Evaluating Place-Based Disadvantage Indices in Heart Transplantation

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**Abstract**

**Introduction.**

US heart transplant candidates from socioeconomically disadvantaged communities have lower access to transplant. The forthcoming continuous distribution policy will provide an opportunity to directly address this disparity, but first the place-based disadvantage index that best captures this relationship must be determined.

**Methods**

We studied all adult heart transplant candidates initially listed between January 1, 2019 and December 31, 2022 using the Scientific Registry of Transplant Recipients.We used competing risk regression to estimate the association of four place-based disadvantage indices, Social Vulnerability Metric (SVM), Social Vulnerability Index (SVI), Area Deprivation Index (ADI), and Distressed Communities Index (DCI), with 1) transplantation and 2) death or deterioration on the waiting list, adjusted for demographic characteristics, durable left ventricular assist device (LVAD), and initial medical urgency status. As a sensitivity analysis, we performed the same analysis, but stratified by candidate listing center.

**Results**

Our final study cohort included 16,639 adult heart transplant candidates. All four place-based disadvantage scores were associated with transplantation to varying extents. In our unstratified regression, we found increasing ADI to be most strongly associated with decreasing likelihood of receiving a transplant and

Candidates in the 10th SVM decile were significantly less likely to receive transplantation than candidates in the 1st decile (sub-HR=0.84, p<0.001). Candidates in the 4th, 7th, and 9th SVI decile were significantly less likely to be transplanted (9th: sub-HR=0.82, p=0.034). Candidates in the 4th through 10th ADI decile were significantly less likely to be transplanted (10th: sub-HR=0.73, p<0.001). Candidates in the 3rd and 10th DCI decile were less likely to receive a transplant (10th: sub-HR=0.87, p=0.006).

**Conclusion**

In this study of US adult heart transplantation candidates, we found that all four place-based disadvantage indices showed that candidates from more vulnerable communities were less likely to receive transplantation and more likely to be removed for death or deterioration. ADI and SVI performed the best out of the indices we studied. There was significant variation between the predictive abilities of the four scores, highlighting the complexity of the relationship between social vulnerability and access to transplant.

**Introduction**

Heart transplantation is the gold standard treatment for end-stage heart failure. The federal Final Rule for organ transplantation states that access to transplantation “shall not be based on the candidate's place of residence or place of listing” except to the extent required by the logistics of organ placement. Previous work has demonstrated how the current heart allocation system fails to satisfy this requirement. Patients living in more vulnerable urban communities that are in close physical proximity to transplant centers are less likely to receive a heart transplant and more likely to die or deteriorate on the waitlist.2-7

The Organ Procurement and Transplant Network (OPTN) is currently creating a continuous distribution system for heart allocation, where candidates will be assigned priority based on five factors combined into a single composite allocation score (CAS).8,9 One of these CAS factors is “patient access”, highlighting equitable distribution as a priority of the new continuous distribution framework. Candidates could receive patient access points proportional to their place-based barrier to transplantation, enhancing the heart allocation system’s compliance with the Final Rule.

There are several established place-based disadvantage indices that rely on different data sources and have different minimum geographic units. The place-disadvantage index that best captures the relationship between socioeconomic barriers to transplant for candidates is unknown. In this manuscript, we compare four place-based disadvantage indices in their ability to predict heart transplant waitlist outcomes, providing insight into how these indices can be used to promote equitable distribution in the forthcoming allocation system.

**Methods**

*Data Source and Study Population*

This study used data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donors, wait-listed candidates, and transplant recipients in the US, submitted by the members of the OPTN.

The study cohort included all adult (≥18 years old at listing) heart transplant candidates with initial listing between January 1, 2019 and December 31, 2022. Combined heart-lung transplant candidates were excluded, but candidates for other multi-organ transplants were included.

This study uses deidentified patient data and was granted an exemption by the Institutional Review Board at the University of Chicago.

*Primary Outcome: Heart Transplantation*

The primary event of interest was heart transplantation. Candidate death or removal from the waitlist due to deterioration served as a competing event. Time to event for each candidate was defined as time from initial listing to first event. Candidates that were removed from the waitlist for other reasons or were still on the waitlist as of March 2024 were censored.

**Place-Based Disadvantage Indices and Covariates**

Candidates were assigned place-based disadvantage index values based on their permanent ZIP code address. We compared four different place-based disadvantage indices as proxies for the social determinants of health (SDoH): Social Vulnerability Metric (SVM), Social Vulnerability Index (SVI), Area Deprivation Index (ADI), and Distressed Communities Index (DCI).

SVI 3,4,11, ADI12-14, and DCI 2 have all been previously utilized as measures of SDoH in solid organ transplantation studies. SVM is a relatively newer model, that was derived from a large set of SDoH variables from multiple nationally representative public use administrative databases using Multidimensional Item Response Theory (MIRT). This robust statistical methodology has shown promise as a potential improvement over existing place-based disadvantage indices.15 The 2022 version of SVI calculated from census tracts was accessed via the US Department of Health and Human Services.16 The 2021 version of ADI was accessed via the University of Wisconsin School of Medicine and Public Health.14 The 2021 version of DCI was purchased through the Economic Innovation Group.17

We scaled each composite index into national percentiles, and candidates were assigned percentile values for each of these place-based disadvantage indices based on their permanent ZIP code. For ADI and SVI, we used crosswalk files from the Department of Housing and Urban Development to assign index values calculated from census tracts (11-digit FIPS code) to a candidate’s permanent 5-digit ZIP code.18 Because a given 5-digit ZIP code may be divided between multiple census tracts, we took the mean ADI and SVI value for each 5-digit ZIP code.

**Statistical Analysis**

For each place-based disadvantage index, we performed a competing risk regression model with the index of interest split by decile (categorical variable). We included age, sex, race and ethnicity, ventricular assist devices (durable LVAD, temporary LVAD, RVAD, LVAD+RVAD, total artificial heart), and initial status (1-6) of candidates as covariates. We categorized race as “White”, “Black or African American”, “American Indian or Alaska Native”, “Asian”, “Native Hawaiian or Other Pacific Islander”, “Arab or Middle Eastern”, or “Other” and ethnicity as “Latinx” or “Not Latinx”. Descriptions of device categorization can be found in Supplemental Table 1.

In a second set of calculations, we also modeled the cause-specific hazard ratio of transplantation and death or deterioration using mixed-effects Cox proportional hazard models for each index percentile (as a continuous variable) using a restricted cubic spline with 5 knots (5th, 27.5th, 50th, 72.5th, and 95th percentile). To determine cause-specific hazard of transplantation, candidates were censored at time of death or deterioration. To determine cause-specific hazard of death or deterioration, candidates were censored at time of transplantation. We also used an unadjusted logistic regression to model the association between durable LVAD usage and place-based disadvantage index percentile (continuous variable). The 50th percentile for each place-based disadvantage index was set as the reference. The fit of each index was evaluated using the area under the receiver operating characteristic curve (AUC) and c-index.

*Sensitivity analyses*

As a sensitivity analysis for each index, we also performed competing risk regression with place-based disadvantage index deciles with all previously mentioned covariates, stratified by the transplant center where each candidate was waitlisted (Supplemental Table 2).

Statistical significance was set at 2-tailed p < 0.05. All analyses were performed using R version 4.4.0 (R Foundation for Statistical Computing).

**Results**

Our final study cohort included 16,639 adult heart transplant candidates from across the country (mean [SD] age at listing, 53 [13] years; 74% male; 0.4% American Indian or Alaska Native, 3.7% Asian, 26% Black or African American, 0.4% Native Hawaiian or Other Pacific Islander, 59% White, 10% Hispanic). 12,399 (74.5%) received heart transplantation, 1,319 (7.9%) died or were removed from the waiting list for deterioration, and 2,921 (17.6%) had been removed for other reasons or were still on the waitlist as of March 2024. Compared to candidates that received a transplant, candidates that died or were removed for deterioration tended to be older, non-White, and live in more vulnerable communities (higher mean place-based disadvantage index values). Table 1 describes our overall study cohort, as well as cohort characteristics for patients in the 1st and 10th ADI decile. Supplemental Figure 1 shows a color map of the SDoH composite score across all ZIP codes in the city of Chicago to provide an example of the variation between different SDoH scores.

When the full set of covariates were included in our competing risks regression models, we found that candidates in the 10th decile of SVM were significantly less likely to receive a transplant, when compared to candidates in the 1st SVM decile (sub-HR = 0.84, CI = [0.76, 0.93], p<0.001). For SVI, candidates in the 4th, 7th, and 9th decile were significantly less likely to receive a transplant than candidates in the 1st SVI decile (4th: sub-HR = 0.81, CI = [0.68, 0.96], p=0.018; 7th: sub-HR = 0.83, CI = [0.69,0.99], p = 0.034; 9th: sub-HR = 0.82, CI = [0.68, 0.98], p = 0.034). For ADI, candidates in the 4th through 10th ADI decile were all significantly less likely to receive a transplant than candidates in the 1st ADI decile (4th decile: sub-HR = 0.84, CI = [0.76, 0.93], p<0.001; 5th: sub-HR = 0.84, CI = [0.76, 0.93], p<0.001; 6th: sub-HR = 0.88, CI = [0.79, 0.97], p=0.012; 7th: sub-HR = 0.81, CI = [0.73, 0.90], p<0.001; 8th: sub-HR = 0.83, CI = [0.75, 0.92], p<0.001; 9th: sub-HR = 0.76, CI = [0.68, 0.85], p<0.001; 10th: sub-HR = 0.73, CI = [0.63, 0.86], p<0.001). For DCI, candidates in the 3rd (sub-HR = 0.90, CI = [0.83, 0.98], p=0.02) and 10th (sub-HR = 0.87, CI = [0.78, 0.96], p = 0.006) deciles were less likely to receive a transplant than candidates in the 1st DCI decile.

For death or deterioration, we found that candidates in the 7th, 9th, and 10th SVM deciles were significantly more likely to die or deteriorate than candidates in the 1st SVM decile (7th: sub-HR = 1.26, CI = [1.01, 1.56], p = 0.038; 9th: sub-HR = 1.35, CI = [1.07, 1.71], p = 0.01; 10th: sub-HR = 1.45, CI = [1.12, 1.87], p = 0.005). SVI decile did not significantly predict a candidate’s likelihood of death or deterioration. For ADI, candidates in the 4th and 7th through 10th decile were significantly more likely to die or deteriorate than candidates in the 1st ADI decile (4th decile: sub-HR = 1.40, CI = [1.02, 1.93], p = 0.038; 7th: sub-HR = 1.81, CI = [1.32, 2.48], p<0.001; 8th: sub-HR = 1.41, CI = [1.02, 1.95], p = 0.037; 9th: sub-HR = 1.94, CI = [1.40, 2.70], p<0.001; 10th: sub-HR = 2.16, CI = [1.43, 3.25], p<0.001). For DCI, candidates in the 3rd, 7th, and 10th DCI decile were more likely to die or deteriorate than candidates in the 1st DCI decile (3rd: sub-HR = 1.28, CI = [1.00, 1.62], p=0.045; 7th: sub-HR = 1.33, CI = [1.04, 1.70], p=0.023; 10th: sub-HR = 1.47, CI = [1.13, 1.91], p=0.004).

Figure 2 shows the cumulative incidence plots for the 1st and 10th decile of each index for transplantation and death or deterioration. Sub-hazard ratios of transplantation and death or deterioration for each ADI decile are shown in Figure 3. Full model effects are shown in Supplemental Tables 2-5. Sub-hazard ratios of transplantation and death or deterioration for SVM, SVI, and DCI are shown in Supplemental Figure 2

**Sensitivity Analysis: Competing Risk Regression Stratified by Transplant Center**

When we stratified our adjusted competing risk regressions by transplant center in our sensitivity analysis, we found that SVM decile did not significantly predict a candidate’s likelihood of receiving a transplant. For SVI, candidates in every SVI decile (2nd – 10th) were significantly less likely to receive a transplant than candidates in the 1st SVI decile (2nd decile: sub-HR = 0.85, p=0.047; 3rd: sub-HR = 0.80, p=0.005; 4th: sub-HR = 0.77, p=0.001; 5th: sub-HR = 0.78, p=0.002; 6th: sub-HR = 0.80, p=0.007; 7th: sub-HR = 0.78, p=0.002; 8th: sub-HR = 0.82, p=0.015; 9th: sub-HR = 0.79, p=0.006; 10th: sub-HR = 0.79, p=0.035). For ADI, candidates in the 9th decile were significantly less likely to receive a transplant than patients in the 1st ADI decile (sub-HR = 0.86, p=0.025). For DCI, candidates in the 3rd decile were significantly less likely to receive a transplant than patients in the 1st DCI decile (sub-HR = 0.91, p=0.048). Full model effects shown in Supplemental Table 6.

**Cause-Specific Hazard of Transplantation with Restricted Cubic Spline**

In our mixed-effects Cox proportional hazard models, we found that the SVM model had an AUC of 0.523 (95% CI = [0.513, 0.534]). The SVI model had an AUC of 0.520 (95% CI = [0.510, 0.530]). The ADI model had an AUC of 0.541 (95% CI = [0.531, 0.551]). The DCI model had an AUC of 0.528 (95% CI = [0.517, 0.539]). The c-index was 0.5130 for SVM (95% CI = [0.5074, 0.5186]), 0.5111 for SVI (95% CI = [0.5055, 0.5168]), 0.5267 for ADI (95% CI = [0.5210, 0.5324]), and 0.5144 for DCI (95% CI = [0.5085, 0.5204]).

**Odds of Durable LVAD with Restricted Cubic Spline**

In our logistic regression models, we found that SVM had a c-index of 0.5582 (95% CI = 0.5474, 0.5688). The SVI model had a c-index of 0.5304 (95% CI = 0.5196, 0.5412). The ADI model had a c-index of 0.5627 (95% CI = 0.5521, 0.5734). The DCI model had a c-index of 0.5561 (95% CI = 0.5448, 0.5673).

**Discussion**

In our analysis of 16,639 adult heart transplant candidates initially listed between 2019 and 2022, we found that all four indices showed some association with transplant, but ADI had the strongest relationship. When we did not stratify by listing center, ADI was significantly associated with receiving a transplant across a greater range of deciles than the other indices we studied. However, after stratifying our competing risk regressions by listing transplant center in our sensitivity analysis, we found that SVI was the most significantly associated with likelihood of transplant. These results highlight the complexity of the relationship between neighborhood and likelihood of transplant, and the importance of thoroughly investigating which place-based disadvantage index could best be used to promote equity in the new allocation system.

The differences in place-based disadvantage index performance between our unstratified and stratified competing risk regressions illustrate the complexity and challenge of quantifying patient access. In liver and kidney transplantation, place-based disadvantage indices had low inter-index concordance in their ability to identify vulnerable communities.10 Another interesting finding was the association between durable LVAD usage and place-based disadvantage index percentile (Figure 4). In our logistic regression models, candidates from more vulnerable communities (regardless of the selected index) have increased odds of having a durable LVAD. This finding is consistent with the fact that receiving a durable LVAD generally lowers a candidate’s status ranking (and thus probability of transplant) under the current system. Previous work has found that among heart transplant recipients who used either a durable LVAD or a temporary LVAD as a bridge-to-transplant, the time period from 2018-2021 showed a gradual decrease in the proportion of recipients using a durable LVAD.21 Given that the 2018 policy change effectively lowered the priority status of most durable LVAD recipients, the downward trend in durable LVAD use may reflect a trend of clinicians choosing to avoid durable LVAD use as a way to advocate for their patients’ chance of receiving a donor heart. If the avoidance of durable LVADs is effectively a form of patient advocacy, it is essential to question whether patients from vulnerable and marginalized communities are less likely to receive such advocacy (and ultimately more likely to receive a durable LVAD in lieu of heart transplantation).

Our own results are consistent with such a bias, with Figure 4 demonstrating a clear trend in which more socially vulnerable patients are more likely to receive LVADs. Previous work has demonstrated that patients from racial-ethnic minority groups are significantly less likely to receive kidneys with a lower chance of graft failure than White patients,22 while another study demonstrated that Black patients are significantly less likely to have their first heart offer accepted by transplant teams.23 Other work has found that patients from vulnerable and marginalized communities are less likely to be referred and selected as heart transplant candidates and have worse post-transplant outcomes.7 To effectively use tools such as Place-based disadvantage indices to promote equitable distribution, it is imperative that we continue to deepen our understanding of the disparities that occur at all stages of the heart transplantation process.

As the first study to quantitatively compare a number of common place-based disadvantage indices in heart transplantation, we hope these findings contribute to meaningful policy changes to work towards previously described disparities in heart allocation.2-7 As OPTN continues to develop the continuous distribution framework for heart transplantation, place-based disadvantage indices offer a readily accessible tool to quantify and adjust for differences in candidate access to transplantation based on social determinants of health. In donor liver allocation, Mankowski et al. used simulation with optimization to preserve the existing policy priorities in liver allocation, while generating a CAS that decreased overall deaths by 1.2%.19 We suggest that a similar optimization methodology could be applied to assign specific weights to index deciles in the development of the heart allocation CAS, combining the strengths of these methods to strive towards equity in heart transplantation.

**Limitations**

Our study has certain limitations based on the available data. First, the SRTR dataset is center-reported. While the data are reviewed by the US Department of Health and Human Services, this data collection protocol introduces potential biases into our study. Second, ADI and SVI were initially calculated using census tracts, whereas DCI and SVM were calculated at the ZIP code level. For the majority of candidates, permanent ZIP code was only available at the 5-digit ZIP code level. Thus, we chose to assign ADI at the 5-digit ZIP code level. We recommend that future work utilize census tract codes or 9-digit ZIP codes (which are mentioned as a viable alternative on the ADI website).

**Conclusion**

In this study of US adult heart transplantation candidates, we compared a series of place-based disadvantage indices (SVM, SVI, ADI, and DCI) in their ability to predict a candidate’s likelihood of transplantation based on their permanent ZIP code. We found that all four indices showed some association with likelihood of transplant. There was significant variation between the predictive abilities of the four indices, highlighting the complexity of the relationship between social vulnerability and access to transplant. We believe that these findings can support the development of the continuous distribution framework as the OPTN works towards eliminating inequities in heart allocation.

**Figure 1: STROBE Diagram**

**A flowchart of a patient

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**Table 1: Cohort Characteristics**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Study Cohort  N = 16,639 | ADI 1st Decile  N = 922 | ADI 10th Decile  N = 390 |
| Age at Listing, mean (SD) | 53 (13) | 55 (13) | 50 (12) |
| Sex, n (%)  Male  Female | 12,234 (74%)  4,405 (26%) | 696 (75%)  226 (25%) | 275 (71%)  115 (29%) |
| Race, n (%)  White  Black  Asian  American Indian or Alaska Native  Native Hawaiian or Other Pacific Islander  Other | 9,766 (59%)  4,392 (26%)  621 (3.7%)  65 (0.4%)  62 (0.4%)  1,733 (10%) | 524 (57%)  127 (14%)  130 (14%)  2 (0.2%)  4 (0.4%)  135 (15%) | 96 (25%)  248 (64%)  0 (0%)  13 (3.3%)  0 (0%)  33 (8.5%) |
| Latinx, n (%) | 1,732 (10%) | 131 (14%) | 33 (8.5%) |
| Ventricular Assist Device, n (%)  Durable LVAD  Temporary LVAD  RVAD  LVAD+RVAD | 3,477 (21%)  1,050 (6.3%)  1,094 (6.6%)  172 (1.0%) | 113 (12%)  48 (5.2%)  52 (5.6%)  5 (0.5%) | 106 (27%)  18 (4.6%)  19 (4.9%)  5 (1.3%) |
| Total Artificial Heart, n (%) | 36 (0.2%) | 0 (0%) | 0 (0%) |
| Initial UNOS Status, n (%)  1  2  3  4  5  6 | 879 (5.4%)  4,149 (25%)  1,782 (11%)  5,953 (36%)  558 (3.4%)  3,057 (19%) | 57 (6.2%)  267 (29%)  137 (15%)  248 (27%)  35 (3.8%)  169 (19%) | 9 (2.3%)  113 (30%)  32 (8.4%)  146 (38%)  13 (3.4%)  70 (18%) |
| SVM Percentile, mean (SD) | 42 (29) | 14 (18) | 91 (8) |
| SVI Percentile, mean (SD) | 49 (21) | 39 (20) | 77 (12) |
| ADI Percentile, mean (SD) | 48 (24) | 6 (2) | 93 (3) |
| DCI Percentile, mean (SD) | 46 (29) | 32 (24) | 91 (10) |
| Received transplant, n (%) | 12,399 (75%) | 744 (81%) | 250 (64%) |

**Figure 2: Cumulative Incidence Plots for 1st and 10th Decile of Each Place-Based Disadvantage Index**

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**Figure 3:** **Adjusted Competing Risk Regression Hazard Ratios by ADI Decile**

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\*Covariates included: age, sex, race and ethnicity, initial UNOS status, use of ventricular assist devices and/or total artificial heart

**Figure 4: Associations between Index Percentile, Transplantation, Death or Deterioration, and Durable LVAD using Restricted Cubic Spline**

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