Associations Between Residential Greenspace, Socioeconomic Status, and Stroke: A Matched Case-Control Study

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Purpose   Studies have shown increased residential greenspace is associated with improved outcome following stroke. This study sought to determine if residential greenspace is an independent stroke risk factor.

Methods   A retrospective 1:4 matched case-control study involving 1174 stroke and 4696 control patients over a 3-year period from Milwaukee County, Wisconsin, was conducted. Greenspace was determined using normalized difference vegetation index (NDVI) for a 250-meter radius surrounding a subject's residence. The area deprivation index (ADI) for the census block tract of a subject's residence was obtained from the Neighborhood Atlas® (University of Wisconsin School of Medicine and Public Health). Relationship between greenspace, ADI, and stroke was determined using conditional logistic regression. Relationships among NDVI, state and national ADI, and proximity to public parks were determined using Spearman's rank-order correlation.

Results   NDVI and stroke risk were inversely correlated (odds ratio [OR]: 0.33, 95% CI: 0.111–0.975; P=0.045), with 19% lowered odds of stroke for patients living in the highest greenspace quartile compared to the lowest quartile (OR: 0.81, 95% CI: 0.672–0.984; P=0.045). Patients living in the most deprived ADI quartile had 28% greater stroke risk than those living in the least deprived ADI quartile (OR: 1.28, 95% CI: 1.02–1.6; P=0.029). Non-Hispanic Black patients lived in residential areas with lower greenspace (P<0.001) and neighborhoods of greater state and national ADI (P<0.001 for both) than non-Hispanic White patients.

Conclusions   In Milwaukee County, living with greater surrounding greenspace or areas of lower deprivation is associated with lower odds of stroke. NDVI represents an independent risk factor for stroke, not simply a proxy for socioeconomic status. (*J Patient Cent Res Rev.* 2022;9:89-97.)

Keywords   greenspace; stroke; area deprivation index; NDVI; socioeconomic status

Greenspace — areas covered with trees, grass, or other vegetation — is increasingly recognized for its benefits to mental and physical health.[1] There is a direct correlation between greenspace and improved attention, mood, and physical activity.[2] Additionally, data from multiple studies indicate that increased greenspace is linked to decreased hospitalizations for heart disease and stroke as well as reduced stroke severity and mortality.[2-5] Investigators from Perth, Australia, reported that the odds of hospitalization for heart disease or stroke was lower for adults living in the highest tertile of greenspace compared to those living in the lowest (odds ratio [OR]: 0.87, 95% CI: 0.60–1.27).[3] A study from Beth Israel Deaconess Medical Center (Boston, MA) found that stroke mortality was lower for patients living in the highest quartile of greenspace compared to the lowest (hazard ratio: 0.78, 95% CI: 0.63–0.97),[5] and in a longitudinal study of 575,000 Canadians, investigators found that stroke mortality was lower in the highest greenspace quartile compared to the lowest (relative risk: 0.96, 95% CI: 0.93–0.95).[6] Investigators from Barcelona, Spain, determined that stroke severity decreased as residential greenspace increased when comparing highest quartile to lowest (OR: 0.75, 95% CI: 0.60–0.95).[7] While clearly linked to stroke outcomes, it remains unknown if greenspace is an independent risk factor for stroke incidence.

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Stroke incidence worldwide is negatively correlated with socioeconomic status (SES).[8] Both in low-SES countries and among low-SES populations within high-income countries, the risk of stroke was reported to be higher.[9] Higher levels of deprivation also have been associated with an increased risk of adverse health and health care outcomes,[10] including stroke.[8-11] Although greenspace might be expected to correlate with SES, it is unclear whether greenspace functions as a proxy for SES.[6]

The primary purpose of this study was to determine if residential greenspace is a risk factor for stroke, independent of SES and individual stroke risk factors. We also sought to determine if neighborhood disadvantage was an independent risk factor for stroke. As the largest study to address the relationships among residential greenspace, geographic SES, and stroke risk, findings may improve our understanding of the interconnectivity between the environment in which we live and health outcomes, knowledge that could be used to inform public policy interventions.

METHODS

Study Design

This retrospective 1:4 matched case-control study was deemed exempt human subjects research by the Advocate Aurora Health institutional review board (per 45 CFR 46.104[d][4i & 4iii]). The primary outcome measures were the odds of stroke as a function of residential greenspace exposure as measured by the normalized difference vegetation index (NDVI). Secondary outcome measures include the odds of stroke as a function of neighborhood socioeconomic status as measured by the area deprivation index (ADI).

Case and Control Ascertainment

Any patient ≥18 years of age discharged from Aurora St. Luke's Medical Center (ASLMC) in Milwaukee Wisconsin, with an International Classification of Diseases (ICD)-coded diagnosis of stroke in calendar years 2016, 2017, or 2018 was included in this study (Figure 1). Patients at ASLMC with a nonstroke diagnosis from the same years were included as potential controls. Stroke was defined as ischemic stroke, transient ischemic attack, subarachnoid hemorrhage, or intracerebral hemorrhage.

Patients with stroke (n=2336 cases) were identified through the Get with the Guidelines database (maintained as a requirement of Comprehensive Stroke Center designation). Patients with no stroke diagnosis (n=328,868 controls) were identified via search of the hospital's electronic health records database (Epic Systems Corporation). Using a 1:M (many) case-control design,[12,13] 1 case (patient with stroke diagnosis) was
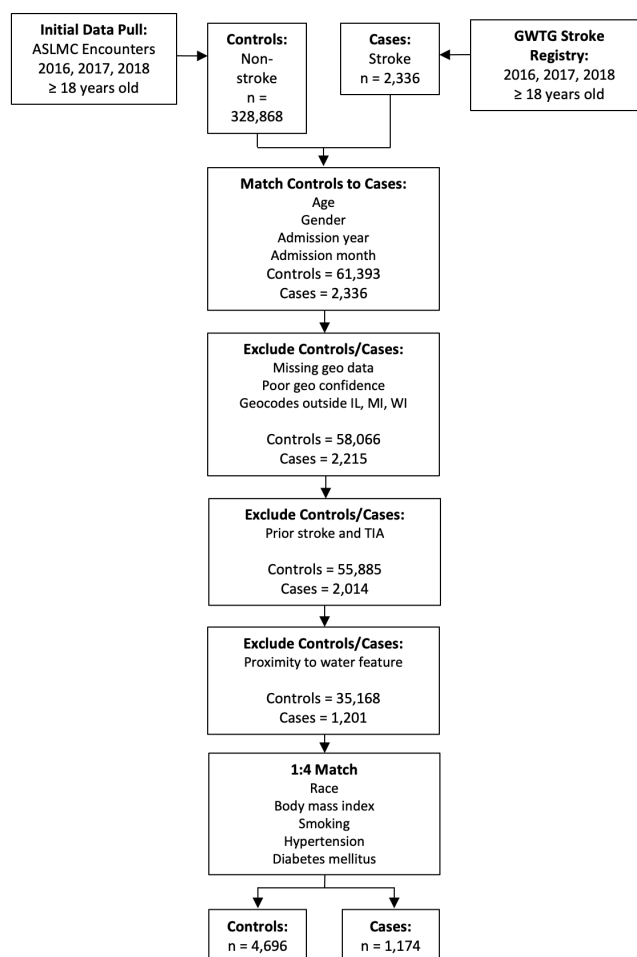

Figure 1. Flow chart of study participants depicting how study participants were chosen and exclusion criteria. ASLMC, Aurora St. Luke's Medical Center; GWTG, Get With The Guidelines; geo, geographic; IL, Illinois; MI, Michigan; TIA, transient ischemic attack; WI, Wisconsin.

matched to up to 4 nonstroke controls without replacement (ie, 1 control could only match 1 case). For each case, a restricted pool of potential controls was identified based on gender, 5-year age group, and admit month and year (n=61,393). Patients with missing geocode data or poor geocode confidence were excluded, as were those with geocodes outside of Milwaukee County. Additional patient exclusions included prior stroke history or the presence of a water feature within 250 meters of their residential zone (n=1201 cases; n=35,168 controls), as living near a body of water confers health benefits distinct from those of greenspace.[14-16]

Controls were matched to stroke cases based on admission year, age, gender, and race. Stroke risk factors also were used as matching criteria and included

hypertension, diabetes, current or past smoking history, body mass index, and cholesterol. Mahalanobis distance matching was utilized to determine the distance between the patients with stroke and patients in the control group based on a set of variables (caliper width of 0.20). This procedure minimizes the Mahalanobis distance between the stroke case and control, and the caliper specifies the chosen cutoff for the maximum distance allowed. If a control was eligible for multiple cases, it was assigned to the case with the fewest potential controls. In the event of a tie, the control was assigned at random. The final study cohort was comprised of 1174 stroke cases and 4696 nonstroke controls (Table 1).

Greenspace by NDVI and Proximity to Public Parks
Residential greenspace exposure was measured in two ways: NDVI uses satellite imagery to determine the amount of greenspace in a particular area and proximity to public parks (PPP) as walking distance on straight line.[1] NDVI quantifies the density of green vegetation as

a ratio of near-infrared (NIR) light reflected to red light absorbed: NDVI = (NIR − Red)/(NIR + Red). NDVI values range from -1 to +1, with greenness increasing with increased NDVI. The NIR light and red light spectral bands are included with Landsat 8 satellite imagery, available through the U.S. Geological Survey's Global Visualization Viewer (GloVis, https://glovis.usgs.gov).

Landsat 8 images (spatial resolution 15 to 100 meters) over Milwaukee County were filtered for May, June, and July (maximal greenness) of 2016, 2017, and 2018 during 0%–20% cloud cover. Satellite images were selected for each of the 3 years based on closest matching dates, then imported into ArcGIS Pro 2.4.1 geospatial mapping software (Esri), and NDVI transformation was performed (Figure 2A, 2B). An XY coordinate layer was added to the NDVI map to permit localization of subjects' residences. Using the zonal statistics tool, a 250-meter radius was drawn around each residence and the average NDVI within that radius calculated (Figure 2C).

Table 1. Study Inclusion/Exclusion Criteria and Characteristics of Population Analyzed

Inclusion/Exclusion criteria	Total patients identified, N=331,204	Stroke cases identified, n=2336	Nonstroke controls identified, n=328,868
Matched for age, gender, admission	63,729	2336	61,393
Remaining after missing data exclusion	60,281	2215	58,066
Remaining after exclusion for prior stroke	57,899	2014	55,885
Within Milwaukee County	36,369	1201	35,168
1:4 matched for race, body mass index, smoking, hypertension, diabetes	5870	1174	4696

| Characteristic	Total, N=5870 (100%)	Stroke cases, n=1174 (20.0%)	Nonstroke controls, n=4696 (80.0%)
Median age	70.0 years	70.0 years	70.0 years
Gender, n (%)			
Female	3111 (53.0)	622 (53.0)	2489 (53.0)
Male	2759 (47.0)	552 (47.0)	2207 (47.0)
Race/Ethnicity, n (%)			
Non-Hispanic White	4071 (69.4)	812 (69.2)	3259 (69.4)
Non-Hispanic Black	933 (15.9)	186 (15.8)	747 (15.9)
Hispanic	674 (11.5)	135 (11.5)	539 (11.5)
Other	192 (3.3)	41 (3.5)	151 (3.2)
Admit year, n (%)			
2016	2020 (34.4)	404 (34.4)	1616 (34.4)
2017	1820 (31.0)	364 (31.0)	1456 (31.0)
2018	2030 (34.6)	406 (34.6)	1624 (34.6)
History of smoking, n (%)	3580 (61.0)	716 (61.0)	2864 (61.0)
Hypertension, n (%)	1910 (32.5)	382 (32.5)	1528 (32.5)
Diabetes, n (%)	735 (12.5)	147 (12.5)	588 (12.5)
Median body mass index	28.0 kg/m^2	28.1 kg/m^2	28.0 kg/m^2
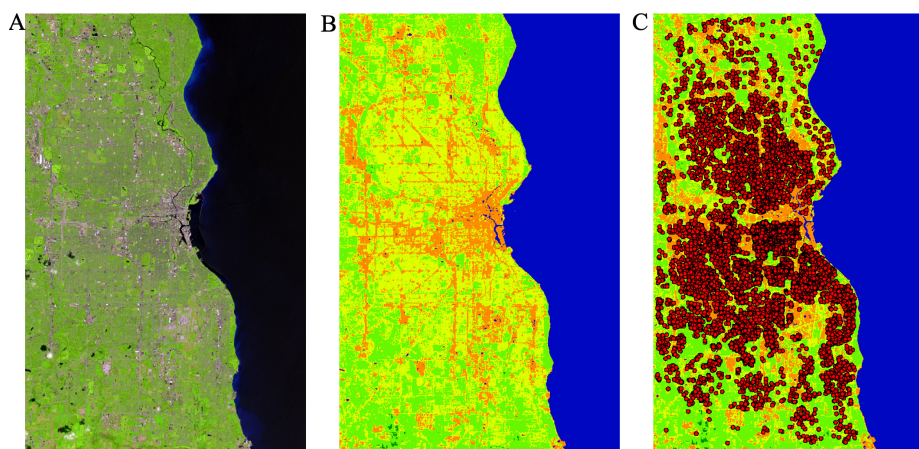
Figure 2. *Determination of residential greenspace. **A:** Representative Landsat 8 image for Milwaukee County from the U.S. Geological Survey's Global Visualization Viewer (GloVis). **B:** The normalized difference vegetation index-transformed satellite image. **C:** Each circle represents a 250-meter radius surrounding a residence.*

Walking distance from a subject's residence at time of admission to the nearest public park was determined using ArcGIS. In addition to the actual distance in meters, a dichotomous variable was created to identify residences ≤1 km from a public park, and those >1 km from a park.

Area Deprivation Index
The Neighborhood Atlas® is an online tool provided by the University of Wisconsin School of Medicine and Public Health (Madison, WI) that provides the ADI for a particular address, based on American Community Survey Five Year Estimates.[17] For our analysis, the 2018 ADI was sourced (https://www.neighborhoodatlas.medicine.wisc.edu/). ADI measures the socioeconomic deprivation within a neighborhood; it uses 17 variables of SES and has been refined and validated to the census block level, defined as the smallest geographic unit used by the U.S. Census Bureau.[11] Two ADI scores are available: national percentile rankings from 1 to 100 and rankings in deciles from 1 to 10 for each state. The national percentiles are constructed by ranking the ADI values from low to high for the United States, which are then grouped by neighborhood for each 1% change in ADI. The state deciles are constructed by ranking ADI values from low to high for each state without consideration of national ADI. Higher ADI represents higher levels of deprivation, ie, the more disadvantaged an area.

Using the Neighborhood Atlas, state decile and national percentile ADI scores were recorded for each subject and transferred to the ArcGIS map (Figure 3A).

Geocoding
Sociodemographic information and geocodes for each subject were obtained from ASLMC's geographic characteristics research database (per IRB no. 15.81) and based on their home address at the time of admission. The geocode included the decimal latitude and longitude and the Federal Information Processing Standard (FIPS) code, a 12-digit number that identifies a street address to its census block level group. ASLMC's research analytics team created the algorithm and code to convert street addresses to FIPS and to provide a confidence score for each match. Geocodes were used to connect ADI, PPP, and NDVI to each subjects' residence.

Statistical Methods
Descriptive statistics were applied to demographic variables. Kolmogorov-Smirnov test was used to check the normality of a variable's distribution. Nonparametric methods were used to compare nonnormally distributed variables. A Spearman's rank-order correlation was performed to determine the relationship between NDVI, state and national ADI, and PPP. Conditional logistic regression was used to examine relationships between a stroke event and NDVI, state and national ADI, and PPP.

Race (ie, non-Hispanic White [NHW] and non-Hispanic Black [NHB]) and gender differences were compared using a *t*-test or Mann-Whitney *U* test as appropriate for the distribution properties of NDVI, ADI state decile, and national ADI percentile. When conducting *t*-test on groups with unequal variance as determined by Levene's test, the degrees of freedom were adjusted as appropriate. Ischemic stroke is the most common type of stroke, so we analyzed these patients as a separate subgroup. NDVI was considered as both a continuous and a categorical (by quartiles) variable. ADI percentiles and deciles were considered as continuous and categorical (by quartiles) variables. Multicollinearity was evaluated using the variance inflation factor.

For all statistical tests, an alpha of P<0.05 denoted significance. Statistical analyses were performed using SAS® 9.4 (SAS Institute Inc.); Stata® 15.1 (StateCorp); and R version 3.6.1 (The R Foundation) software.

RESULTS

Characteristics of the study population are summarized in Table 1. The initial matching process identified 63,729 patients (2336 cases and 61,393 potential controls; Figure 1). Following exclusion of cases or controls for missing or poor geographic confidence (n=3327), residence outside Milwaukee County (n=20,717), a prior history of stroke (n=2181), and proximity to a water feature, there were 1201 stroke cases and 35,168 controls. Upon completion of 1:4 matching, the study cohort comprised 1174 cases and 4696 controls. There were 27 unmatched cases — 18 patients with stroke were missing body mass index data, 8 were missing race data, and 1 was missing both (Table 1, Online Supplemental Figure S1, and Online Supplemental Table S1). Unmatched cases were not included in the analysis.

Following the analysis of overall stroke cases, we determined whether there was an association between greenspace and ischemic stroke. After determining geographic distribution, stroke cases (Figure 3B, purple dots) and nonstroke controls (Figure 3C, green dots) were plotted using the average nearest neighbor tool in ArcGIS. An overlay of the cases and controls (Figure 3D) found that both the nonstroke patients and patients with stroke were clustered rather than randomly distributed throughout the county (Figure 3, insets).

Relationship Between Greenspace and Sociodemographic Variables

Of the greenspace and sociodemographic variables tested, only NDVI was normally distributed. Therefore, Spearman's rank-order correlation determined the relationship between NDVI, ADI state decile, national ADI percentile, and PPP (Online Supplemental Table S2). There was a strong positive correlation between the ADI state decile and ADI national percentile ($r_s(5870)=0.992$; P<0.001), indicating that these two measurements were consistent with one another. There was a weakly positive correlation between PPP and both the ADI state decile ($r(5870)=0.092$; P<0.001) and national ADI percentile ($r(5870)=0.085$; P<0.001). This indicates that the further away from a public park, the greater the neighborhood disadvantage (ie, higher ADI). There were moderate negative correlations between NDVI and the ADI state decile ($r_s(5870)=-0.550$; P<0.001) and national ADI
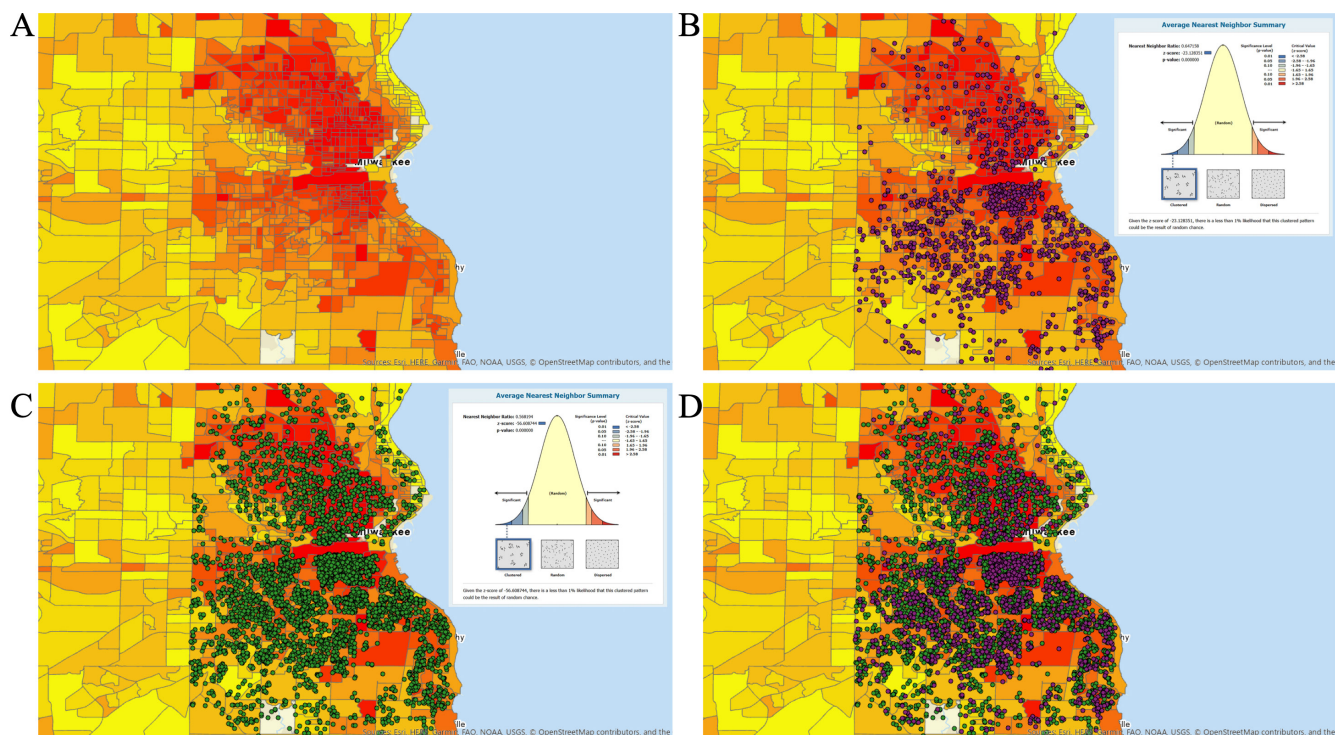

Figure 3. *Visualization of deprivation index and stroke patients.* **A:** *The area deprivation index (ADI) for Milwaukee County obtained from the University of Wisconsin Neighborhood Atlas. The darker the color, the more disadvantaged the block group.* **B:** *Stroke cases were laid over the ADI map, where each purple dot indicates a stroke case. Inset: results of the Nearest Neighbor summary.* **C:** *Controls also were overlaid, with each control shown as a green dot. Inset: results of the Nearest Neighbor summary.* **D:** *Comparative ADI map showing both stroke (purple) and control (green) patients.*

percentile (r_s(5870)=-0.548; P<0.001). This indicates that increased greenspace (ie, higher NDVI) correlates, at least modestly, with lower neighborhood deprivation.

Relationships Among NDVI, ADI, Gender, and Race

No difference was detected in NDVI values between males (mean ± standard deviation [SD]: 0.28 ± 0.06) and females (0.28 ± 0.06); t(5712)=0.16; P=0.874; d=0.004. Similarly, there was no detectable difference in either the median ADI state deciles (P=0.1450) nor the median national ADI percentiles (P=0.1535) for males and females.

The relationship between greenspace and race was analyzed. Mean residential NDVI values were significantly lower for NHB patients (0.27 ± 0.05) than for NHW patients (0.29 ± 0.06), indicating NHB patients lived in less green areas than NHW patients (t[1569]=10.07; P<0.001; d=0.37) (Figure 4A). As Levene's test indicated unequal variances (F=29.80; P<0.001), the degrees of freedom were adjusted from 5002 to 1569.

Deprivation scores (both state and national) also were compared by race. ADI state decile scores were higher for NHB patients (median: 10, interquartile range [IQR]: 1) than for NHW patients (median: 5, IQR: 5), indicating that NHB patients lived in neighborhoods with higher levels of disadvantage (U=514,124; z=-35.03; P<0.001; r=0.50) (Figure 4B). The national ADI percentile scores also were higher for NHB patients (median: 85, IQR: 21) than for NHW patients (median: 47, IQR: 23), confirming the observation of disadvantage seen at the state level (U=488,654; z=-35.44; P<0.001, r=0.50) (Figure 4C). Thus, in Milwaukee County, NHB patients were more likely to live in areas of greater deprivation and lower greenspace than NHW patients.

NDVI and All Stroke Cases

Mean NDVI was higher for nonstroke controls (0.283 ± 0.062) than for stroke cases (0.279 ± 0.062; P=0.057). On conditional logistic regression, there was an inverse relationship between NDVI and stroke: as NDVI increased, the odds of stroke decreased (OR: 0.33, 95% CI: 0.111–0.975; P=0.045) (Table 2). For analysis of the relationship with a stroke event, NDVI values were grouped into categorical quartiles, then evaluated using conditional logistic regression. The odds of stroke were 19% lower for patients living in areas with the highest level of greenspace (highest NDVI quartile) compared to those patients living in the areas with the least amount of greenspace (lowest NDVI quartile) (OR: 0.81, 95% CI: 0.672–0.984; P=0.034).

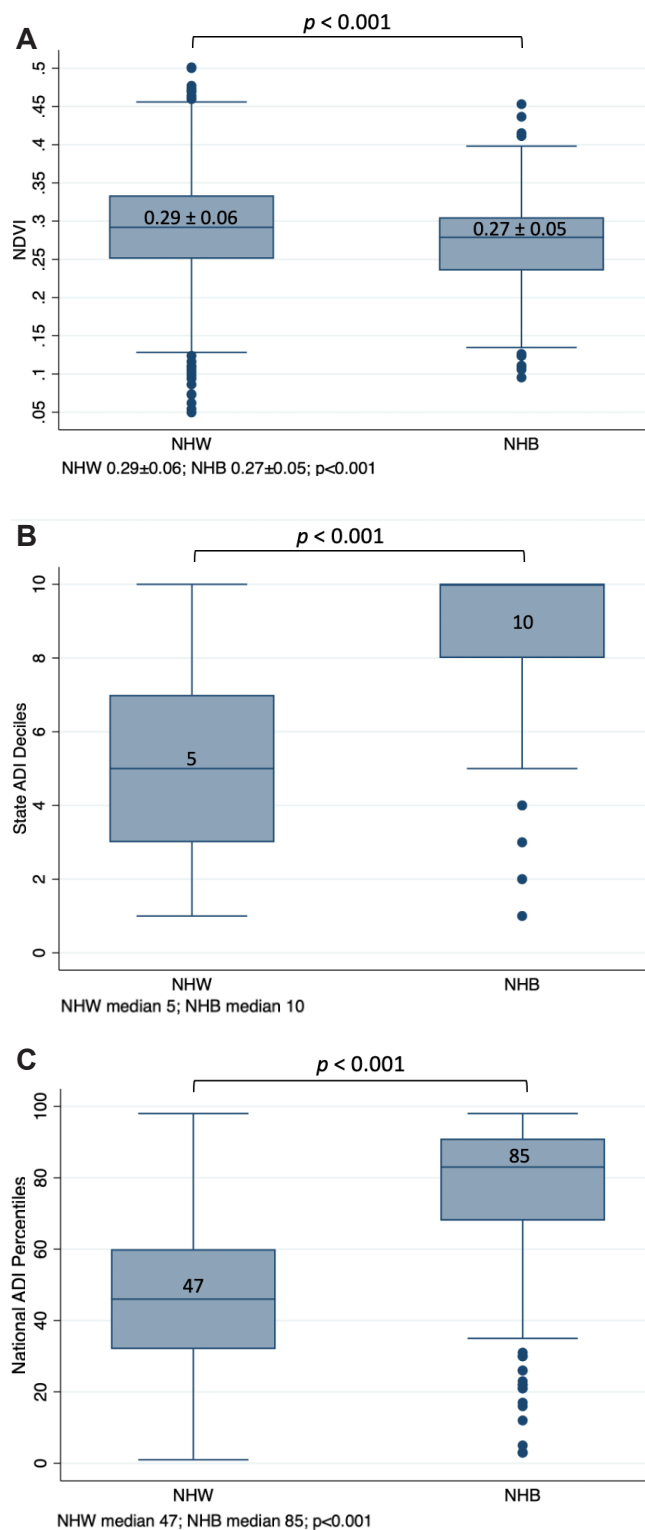NDVI values were rescaled using IQR for a more intuitive interpretation, and the IQR-rescaled predictor

Figure 4. *Racial disparity and greenspace.*
*A: Analysis of the relationship between race and greenspace (as NDVI). State ADI (**B**) and national ADI (**C**) stratified by race. P-values are shown below each graph. ADI, area deprivation index; NDVI, normalized difference vegetation index; NHB, non-Hispanic Black; NHW, non-Hispanic White.*

Table 2. Analysis of Associations Between a Stroke Event, Greenspace, and Area Deprivation

	Total, N=5870	Stroke cases, n=1174 (20.0%)	Nonstroke controls, n=4696 (80.0%)	Univariate odds ratio (95% CI)	*P*
Mean NDVI (SD)	0.282 (0.06)	0.279 (0.06)	0.282 (0.06)	0.33 (0.111–0.975)	0.045
NDVI quartiles,* n					
2	1467	295	1172	0.92 (0.76–1.10)	0.344
3	1468	295	1173	0.91 (0.76–1.10)	0.321
4 (highest)	1467	270	1197	0.81 (0.67–0.98)	0.034
Mean ADI National percentile (SD)	54.0 (36.0)	54.0 (34.0)	53.0 (37.0)	1.00 (0.998–1.005)	0.274
ADI National quartiles,* n					
2	1502	323	1179	1.23 (1.03–1.47)	0.023
3	1424	286	1138	1.14 (0.95–1.38)	0.165
4 (highest)	1410	284	1126	1.16 (0.93–1.44)	0.187
Mean ADI State decile (SD)	6.0 (5.0)	6.0 (5.0)	6.0 (6.0)	1.01 (0.985–1.038)	0.392
ADI State quartiles,* n					
2	1375	292	1083	1.18 (0.98–1.41)	0.075
3	1688	321	1367	1.05 (0.88–1.26)	0.576
4 (highest)	1146	249	897	1.28 (1.02–1.60)	0.029
Median proximity to public parks (IQR)	606.3 (593.5)	583.4 (606.8)	613.1 (590.0)	1.00 (1.00–1.00)	0.456
Resides within 1 km of a park, n (%)	4580 (78.0)	911 (77.6)	3669 (78.1)	1.03 (0.885–1.202)	0.694

Compared to lowest quartile.

ADI, area deprivation index; IQR, interquartile range; NDVI, normalized difference vegetation index; SD, standard deviation.

was achieved by dividing NDVI by its IQR (0.08). Conditional logistic regression was used to examine the relationship between a stroke event and NDVI scaled by IQR while taking matching into account. For 1 IQR increase in NDVI, there was an 8% decrease in the odds of stroke (OR: 0.92, 95% CI: 0.839–0.998; P=0.045).

ADI, PPP, and Stroke

Neither the ADI state decile nor national ADI percentile for stroke cases versus controls were significantly different (Table 2) as analyzed by Mann-Whitney (6 vs 6 [P=0.501] and 53 vs 54 [P=0.360], respectively). Additional analysis indicated that odds of stroke also did not significantly differ (OR: 1.01, 95% CI: 0.985–1.038 [P=0.392] and OR: 1.00, 95% CI: 0.998–1.005 [P=0.274], respectively). The national ADI percentiles and ADI state deciles were categorized into quartiles for direct comparison. Conditional logistic regression determined that patients living in the second highest national ADI quartile had odds of stroke that were 23% higher than those living in the lowest national ADI percentile (OR: 1.23, 95% CI: 1.029–1.474; P=0.023). Also, patients living in the highest quartile of state ADI (most disadvantage) had 28% higher odds of stroke compared to those living in the lowest quartile (ie, least disadvantaged) neighborhoods (OR: 1.28, 95% CI: 1.02–1.6; P=0.029).

No difference was found in the odds of stroke associated with the distance (in meters) from a patient's residence to a public park (OR: 1.00, 95% CI: 1.000–1.000; P=0.456) (Table 2). In addition, residing within 1 km walking distance of a park (yes/no) was not associated with the odds of a stroke event (OR: 1.03, 95% CI: 0.885–1.202; P=0.694). Therefore, although residential greenspace was associated with stroke, distance to a public park was not.

Ischemic Stroke Subgroup

To exam the interplay between greenspace, deprivation, and ischemic stroke, a subgroup of patients with ischemic stroke were identified within the original stroke case population. This subgroup included 830 ischemic stroke cases and 3320 matched controls (for a total of 4150 patients). Conditional logistic regression determined relationships between and ischemic stroke event and NDVI, national ADI, or state ADI. All conditional analyses were stratified on the matching criteria, and each predictor was analyzed individually. No statistical differences were detected in NDVI (OR: 0.32, 95% CI: 0.088–1.178; P=0.087;), national ADI percentile (OR: 1.0, 95% CI: 0.999–1.007; P=0.177), or ADI state decile (OR: 1.02, 95% CI: 0.988–1.052; P=0.238).

Interaction Between NDVI and ADI

To determine if NDVI was simply a proxy for ADI, univariate and multivariate conditional logistic regression models were compared. The similarity of the regression coefficients for NDVI when used in a multivariate model with state or national ADI and when used in a univariate model were well within each other's confidence intervals, suggesting that NDVI was not simply a proxy for ADI. No significant interaction between NDVI and state or national ADI was detectable (Online Supplemental Tables S3 and S4). Variance inflation was used to estimate the extent of multicollinearity. The variance inflation factor was 3.44 for NDVI and state ADI and 4.30 for NDVI and national ADI. These values indicate moderate collinearity and no adverse effect on the regression model.

DISCUSSION

In this study, we asked if residential greenspace (as measured by NDVI) and neighborhood disadvantage (as measured by ADI) were related to stroke risk in Milwaukee County, Wisconsin. We found that there was an inverse relationship between NDVI and stroke. Specifically, the odds of stroke decreased with increasing greenness: people living in the greenest quartile had 19% lower odds of stroke than people living in the least green quartile. Additionally, patients living in the most disadvantaged ADI state quartile had 28% higher odds of stroke compared to patients living in the least disadvantaged state quartile, consistent with previous reports on the association between neighborhood SES and stroke incidence.[9] Interestingly, a study out of the University of Miami presented at the 2021 International Stroke Conference analyzed Medicare records and found a reduction in ischemic stroke with increased greenness.[18]

The mechanism(s) by which residential greenspace exposure contributes to positive health outcomes is unsettled but may include its modifying the microclimate by absorbing solar radiation and air pollutants, enhancing air quality,[19] buffering wind and noise,[4] and reducing heat.[20] Greenspaces can also promote physical activity and social contact.[21] The former mitigates the effects of a sedentary lifestyle such as obesity and hypertension; the latter contributes to wellness through decreased mental stress.[17,22] Whatever the mechanism(s) of action, positive health benefits of greenspace exposure are myriad. A study on the relationship between residential greenspace, PPP, and pregnancy outcomes in Lithuania found that subjects who lived in areas with low surrounding greenness and those who were further from a park were at increased risk for term low birth weight and preterm birth.[23] In Hong Kong, a 10% increase in greenspace was significantly associated with a reduction in all-cause mortality, circulatory system-caused mortality, and stroke-caused mortality, independent of variables age, sex, marital status, education level, SES, smoking, and alcohol intake.[4] In a cross-sectional study from the University of Louisville, residential greenness was associated with lower levels of sympathetic activation, reduced oxidative stress, and higher angiogenic capacity, again, independent of age, sex, race, ADI, and statin use.[22] A multicase-control study from Spain found that the risk of breast cancer was reduced among participants who had urban green areas within 300 meters of their residence compared to those with no urban green areas within that distance.[7]

With the novel findings from our study, stroke risk can now be added to the growing list of health issues impacted by residential greenspace. Our data also confirmed neighborhood disadvantage as a risk factor for stroke, further suggesting the environment in which we live is an independent risk factor for stroke after controlling for individual characteristics. This is important from a public health perspective. Greenspace is a readily modifiable environmental factor that should be protected and expanded in the face of relentless urbanization. Modifying neighborhood disadvantage, though more challenging, also should be considered as a means to improve health in general and decrease stroke risk in particular.

Limitations

The mechanism of action establishing greenspace as a mitigating factor for stroke risk is not known. Proposed causal pathways such as improved air quality, increased physical activity, improved social contact, and stress reduction were not evaluated in this study. Dose and duration of greenspace exposure needed to impact health outcomes are not known. The research team did not have a mechanism to quantify length of time a patient has lived at a particular address. We also could not measure the extent of greenspace exposure outside the home — at work or school, for example. Lastly, Milwaukee's extreme segregation may be associated with independent health risks; segregation has been shown to be associated with poor birth outcomes, health behaviors, and chronic diseases,[24,25] and its relationship to stroke risk warrants further study.

CONCLUSIONS

Residential greenspace correlates to stroke risk, with patients who live amidst the most greenspace significantly less likely to have a stroke event than those surrounded by the least greenspace. Similarly to, but independently of, greenspace, patients from Milwaukee County's most socioeconomically disadvantaged neighborhoods were significantly more likely to have stroke than those residing in its least deprived neighborhoods. These findings stress the influence of environment as a risk factor for stroke.

Acknowledgments

Author Contributions

Study design: Cheruvalath, Vilar, Kassam, Rovin. Data acquisition or analysis: Cheruvalath, Homa, Singh, Rovin. Manuscript drafting: Homa, Rovin. Critical revision: Rovin.

Conflicts of Interest

None.

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