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Neighborhood Accessibility as a Socio-Environmental Determinant in Kidney Transplant Health Services

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Environmental Health-Epidemiology

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By

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Bachelor of Arts
Pomona College
2020

Thesis Committee Chair: Katherine Ross-Driscoll, PhD, MPH

An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Science in Public Health
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Abstract

Neighborhood Accessibility as a Socio-Environmental Determinant in Kidney Transplant Health Services

By Jonathan Gunasti

Introduction: We investigated whether neighborhood accessibility to destinations by car, considered a proxy for spatial access to resources, was associated with days alive and out of the hospital (DAOH) or missed appointments after kidney transplant.

Methods: We identified a cohort of adult patients who received a kidney transplant between 2008 and 2018 from Emory University's clinical data warehouse. Our primary outcomes were 1) DAOH at three years and 2) missed appointments per follow up time within one year. Patients' residential addresses were geocoded and joined to the EPA Smart Location Database's relative index of regional centrality. We used Poisson regression to estimate the associations between neighborhood accessibility, DAOH, and missed appointments, accounting for individual and ecological covariates.

Results: Our cohort included 1,926 kidney transplant recipients. The median neighborhood accessibility among patients was 0.35 out of 1 (IQR: 0.15 to 0.54). There was no association between neighborhood accessibility and DAOH at three years in the general cohort (RR: 1.00, 95% CI: 0.96 to 1.02). However, there was effect modification by suburban residence (RR: 1.11, 95% CI: 1.02, 1.21). Neighborhood accessibility was associated with missed appointments in the fully adjusted model (RR: 1.11, 95% CI: 1.01, 1.23).

Conclusions: There was no association between neighborhood accessibility and DAOH, suggesting that neighborhood accessibility does not pose a barrier for most transplant recipients. However, those living in suburban settings may face unique challenges. In contrast, lower accessibility was associated with fewer missed appointments. This may be due to the additional planning required among those in inaccessible areas or patient selection during the waitlisting process.

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Background

Introduction

Approximately one in seven Americans live with chronic kidney disease (CKD), a condition in which one's kidneys do not clear wastes from the bloodstream or regulate blood pressure as well as healthy kidneys.[1] Approximately 2 in 1,000 Americans live with end stage kidney disease (ESKD).[2] Without treatment, ESKD can lead to death within days to weeks as wastes accumulate in the body. Kidney transplant is the optimal treatment choice for patients with end stage kidney disease (ESKD), offering the best quality of life and reductions in morbidity and mortality when compared to long-term hemodialysis or peritoneal dialysis.[3] In 2019, there were 24,502 kidney transplants in the USA, and 78,690 patients remained on the waitlist to receive a kidney transplant at the end of the year.[4]

Definition of Chronic Kidney Disease

Chronic kidney disease (CKD) is a general term that refers to the presence of an abnormality in the structure or function of the kidney that has lasted for at least three months.[5] Diagnosis includes at least of the following criteria: 1) glomerular filtration rate (GFR) of under 60 mL/minute, 2) albuminuria of 30 mg or greater per 24 hours, 3) urine sediment abnormalities, imaging, or histology that suggests kidney damage, 4) renal tubular disorder, or 5) history of kidney transplantation.[5] CKD is distinct from acute kidney injury, which refers to change in kidney function that occurs within 2 to 7 days, and from acute kidney disease, which refers to an abnormality in kidney function that has lasted for 3 months or less.[5]

CKD is classified into five stages of disease based on glomerular filtration rate (GFR), a measure of kidney function, and albuminuria, both of which can be estimated through routine laboratory testing. By GFR, the stages of disease include: more than 90 mL/min per 1.73 m^2 (stage 1), 60 to 89 mL/min per 73 m^2 (stage 2), 30 to 59 mL/min/1.73 m^2 (stage 3), 15 to 29 mL/min/1.73 m^2 (stage 4), and less than 15 mL/min/1.73 m^2 (stage 5). GFR is generally approximated and reported as an estimated GFR (eGFR) using equations that relate either creatinine or creatinine and cystatin C to eGFR values. Disease staging also incorporates albuminuria, which is classified as: A1 (urine albumin-to-creatinine ratio <30 mg/g), A2 (30 to 300 mg/g), or A3 (>300 mg/g).

End stage kidney disease (ESKD) refers to the final stage of CKD (stage 5). Patients' kidneys cease to function adequately at this advanced stage of disease. Without treatment, ESKD will lead to death within days to weeks. The first three stages of CKD are usually treated by the management of comorbid conditions, such as diabetes and hypertension, and through behavioral and dietary changes. In contrast, stage 4 and stage 5 CKD require more intensive intervention, with treatment options including dialysis, otherwise known as renal replacement therapy, and kidney transplantation.

CKD and ESKD in the United States

Approximately 37 million Americans, or 15% of the US adult population, live with chronic kidney disease (CKD).[1] The prevalence of CKD in the U.S. adult population has remained relatively constant since 2003.[6] However, there have been notable changes in CKD prevalence among subpopulations during this same period of time. For example, CKD prevalence decreased from 43.2% to 36.8% among those 65 or older since 2003.[4] Most patients with CKD are asymptomatic, and as many as 90% of CKD cases in the general U.S. population remain undiagnosed.[1] Similarly, approximately 40% of patients with severe CKD are unaware that they have kidney disease.[1]

782,818 patients were living with diagnosed ESKD in the USA in 2019, which represents an increase of over 40% from the 2009 prevalence of ESKD.[4] The adjusted 2019 prevalence of ESKD is 2252 per million population (pmp), which also reflects an increase from 2009 and an all-time high U.S. prevalence.[4] 130,400 patients were newly diagnosed with ESKD in the USA in 2019, which represents a 15% increase from the 2009 ESKD incidence.[4] However, the adjusted U.S. incidence of ESKD fell from 418 per million population (pmp) in 2006 to 272 pmp in 2019.[4]

Definition of Kidney Transplantation

Kidney transplant is the optimal treatment choice for patients with ESKD, offering the best quality of life and reductions in morbidity and mortality when compared to long-term hemodialysis or peritoneal dialysis. Additionally, the cost of maintaining a kidney transplant is less than a third of the cost of long-term dialysis.[2] There are currently two types of kidney transplant available to patients: living donor and deceased donor transplant.

Living donor transplant is the best option for patients, offering better long-term graft survival and function in comparison to deceased donor transplant.[7] In living donor transplant, a healthy kidney is removed from a living, compatible donor and used to replace a kidney that is no longer functioning properly. People often receive living donor transplants with kidneys donated by genetically related family members because family members tend to be compatible donors. Another pathway for living donor transplant is non-directed donation, a donation process in which a healthy person donates a kidney out of beneficence to an unknown recipient. A third option is paired donation. In paired donation, a donor may not be compatible with the recipient to whom they wish to donate an organ, however, they can donate their kidney to another patient in return for a compatible kidney donation from this patient's donor. If a patient does not have a living donor, they can receive a deceased donor transplant. In deceased donor transplantation, a kidney is removed from the deceased donor's body, stored, and later transplanted into the recipient's body.

A benefit of living donor transplant in comparison to deceased donor transplant is that patients spend less time waiting for a needed organ. Because the demand for kidneys is greater than the supply of deceased donors, patients must join a national waitlist and wait for a compatible organ to receive a deceased donor transplant. Most patients spend one to five years on the waitlist before they are matched with a deceased donor from the Organ Procurement Organization (OPO) through which they were added to the waitlist.[4,8] The median time spent on the kidney transplant waitlist in 2019 was 4.3 years.[4] The overall number of kidney transplants in the United States has increased in recent years; there were 24,502 kidney transplants in 2019, which represented a 10% increase from 2018.[4]

Disparities in Kidney Transplantation

Pervasive racial and socioeconomic disparities exist in the kidney transplant process. In 2019, the incidence of ESKD among Black patients was approximately three times the incidence among White patients.[4] Despite this difference, Black patients remain less likely to be placed on the kidney transplant waitlist than White patients.[4] Racial and socioeconomic disparities exist following kidney transplant as well. Patients from lower socioeconomic status neighborhoods face higher rates of graft failure[9] and hospitalization[10] following kidney transplant. Similarly, Black patients face higher rates of acute rejection and poor graft survival in comparison to White patients.[11] Recent policy reform has attempted to address national racial disparities in the kidney transplant processes, however, progress remains to ensure equitable access to transplant.[12] Although disparities have reduced in severity in recent years[4], further social, political, and structural interventions are necessary to increase equity in the kidney transplant process.

Neighborhood Factors and Kidney Transplant Outcomes

Few studies have investigated the relationship between neighborhood factors and outcomes following kidney transplant. Studies that have considered the relationship between neighborhood environments and transplant outcomes have focused mainly on neighborhood socioeconomic status, mortality, and graft failure. A large, national retrospective cohort study determined that several community health indicators, including household income, percent inactivity, and percent low birth weight, were associated with post-transplant mortality.[13] Another national cohort study determined that there is an association between neighborhood poverty, death, and graft failure, and that this association was stronger among women than it was among men.[14] Likewise, a single-county retrospective cohort study found that patients living in neighborhoods of higher socioeconomic status experienced a lower hazard of graft failure.[9] Although research has focused on SES and neighborhood deprivation, SES has not been the only neighborhood factor of concern: a national cohort study also determined that zip code-level $PM_{2.5}$ air pollution, a product of the built environment, was associated with graft failure, acute rejection, and 1-year mortality among kidney transplant recipients.[15] Together, these findings suggest that even following the selection process implicated in waitlisting for a kidney transplant, neighborhood factors play important roles as determinants of transplant outcomes. Interventions to promote positive outcomes among transplant recipients, especially among recipients who already face social and structural barriers to successful transplant outcomes, must consider the impacts of neighborhood environments.

Kidney Transplant and Transportation

Transportation has been identified as a barrier to ongoing medical care in the United States. However, little is known regarding the specific impacts of transportation on population-level surgical disparities and, more specifically, on post-surgical outcomes. Despite anecdotal reports from kidney transplant candidates that transportation is a barrier during the kidney transplant process, there have been conflicting results regarding whether distance to kidney transplant centers is a determinant of pre- and post-kidney transplant outcomes. A recent large, national cohort study among all patients waitlisted for a kidney transplant in the USA found that distance from the transplant center was not associated with referral to care or transplant evaluation initiation.[16] Similarly, a 12-year national cohort study determined that distance to the transplant center was not associated with time to transplant.[17] However, the adjusted hazard of kidney transplant was greater among residents of micropolitan (HR: 1.13, 95% CI: 1.11-1.15) and urban areas (HR: 1.15, 95% CI: 1.13-1.18) in comparison to urban areas, indicating that other neighborhood factors may influence access to care.[17]

In contrast, two other large national cohort studies determined that the adjusted hazard of deceased donor kidney transplant is greater among those living closer to a transplant center while the adjusted hazard of living donor transplant is higher among those living farther from the transplant center. One study found that the adjusted hazard of kidney transplant among those in the third tertile of excess travel vs. the first tertile of excess travel for deceased donor transplant was 1.04 (95% CI: 1.02-1.06).[18] Another study found that the adjusted hazard of living donor transplant among those in the top travel distance quartile was 1.20 times the hazard among those in the first travel distance quartile (95% CI 1.16 to 1.24).

An important limitation of these large cohort studies is that they must rely on zip code data for geographic information. Zip codes are not a granular or precise measure, and exposures assigned using zip codes are subject to substantial exposure measurement error. Similarly, those in the highest quartile of exposure in these national studies are likely traveling between state and regional boundaries, and so this group of patients may not reflect differences in local access to transportation. Differences in the measures of associations observed between these large national cohort studies are also likely due to differences in the ecological covariates included in their models and methodological differences in the modeling approach employed, including differences in categorization of the exposure.

Two smaller cohort studies have investigated the association between transportation barriers and kidney transplant outcomes. A small cohort study of 585 transplant recipients at a single British transplant center determined that distance from the transplant center had no association with important kidney transplant outcomes, including acute rejection, renal graft survival, and patient survival, over a 5-year follow-up period.[19] Another small cohort study of 141 patients determined that patients who traveled longer distances did not experience higher hospital readmission rates or higher rates of graft failure.[20] While these smaller cohort studies overcome the exposure measurement error that occurs in the larger national studies by using address data in lieu of zip code data, neither account comprehensively for ecological covariates or effect modifiers other than urban/rural designations. Furthermore, they lack adequate power to detect more subtle differences in outcomes among demographic groups or by neighborhood characteristics.

Overall, the literature suggests that distance from the transplant center is not an impactful determinant of transplant outcomes. However, these results also suggest that neighborhood factors, like neighborhood SES, require investigation with more granular data. The literature is not yet conclusive on the role of specific neighborhood factors on post-transplant outcomes, and future research requires 1) larger sample sizes, 2) more granular spatial identifiers, and 3) more intentional methodological integration of individual and ecological variables to investigate neighborhood effects on kidney transplant outcomes.

Introduction

Transportation is a well-documented barrier to medical care in the United States. Approximately 3.6 million patients miss at least one medical appointment per year due to transportation barriers, and these patients tend to primarily be of lower socioeconomic status, older, and of non-White race.[21] Patients who face difficulties traveling to healthcare facilities delay care[22] or fail to fill prescriptions[23] more often than patients who do not face transportation barriers. These delays and missed appointments exacerbate existing socioeconomic and racial disparities in outcomes from care.[24,25] Identifying transportation-related barriers is therefore an important first step to reducing disparities in access to and outcomes from care.

Pervasive racial and socioeconomic disparities exist in the kidney transplant process.[26] Kidney transplantation is the optimal treatment for patients with end-stage kidney disease (ESKD), providing the best survival and quality of life in comparison to long-term dialysis.[27]

However, racial and socioeconomic disparities exist in access to transplant and post-transplant outcomes. Nationally, Black patients receive living donor kidney transplants at nearly one fourth of the rate of White patients.[28] Although disparities in outcomes have narrowed in recent years, Black patients are still 10% more likely to experience 5-year graft loss following deceased donor kidney transplant (DDKT) and 37% more likely to experience 5-year graft loss following living donor kidney transplant (LDKT) in comparison to White patients.[29] Waitlisted kidney transplant candidates of the highest socioeconomic status quartile have a higher likelihood of transplantation and lower likelihoods of graft failure and post-transplant mortality in comparison to candidates of lower socioeconomic status.[30]

Despite anecdotal reports from kidney transplant candidates[31,32] and providers[33,34] that transportation is a barrier during the kidney transplant process, there have been conflicting results regarding whether spatial access to kidney transplant centers impacts pre- and post-kidney transplant outcomes. Several large, national cohort studies have determined that race is associated with the distance that patients live from the nearest transplant center, with Black patients living closer to centers than White patients[30,35,36]. However, a national retrospective cohort study found no meaningful differences in graft failure or post-transplant mortality by distance to the nearest transplant center after adjusting for race.[35] Another national retrospective cohort study found that time to transplantation decreased with distance from transplant centers, with White patients experiencing greater benefit with distance and Black patients not experiencing any additional benefit.[36] In contrast, another national retrospective cohort study found that while time to deceased donor transplant decreased with longer travel time to the center, time to living donor transplant increased with increasing travel time.[30]

Methodological complications challenge research that seeks to characterize transportation-related barriers to care. Because a patient's zip code is the most granular geographic information available in national registry data, studies tend to use the Euclidian distance or drive time between zip code centroids and transplant centers as proxy measures of transportation burden. However, these approaches do not sufficiently identify areas with spatial difficulties in accessing care.[37] The true boundaries of a zip code are often unknown and change over time[38], and driving distance is not a precise measure of the spatial accessibility of care among those without cars. Distance from a transplant center also may not be indicative of more general spatial barriers to accessing health-promoting resources, such as healthy food or primary care. Residences more distant from transplant centers may at times have higher access to such resources. As distance to the nearest transplant center may not accurately measure transportation barriers, other approaches are necessary to determine whether spatial variation in access to resources influences transplant outcomes and disparities.

We conducted a retrospective cohort study among transplant recipients at Emory University Transplant Center using the EPA's Regional Centrality Index (Auto), a measure of access to regional employment opportunities by car, to assess the extent to which neighborhood accessibility impacts transplant outcomes. We considered this index as a proxy for spatial access to resources and opportunities. Our first objective was to determine whether patients who live in less accessible census block groups receive more intensive care after transplant. Our second objective was to determine whether patients live in less accessible census block groups miss scheduled appointments, including cancellations and no-shows, in the first year after transplant with a greater frequency than those who live in more accessible block groups. We hypothesized that, on average, those who live in less accessible block groups experience fewer days alive and out of the hospital (DAOH) and miss appointments more frequently after surgery.

Methods

Data Source

We identified a cohort of 1,926 patients who had undergone kidney transplant at Emory University Transplant Center. Patients were eligible for inclusion if they received a kidney transplant at Emory between January 1, 2008, and December 31, 2018, and were at least 18 years old at the time of transplant. Patients were excluded if they were missing a residential address, listed a PO box as a residential address, or lived outside the United States. Only the first kidney transplant was considered for patients with multiple transplants during the study period. The cohort was constructed using the Emory University Transplant Data Mart, a data repository which contains information on all kidney transplant recipients at Emory from the Clinical Data Warehouse, Organ Transplant Tracking Record, Nautilus Laboratory Information Systems, HistoTrac, and RedCAP.

Neighborhood Accessibility

The Regional Centrality Index - Auto (D5cri) was obtained at the census block group level from the EPA's Smart Location Database. This index is a proportion and represents relative accessibility of regional destinations in comparison to the maximum accessibility in the metropolitan region. The index is calculated by quantifying accessibility to employment opportunities by estimated travel time. The index uses a travel-time decay formula so that employment closer to the residential block group is weighted more heavily than employment farther away. Patient addresses were geocoded using the U.S. Census Geocoding tool and the Google Geocoding API and then joined to their corresponding census block groups.

Calculation of Outcomes

Days alive and out of the hospital (DAOH) was calculated as the difference between the follow-up period (3 years) and the duration of hospital stay for any reason within that period at Emory. The date of transplant was assigned to be day 0. Those who died within 30 days of transplant were assigned a DAOH of 0, regardless of their days alive and outside of the hospital after surgery, consistent with prior studies[39–41]. DAOH was calculated for those who died after the 30-day postoperative period as the difference between days alive following transplant and the total duration of hospital stay. For example, if a patient received a transplant on day 0, remained in the hospital for five days and was not readmitted to the hospital in the first year following surgery, they were assigned a DAOH of 360. Similarly, if a patient remained in the hospital for six days after transplant, was later readmitted to the hospital for four days, and died at day 50, they were assigned a DAOH of 40. Missed appointments were identified in appointment data as either "no-call, no-shows" or cancellations. Appointment days on which the data did not indicate that a patient attended any of their scheduled procedures or visits were coded as missed appointments, and days on which patients were marked as having attended at least one visit or procedure were coded as attended appointments. We chose to model missed appointments as a rate per follow-up time rather than as a proportion to account for larger denominators among those who cancel and re-schedule appointments. For example, a patient who re-scheduled 10 out of 40 appointments in one year would have a missed appointment proportion of 10/50 according to the data, even though their "true" proportion of rescheduled appointments should be 10/40. Likewise, we believe that there is an important distinction between a patient who reschedules 10 out of 20 appointments per year and a patient who reschedules 30 out of 60 appointments per year, even though both would have a missed appointment proportion of 0.5.

Coding of Covariates

Potential covariates were identified using a directed acyclic graph (DAG). Demographic and clinical covariates included sex, race (White, Black, or other/unknown), education (high school or less vs. some college or more), primary insurance at listing (Medicare, Medicaid, private, or other), donor type (living or deceased donor), BMI (less than 35 or 35 and greater), and age at transplant. Neighborhood-level covariates included the Area Deprivation Index (ADI) state rank by census block group, the percent of the population living below the poverty line by census block group, and Rural/Urban census designation (RUCA) by census tract, categorized as rural, urban, or suburban.

Statistical Analysis

Multi-level Poisson regression was used to assess 1) the association between neighborhood accessibility and DAOH and 2) the association between neighborhood accessibility and missed appointments during the first year after transplant with an offset of log follow up time. The follow up period for each patient was three years (1095 days) following the date of transplant. Robust standard errors were used to account for clustering by census block group. We used three models to assess each association: an unadjusted model, a minimally adjusted model, and a fully adjusted model. The minimally adjusted model included the minimally sufficient set to account for confounding: age, ADI, percent poverty, and RUCA category. The fully adjusted model contained a greater number of potential covariates to better estimate the direct effect of neighborhood accessibility. All analyses were performed in R 4.1.0.

Results

Cohort Characteristics and Relative Neighborhood Accessibility

Our cohort included 1,926 patients who received a kidney transplant at Emory University Transplant Center. Overall, the mean age at transplant was 50.1, 76.7% of patients had a BMI of 35 or less, and 40.7% of the cohort was female (Table 1). Most patients lived in urban census tracts (76.5%), while a minority of patients lived in suburban (12.1%) or rural tracts (11.4%). The median relative neighborhood accessibility in our cohort was 0.31 out of 1, and 71.4% of patients in the cohort had a relative neighborhood accessibility of less than 0.5. Relative neighborhood accessibility was not correlated with the Area Deprivation Index ($r = 0.08$) or the proportion of the census block group with an income under the federal poverty line ($r = 0.25$) in our sample. The highest quartile of neighborhood accessibility included a greater proportion of patients who received a deceased donor transplant, were not married, and were Black in comparison to the lowest accessibility quartile (Table 1). Urban census block groups tended to have the greatest accessibility, however, there was variation in both neighborhood accessibility and the proportion of the population living under the poverty line within all classifications of urbanity (Figure 1).

Days Alive and Out of the Hospital

Overall, transplant recipients in our cohort spent an average of 1034 (SD: 181) days alive and out of the hospital in the three years following kidney transplant (Table 3). Those with a BMI greater than or equal to 35, of Hispanic or Latinx ethnicity, of male sex, and who had Medicaid experienced fewer DAOH at three years (Table 3). There were no differences in DAOH by race. Neighborhood accessibility was not associated with DAOH in the 3 years following transplant in the minimally adjusted model or the fully adjusted model (Table 2).

We explored effect modification of the relationship between neighborhood accessibility and DAOH in the minimally adjusted model (Table 7). Neighborhood accessibility was associated with greater DAOH among those who had received a prior transplant (RR: 1.13, 95% CI: 1.01, 1.25), but fewer DAOH among those who had received their first transplant (RR: 0.98, 95% CI: 0.95, 1.01). The association between neighborhood accessibility and DAOH was greater among those living in suburban census tracts (RR: 1.11, 95% CI: 1.02, 1.21) in comparison to those living in urban (RR: 0.97, 95% CI: 0.94, 1.01) or rural (RR: 1.00, 95% CI: 0.94, 1.06) tracts. Similarly, the association between neighborhood accessibility was different among White patients (RR: 1.02, 95% CI 0.97, 1.07) and Black patients (RR: 0.97, 95% CI: 0.93, 1.01).

Missed Appointments

In our three-year study period, the mean scheduled appointment count was 71.1 (SD = 29.7), and patients missed a mean of 25.7 (SD = 14.0) appointments (Table 6). Both the count of scheduled appointments and the count of missed appointments decreased in the years following transplant. In the first year after transplant, patients had a mean missed appointment count of 13.7 (SD = 7.4) appointments out of 40.4 (SD = 11.1) scheduled appointments, while in the second year, patients had a mean missed appointment count of 8.6 (SD = 6.7) out of 19.9 (SD = 12.6) scheduled appointments. In the third year after transplant, patients had a mean missed appointment count of 4.3 (SD = 4.5) out of 13.0 (SD = 10.8) scheduled appointments. Patients with Medicare missed appointments at a greater rate than patients with Medicaid or private insurance (Table 5). Although missed appointment rates were comparable among Black and White patients, there was substantially more variation in the missed appointment rate among Black patients (Mean: 14.6, SD: 23.7) in comparison to White (Mean: 14.7, SD: 9.3) patients in the first year following kidney transplant.

Neighborhood accessibility was associated with missed appointments in the first year following kidney transplant in our fully adjusted model. Those living in the most accessible census block groups missed appointments at 1.11 times the rate at which those in the least accessible census block groups missed appointments (95% CI: 1.01, 1.23). Neighborhood accessibility was not associated with missed appointments in the crude model (RR: 1.09, 95% CI: 0.98, 1.19) or the minimally adjusted model (RR: 1.11, 95% CI: 1.00, 1.23).

Discussion

In this retrospective cohort study, we geocoded kidney transplant recipients' addresses to identify their neighborhood accessibility, or access to regional destinations by car. We considered this measure to be a proxy for transportation-related barriers to health-promoting resources. While we did not observe an overall association between neighborhood accessibility and days alive and out of the hospital (DAOH) in our cohort, we observed protective associations among those living in suburban areas and those who had received a prior transplant. In contrast, we observed an overall increase in missed appointment rate with increasing neighborhood accessibility. This association was modified by race, BMI, and area deprivation. Black patients in the most accessible neighborhoods missed appointments at 1.18 times the rate of Black patients in the least accessible neighborhoods (95% CI: 1.02, 1.36), whereas there was no significant association among White patients.

Our results suggest that the relationship between neighborhood accessibility and DAOH is not universal. It is possible that those with intermediate spatial access to resources, mainly those in suburban settings, have a uniquely burdensome experience of transportation-related barriers in comparison to those with lower neighborhood accessibility. Providers might follow rural patients more closely than suburban patients due to perceived vulnerability, attenuating the relationship that might otherwise exist between neighborhood accessibility and DAOH among rural patients. For example, rural patients are often held at the transplant center for a longer duration after surgery to ensure that they have a lower risk of complications before returning home[33]. It may also be more difficult to identify urban or suburban patients who face transportation-related barriers to daily living, and these patients might not receive adequate support to overcoming these barriers in the years following transplant. The association between neighborhood accessibility and missed appointment rate was also greater among suburban patients in comparison to rural patients, although no stratified rate ratio was significant. One potential explanation for this trend is that patients who live in distant areas must develop strategies to overcome barriers of distance as a part of routine life. It is likely that such patients develop a strong understanding of the time and planning required to attend an appointment in a faraway location, regardless of access to resources. In contrast, those in suburban settings with higher access to resources might perceive less risk from missing an appointment or may be less successful planning for lengthy trips.

Differences in our observed associations were also evident by race. White patients experienced a subtle benefit in their DAOH as neighborhood accessibility increased whereas Black patients did not, although neither the stratified rate ratios nor the overall association was significant. As the association was protective among White patients but hazardous among Black patients, a racial disparity may exist regarding one's ability to benefit from resources, regardless of physical proximity. This difference may have important downstream impacts on clinical outcomes. However, further research is necessary to determine whether such a disparity exists in the context of kidney transplant. The association between neighborhood accessibility and missed appointment rate was substantially greater among Black patients (RR: 1.18, 95% CI: 1.02, 1.36) in comparison to White patients (1.07, 95% CI: 0.92, 1.24). It is possible that differences in car ownership, driving ability, or social support exist among patients of different races in our cohort, which would lead to different magnitudes of association with neighborhood accessibility. Given these differences, social and structural interventions are necessary to promote equity among transplant recipients. Possible interventions include transportation programs to help those facing barriers to attend appointments, access healthy food, and engage in exercise opportunities in the years following transplant.

To the best of our knowledge, this is the first study to assess the association between a neighborhood factor, DAOH, and missed appointments among adult kidney transplant recipients. While prior studies have considered distance from the surgical center as a potential determinant of kidney transplant outcomes[19,20], other neighborhood characteristics are critical to consider because patients' long-term health depends both on services rendered at the surgical center and quality of life at home. As a patient-centered outcome, DAOH represents overall quality of life in addition to morbidity and mortality. Missed appointments, furthermore, act as an early sign of social difficulties post-transplant and represent an actionable and measurable opportunity for intervention.

While few studies have considered neighborhood factors and adult transplant outcomes, several studies have determined that neighborhood factors are relevant for pediatric surgical outcomes. A national cohort study among pediatric liver transplant recipients determined that children in more deprived neighborhoods have increased adjusted risks of graft failure and death[42]. Similarly, a national cohort study determined that pediatric cardiac surgery recipients from lower-income neighborhoods had increased odds of post-surgical mortality and 7% longer lengths of stay, adjusting for race and primary payer.[43] Neighborhood factors have been relevant in the context of adult surgical outcomes, as well. A national cohort study among adult patients found that neighborhoods with increased neighborhood high school graduation rates had increased hospital readmission rates in the five years following artery bypass grafting.[44] Our findings extend this knowledge to demonstrate that neighborhood factors have important relationships with kidney transplant outcomes, as well, and that these relationships are not universal among demographic populations.

This study builds upon earlier research that has relied predominantly on distance from the transplant center as a proxy for transportation-related barriers, incorporating a more relational perspective on access to resources. A small cohort study of 585 kidney transplant recipients at a British transplant center determined that distance from the transplant center had no association with outcomes including acute rejection, renal graft survival, and patient survival, over a 5-year follow-up period.[19] Another small cohort study of 141 patients determined that patients who traveled longer distances did not experience higher hospital readmission rates or higher rates of graft failure.[20] Although we did not directly assess the role of distance on transplant outcomes, by considering access to destinations more broadly we observed an effect whereas these prior studies did not. This difference suggests that transportation-related barriers are more complex than distance to the surgical center, and perhaps neighborhood-level indices more accurately model the relational[45] experience of social and spatial barriers.

It is important to acknowledge several limitations to this study. As a single-center study, these results may not be generalizable to other transplant centers or to regions beyond the Southeast. Our main exposure, the EPA's index of relative access to regional destinations by car, measures access to employment opportunities, which, while often an appropriate proxy, is not synonymous with access to health-promoting resources. Our exposure is likely inappropriate for some individuals who live in downtown urban areas and do not have access to resources even though they reside close to employment opportunities. This analysis also relied on data from our local clinical warehouse. Should patients have sought care at another hospital, any days in which they were admitted would not have been subtracted from their DAOH. Patients who traveled longer distances for their transplants, in particular, may have sought care at other hospitals. Given that we would expect non-differential misclassification of the exposure or of the outcome from these limitations, we would expect any potential bias in our results to be in the direction of the null hypothesis, and so our observed associations remain notable. As this analysis considered only transplant recipients, our results are applicable only to patients who have completed the rigorous patient selection process involved with waitlisting for a kidney transplant. The association that would be observed between neighborhood accessibility and DAOH or missed appointments among all patients who could benefit from a kidney transplant may be different from the associations that we observed in this study. Considering our limitations, major strengths of this study include assessing two novel outcomes for kidney transplant, DAOH and missed appointment rate, and assessing a novel neighborhood factor.

In conclusion, we found that among the general adult kidney transplant cohort, there was no association between neighborhood accessibility and DAOH. However, this relationship was modified by race, whether the patient had received a prior transplant, BMI, and neighborhood urbanity. In contrast, we found that spatial accessibility was associated with missed appointments, and this relationship was modified by race, BMI, and area deprivation. Future research should focus on the mechanism for the observed differences in the burden of transportation-related barriers to care by race and urbanity and assess interventions to promote access to resources among those who live in inaccessible neighborhoods. Transplant centers, insurance companies, or public health agencies may wish to implement transportation programs to ease the burden of accessing resources and to improve surgical outcomes.

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Tables

Table 1. Demographic, Clinical, and Ecological Characteristics of Study Population

Accessibility Quartile	**1** (N=484)	**2** (N=479)	**3** (N=481)	**4** (N=482)	**Overall** (N=1926)
Age at Transplant					
Mean (SD)	48.9 (12.8)	50.3 (12.7)	50.4 (13.0)	51.0 (13.0)	50.1 (12.9)
Median [Min, Max]	49.0 [18.0, 79.0]	52.0 [20.0, 78.0]	51.0 [20.0, 82.0]	52.0 [20.0, 77.0]	51.0 [18.0, 82.0]
BMI					
<35	368 (76.0%)	388 (81.0%)	371 (77.1%)	351 (72.8%)	1478 (76.7%)
>=35	37 (7.6%)	31 (6.5%)	38 (7.9%)	39 (8.1%)	145 (7.5%)
Missing	79 (16.3%)	60 (12.5%)	72 (15.0%)	92 (19.1%)	303 (15.7%)
Sex					
Female	207 (42.8%)	195 (40.7%)	194 (40.3%)	188 (39.0%)	784 (40.7%)
Male	277 (57.2%)	284 (59.3%)	287 (59.7%)	294 (61.0%)	1142 (59.3%)
Ethnicity					
Non-Hispanic or Latino	416 (86.0%)	419 (87.5%)	429 (89.2%)	412 (85.5%)	1676 (87.0%)
Hispanic or Latino	26 (5.4%)	33 (6.9%)	19 (4.0%)	12 (2.5%)	90 (4.7%)
Other or Unknown	42 (8.7%)	27 (5.6%)	33 (6.9%)	58 (12.0%)	160 (8.3%)
Marital Status					
Married[a]	233 (48.1%)	277 (57.8%)	311 (64.7%)	314 (65.1%)	1135 (58.9%)
Not Married or Separated[b]	249 (51.4%)	200 (41.8%)	170 (35.3%)	166 (34.4%)	785 (40.8%)
Unknown	2 (0.4%)	2 (0.4%)	0 (0%)	2 (0.4%)	6 (0.3%)
Race					
White	151 (31.2%)	157 (32.8%)	183 (38.0%)	280 (58.1%)	771 (40.0%)
Black	282 (58.3%)	286 (59.7%)	256 (53.2%)	169 (35.1%)	993 (51.6%)
Other or Unknown	51 (10.5%)	36 (7.5%)	42 (8.7%)	33 (6.8%)	162 (8.4%)
Primary Payer at Listing					

Private	191 (39.5%)	202 (42.2%)	210 (43.7%)	210 (43.6%)	813 (42.2%)
Medicaid	16 (3.3%)	10 (2.1%)	11 (2.3%)	11 (2.3%)	48 (2.5%)
Medicare	189 (39.0%)	191 (39.9%)	171 (35.6%)	184 (38.2%)	735 (38.2%)
Other	88 (18.2%)	76 (15.9%)	89 (18.5%)	77 (16.0%)	330 (17.1%)
Education					
College or Higher	255 (52.7%)	257 (53.7%)	257 (53.4%)	214 (44.4%)	983 (51.0%)
High school or less	138 (28.5%)	136 (28.4%)	131 (27.2%)	181 (37.6%)	586 (30.4%)
Unknown or Other	91 (18.8%)	86 (18.0%)	93 (19.3%)	87 (18.0%)	357 (18.5%)
Donor Type					
Deceased Donor	328 (67.8%)	320 (66.8%)	307 (63.8%)	287 (59.5%)	1242 (64.5%)
Living Donor	156 (32.2%)	159 (33.2%)	174 (36.2%)	195 (40.5%)	684 (35.5%)
First Transplant					
Yes	443 (91.5%)	429 (89.6%)	440 (91.5%)	457 (94.8%)	1769 (91.8%)
No	41 (8.5%)	50 (10.4%)	41 (8.5%)	25 (5.2%)	157 (8.2%)
Death During Follow Up					
0	444 (91.7%)	444 (92.7%)	442 (91.9%)	454 (94.2%)	1784 (92.6%)
1	40 (8.3%)	35 (7.3%)	39 (8.1%)	28 (5.8%)	142 (7.4%)
Follow Up Time (Days)					
Mean (SD)	1050 (192)	1060 (154)	1050 (195)	1060 (157)	1050 (175)
Median [Min, Max]	1100 [8.00, 1100]	1100 [1.00, 1100]	1100 [4.00, 1100]	1100 [5.00, 1100]	1100 [1.00, 1100]
Relative Accessibility Index					
Mean (SD)	0.719 (0.124)	0.412 (0.0661)	0.222 (0.0481)	0.0591 (0.0485)	0.353 (0.258)
Median [Min, Max]	0.697 [0.544, 1.00]	0.401 [0.312, 0.543]	0.220 [0.150, 0.311]	0.0551 [0, 0.149]	0.312 [0, 1.00]
Area Deprivation Index					
Mean (SD)	5.16 (2.82)	4.92 (2.49)	4.10 (2.25)	4.89 (2.47)	4.77 (2.55)
Median [Min, Max]	5.00 [1.00, 10.0]	5.00 [1.00, 10.0]	4.00 [1.00, 10.0]	5.00 [1.00, 10.0]	5.00 [1.00, 10.0]
Missing	10 (2.1%)	3 (0.6%)	5 (1.0%)	4 (0.8%)	22 (1.1%)

Rural/Urban Category					
Urban	415 (85.7%)	428 (89.4%)	421 (87.5%)	210 (43.6%)	1474 (76.5%)
Rural	61 (12.6%)	19 (4.0%)	16 (3.3%)	123 (25.5%)	219 (11.4%)
Suburban	8 (1.7%)	32 (6.7%)	44 (9.1%)	149 (30.9%)	233 (12.1%)
Proportion of Census Block Group Under Poverty Line					
Mean (SD)	0.202 (0.151)	0.137 (0.110)	0.107 (0.0916)	0.137 (0.106)	0.146 (0.122)
Median [Min, Max]	0.170 [0, 0.831]	0.111 [0, 0.605]	0.0811 [0, 0.619]	0.102 [0, 0.601]	0.112 [0, 0.831]
Smoking					
No	270 (55.8%)	268 (55.9%)	274 (57.0%)	252 (52.3%)	1064 (55.2%)
Missing	77 (15.9%)	71 (14.8%)	69 (14.3%)	81 (16.8%)	298 (15.5%)
Yes	137 (28.3%)	140 (29.2%)	138 (28.7%)	149 (30.9%)	564 (29.3%)
Prior Cancer					
No	390 (80.6%)	395 (82.5%)	396 (82.3%)	390 (80.9%)	1571 (81.6%)
Missing	77 (15.9%)	71 (14.8%)	69 (14.3%)	81 (16.8%)	298 (15.5%)
Yes	17 (3.5%)	13 (2.7%)	16 (3.3%)	11 (2.3%)	57 (3.0%)
Hypertension					
No	38 (7.9%)	46 (9.6%)	40 (8.3%)	62 (12.9%)	186 (9.7%)
Missing	77 (15.9%)	71 (14.8%)	69 (14.3%)	81 (16.8%)	298 (15.5%)
Yes	369 (76.2%)	362 (75.6%)	372 (77.3%)	339 (70.3%)	1442 (74.9%)
Congestive Heart Failure					
No	321 (66.3%)	311 (64.9%)	327 (68.0%)	338 (70.1%)	1297 (67.3%)
Missing	77 (15.9%)	71 (14.8%)	69 (14.3%)	81 (16.8%)	298 (15.5%)
Yes	86 (17.8%)	97 (20.3%)	85 (17.7%)	63 (13.1%)	331 (17.2%)
Coronary Artery Disease					
No	295 (61.0%)	287 (59.9%)	300 (62.4%)	264 (54.8%)	1146 (59.5%)
Missing	77 (15.9%)	71 (14.8%)	69 (14.3%)	81 (16.8%)	298 (15.5%)

Yes	112 (23.1%)	121 (25.3%)	112 (23.3%)	137 (28.4%)	482 (25.0%)
Chronic Obstructive Pulmonary Disease					
No	395 (81.6%)	394 (82.3%)	402 (83.6%)	384 (79.7%)	1575 (81.8%)
Missing	77 (15.9%)	71 (14.8%)	69 (14.3%)	81 (16.8%)	298 (15.5%)
Yes	12 (2.5%)	14 (2.9%)	10 (2.1%)	17 (3.5%)	53 (2.8%)
Peripheral Vascular Disease					
No	374 (77.3%)	371 (77.5%)	378 (78.6%)	367 (76.1%)	1490 (77.4%)
Missing	77 (15.9%)	71 (14.8%)	69 (14.3%)	81 (16.8%)	298 (15.5%)
Yes	33 (6.8%)	37 (7.7%)	34 (7.1%)	34 (7.1%)	138 (7.2%)

[a]Married or life partner

[b]Single, divorced, widowed, or separated

Table 2. Association between Accessibility Index and Days Alive and Out of the Hospital

	Crude (Rate Ratio, 95% CI)	Adjusted (Rate Ratio, 95% CI)	Fully Adjusted (Rate Ratio, 95% CI)
Accessibility Index (0 to 1)	0.98 (0.95, 1.01)	0.99 (0.96, 1.02)	0.99 (0.96, 1.02)
ADI State Rank (1 to 10)		1.00 (0.99, 1.00)	1.00 (1.00, 1.00)
Proportion Poverty in CBG		0.94 (0.85, 1.04)	0.92 (0.84, 1.02)
Urban/Rural Category			
Urban		ref	ref
Suburban		1.01 (0.98, 1.03)	1.01 (0.98, 1.03)
Rural		1.00 (0.98, 1.03)	1.01 (0.99, 1.04)
Age at Transplant			
18-34		ref	ref
35-49		1.00 (0.98, 1.02)	1.00 (0.98, 1.02)
50-64		0.97 (0.95, 0.99)	0.97 (0.95, 0.99)
65+		0.92 (0.89, 0.95)	0.93 (0.90, 0.96)
Race			
White			ref
Black			1.01 (0.99, 1.04)
Other/Unknown			1.01 (0.98, 1.04)
Ethnicity			
Non-Hispanic or Latino			ref
Hispanic or Latino			0.99 (0.94, 1.03)
Other/Unknown			0.92 (0.87, 0.97)
Education			
College or higher			ref
High school or less			1.02 (1.00, 1.04)
Unknown or other			0.98 (0.91, 1.07)
Primary Payer			
Private			ref
Medicare			0.97 (0.95, 0.99)
Medicaid			0.99 (0.96, 1.03)
Other or Unknown			1.06 (0.97, 1.17)
Donor Type			
Deceased Donor			ref
Living Donor			1.03 (1.01, 1.05)

Sex	
Female	ref
Male	0.98 (0.97, 1.00)
BMI	1.00 (1.00, 1.00)
<35	ref
35+	0.99 (0.96, 1.02)
Missing	0.99 (0.97, 1.01)
First Transplant	
Yes	ref
No	1.00 (0.97, 1.03)

Table 3. Mean Days Alive and Out of the Hospital

	Mean (SD) DAOH
Overall	1034 (181)
Donor Type	
Living	1061 (118)
Deceased	1020 (207)
BMI	
>=35	1020 (200)
<35	1036 (177)
Race	
White	1033 (189)
Black	1036 (172)
Other or Unknown	1035 (204)
Ethnicity	
Non-Hispanic or Latino	1043 (158)
Hispanic or Latino	1029 (211)
Other or Unknown	950 (319)
Sex	
Female	1045 (153)
Male	1027 (198)
Primary Payer	
Private	1052 (144)
Medicare	1013 (217)
Medicaid	1057 (120)
Other or Unknown	1036 (180)
Education	
College or higher	1033 (185)
High school or less	1036 (172)

Other or unknown	1035 (186)
Death During Follow Up	
Yes	466 (355)
No	1078 (23)
First Transplant	
Yes	1034 (182)
No	1034 (173)

Table 4. Association Between Neighborhood Accessibility and Missed Appointments 1 Year After Transplant

	Crude (Rate Ratio, 95% CI)	Adjusted (Rate Ratio, 95% CI)	Fully Adjusted (Rate Ratio, 95% CI)
Accessibility Index	1.08 (0.98, 1.19)	1.11 (1.00, 1.23)	1.11 (1.01, 1.23)
ADI State Rank		1.00 (0.98, 1.01)	1.00 (0.99, 1.01)
Proportion Poverty in CBG		1.06 (0.78, 1.44)	1.05 (0.76, 1.38)
Urban/Rural Category			
Urban		ref	ref
Rural		1.09 (1.02, 1.18)	1.08 (1.00, 1.16)
Suburban		1.06 (0.97, 1.14)	1.05 (0.96, 1.14)
Age at Transplant			
18-34		ref	ref
35-49		1.02 (0.94, 1.11)	1.03 (0.95, 1.11)
50-64		0.98 (0.91, 1.07)	0.99 (0.92, 1.08)
65+		1.05 (0.95, 1.15)	1.03 (0.94, 1.13)
Race			
White			ref
Black			0.91 (0.86, 0.97)
Other/Unknown			0.98 (0.86, 1.05)
Ethnicity			
Non-Hispanic or Latino			ref
Hispanic or Latino			0.89 (0.76, 1.02)
Other/Unknown			0.87 (0.79, 0.96)
Education			
College or higher			ref
High school or less			0.95 (0.90, 1.01)
Other or unknown			1.01 (0.87, 1.16)
Primary Payer			
Private			ref

Medicare	1.16 (1.10, 1.23)
Medicaid	1.01 (0.84, 1.21)
Other or Unknown	1.07 (0.93, 1.24)
Donor Type	
Deceased Donor	ref
Living Donor	1.03 (0.98, 1.09)
Sex	
Female	ref
Male	0.96 (0.92, 1.01)
BMI	1.00 (1.00, 1.00)
<35	ref
35+	1.05 (0.95, 1.15)
Missing	0.93 (0.86, 0.99)
First Transplant	
Yes	ref
No	1.12 (1.02, 1.22)

Table 5. Mean Missed Appointments Per Follow Up Time (Years) by Year Since Transplant

	Overall	Year 1	Year 2	Year 3
Overall	10.1 (18.4)	14.6 (18.7)	9.0 (8.2)	4.4 (4.8)
Donor Type				
Living	9.0 (4.9)	14.0 (7.2)	8.9 (6.9)	4.0 (4.3)
Deceased	10.7 (22.5)	15.0 (25.6)	9.1 (8.9)	4.6 (5.0)
BMI				
35+	10.4 (20.5)	14.9 (721.0)	9.3 (7.9)	4.6 (5.0)
<35	10.1 (7.5)	15.0 (8.0)	9.6 (12.6)	4.2 (4.4)
Race				
White	9.5 (8.2)	14.7 (9.3)	8.4 (7.4)	3.7 (4.3)
Black	10.5 (23.4)	14.6 (23.7)	9.6 (9.0)	4.9 (5.1)
Other or Unknown	10.1 (12.2)	14.7 (12.4)	9.6 (9.8)	4.3 (4.6)
Ethnicity				
Non-Hispanic or Latino	10.2 (18.6)	14.8 (19.1)	9.4 (8.4)	4.5 (4.8)
Hispanic or Latino	11.6 (24.0)	15.1 (22.5)	7.9 (6.4)	4.3 (4.6)
Other or Unknown	7.7 (9.3)	13.0 (10.1)	5.1 (5.9)	2.8 (3.2)
Sex				
Female	9.7 (6.9)	14.2 (8.4)	9.5 (8.0)	4.8 (5.2)
Male	10.4 (23.1)	14.9 (23.1)	8.6 (8.3)	4.1 (4.4)
Primary Payer				
Medicare	11.8 (27.7)	16.4 (27.7)	9.8 (8.6)	4.7 (4.9)

Medicaid	8.6 (5.0)	12.6 (7.9)	8.3 (6.5)	5.2 (5.0)
Private	8.6 (6.4)	13.2 (8.1)	8.1 (7.1)	4.1 (4.7)
Other or Unknown	10.2 (12.0)	14.7 (12.2)	9.7 (9.7)	4.3 (4.6)
Education				
College or higher	10.3 (23.0)	15.0 (23.3)	9.0 (7.7)	4.5 (4.9)
High school or less	9.8 (11.9)	14.1 (12.1)	8.7 (8.1)	4.3 (4.6)
Other or unknown	10.1 (11.7)	14.7 (12.0)	9.5 (9.5)	4.2 (4.6)
Death During Follow Up				
Yes	29.2 (64.2)	30.2 (64.8)	19.6 (22.4)	9.6 (10.9)
No	8.6 (4.6)	13.5 (7.2)	8.5 (6.6)	4.2 (4.5)
First Transplant				
Yes	10.1 (19.1)	14.6 (19.3)	9.0 (8.2)	4.3 (4.6)
No	9.8 (6.3)	15.3 (8.6)	9.3 (7.9)	4.9 (6.2)

Table 6. Mean Appointment Counts

	Overall	Year 1	Year 2	Year 3
Scheduled Appointment Count	71.1 (29.7)	40.4 (11.1)	19.9 (12.6)	13.0 (10.8)
Missed Appointment Count	25.7 (14.0)	13.7 (7.4)	8.6 (6.7)	4.3 (4.5)

Table 7. Effect Measure Modification of Accessibility Index on Days Alive and Out of the Hospital

	Rate Ratio (95% CI)
BMI	
< 35	1.10 (1.00, 1.21)
35+	0.98 (0.95, 1.01)
Prior Transplant	
First Transplant	0.98 (0.95, 1.01)
Prior Transplant	1.13 (1.01, 1.25)
Race	
White	1.02 (0.97, 1.07)
Black	0.97 (0.93, 1.01)
Other/Unknown	0.97 (0.88, 1.06)
Ethnicity	
Not Hispanic or Latino	1.02 (0.89, 1.16)
Hispanic or Latino	0.99 (0.96, 1.02)
Other or Unknown	1.02 (0.86, 1.21)
Age	
18-35	1.04 (0.99, 1.09)
35-49	0.98 (0.94, 1.05)
50-64	0.99 (0.94, 1.05)

65+	0.96 (0.85, 1.08)
Insurance	
Private	0.99 (0.97, 1.04)
Medicare	0.98 (0.93, 1.04)
Medicaid	1.04 (0.95, 1.14)
Other or Unknown	0.96 (0.88, 1.04)
Block Group Percent Poverty	
75%	0.87 (0.73, 1.02)
50%	0.92 (0.83, 1.01)
25%	0.97 (0.93, 1.01)
RUCA Category	
Urban	0.97 (0.94, 1.01)
Suburban	1.11 (1.02, 1.21)
Rural	1.00 (0.94, 1.06)
ADI State Rank	
10	0.99 (0.92, 1.06)
5	0.99 (0.96, 1.02)
1	0.99 (0.93, 1.05)

Adjusting for ADI, proportion of CBG under poverty line, rural/urban classification, age

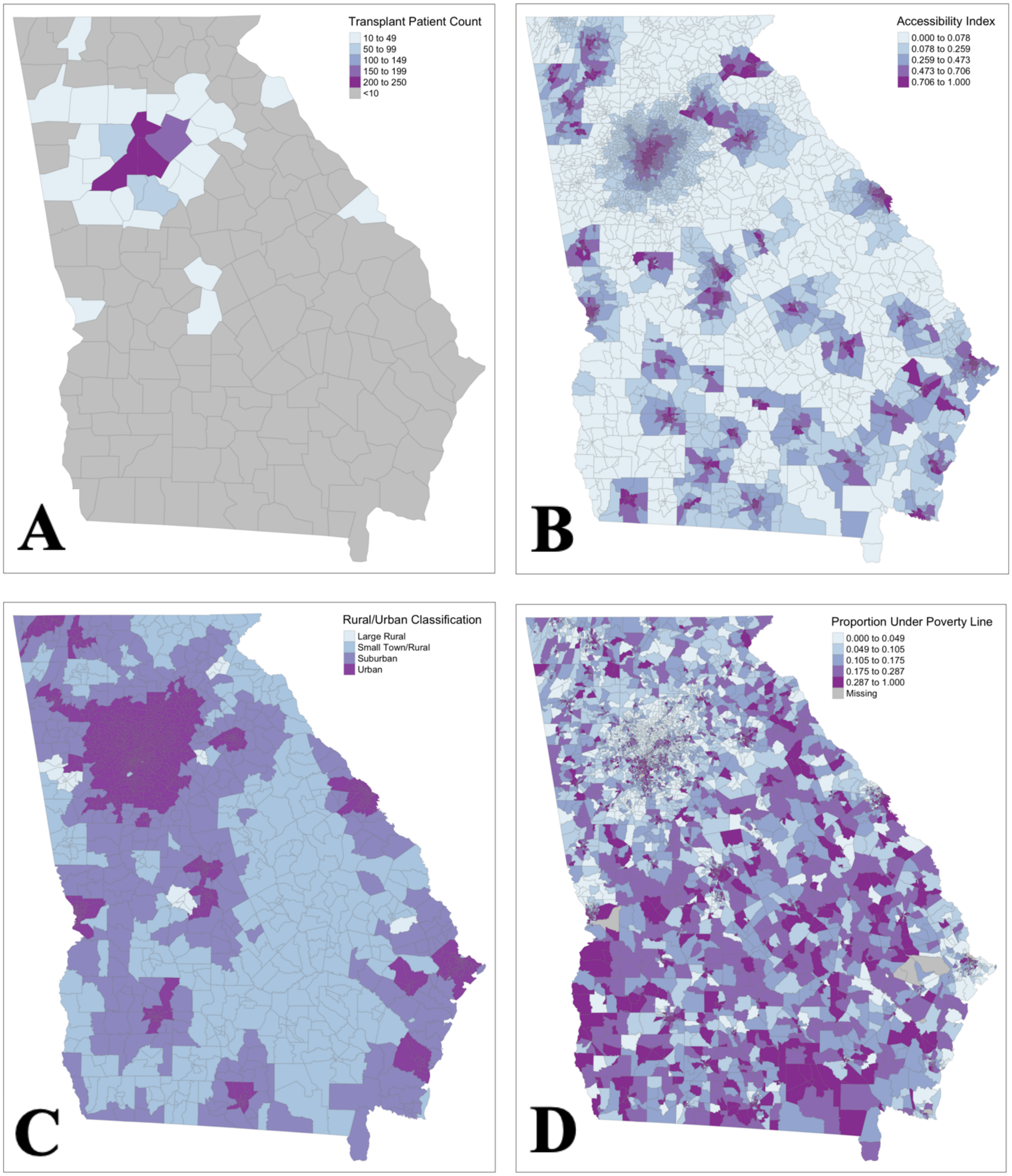
Table 8. Effect Measure Modification of Accessibility Index on Missed Appointments per Year of Follow Up

	Rate Ratio (95% CI)
BMI	
<35	1.14 (1.02, 1.28)
35+	0.84 (0.59, 1.19)
Prior Transplant	
First Transplant	1.09 (0.98, 1.22)
Prior Transplant	1.19 (0.85, 1.66)
Race	
White	1.07 (0.92, 1.24)
Black	1.18 (1.02, 1.36)
Other or Unknown	1.06 (0.76, 1.47)
Ethnicity	
Not Hispanic or Latino	1.09 (0.97, 1.22)
Hispanic or Latino	1.13 (0.69, 1.84)
Other or Unknown	1.34 (0.98, 1.85)

Age	
18-34	1.28 (0.99, 1.66)
35-49	1.12 (0.94, 1.33)
50-64	1.07 (0.91, 1.26)
65+	1.01 (0.79, 1.29)
Insurance	
Private	1.10 (0.93, 1.30)
Medicare	1.17 (1.02, 1.35)
Medicaid	1.41 (0.71, 2.81)
Other or Unknown	0.95 (0.75, 1.20)
Block Group Percent Poverty	
75%	0.99 (0.64, 1.52)
50%	1.04 (0.80, 1.34)
25%	1.09 (0.97, 1.22)
RUCA Category	
Urban	1.12 (0.99, 1.27)
Suburban	1.21 (0.81, 1.81)
Rural	1.04 (0.86, 1.27)
ADI State Rank	
10	0.99 (0.81, 1.21)
5	1.11 (1.00, 1.23)
1	1.21 (1.01, 1.46)

Adjusting for ADI, proportion of census block group under poverty line, rural/urban classification, age

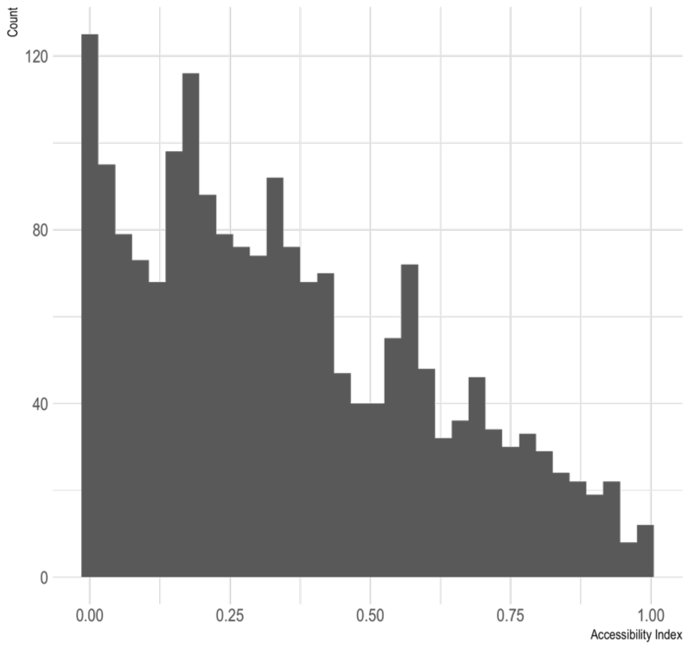
Figure 1. Maps of Patient Residences and Ecological Factors



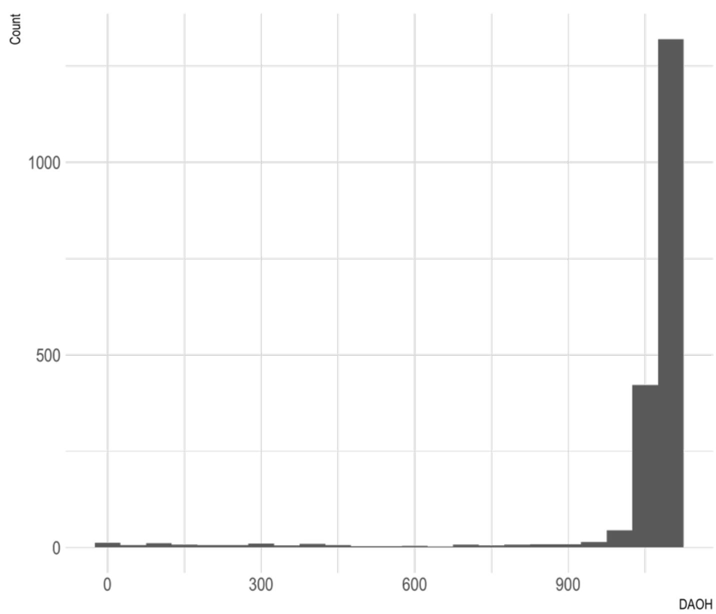
A – Transplant Patient Count, B – Accessibility Index, C – Rural/Urban Classification of Census Tract, D – Proportion of Census Block Group Under Poverty Line

Supplementary Material

Supplementary Figure 1. Distribution of Accessibility Index in Cohort



Supplementary Figure 2. Distribution of Days Alive and Out of the Hospital (DAOH)



Supplementary Figure 3. Distribution of Missed Visits in First Year Following Transplant