Disparities in spatial access to neurological care in Appalachia: a cross-sectional health services analysis

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Summary

Background Appalachia is rural and socioeconomically deprived with a heavy burden of neurological disorders and poor access to healthcare providers. Rates of neurological disorders are increasing over time without equal increases in providers, indicating that Appalachian disparities are likely to worsen. Spatial access to neurological care has not been robustly explored for U.S. areas, so we aimed to examine disparities in the vulnerable Appalachian region.

Methods Using 2022 CMS Care Compare physician data, we conducted a cross-sectional health services analysis, where we computed spatial accessibility of neurologists for all census tracts in the 13 states with Appalachian counties. We stratified access ratios by state, area deprivation, and rural-urban commuting area (RUCA) codes then utilized Welch two-sample t-tests to compare Appalachian tracts with non-Appalachian tracts. Using stratified results, we identified Appalachian areas where interventions would have the largest impact.

Findings Appalachian tracts (n = 6169) had neurologist spatial access ratios between 25% and 35% lower than non-Appalachian tracts (n = 18,441; p < 0.001). When stratified by rurality and deprivation, three-step floating catchment area spatial access ratios for Appalachian tracts remained significantly lower in the most urban (RUCA = 1 [p < 0.0001) and most rural tracts (RUCA = 9 [p = 0.0093]; RUCA = 10 [p = 0.0227]). We identified 937 Appalachian census tracts where interventions can be targeted.

Interpretation After stratifying by rural status and deprivation, significant disparities in spatial access to neurologists remained for Appalachian areas, indicating both poorer access in Appalachia and that neurologist accessibility cannot be determined solely by remoteness and socioeconomic status. These findings and our identified disparity areas have broad implications for policymaking and intervention targeting in Appalachia.

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Introduction

The Appalachian region of the U.S. has a heavy burden of neurological disorders, including stroke, brain/central nervous system cancer, and Alzheimer's disease and related dementias.[1–4] Perhaps most notably, a substantial portion of southern Appalachia is included in the 'stroke belt,' which is a long-studied geographic phenomenon of particularly high rates of stroke incidence and mortality in the southeastern U.S.[5] Strokes are linked to other neurological disorders, including dementia and cognitive decline,[6,7] so the high rates in the southeast and Appalachia may be particularly burdensome on population neurological health in these areas. Detrimental modifiable factors and clinical characteristics, such as poor diet, smoking, low levels of physical activity, obesity, hypertension, and insufficient sleep, are

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Research in context

Evidence before this study

Based on Google Scholar and PubMed searches from January 1, 1998 to August 12, 2022 using the terms "geographic access neurologists", "geographic access neurological care," "spatial access neurologists," and "spatial access neurological care," we identified eight prior original research articles directly or indirectly examining geographic patterns of access to neurologists in the United States. Citing articles and reference lists of each identified paper were also searched for any relevant references. Only studies mentioning regional differences in neurologist accessibility or other aspects of geography were retained as relevant. In the identified papers, geographic differences in neurologist availability and density across regions were apparent, yet none directly computed measures of geographic access using spatial methods.

Added value of this study

To the best knowledge of the authors, this is the first study quantifying spatial access to care for neurologists in an entire region of the United States. Applying geographic accessibility measures towards studying the uniquely disadvantaged Appalachian region, we 1) found the region to have poor geographic access to neurologists independent of area remoteness and socioeconomic status and 2) identified actionable disparity areas where interventions may have the largest impact.

Implications of all the available evidence

Population access to neurologists varies across regions of the United States. The vulnerable Appalachian region has both a heavy burden of neurological diseases and poor spatial access to neurologists. Interventions such as adjustments to specialist physician loan forgiveness programs, teleneurology, and mobile stroke units may improve access to care for Appalachia and other low access areas.

common in Appalachian populations and may be driving the noted burden of neurological disorders in the region.[8–16] Rates of neurological disorders are also expected to increase over time in the U.S. without equal increase in providers, indicating a potential shortage of neurological care providers nationwide.[17] Any shortage of neurologists in Appalachia may further complicate efforts to reduce regional neurological disorder disparities. Within the last decade, telehealth has emerged as a new strategy to combat shortages of neurology providers in Appalachia, yet barriers persist due to insufficient access to internet/internet-connected devices and limited digital literacy, among others.[18,19] Overcoming these barriers via policymaking and public health campaigns will be critical for expanding Appalachian teleneurology capabilities.

Due to factors unique to Appalachia, such as an abnormally high density of both rurality and low socioeconomic status,[20,21] residents of Appalachia not only have exceptional difficulty accessing primary and specialist care, but also have poorer health outcomes than other areas of the U.S.[21,22] Factors such as socioeconomic deprivation, hospital closures, lower supply of healthcare workers, topography, low education levels, adverse health beliefs, poor health literacy, and urbanization commonly are cited as factors contributing to healthcare access disparities in the region.[20,23] Access disparities for both primary and specialist care have been repeatedly identified and linked to poorer health outcomes in Appalachia,[21,22,24,25] but literature exploring access to neurological care in the region is comparatively sparse.[26] This is particularly true for examination of spatial access to care, which is a sub-category of healthcare accessibility specifically referring to the ability of a population in a given area to physically reach health services.[27] Spatial accessibility is an important piece of the broader access to care continuum, along with health insurance coverage, timeliness of care, and a capable healthcare workforce.[28] Some studies have noted geographic variations and fluctuating densities of neurological care in the U.S.,[17,26,29–34] but none have 1) integrated robust geographic access-specific measures to determine disparities in accessibility or 2) examined accessibility for small areas (e.g., census tracts). The Appalachian region is an ideal candidate for deeper study of neurological care spatial accessibility due to the high burden of neurological disease and the previously identified disparities in access to both primary and specialized care.

In this study, we used a comprehensive physician location dataset to construct neurological care spatial accessibility measures for all census tracts in the 13 states with Appalachian counties. We aimed to compare neurologist spatial access in Appalachian census tracts to spatial access in non-Appalachian census tracts and to identify fine scale localities where intervention campaigns could be targeted. Our overarching objectives were to provide direct evidence of neurological care spatial accessibility disparities in the Appalachian region and to assist in pinpointing small areas where policies and interventions may have the largest impact.

Methods

Data sources & processing

We obtained data from four sources: 1) neurologist street addresses from the 2022 Care Compare national downloadable file from the Centers for Medicare and

Medicaid Services (CMS), 2) census tract population counts from the U.S. Census Bureau's 2010 Census Summary File 1, 3) 2010 census tract distance matrix data from the National Bureau of Economic Research's Public Use Data Archive,[35] and 4) 2010 census tract polygons from the U.S. Census Bureau's TIGER/Line shapefiles database. For analysis of the effects of SES, 2010–2020 area deprivation index (ADI) values were obtained from the '*sociome*' R package, which derives ADI from American Community Survey 5-year estimates.[36] We classified ADI values into quintiles based on values from all U.S. census tracts to more accurately represent deprivation in the study area. To account for the effects of urban/rural status on spatial access, we used 2010 census tract-level rural-urban commuting area (RUCA) codes from the United States Department of Agriculture.

Primary physician specialty of "neurology" was used to derive active neurologists from 2022 Care Compare data, which is updated monthly for healthcare providers who practiced and billed Medicare or Medicaid in the previous year. Geocoding of neurologist street addresses was primarily completed via Census Geocoder batch geocoding and OpenStreetMap Nominatim single address geocoding in the *'tidygeocoder'* R package,[37] with ArcGIS World Geocoding Service in ArcGIS Pro version 2.8 serving as a reserve method to geocode unmatched addresses. Spatial points were spatially joined to a geodatabase containing population counts linked to census tract polygons. For physicians with multiple practice locations, such as those with both a permanent practice address and separate clinic addresses, all locations were retained. CMS Care Compare was selected over other physician location data, such as the American Medical Association (AMA) Physician Masterfile, due to frequent updates on practicing physicians, relative completeness due to the ubiquity of Medicare/Medicaid billing, and previous use in the physician spatial access literature.[38–40]

Study area

Appalachia is a vast cultural region in the eastern U.S. made up of 423 counties in 13 states spanning 206,000 square miles, roughly following the Appalachian mountain range.[41] We selected the 13 U.S. states with Appalachian counties as the study area (Supplementary Fig. S1), with Appalachian areas designated by county classifications from the Appalachian Regional Commission (ARC), a federal-state partnership.[42] We included all census tracts in the 13 states to allow comparison between Appalachian tracts and non-Appalachian tracts.

Spatial access measures

Using the "*access*" package version 1.1 from the PySAL Python library,[43] we conducted a cross-sectional health services analysis by constructing neurologist spatial access measures in Appalachian states using spatial access ratios (SPARs) derived from 3 separate floating catchment area (FCA) methods: the two-step floating catchment area (2SFCA) method, the enhanced two-step floating catchment area (E2SFCA) method, and the three-step floating catchment area (3SFCA) method. The E2SFCA method and 3SFCA method are more advanced methods for measuring spatial access to care,[44,45] while basic 2SFCA method is also still useful. Briefly, the original 2SFCA method is a special form of gravity model first formulated by Luo et al. (2003) for measuring spatial access to primary care providers.[46] Further updates included the addition of distance decay functions (E2SFCA) and spatial impedance to account for more realistic healthcare supply and demand (3SFCA).[44,45] A key consideration in building spatial access measures is the maximum distance or time that is reasonable for patient travel, the catchment size.[47] Though there is a lack of consensus on an ideal maximum catchment size, catchment sizes for primary care are commonly set to 30 min.[44,46,48] Generally, patients travel further for specialty care and previous work examining distance to specialty care acknowledged that rural patients travel further for care than urban patients.[49–51] Because Appalachia is estimated to be over twice as rural compared to the U.S. overall,[20] a larger catchment area is likely to more accurately capture patient travel behavior to specialist physicians. Considering these factors, we designated 60 miles (proxy for minutes) as the catchment size. Further detail about each floating catchment access measure can be found in the Supplementary Material.

Statistical analysis

To compare spatial access to neurologists between Appalachian and non-Appalachian census tracts in the study area, we first categorized each census tract as Appalachian or not Appalachian via county classifications from ARC.[42] We used two-sided Welch two-sample t-tests to compare Appalachian and non-Appalachian SPARs stratified by state, ADI, and RUCA code. We used six-category Jenks natural breaks for 3SFCA SPARs and RUCA code categories to identify Appalachian census tract intervention targets and produce maps for the study area. Natural breaks were selected for categorization of spatial accessibility due to support in the literature.[46,52] 3SFCA SPARs were used for identification of intervention areas over the other measures due to stronger weighting of nearby physicians and thus more realistic representations of patient provider-seeking behavior. All statistical analysis was completed in R version 4.2.

We also performed sensitivity analyses to examine how certain methodological decisions may have affected our results. These included examining the effect of the 2010 population count data we utilized and whether spatial access to neurologists was simply measuring broader physician access. Full accounting of these analyses can be found in the Supplementary Material.

Role of the funding source

Funders of this work had no role in study design, data collection, data analysis, interpretation, or writing of this manuscript.

Results

The 13-state study area had a total 2010 population of 101,525,560 with 25,446,136 (25.1%) residing in 6169 Appalachian census tracts and 76,079,424 (74.9%) in 18,441 non-Appalachian tracts. The study area contained 5669 neurologists at 12,722 practice locations, with 1123 neurologists (19.8%) at 2184 locations in Appalachian tracts and 4546 (80.2%) at 10,538 locations in non-Appalachian tracts. The neurologist dataset for the entire U.S. contained 15,852 active physicians, roughly matching estimates by the AMA and American Academy of Neurologists.[53,54] Neurologist SPAR averages in the 13-state study area of both Appalachian and non-Appalachian tracts closely matched the average of the entire nation (1.0), where the mean study area SPARs for 2SFCA, E2SFCA, and 3SFCA were 1.003, 1.102, and 1.035, respectively. In comparison to the maximum 2SFCA (2.553) and E2SFCA (2.883) SPARs, the maximum SPAR for 3SFCA was much higher (7.180), which is likely due to the 3SFCA spatial impedance function placing more emphasis on nearby physicians. SPARs for neurologists were significantly lower in Appalachian tracts compared with non-Appalachian tracts, with mean differences of −0.252 or −25.2% ($p < 0.0001$), −0.329 or −32.9% ($p < 0.0001$), and −0.346 or −34.6% ($p < 0.0001$) for 2SFCA, E2SFCA, and 3SFCA, respectively. Visual inspection of census tract-level SPARs in Fig. 1 shows the strong effect that the selected access method has on resulting measures, where integration of distance decay (panel B) and spatial impedance (panel C) substantially modulate SPARs, particularly in reducing the likely overestimation of access seen in the 2SFCA method (panel A).

When classified into RUCA categories, exposure-response relationships were identified for all calculated neurologist SPARs, where SPARs decreased nearly continuously as tracts became more rural and remote (Table 1). SPARs for 2SFCA were less linear in their RUCA exposure-response relationships, while SPARs from the E2SFCA method and the 3SFCA method had stronger downward trends as tracts became more rural, which is likely due to their distance decay and impedance functions, respectively. Interestingly, exposure-response relationships were weaker for bivariate ADI-SPAR relationships, where upper quintiles of deprivation were similar to lower quintiles. Comparing SPARs between Appalachian and non-Appalachian tracts by state revealed that for a large majority of states, Appalachian tracts have significantly poorer spatial access to neurologists (Supplementary Table S1). In Alabama and Georgia, the opposite relationships were found, where non-Appalachian tracts had poorer access to neurologists. However, sensitivity analyses showed that SPARs in Alabama and Georgia were likely modulated by socioeconomic deprivation, as non-Appalachian tracts had higher deprivation than Appalachian tracts in these two states, which was not seen in the other 11 states in our analysis (Supplementary Table S2). ADI values and

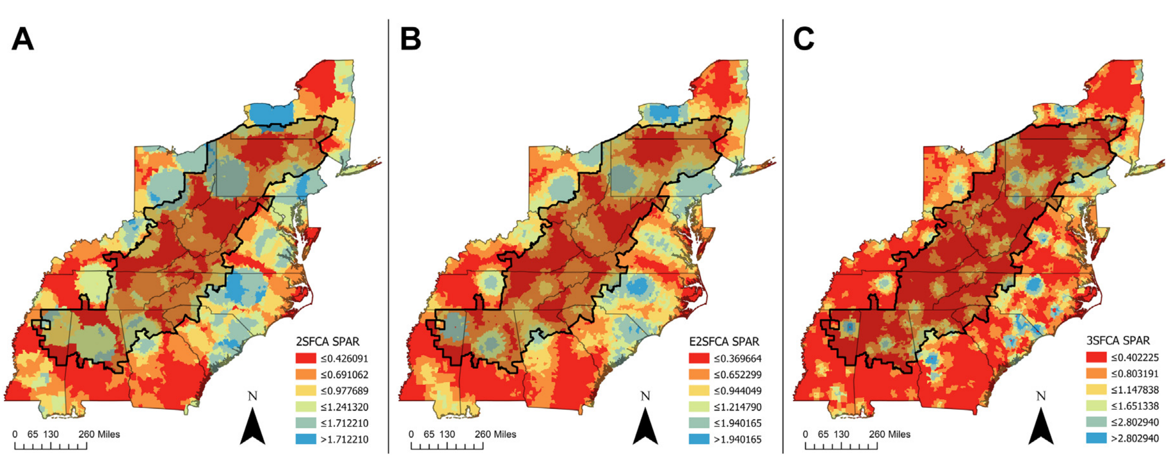

Fig. 1: **Jenks natural breaks maps of two-step floating catchment area (A), enhanced two-step floating catchment area (B), and three-step floating catchment area (C) spatial access ratios for neurological care (N = 24,610).** Red denotes areas with poorer spatial access to neurologists and blue denotes areas with better spatial access to neurologists. The bolded and outlined area is the boundary of Appalachia, as classified by the Appalachian Regional Commission.

Characteristic	Two-step floating catchment area spatial access ratio			Enhanced two-step floating catchment area spatial access ratio			Three-step floating catchment area spatial access ratio		
	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max
Rural-urban commuting area codes[a]									
1	1.088 (0.361)	0.117	2.497	1.182 (0.648)	0.091	2.830	1.260 (0.608)	0.035	5.611
2	0.929 (0.468)	0.022	2.496	0.843 (0.533)	0.008	2.776	0.723 (0.560)	0.001	5.994
3	0.923 (0.463)	0.056	2.536	0.723 (0.462)	0.046	2.207	0.573 (0.561)	0.003	4.279
4	0.838 (0.495)	0.057	2.498	0.662 (0.449)	0.023	2.323	0.585 (0.554)	0.002	5.875
5	0.747 (0.474)	0.046	2.450	0.568 (0.507)	0.034	2.301	0.496 (0.573)	0.002	7.180
6	0.942 (0.519)	0.083	2.497	0.674 (0.377)	0.091	2.185	0.451 (0.469)	0.007	5.311
7	0.716 (0.483)	0.011	2.536	0.548 (0.438)	0.007	2.380	0.425 (0.511)	0.001	3.980
8	0.569 (0.416)	0.011	2.319	0.434 (0.329)	0.007	2.220	0.324 (0.440)	0.001	4.095
9	0.770 (0.482)	0.102	2.368	0.546 (0.340)	0.088	2.086	0.366 (0.479)	0.004	4.192
10	0.677 (0.486)	0.0	2.553	0.509 (0.419)	0.0	2.667	0.381 (0.458)	0.0	3.470
99/NA	1.033 (0.368)	0.031	1.922	1.039 (0.666)	0.012	1.799	1.050 (0.532)	0.003	2.135
Area deprivation index quintiles									
Lowest[b]	1.111 (0.0)	1.111	1.111	1.278 (0.0)	1.278	1.278	0.936 (0.0)	0.936	0.936
Mid-lower	1.140 (0.323)	0.148	2.497	1.210 (0.625)	0.086	2.776	1.224 (0.570)	0.014	5.096
Middle	1.044 (0.431)	0.049	2.553	1.060 (0.674)	0.031	2.830	1.073 (0.636)	0.005	5.994
Mid-upper	0.925 (0.447)	0.0	2.536	0.891 (0.686)	0.0	2.721	0.865 (0.657)	0.0	7.180
Upper	0.935 (0.436)	0.0	2.536	0.961 (0.791)	0.0	2.665	1.021 (0.747)	0.0	5.875
Total	1.003	0.0	2.553	1.102	0.0	2.830	1.035	0.0	7.180

[a]Rural-urban commuting area codes are categorical rural-urban classifications numbered 1–10, where 1 is the most urban (Metropolitan area core) and 10 is the most rural (Rural areas). [b]Represents observation from single census tract.

Table 1: **Census-tract level neurologist spatial access ratio descriptive statistics by rural urban commuting area codes and area deprivation quintile (n = 24,610 tracts).**

RUCA codes by census tract can be viewed for the study area in Supplementary Fig. S2.

Comparison of SPARs between Appalachian and non-Appalachian census tracts by RUCA code revealed that even after stratifying by urban/rural status, significant disparities remained in spatial access to neurologists for both urban and rural Appalachian populations (Table 2). Specifically, tracts designated as metropolitan area cores, metropolitan area high commuting, small town core, small town high commuting, and rural Appalachian tracts had significantly lower SPARs than non-Appalachian areas. For 2SFCA and E2SFCA, Appalachian SPARs were also significantly lower than non-Appalachian SPARs in metropolitan area low commuting and micropolitan core designations, though significance did not hold for these designations in the 3SFCA method. Across three of the five ADI quintiles, Appalachian tracts had significantly lower SPARs than non-Appalachian tracts and a relatively consistent exposure-response relationship was identified, particularly for E2SFCA and 3SFCA (Supplementary Table S3). There were no Appalachian tracts and only a single non-Appalachian tract in the lowest deprivation quintile (<40.68), so little can be ascertained from this quintile. When stratified by both RUCA code and ADI, the most urban (codes 1–2) and most rural (code 9–10) Appalachian tracts had significantly lower SPARs than non-Appalachian tracts across the various spatial access measures, even when broken into ADI categories (Table 3). Also, in the RUCA code and ADI stratification, RUCA codes generally had a stronger effect on SPARs than ADI. Based on this, we mapped results from Table 2 to identify Appalachian tracts both in the lowest natural breaks category of 3SFCA SPARs (≤0.4022) and with the following RUCA codes: 1, 2, and 10 (Fig. 2). The 937 Appalachian tracts where interventions could be targeted contained a total population count of 3,754,508. ADI thresholds were not utilized to identify intervention target areas due to a lack of clear delineation between ADI categories in Table 3. Results from the sensitivity analyses can be found in the Supplementary Material.

Discussion

We constructed neurologist spatial access measures for the 13 states with Appalachian counties and found considerable disparities in accessibility among Appalachian populations. Depending on the specific spatial access measure, Appalachian tracts had SPARs that were between 25% and 35% lower than non-Appalachian tracts. These broad figures were modulated by urban and rural status, as significant differences in geographic access between Appalachia and non-Appalachia only held in the most urban (RUCA = 1, 2)

Rural-urban commuting area code	Two-step floating catchment area spatial access ratio, 60 miles			Enhanced two-step floating catchment area spatial access ratio, 60 miles			Three-step floating catchment area spatial access ratio		
	Appalachian tract mean (SD)	Non-Appalachian tract mean (SD)	Difference (p-value)	Appalachian tract mean (SD)	Non-Appalachian tract mean (SD)	Difference (p-value)	Appalachian tract mean (SD)	Non-Appalachian tract mean (SD)	Difference (p-value)
Metropolitan area core (1)	0.927 (0.411)	1.122 (0.340)	**−0.195 (p < 0.0001)**	0.987 (0.632)	1.224 (0.643)	**−0.237 (p < 0.0001)**	1.089 (0.587)	1.297 (0.606)	**−0.208 (p < 0.0001)**
Metropolitan area high commuting (2)	0.749 (0.363)	1.028 (0.489)	**−0.279 (p < 0.0001)**	0.682 (0.368)	0.931 (0.593)	**−0.249 (p < 0.0001)**	0.585 (0.389)	0.798 (0.623)	**−0.213 (p < 0.0001)**
Metropolitan area low commuting (3)	0.777 (0.389)	1.024 (0.484)	**−0.247 (p < 0.0001)**	0.618 (0.405)	0.795 (0.498)	**−0.177 (p = 0.0007)**	0.520 (0.454)	0.610 (0.623)	−0.090 (p = 0.144)
Micropolitan area core (4)	0.787 (0.407)	0.873 (0.546)	**−0.086 (p = 0.0003)**	0.625 (0.579)	0.688 (0.434)	**−0.063 (p = 0.0185)**	0.608 (0.600)	0.569 (0.519)	**−0.039 (p = 0.039)**
Micropolitan area high commuting (5)	0.715 (0.387)	0.774 (0.538)	−0.059 (p = 0.055)	0.543 (0.567)	0.589 (0.447)	−0.046 (p = 0.1773)	0.496 (0.586)	0.496 (0.562)	0.0 (p = 1.0000)
Micropolitan area low commuting (6)	0.875 (0.422)	0.995 (0.579)	−0.120 (p = 0.071)	0.605 (0.308)	0.729 (0.424)	**−0.124 (p = 0.011)**	0.418 (0.342)	0.477 (0.549)	−0.059 (p = 0.3194)
Small town core (7)	0.642 (0.380)	0.769 (0.540)	**−0.127 (p = 0.0005)**	0.493 (0.395)	0.589 (0.467)	**−0.096 (p = 0.0047)**	0.390 (0.410)	0.450 (0.571)	−0.060 (p = 0.1188)
Small town high commuting (8)	0.477 (0.302)	0.655 (0.486)	**−0.178 (p < 0.0001)**	0.390 (0.253)	0.476 (0.388)	**−0.086 (p = 0.0186)**	0.283 (0.287)	0.363 (0.546)	−0.080 (p = 0.099)
Small town low commuting (9)	0.785 (0.487)	0.761 (0.481)	0.024 (p = 0.75)	0.545 (0.243)	0.546 (0.389)	−0.001 (p = 0.983)	0.311 (0.272)	0.401 (0.572)	−0.090 (p = 0.164)
Rural areas (10)	0.566 (0.365)	0.774 (0.553)	**−0.208 (p < 0.0001)**	0.413 (0.312)	0.592 (0.483)	**−0.179 (p < 0.0001)**	0.284 (0.356)	0.465 (0.516)	**−0.181 (p < 0.0001)**
Not coded (99)	1.227 (0.291)	1.023 (0.370)	0.204 (p = 0.270)	1.256 (1.211)	1.028 (0.636)	0.228 (p = 0.733)	1.401 (0.956)	1.032 (0.506)	0.369 (p = 0.499)

Bold: Welch t-test significance <0.05.

Table 2: **Census tract neurologist spatial access ratio averages by rural-urban commuting area codes and status as Appalachian (n = 6169) or non-Appalachian (n = 18,441) tract (total N = 24,610 tracts).**

and rural (RUCA = 10) tracts after stratifying by both area deprivation and RUCA code. Though other studies have found that Appalachian populations have difficulty accessing primary and specialist care,[22,24,25,55] this is the first examination of spatial access to neurological care for the Appalachian region. More broadly, though other studies have identified geographic variation in neurological care across the U.S.,[17,26,29–33] this is also the first study to directly compute spatial access to neurologist measures for an entire U.S. region. We revealed that urban and rural status are more important drivers of neurologist spatial access than socioeconomic status, as ADI categories had weaker effects on SPARs than RUCA codes when stratifying by ADI and RUCA code. Furthermore, we found that in the most urban and rural areas, the differences in SPARs between Appalachian and non-Appalachian tracts were most stark, which suggests that neurologist access disparities are not only problematic in rural Appalachia, but also in Appalachian metropolitan areas. Though specialist physicians are more frequently located in urban areas,[56] our analysis indicates that Appalachian urban areas, such as Knoxville, TN; Greenville, SC; and Charlestown, WV have substantially poorer spatial access to neurologists than non-Appalachian metro areas. Though there is a lack of direct empirical work as to why neurologist access may be lower specifically in urban Appalachia, potential reasons include difficulty recruiting specialty physicians due to limited budgets of state funding-dependent hospital/academic departments and higher numbers of uninsured patients, as six of the thirteen Appalachian states have opted out of Medicaid expansion. Lower health insurance coverage combined with cultural attitudes in Appalachia may be resulting in a potential cascade effect of reduced specialist care-seeking behavior, lower demand for specialist services, and correspondingly, fewer specialist services and physicians.[57–59] Medicaid expansion in Alabama, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee may improve urban access to care in these Appalachian states. Beyond tabulating access disparities, our mapping results provide actionable, fine-scale disparity target areas, where policies and intervention campaigns can be directed for highest impact. These maps have the potential to be broadly useful to policymakers, public health practitioners, and clinicians. Overall, our results suggest that basic measures of socioeconomic deprivation and rurality are insufficient to describe access to neurological care.

Several intervention strategies and policies have been proposed to improve access to neurological care, including expansion of telemedicine, adjustments to physician visa waiver and loan forgiveness programs, and quick response mobile units for treatment of acute conditions. Recent literature suggests that teleneurology is broadly beneficial for care access across the spectrum of acute and chronic neurological disorders, including

Area deprivation by rural-urban commuting area code	Two-step floating catchment area spatial access ratio, 60 miles			Enhanced two-step floating catchment area spatial access ratio, 60 miles			Three-step floating catchment area spatial access ratio		
	Appalachian tract mean (SD)	Non-Appalachian tract mean (SD)	Difference (p-value)	Appalachian tracts (SD)	Non-Appalachian tract mean (SD)	Difference (p-value)	Appalachian tract mean (SD)	Non-Appalachian tract mean (SD)	Difference (p-value)
Metropolitan area core (1)									
Lowest deprivation[a]	–	1.111 (0.0)	–	–	1.278 (0.0)	–	–	0.936 (0.0)	–
Middle deprivation	0.917 (0.403)	1.130 (0.366)	**−0.213 (p < 0.00001)**	0.987 (0.591)	1.219 (0.653)	**−0.239 (p < 0.0001)**	1.086 (0.553)	1.284 (0.624)	**−0.204 (p < 0.0001)**
Upper deprivation	0.922 (0.438)	1.089 (0.350)	**−0.167 (p < 0.0001)**	0.940 (0.681)	1.229 (0.665)	**−0.289 (p < 0.0001)**	1.063 (0.625)	1.375 (0.634)	**−0.312 (p < 0.0001)**
Metropolitan area high commuting (2)[b]									
Middle deprivation	0.836 (0.396)	1.110 (0.507)	**−0.274 (p < 0.0001)**	0.791 (0.367)	1.021 (0.569)	**−0.230 (p < 0.0001)**	0.712 (0.390)	0.875 (0.624)	**−0.163 (p < 0.0001)**
Upper deprivation	0.655 (0.310)	0.841 (0.453)	**−0.186 (p < 0.0001)**	0.530 (0.284)	0.743 (0.759)	**−0.213 (p < 0.0001)**	0.347 (0.287)	0.690 (0.823)	**−0.343 (p < 0.0001)**
Metropolitan area low commuting (3)[b]									
Middle deprivation	0.716 (0.340)	1.102 (0.560)	**−0.386 (p = 0.0002)**	0.706 (0.459)	0.890 (0.330)	−0.184 (p = 0.0645)	0.722 (0.529)	0.634 (0.460)	0.088 (p = 0.4539)
Upper deprivation	0.702 (0.371)	0.927 (0.427)	**−0.225 (p = 0.0239)**	0.524 (0.370)	0.688 (0.656)	−0.164 (p = 0.1897)	0.356 (0.312)	0.564 (0.765)	−0.208 (p = 0.1217)
Micropolitan area core (4)[b]									
Middle deprivation	0.818 (0.405)	0.954 (0.523)	**−0.136 (p = 0.0168)**	0.678 (0.511)	0.730 (0.343)	−0.052 (p = 0.3599)	0.686 (0.554)	0.592 (0.380)	0.094 (p = 0.1295)
Upper deprivation	0.779 (0.393)	0.812 (0.546)	−0.033 (p = 0.3565)	0.598 (0.553)	0.646 (0.470)	−0.048 (p = 0.2381)	0.554 (0.571)	0.547 (0.581)	0.007 (p = 0.8758)
Micropolitan area high commuting (5)[b]									
Middle deprivation	0.798 (0.441)	0.910 (0.551)	−0.112 (p = 0.1298)	0.597 (0.290)	0.703 (0.372)	**−0.106 (p = 0.0319)**	0.535 (0.342)	0.618 (0.458)	−0.083 (p = 0.1617)
Upper deprivation	0.604 (0.327)	0.581 (0.456)	0.023 (p = 0.6570)	0.472 (0.663)	0.462 (0.467)	0.010 (p = 0.8934)	0.457 (0.698)	0.409 (0.472)	0.048 (p = 0.5361)
Micropolitan area low commuting (6)[b]									
Middle deprivation	1.286 (0.531)	1.074 (0.537)	0.212 (p = 0.2037)	0.813 (0.401)	0.842 (0.317)	−0.029 (p = 0.8044)	0.595 (0.482)	0.656 (0.420)	−0.061 (p = 0.6714)
Upper deprivation	0.727 (0.321)	0.891 (0.578)	−0.164 (p = 0.1791)	0.532 (0.221)	0.598 (0.278)	−0.066 (p = 0.3150)	0.263 (0.211)	0.277 (0.251)	−0.014 (p = 0.8169)
Small town core (7)[b]									
Middle deprivation	0.640 (0.401)	0.815 (0.550)	−0.175 (p = 0.1623)	0.538 (0.487)	0.589 (0.371)	−0.051 (p = 0.6857)	0.584 (0.485)	0.495 (0.463)	0.089 (p = 0.5016)
Upper deprivation	0.608 (0.331)	0.701 (0.515)	**−0.093 (p = 0.0433)**	0.457 (0.353)	0.559 (0.532)	**−0.102 (p = 0.0341)**	0.351 (0.378)	0.449 (0.662)	−0.098 (p = 0.0842)
Small town high commuting (8)[b]									
Middle deprivation	0.381 (0.168)	0.621 (0.325)	**−0.240 (p = 0.0249)**	0.293 (0.275)	0.487 (0.198)	**−0.194 (p = 0.0490)**	0.357 (0.400)	0.503 (0.400)	−0.146 (p = 0.3528)
Upper deprivation	0.454 (0.314)	0.664 (0.466)	**−0.210 (p = 0.0033)**	0.378 (0.217)	0.482 (0.462)	−0.104 (p = 0.1094)	0.239 (0.240)	0.371 (0.589)	−0.132 (p = 0.1045)
Small town low commuting (9)[b]									
Middle deprivation	0.701 (0.553)	1.011 (0.525)	−0.310 (p = 0.3706)	0.539 (0.083)	0.772 (0.259)	**−0.233 (p = 0.0032)**	0.337 (0.063)	0.561 (0.375)	**−0.224 (p = 0.0093)**
Upper deprivation	0.531 (0.321)	0.626 (0.370)	−0.095 (p = 0.3947)	0.394 (0.148)	0.453 (0.558)	−0.059 (p = 0.5460)	0.207 (0.179)	0.430 (0.838)	−0.223 (p = 0.1194)
Rural areas (10)[b]									
Middle deprivation	0.658 (0.431)	0.937 (0.581)	**−0.279 (p = 0.0046)**	0.506 (0.358)	0.702 (0.262)	**−0.196 (p = 0.0055)**	0.392 (0.489)	0.528 (0.322)	−0.136 (p = 0.1393)
Upper deprivation	0.487 (0.292)	0.597 (0.486)	**−0.110 (p = 0.0192)**	0.352 (0.281)	0.427 (0.479)	−0.075 (p = 0.1023)	0.211 (0.289)	0.326 (0.534)	**−0.115 (p = 0.0227)**

Bold: Welch t-test significance <0.05. [a]Represents observation from single census tract. [b]Lowest deprivation category not tabulated due to zero observations.

Table 3: **Census tract neurologist spatial access ratio averages by rural-urban commuting area codes, area deprivation, and status as Appalachian (n = 6169) or non-Appalachian (n = 18,441) tract (total N = 24,610 tracts).**

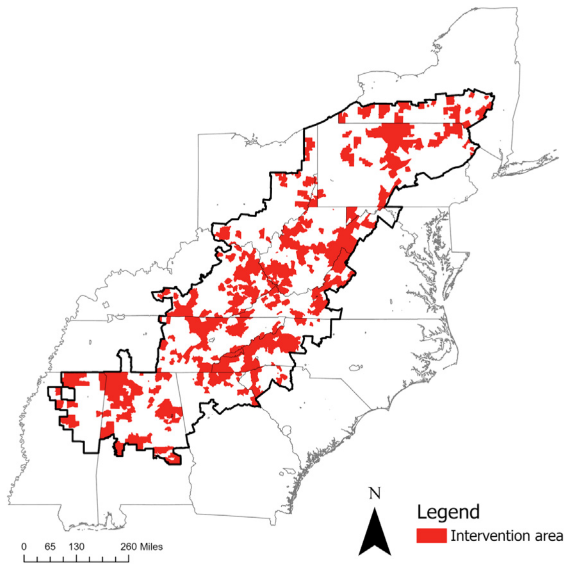

Fig. 2: **Appalachian census tract neurologist spatial accessibility intervention areas (N = 937).** Intervention areas include those tracts existing in the lowest natural breaks category of three-step floating catchment area spatial access ratios (≤0.4022) and with the following 2010 rural-urban commuting area codes: 1, 2, and 10.

stroke, traumatic brain injury, epilepsy, movement disorders, and general neurology.[60] The importance and effectiveness of teleneurology in Appalachia specifically is also beginning to be understood,[18] yet barriers persist, especially among the most marginalized Appalachian groups: older individuals, the non-Hispanic Black population, and those on government insurance. The 'digital divide' is well-documented in the Appalachian region,[61–63] and the disparities seem to translate to teleneurology, where lack of internet, smartphones, and computers have been cited as barriers to care.[18] Policies to increase access to these technologies among marginalized Appalachian populations, such as the recent infrastructure law passed by the U.S. congress,[64] may help ease barriers identified. Other policy solutions could increase the supply of neurologists serving Appalachia: 1) the recent revision of Conrad 30 ARC J-1 visa waiver policies to include foreign specialist physicians in addition to foreign primary care providers and 2) expansion of domestic medical graduate loan forgiveness programs to include Appalachian specialist physicians.[65,66] ARC J-1 visa waiver policies were changed in 2019 to include specialist physicians,[67(p30)] but the effects are not yet clear. Domestic medical graduate loan repayment/forgiveness programs for Appalachia are typically reserved for primary care providers and targeted specifically to healthcare shortage areas.[68–70] As shown in our analysis, neurologist access does not necessarily follow broader physician access/shortage patterns, which further indicates the utility of specialty-specific spatial access measures in formulating loan forgiveness policy. Another recent advancement to address access to neurological care is the proliferation of quick response mobile units to treat acute conditions, commonly known as mobile stroke units (MSUs).[71] MSUs contain imaging equipment, laboratory systems, and hospital telemedicine linkage to provide care at the site of emergency.[72] Mobile units have potential to improve treatment timeliness of stroke and other acute neurological conditions in areas with poor access to physical neurologist offices. These solutions could be directed to the disparity target areas we identified in Fig. 2. These intervention areas could be further refined for subspecialties within neurology and incorporate other important factors (e.g., broadband internet) that would impact the delivery of the specific intervention. Beyond adjustments in health policy, hospital, and physician-related factors, patient-level educational and intervention campaigns could be directed to disparity areas to reduce the burden of neurological disorders on the Appalachian region. For example, potential avenues include educational campaigns to improve knowledge of stroke symptoms or intervention campaigns targeting primary prevention of adverse health behaviors.

This study had several strengths, including use of robust SPAR measures, use of comprehensive physician location data, and stratification of spatial access by rurality and ADI. The E2SFCA and 3SFCA SPARs utilized are not only advanced spatial statistics-based representations of access to care,[24,45,73] but are also novel in the context of our application towards neurologist access. In terms of physician locations, the CMS Care Compare data had high coverage of active physicians, where roughly 97% of neurologists are estimated to be captured by the database.[74] Another strength was stratification of our access measures by rurality and ADI, which allowed for more granular examination of where and why access disparities exist. This study also had several limitations, including possible over- or underestimation of the physician population, inability to fully explore areas of lowest deprivation, use of 2010 distance matrix and population data, use of a Euclidean distance matrix, and the possibility that poor spatial access to neurologists was simply measuring poorer overall access to physicians. CMS Care Compare physician data may also have over- or underestimated the number and/or density of neurologists in the study area. Because the data are estimated to capture roughly 97% of neurologists,[74] a slight undercount is possible. Other 'comprehensive' physician datasets by the AMA and CMS face similar issues with cataloging of physicians,[75] indicating a lack of better options in addition to the noted high coverage of Care Compare. Also, we included all physician practice locations, as no variable exists in Care Compare by which to restrict to primary practice location, which could have overestimated physician density in certain areas. We used nationwide quintiles for better representation of the true area socioeconomic deprivation of the study area. Only a single tract in the study area existed in the lowest socioeconomic deprivation quintile, which resulted in NAs in our tabulated ADI results. However, using study area-specific quantiles would have underestimated the widespread socioeconomic deprivation in Appalachia, indicating that nation-based ADI quantiles were optimal. We used 2010 distance matrix and population data due to availability and accuracy. In a supplementary analysis of 2010–2019 population change, we found that there was little concern for differential misclassification (Supplementary Materials). Euclidean distance matrices tend to overestimate access to care, particularly for urban areas, as they do not account for the complexity of road networks and other transit modalities, such as urban rail. Although we acknowledge that it would be ideal to account for complex transportation matrices, this requires exponentially more computational and memory requirements, which was not feasible for a census tract-level analysis. Future work may consider using advanced routing methods to build more representative travel matrices. In addition, for 82 or 0.33% of census tracts in the study area, RUCA codes were unavailable. For the 82 missing values, 78 were non-Appalachian tracts, 4 were Appalachian, and overall SPARs were close to 1 for each of the FCA methods. Due to only a small proportion of missing values, significant differential effects due to missingness were exceedingly unlikely. Finally, our supplementary construction of a geographic access measure for primary care providers displayed that our neurologist SPARs were not simply identifying areas with poor overall spatial access to providers (Supplementary Fig. S3). Though there was moderate to strong Spearman correlation between neurologist and primary care provider SPARs, visual inspection showed substantial differences. For example, SPARs for primary care providers in Appalachian metro areas, such as Knoxville, TN and Charleston, WV were substantially higher than SPARs for neurologists in the same areas, revealing the utility of directly studying spatial access to neurologists.

This study demonstrated the significant disparities in geographic access to neurological care in the Appalachian region. Our geographic access measures highlight that access to neurologists cannot be solely defined by rural/urban location or socioeconomic status. Future intervention studies attempting to address disparities in neurological care access should consider incorporating spatial access measures to target areas of greatest need.

Contributors

R.B.B.: Conceptualization: Equal; Data curation: Lead; Formal analysis: Lead; Investigation: Equal; Methodology: Lead; Software: Lead; Validation: Equal; Visualization: Lead; Writing – original draft: Lead. E.G.G.: Writing – review & editing: Supporting; M.A.W.: Writing – review & editing: Supporting; Supervision: Supporting; M.P.M.: Conceptualization: Equal; Data curation: Supporting; Investigation: Equal; Validation: Equal; Writing – original draft: Supporting; Supervision: Supporting.

Ethics committee approval

Cleveland Clinic IRB Study #22-464.

Editor's note

The Lancet Group takes a neutral position with respect to territorial claims in published maps and institutional affiliations.

Data sharing statement

Raw data available in supplemental material.

Declaration of interests

R.B.B.: None; E.G.G.: None; M.A.W. has received speaking fees from Biogen, Bristol-Meyers Squibb, and Alexion and has received consulting fees from Biogen, Alexion, Greenwich Biosciences, Horizon, and Alexion; M.P.M. has received consulting fees from Genentech, Genzyme, and Octave and has received research support from Novartis and Biogen.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2022.100415.

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