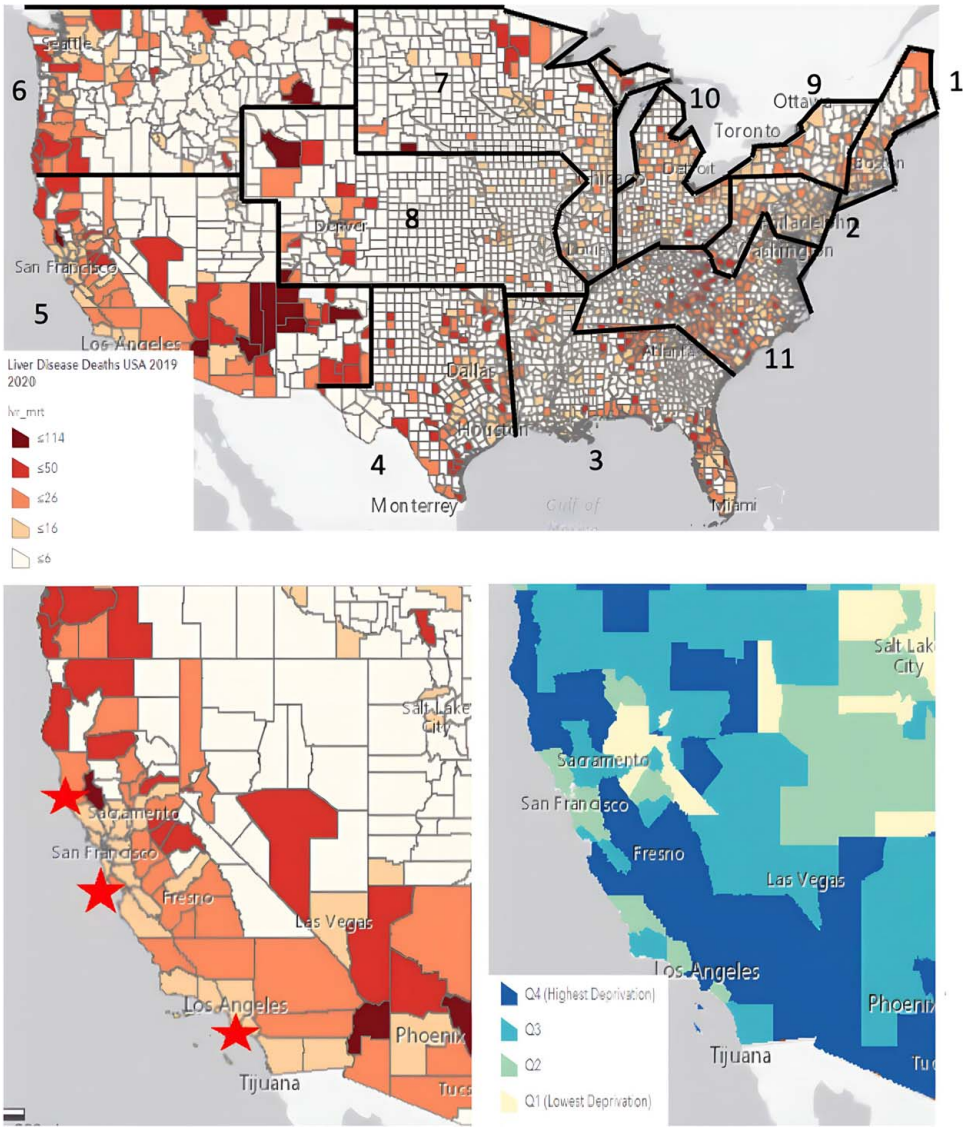

FIGURE 2 Progression of patients through the liver transplant cascade.

waitlisting compared to private insurance. Unemployed (HR 0.68, 95% CI 0.48 – 0.97, $p = 0.03$), disability (HR 0.56, 95% CI 0.37 – 0.83, $p = 0.004$), and those with unknown/missing employment status (HR 0.13, 95% CI 0.03 – 0.52, $p = 0.004$) were all associated with lower rates of waitlisting (Table 2).

Similarly, both community-level vulnerability and individual measures of SES were associated with rate of transplantation (Table 3). Patients residing in more vulnerable communities had 6% lower rate of transplantation per 0.1 U increase in overall SVI (HR 0.94, 95% CI 0.91 – 0.98, $p = 0.002$). As for the SVI domains, a 0.1 U increase in SES domain (HR 0.95, 95% CI 0.92 – 0.98, $p = 0.004$) and household characteristics domain (HR 0.95, 95% CI 0.92 – 0.99; $p = 0.008$) were associated with a lower rate of transplantation. For individual measures of SES, both insurance type and employment status were associated with rate of transplantation. Patients with Medicaid (HR 0.41, 95% CI 0.29 – 0.56, $p < 0.001$) or Medicare (HR 0.50, 95% CI 0.39 – 0.66, $p < 0.001$) insurance have lower rates of transplantation compared to privately insured patients. Unknown/missing employment status (vs working; HR 0.08, 95% CI 0.01 – 0.54, $p = 0.01$) was associated with 92% lower rate of transplantation.

In contrast, neither community-level vulnerability nor individual measures of SES were significantly associated with mortality prior to waitlisting (Table 2; $p > 0.05$) or mortality while on the waitlist (Table 3; $p > 0.05$).

Results from univariate cause-specific HR models for the rate of waitlisting are shown in Supplemental Table 2, http://links.lww.com/HC9/A335. Patient characteristics, including insurance type, SVI, disease etiology, and HCC status, differed significantly between

TABLE 2 Multivariable HR models for waitlisting: community-level vulnerability versus individual measures of SES

		Cause-Specific HR	
Model[a]	**Variable**	**Waitlisting (95% CI)**	**Mortality prior to Waitlisting (95% CI)**
1	**Overall SVI (community-level vulnerability)**	**0.92 (0.87, 0.96)**	1.02 (0.96, 1.08)
	Socioeconomic status domain	**0.92 (0.89, 0.96)**	1.02 (0.95, 1.07)
	Household characteristics domain	**0.94 (0.91, 0.98)**	0.98 (0.92, 1.04)
	Housing type & transportation domain	**0.94 (0.90, 0.97)**	1.02 (0.96, 1.09)
	Racial & ethnic minority status domain	**0.94 (0.89, 0.99)**	1.05 (0.96, 1.15)
2	**Individual measures of SES**	—	—
	Insurance Type (ref = private)	—	—
	Medicaid	**0.50 (0.34, 0.73)**	0.83 (0.51, 1.34)
	Medicare	**0.68 (0.50, 0.91)**	0.87 (0.58, 1.31)
	Employment status (ref = working)	—	—
	Unemployed	**0.68 (0.48, 0.97)**	1.05 (0.60, 1.82)
	Disabled	**0.56 (0.37, 0.83)**	1.03 (0.58, 1.81)
	Retired	0.80 (0.59, 1.10)	1.17 (0.69, 1.96)
	Unknown/missing	**0.13 (0.03, 0.52)**	0.84 (0.43, 1.63)

Notes: Race and ethnicity include categorical variable with non-Hispanic White patients (reference group), non-Hispanic other patients (American Indian, Asian, and Pacific Islander patients), Non-Hispanic Black patients, Hispanic/Latinx patients, and missing/unknown.
Variables with >5% missing data that was significantly associated with waitlisting on univariate analysis were included with a missing/unknown category.
HR = hazard ratio; bolded = p-value < 0.05.
[a]All adjusted for age, sex, MELD at referral, HCC Status, disease etiology, race, and ethnicity.

the group without missing data (n = 1297) and the group with missing data (n = 360), indicating that the data are not missing at random (Supplemental Table 1, http://links.lww.com/HC9/A335). The main models, which included the missing category for variables with >5% missing data, had notable differences when compared to multiply imputed (Supplemental Tables 3 and 5, http://links.lww.com/HC9/A335) and complete case models (Supplemental Tables 4 and 6, http://links.lww.com/HC9/A335) performed as sensitivity analyses. These differences included individual educational level, insurance type, and employment status.

TABLE 3 Multivariable HR models for transplantation: community-level vulnerability versus individual measures of SES

		Cause-specific hazard ratio	
Model[a]	**Variable**	**Transplantation (95% CI)**	**Mortality while on the Waitlist (95% CI)**
1	**Overall SVI (community-level vulnerability)**	**0.94 (0.91, 0.98)**	1.02 (0.98, 1.06)
	Socioeconomic status domain	**0.95 (0.92, 0.98)**	1.02 (0.98, 1.06)
	Household characteristics domain	**0.95 (0.92, 0.99)**	0.99 (0.96, 1.03)
	Housing type & transportation domain	**0.96 (0.93, 1.00)**	1.02 (0.98, 1.05)
	Racial & ethnic minority status domain	0.96 (0.92, 1.00)	1.02 (0.96, 1.07)
2	Individual measures of SES		
	Insurance Type (ref = private)		
	Medicaid	**0.41 (0.29, 0.56)**	0.86 (054, 1.39)
	Medicare	**0.50 (0.38, 0.66)**	0.90 (0.60, 1.34)
	Employment status (ref = working)		
	Unemployed	1.00 (0.74, 1.35)	1.26 (0.91, 1.74)
	Disabled	1.01 (0.74, 1.37)	1.06 (0.75, 1.49)
	Retired	0.84 (0.65, 1.10)	1.09 (0.80, 1.49)
	Unknown/missing	**0.08 (0.01, 0.54)**	0.84 (0.48, 1.48)

Notes: Variables with > 5% missing values in model included an unknown/missing category.
Race and ethnicity include categorical variable with non-Hispanic White patients (reference group), non-Hispanic other patients (American Indian, Asian, and Pacific Islander patients), Non-Hispanic Black patients, Hispanic/Latinx patients, and missing/unknown.
Variables with >5% missing data that was significantly associated with waitlisting on univariate analysis were included with a missing/unknown category.
bolded = p-value <0.05.
[a]All models adjusted for age, sex, MELD at referral, HCC Status, disease etiology, race, and ethnicity.

DISCUSSION

LT is the only lifesaving procedure for ESLD. While there are national databases on waitlisted patients, there are no centralized or standardized data on prewaitlist patients. This has created a knowledge gap in our understanding of early barriers to LT. Within this context, there has been increasing calls to standardize data collection of patient socioeconomic factors and social deprivation indices based on geography.[8] We found that increasing community-level vulnerability, individual government insurance, and individual employment status were associated with lower rates of waitlisting and transplantation. We also found nonignorable missingness in employment status associated with lower rates of LT.

In our study, a 0.1 U increase in community-level vulnerability was associated with 8% lower rate of waitlisting and 6% lower rate of transplantation. Our findings support the growing body of evidence that a patient's neighborhood impacts LT evaluation outcome. In a single-center cohort study, Mohamed et al found that patients from low-income neighborhoods have a 44% lower odds of waitlisting;[7] in a Canadian cohort study, Flemming et al found that patients living in the most vulnerable neighborhoods had 45% lower odds of LT.[13] Although the study by Mohamed et al and our study are based in two distinctly different waitlist UNOS regions, they suggest that neighborhood poverty might be associated with lower rates of waitlisting and transplantation.[7] Combined, these studies suggest that community-level vulnerability is an independent predictor of poor LT evaluation outcome. In addition, our study further identifies the components of community-level vulnerability that are associated with waitlisting and transplantation, giving us further insight into the patient's socioeconomic living environment that might contribute to their LT evaluation outcomes.

We identified several SVI domains, including SES and household characteristics, that were associated with lower rates of waitlisting and transplantation. Specifically, individuals residing in higher SES domains, characterized by living below the poverty line, not having a high school diploma, being unemployed, and having a low median income,[11] had lower rates of waitlisting and transplantation. It is well known that patients with a high school degree or less have low health literacy, which in turn, has been associated with a lower likelihood of waitlisting.[14] Improving the readability of LT educational materials has been associated with increased waitlisting, particularly for patients with education less than a high school.[15] As such, the National Institute of Health recommends a seventh-grade level of online readability for LT educational materials.[16] Educational achievement has an even broader impact through its influence on a patient's employment and income,[17] which may, in turn, impact their LT evaluation outcome. While additional studies are needed to explore how best to leverage these SVI domains, the significance of the SES domain for our study population suggests education, employment, and income are critical in LT evaluation outcomes, even at the neighborhood level. One potential strategy would be to use SES domain to identify patients who might benefit from additional financial and social support in the form of case managers, social workers, and patient navigators.

Our study revealed an intriguing association between racial and ethnic minority status domain and LT evaluation outcome: while it was associated with lower waitlisting, it did not appear to significantly affect the transplantation rate. This domain comprises the neighborhood's racial and ethnic minority status and the proportion of individuals speaking English "less than well."[11] The language component of this domain is worth noting since only a fraction of LT centers have online materials available in languages other than English.[18] Regarding racial and ethnic minority status, we know that racial residential segregation can exacerbate the unequal distribution of social resources[19] and partially mediate structural racism.[20] Moreover, research has demonstrated that the negative health effects of racial segregation are not independent of neighborhood deprivation.[21] While this is a neighborhood-level finding, its significance underscores the importance of structural practices and policies that revolve around race and ethnicity during LT evaluation. These factors may play a considerable role in determining evaluation outcomes, although their significance may lessen once patients are waitlisted.

To avoid ecological fallacy,[22] we also examined the association between individual-level socioeconomic factors and LT evaluation outcome. Like Mohamed et al, we found that patients with Medicaid insurance had lower rates of waitlisting,[7] but unlike their finding, we found Medicare insurance associated with a lower rate of transplantation. On the other hand, we found both Medicaid and Medicare associated with lower rates of LT receipt. A national study of 177,862 LT candidates found that 59% were privately insured, 21% by Medicare, and 16% by Medicaid,[23] with government-insured patients less likely to receive LT.[23,24] This might be due to the fact that patients with government insurance present with higher MELD scores at waitlisting and have a higher risk of waitlist mortality.[25,26] In addition, patients with Medicaid and Medicare have a higher incidence of delisting compared to patients with private insurance.[25] A policy goal ensuring Medicare Advantage coverage for patients with ESLD, like what is currently available for patients with end-stage renal disease, might help address some of the inequities observed. While Medicare coverage for ESLD might improve the odds of allograft receipt, we must keep in mind the current limitations of Medicare in the post-LT phase. Medicare drug coverage is limited to 3 years after transplant for patients younger than 65 years and not disabled, with loss of coverage associated with 140%–740% higher allograft loss after

Medicare loss.[27] In addition, it does not cover off-label immunosuppressive drug coverage,[28,29] which accounts for ~17% of prescriptions in LT.[29]

When it came to employment status, we found nonignorable missingness in EHR data. Even though missing data has been previously handled through complete case analysis, multiple imputation has gained recent traction as a potential solution.[30] Yet in our study, our missing/unknown data did not meet the criteria for multiple imputation—missingness was associated with our outcome, suggesting these values were not missing at random.[31] Similarly, complete case analysis led to significantly different associations between the SES predictors and outcomes compared to results from our main analysis. As there is no protocol that specifies what data are to be collected, our findings suggest that data missingness warrants further consideration. For instance, we found that missing employment status was associated with 87% and 92% lower rates of waitlisting and transplantation, respectively. This highlights the importance of standardizing prewaitlist data to not only minimize "missing values" but to also identify which patient-level SES factors impact LT evaluation outcomes. Beyond that, we should aim to gather more granular occupation categories based on either labor type (manual vs. nonmanual) or graded hierarchy of skills[32] instead of using employment status as a proxy measure. While we must be cautious to draw conclusions about individuals based solely on the neighborhoods they live in,[22] neighborhood-level measures of SES have emerged as potential solutions to address missing SES data,[3] and at times, might provide helpful contextual information regarding a patient's environmental and socioeconomic milieu that would otherwise not be available to providers.

Limitations

This study has limitations. First, although the first barrier in the path to LT is a referral to a transplant center, our study did not address the pre-referral stage. This stage is not well studied, but 1 study demonstrated that Black veterans were 85% less likely than White veterans to be referred for LT.[33] During our study period, the Center for Disease Control WONDER Wide-ranging Online Data for Epidemiology Research (Centers for Disease Control and Prevention WONDER) database had 18,049 individuals in California with liver disease, with a crude death rate of 15.5 per 100,000.[34] This information underscores the overall liver disease burden in California and that UCSF gets a small fraction of patients with ESLD. Within this context, of the 1657 patients referred to UCSF for LT evaluation, 46% were not waitlisted, which suggests that this might be the first barrier to transplantation at our center. Our data may not have been missing at random, so we could not justify the use of multiple imputations or complete case analysis. The differences found in the results from our sensitivity analyses compared to our main results, which included analysis of the missing/unknown categories, further indicate the potential for biased estimates when omitting missing data or imputing values. There is potential nonignorable missingness in EHR data, as there is no study protocol that specified when and what data are to be collected. Second, while we had some measures of SES, we recognize that unmeasured aspects of SES, such as income and occupation type,[32] may have a plausible role, and our findings should be understood within this context.

CONCLUSION

Overall, our study has identified patients with lower rates of waitlisting and transplantation as those from more vulnerable communities, those with government insurance, and those not working. Our findings also suggest that there might be a role for both composite community-level vulnerability and its individual domains in identifying patients who might benefit from additional support while navigating LT evaluation. The National Academies Sciences, Engineering, and Medicine recommends establishing a standardized data collection of race, ethnicity, language, geographic social deprivation index, and "other factors" to better understand and reduce disparities.[8] As we start working toward this goal, we need to carefully consider which SES variables to standardize and collect. A growing body of evidence suggests that community measures of SES (SVI, area deprivation index, and neighborhood deprivation) can help identify patients who have lower odds of being on waitlist[7] or transplanted.[13] We propose that in addition to individual-level measures of SES, we should consider both composite measures of community vulnerability and its individual domains in identifying and providing targeted interventions to achieve transplant equity.

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CONFLICTS OF INTEREST

The authors have no conflicts to report.

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical considerations.

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