DOI: 10.1111/1475-6773.13562

RESEARCH ARTICLE

HSR Health Services Research

Spatial accessibility to colonoscopy and its role in predicting late-stage colorectal cancer

Whitney E. Zahnd PhD[1,2] | Michele J. Josey PhD[3] | Mario Schootman PhD[4] | Jan M. Eberth PhD[1,2,3]

[1]Rural & Minority Health Research Center, Arnold School of Public Health, University of South Carolina, Columbia, South Carolina, USA

[2]Big Data Health Science Center, Arnold School of Public Health, University of South Carolina, Columbia, South Carolina, USA

[3]Department of Epidemiology and Biostatistics, Arnold School of Public Health, University of South Carolina, Columbia, South Carolina, USA

[4]SSM Health, Department of Clinical Analytics, Center for Clinical Excellence, St. Louis, Missouri, USA

Correspondence
Jan M. Eberth, PhD, 220 Stoneridge Suite 204, Columbia, SC 29210, USA.
Email: jmeberth@mailbox.sc.edu

Funding information
National Institute of General Medical Sciences, Grant/Award Number: T32-GM081740; American Cancer Society, Grant/Award Number: MRSG-15-148-01-CPHPS

Abstract

Objective: To better determine the relationship between spatial access to colonoscopy and colorectal cancer (CRC) outcomes, our objective was to examine the agreement of the classic, enhanced, and variable two-step floating catchment area (2SFCA) methods in evaluating spatial access to colonoscopy and to compare the predictive validity of each method related to late-stage CRC. 2SFCA methods simultaneously consider supply/demand of services and impedance (ie, travel time).

Data Sources: Colonoscopy provider locations were obtained from the South Carolina Ambulatory Surgery Database. ZIP code tabulation area (ZCTA) level population estimates and area-level poverty level were obtained from the American Community Survey. Rurality was determined by the United States Department of Agriculture's Rural-Urban Commuting Area codes. Individual-level CRC data were obtained from the South Carolina Central Cancer Registry.

Study Design: Using the classic, enhanced, and variable 2SFCA methods, we calculated ZCTA-level spatial access to colonoscopy. We assessed agreement between the three methods by calculating Spearman's rank coefficients and weighted Kappas (K). Global and Local Moran's I were used to assess spatial clustering of accessibility scores across 2SFCA methods. We performed multilevel logistic regression analyses to examine the association between spatial accessibility to colonoscopy, area- and individual-level factors, and late-stage CRC.

Principal Findings: We found strong agreement (Weighted K = 0.82; 95% CI = 0.79-0.86) and identified similar clustering patterns with the classic and enhanced 2SFCA methods. There was negligible agreement among the classic/enhanced 2SFCA and the variable 2SFCA. Across all 2SFCA methods, regression models showed that spatial access to colonoscopy, rurality, and poverty level were not associated with greater odds of late-stage CRC, though Black race was associated with late-stage CRC across all models.

Conclusions: None of the 2SFCA methods showed an association with late-stage CRC. Future studies should explore which elements (spatial or nonspatial) of access to care have the greatest impact on CRC outcomes.

KEYWORDS
colonoscopy, colorectal cancer, GIS, spatial accessibility, two-step floating catchment area method

1 | INTRODUCTION

Colorectal cancer (CRC) is the third leading cause of cancer among both men and women in the United States and the second leading cause of death.[1] CRC can be prevented and detected at an earlier, more treatable stage by following screening recommendations. The United States Preventive Services Task Force (USPSTF) recommends that average-risk individuals be screened for CRC between the ages of 50 to 75.[2] While several screening modalities can be used, colonoscopy is the most frequently used (~60 percent of all screenings) and is able to prevent cancer by removing potentially malignant polyps.[3,4] Geographic barriers to accessing these services may affect adherence to screening recommendations, subsequently contributing to CRC being detected at a late stage. Previous studies have examined the relationship between spatial access, as measured by travel distance/time to colonoscopy providers, and colonoscopy adherence and/or stage at diagnosis.[5-9] However, these studies have not examined spatial access using population-based (ie, all-payer) data, nor have they used spatial accessibility measures that take into account all three key principles of spatial accessibility: supply, demand, and impedance (ie, distance or travel time).[10]

Two-step floating catchment area (2SFCA) methods, based on gravity modeling, consider the supply of healthcare services (colonoscopy providers), the demand for services (populations of recommended screening age), and impedance between a point of origin and destination (travel distance or time).[11] The 2SFCA approach creates an area-based spatial accessibility score, typically measured for ZIP codes, census tracts, or other small area units. These methods have advantages over travel distances, which do not account for the population demand for healthcare services, and over container measures, which assume that persons do not use services outside of the "container" (eg, county boundary) in which they reside. The 2SFCA method has been frequently used to examine spatial access to primary care and breast cancer screening services, but have been underutilized in the examination of access to colonoscopy services.[12-15]

As its name indicates, the classic 2SFCA method is performed in two steps. The first step determines a provider-to-population ratio within a provider catchment area, while the second step sums the provider-population ratios of providers within an area's catchment to calculate a score. In this classic application, the catchment area size is based on a predetermined distance or travel time threshold (eg, 30-minute buffer). Variations of the 2SFCA aim to account for some of the method's inherent limitations. For example, the enhanced two-step floating catchment area method (E2SFCA) also considers distance decay, the concept that persons may be less likely to use services that are farther away, by dividing the catchment area into zones and weighting each zone based upon distance from service.[16] Similarly, the variable two-step floating catchment area (V2SFCA) considers both distance decay by applying weights within zones like the E2SFCA method, but also allows the catchment area size to vary, which has particular applicability when study regions include both rural and urban areas.[17] In sum, all 2SFCA methods consider the three key components of spatial access—supply, demand, and impedance. However, both the E2SFCA and V2SFCA methods address the phenomenon of distance decay, and the V2SFCA allows for varying catchment areas for more appropriate application across areas with varying rurality. Previous studies have found varying predictive validity of spatial access measures and late-stage breast cancer, but these studies did not examine the nuances of variations of 2SFCA methods.[15,18]

Our objective was to compare the 2SFCA, E2SFCA, and V2SFCA methods applied to access to colonoscopy providers in South Carolina using both descriptive and spatial statistics. Further, we aimed to evaluate the predictive validity of these scores by comparing the association of these scores to late-stage CRC diagnoses after accounting for individual and contextual factors using multilevel modeling.

What Is Already Known on This Topic

- Spatial accessibility scores can be used to evaluate the relationship between access to cancer screening services such as colonoscopy and stage at cancer diagnosis.
- Spatial access can be measured using methods that simultaneously consider "supply" of screening providers, potential "demand" for screening services (ie, number of persons of recommended screening age), and travel time within a catchment area of interest.

What This Study Adds

- None of the three spatial access methods we tested showed an association between spatial access to colonoscopy providers and late-stage cancer diagnosis.
- Current methods can be enhanced by considering provider volume, not solely location, to better understand how spatial access to screening may be associated with late-stage cancer diagnosis.

2 | METHODS

2.1 | Study population

The study area included all 424 ZIP code tabulation areas (ZCTA) in South Carolina from the 2010 census. There were 1 433 535 people

in South Carolina aged 50-74, the age for which ZCTA-level data are available that are most congruent with USPSTF screening recommendations for colorectal cancer screening in average-risk individuals. We obtained data on 10 692 adults diagnosed with CRC in South Carolina between 2010 and 2014 from the population-based South Carolina Central Cancer Registry (SCCCR).

2.2 | Spatial accessibility measures to evaluate spatial accessibility to colonoscopy services

We also acquired address data from the South Carolina Ambulatory Surgery Database (ASD) of providers who performed at least one colonoscopy on a patient aged 50-74 in 2014, as described elsewhere.[19] The ASD is a population-based administrative data source that provides patient-level data on outpatient surgical procedures (conducted at both hospitals and free-standing facilities) including colonoscopy. Using data from ASD, we geocoded the locations of every facility that had a provider who performed at least one colonoscopy in 2014 (n = 91) and summed the number of unique medical providers who provided colonoscopies at each location. Because colonoscopy providers may perform colonoscopies at multiple locations, we determined the proportion of colonoscopies providers performed at a given location to determine the number of colonoscopy providers at each site based upon their practice patterns. For example, if a provider performed all their colonoscopies at a single location, they would be counted as "1" at the location. If they provided 60 percent of their colonoscopies at one location and 40 percent at another location, they would be counted as 0.6 and 0.4 at each location, respectively. We estimated the number of adults of recommended colorectal cancer (CRC) screening age (50-74 years of age) in each ZCTA using a rolling average of 5-year American Community Survey (ACS) population estimates that were available at the time of study initiation and inclusive of 2014 (ie, 2010-2014, 2011-2015, 2012-2016 5-year estimates). These data were used to calculate three different two-step floating catchment area (2SFCA) approaches to evaluate spatial accessibility to colonoscopy.[20]

2.3 | Two-Step Floating Catchment Area (2SFCA) method

We employed the classic 2SFCA method to calculate a spatial accessibility score for each ZCTA in SC. In brief, this method considers both supply of colonoscopy providers (eg, endoscopists of any specialty) and potential demand for colonoscopy services (eg, populations of recommended screening age) within a given catchment area (eg, 30-minute drive time) and is described in greater detail elsewhere.[11] For the first step, we created 30-minute drive time catchment areas around each colonoscopy facility to compute the endoscopist-to-population ratio for each facility using the Network Analyst extension in ArcGIS 10.5.1 (Redlands, CA). Thirty-minute drive time catchment areas are commonly used for analyses of access to care in individual states and multi-county regions and is a threshold for health provider shortage designations for different healthcare service types.[16,21] For each colonoscopy location, the number of endoscopists was determined by their practice location and proportion of procedure volume performed at each location as described above. The catchment population included all individuals aged 50-74 within any ZCTA whose centroid fell within the catchment area. For the second step, we created a 30-minute drive time catchment area around each ZCTA centroid and summed the endoscopist-to-population ratio of all facility locations within each ZCTAs' catchment area. This creates a spatial accessibility index for each ZCTA where 0 indicates no access to an endoscopist within 30 minutes of a ZCTA to a theoretical, but unrealistic, upper value of 1, which would indicate one endoscopist for every person of recommended screening age.

2.4 | Enhanced Two-Step Floating Catchment Area (E2SFCA) method

We also used the E2SFCA method, an enhanced variation of the 2SFCA method that considers distance decay, to calculate spatial accessibility to colonoscopy providers in SC. This method is described in greater detail by Luo and Qi.[16] Distance decay is the concept that patients are more likely to use healthcare services that are closer to them and less likely to use more distant services. An advantage of accounting for this is that it may be more reflective of patients' healthcare decisions especially when examining areas with both rural and urban areas.[22] Thus, in the E2SFCA method, we implemented a similar approach as the 2SFCA method, but we applied a distance decay weight within 3 zones in the 30-minute drive time catchment area for both steps 1 and 2 of the equation. These three zones were 0-10, >10-20, and >20-30 minutes with corresponding-decay weights of 1.00, 0.42, 0.03, respectively, determined by a stepwise Gaussian function applied to three zones as has been used in previous studies.[16,17]

2.5 | Variable Two-Step Floating Catchment Area (V2SFCA) method

Finally, we employed was the V2SFCA method. Instead of using a fixed catchment size for each step as employed in the 2SFCA and E2SFCA, the V2SFCA varies the catchment area size to reflect different patterns of healthcare utilization based upon geography while also considering distance decay.[22] In brief, for step 1, the catchment area is varied for each provider until a threshold population is reached; for step 2, the catchment area is varied for each ZCTA until a specified provider-to-population ratio is reached. Additional details on this method are provided elsewhere.[17] In our implementation of this method, for step 1, we varied the catchment area for each endoscopist until the catchment area contained the ZCTA centroids inclusive of the average

TABLE 1 Distribution of spatial accessibility scores to colonoscopy in South Carolina

Variable	Mean	SD	Median	IQR	Range
2SFCA	0.000629	0.000781	0.000429	0.000970	0.00528
E2SFCA	0.00127	0.00253	0.000127	0.00128	0.0129
V2SFCA	0.000964	0.000319	0.000319	0.000639	0.0460

Abbreviations: 2SFCA, two-step floating catchment area; E2FCA, enhanced two-step floating catchment area; IQR, interquartile range; SD, standard deviation; V2SFCA, variable two-step floating catchment area.

population size of recommended screening age within 30 minutes travel time for colonoscopy facilities in SC, which was 70 412 people. To determine the catchment area size for each colonoscopy facility, we tested catchments in 15-minute travel-time increments capping the catchment size at 90 minutes. Thus, each facility had a catchment of either 15, 30, 45, 60, 75, or 90 minutes travel time. After the catchment size was determined, we calculated an endoscopist-to-population ratio for each colonoscopy location by dividing each catchment into three equal time zones (eg, if a catchment is 60 minutes, then zones are 1-20, >20-40, and >40-60 minutes) and applying a decay weight of 1.00, 0.42, and 0.03 for each respective zone. For step 2, to determine catchment sizes for each ZCTA centroid, we varied the catchment until the threshold overall statewide endoscopist-to-population ratio was achieved. Like in step 1, we tested catchments at 15-minute intervals capping at 90-minute travel time. Once that catchment was determined, we applied decay weights for three equal time zones across the catchment for each ZCTA summing the endoscopist-to-population ratios within each zone with appropriate weighting. This process produced a spatial accessibility score for each ZCTA. Because catchment areas are varied until they reach the threshold provider-population ratio, all ZCTAs will have a spatial accessibility score larger than 0, but still less than 1.

2.6 | Statistical and spatial analyses

We compared the scores generated by these three 2SFCA method approaches. We calculated measures of central tendency and dispersion for each approach. We then compared the scores by calculating Spearman's rank coefficients to determine their level of correlation. We also calculated weighted Kappa coefficients by placing each score into quartiles. The level of agreement was determined by using a common scale: $\kappa < 0$, no agreement; $\kappa = 0.01$-0.2, slight agreement; $\kappa = 0.21$-0.40, fair agreement; $\kappa = 0.41$-0.60, moderate agreement; $\kappa = 0.61$-0.80, substantial agreement; and $\kappa > 0.801$, perfect agreement.[23]

We also examined the differences in these scores using spatial statistics. We computed Global Moran's I and Local Moran's *I* statistics for each approach using the spatial statistics tool in ArcGIS to assess spatial autocorrelation and spatial patterns, respectively. We used an "inverse distance" weight function and standardized row values for both statistics. Global Moran's *I* is a statistic that evaluates spatial autocorrelation to generate a value of −1 (perfect dispersion) to +1 (perfect clustering). The Local Moran's I analysis identifies areas of no clustering, spatial clusters of high or low values, and outliers.[24] Outliers are areas with high values surrounding by low values or vice versa.

To determine predictive validity, we examined the relationship between each of the three accessibility scores and late-stage CRC diagnosis using 2-level multilevel logistic regression models with individuals nested within ZCTAs. Late stage was defined as "regional" or "distant" using Surveillance Epidemiology and End Results (SEER) summary staging. We performed univariate multilevel logistic regression, followed by multivariable multilevel logistic regression of increasing complexity adjusting for individual and area-level characteristics similar to the approach used by Lian et al[15] to explore the relationship between spatial access to mammography and late-stage breast cancer diagnosis. Model 1 included gender, age, race/ethnicity, and each respective spatial accessibility score. Model 2 included all variables from Model 1, as well as rurality. ZCTA-level rurality was defined using the United States Department of Agriculture's Rural-Urban Commuting Area (RUCA) primary codes which are defined at the census tract level with available ZCTA approximations.[25] RUCA codes range from 1 to 10 and are categorized based upon their population size and commuting patterns; codes >3 are indicative of rural areas. Model 3 included all variables from Model 2 as well as the ZCTA-level percent of people living in poverty. We considered race, poverty level, and rural-urban status in our models, as ecological studies have shown that Black persons, as well as those living in areas of high poverty and those living in rural areas, have higher rates of late-stage CRC.[26-28] Poverty level, % of the population living in poverty, was determined using the 2013-2017 American Community Survey estimates. Spatial accessibility scores from the three models were categorized in tertiles of high, middle, and low access. We assessed the presence of multicollinearity, and all variance inflation factor values were <1.1, indicating no multicollinearity.

Statistical analyses were performed using SAS 9.4. Spatial statistics and mapping were performed in ArcGIS 10.5.1. This study was reviewed and determined to be exempt from oversight by the [redacted for review] Institution Review Board.

3 | RESULTS

Table 1 displays the measures of central tendency and dispersion among the three spatial accessibility score types. The 2SFCA had the smallest range of scores while the two score types that employed

decay weights had broader ranges of scores. Figure 1 shows the distribution of these scores across ZCTAs by quartiles.

Table 2 indicates that the 2SFCA and E2SFCA methods show both high levels of correlation and high agreement based on Spearman's rho and weighted κ values of 0.92 and 0.82, respectively. The 2SFCA and V2SFCA methods showed weak correlation (Spearman's rho = 0.30) and slight agreement (weighted κ = 0.23). The E2SFCA and V2SFCA similarly showed weak correlation (Spearman's rho = 0.36) and only slight agreement (weighted κ = 0.29).

Our spatial analysis showed that there was significant clustering of values for all three spatial accessibility score types with the strongest clustering indicated for the E2SFCA (Global Moran's I = 0.82; $P < .0001$). Moran's I values for the 2SFCA and V2SFCA were 0.54 and 0.28, respectively ($P < .0001$) for both. Figure 2 shows the Local Moran's I results. Both the 2SFCA (Figure 2A) and E2SFCA (Figure 2B) show large clustering of low access in the southwesternmost part of the state with clusters of high access in the metropolitan areas of Columbia (the central part of the state), Charleston (the central part of the coast), and the Greenville-Spartanburg (the northeastern part of the state). Figure 2C shows the clustering for the V2SFCA method for which there is only a few scattered, small clusters of both low and high access.

In our two-level models, the intercept-only model showed very small variation attributable to the ZCTA (ICC = 0.0163; 1.63 percent of the variation explained by ZCTA), but this was statistically significant ($P < .0001$). Our univariate models (Models 1) showed no association between 2SFCA, V2SFCA, or E2SFCA scores and the odds of late-stage CRC diagnosis (Table 3). Across 2SFCA multivariable models, Black race was the only covariate associated with late stage at diagnosis (eg, OR = 1.16, 95% CI = 1.04-1.28 for Model III). Similar for the E2SFCA and V2SFCA, there were no statistically significant associations between spatial accessibility and late-stage CRC diagnosis in any multivariable models, but Black race was associated with late stage at diagnosis across all models. Conversely, female cancer patients and those in any age group older than 50 were less likely to be diagnosed with late-stage CRC across all models.

4 | DISCUSSION

We examined three different 2SFCA-based methods to calculate ZCTA-level spatial accessibility to colonoscopy providers in South Carolina and determine predictive validity in their associations with odds of late-stage colorectal cancer. We found that the classic 2SFCA and E2SFCA methods produced scores that were highly correlated with perfect agreement, but scores of these two methods were weakly correlated with the scores produced by the V2SFCA method. Spatial analysis showed similar significant clustering of high and low scores with the 2SFCA and E2SFCA methods, but the V2SFCA method showed notably different patterns.

Our multilevel models found that none of the 2SFCA-based methods we examined were associated with late-stage CRC. This corroborates previous studies that showed no association between spatial access, as measured by travel time, and late-stage CRC diagnosis.[5,7-9] However, for other screen-detectable cancers, such as breast cancer, the relationship between spatial access to screening

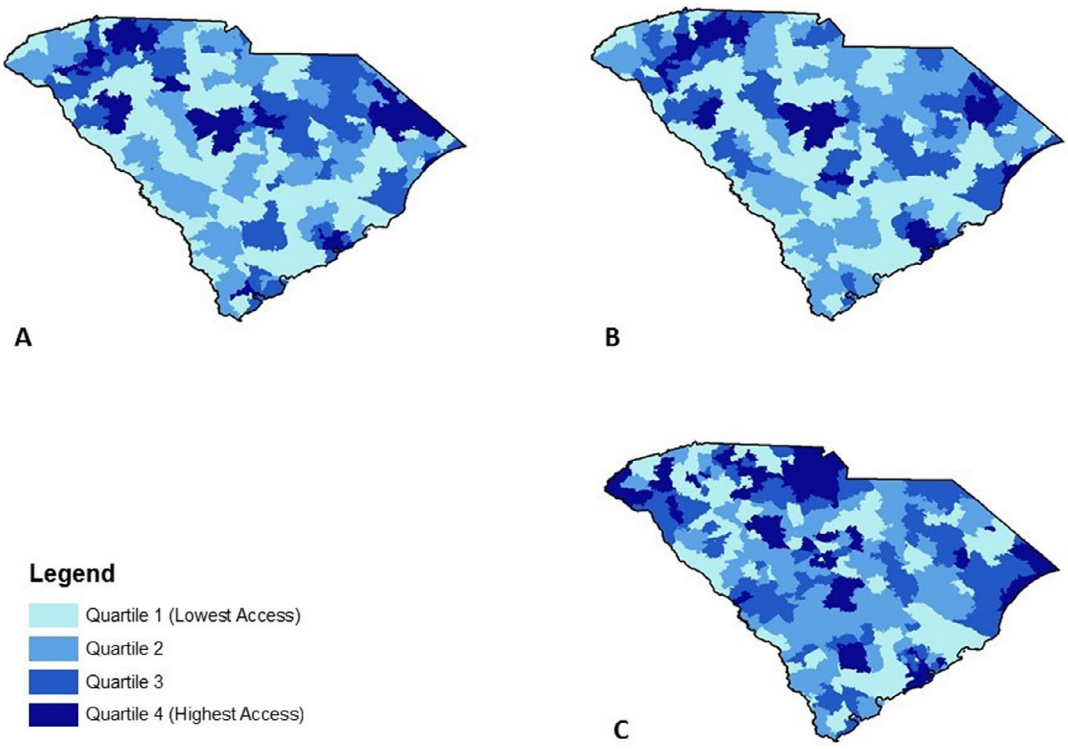

FIGURE 1 Distribution of Scores (Quartiles) by ZCTA: A, 2SFCA; B, E2SFCA; C, V2SFCA. Abbreviations: 2SFCA, two-step floating catchment area; E2FCA, enhanced two-step floating catchment area; V2SFCA, variable two-step floating catchment area [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Analyses of agreement between spatial accessibility scores to colonoscopy in South Carolina

		2SFCA	E2SFCA
2SFCA	Spearman's Correlation	1.00	—
	Kappa (95% CI)	—	
E2SFCA	Spearman's Correlation	0.92	1.00
	Kappa (95% CI)	0.82 (0.79-0.86)	—
V2SFCA	Spearman's Correlation	0.30	0.36
	Kappa (95% CI)	0.23 (0.17-0.31)	0.29 (0.22-0.36)

Abbreviations: 2SFCA, two-step floating catchment area; E2FCA, enhanced two-step floating catchment area; V2SFCA, variable two-step floating catchment area.

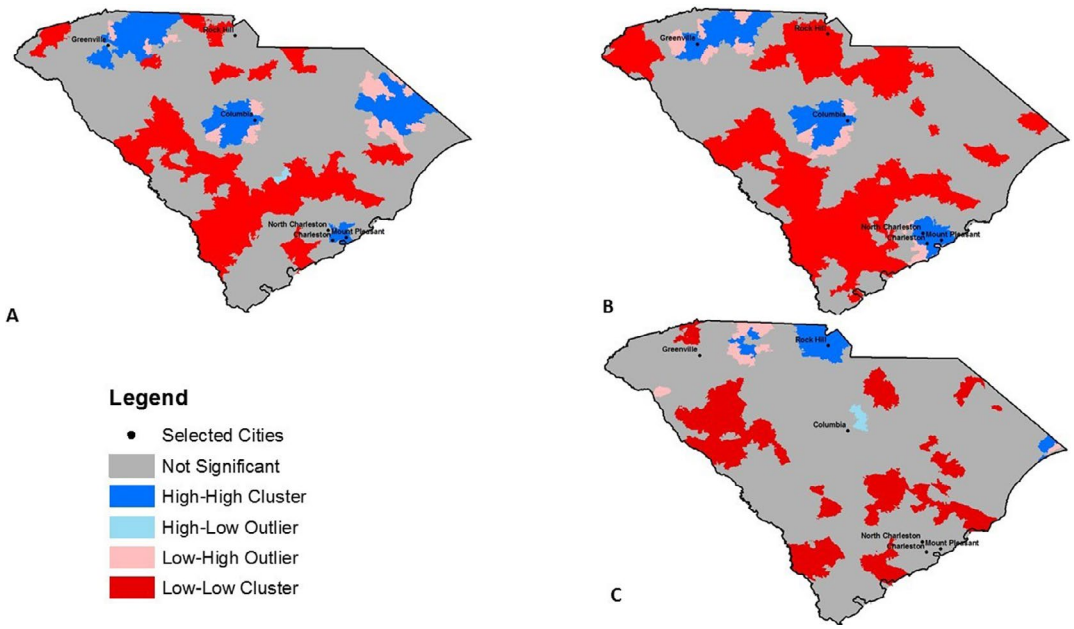

FIGURE 2 Spatial Patterns in Spatial Accessibility Scores A, 2SFCA; B, E2SFCA; C, V2SFCA. Abbreviations: 2SFCA, two-step floating catchment area; E2FCA, enhanced two-step floating catchment area; V2SFCA, variable two-step floating catchment area [Color figure can be viewed at wileyonlinelibrary.com]

and advanced stage at diagnosis has been mixed. A lack of association between spatial access to colonoscopy and late-stage CRC may be, in part, due to the complexities of CRC screening that are not existent with other forms of cancer screening. First, colonoscopy is one of several recommended CRC screening modalities. Individuals may opt to do a home-based fecal immunochemistry test (FIT) or fecal occult blood (FOBT) in lieu of colonoscopy as their initial form of screening.[2] Thus, they may only have a colonoscopy if they first had an abnormal FIT or FOBT. Additionally, colonoscopies can be preventive in nature, not solely an opportunity for early detection, as precancerous polyps can be removed during a colonoscopy procedure. Consequently, access to colonoscopy may not only identify early detection of colorectal cancer, but also prevent cancer from developing. Further, a colonoscopy requires sedation, and thus, a patient undergoing colonoscopy needs to have someone available to take them home. This makes colonoscopy utilization more directly dependent on social support than other types of screening; subsequently, spatial access to endoscopy may not play a large role in screening utilization and/or stage at diagnosis. While these colonoscopy-specific complexities do not negate the importance of adequate spatial access to endoscopy services, they may help explain the lack of association between area-level spatial access and late stage at diagnosis that have been identified in our study and other previous studies.

Unlike previous CRC studies, our findings showed that accounting for spatial accessibility to colonoscopy did not help explain racial differences in late-stage CRC diagnosis.[5] However, our study was the first population-based study among those aged 50-74 years to examine the relationship between spatial access to colonoscopy and stage at CRC diagnosis, as previous studies examined only those who were covered under Medicare. Breast cancer studies have examined the dynamics of race at an area-level (ie, racial segregation) and spatial access to screening facilities, but this has yet to be more completely examined for colorectal cancer.[29] Future CRC studies should explore the dynamics of race, access to screening services (spatial and nonspatial components), and cancer outcomes.

Our study found that the classic 2SFCA and the E2SFCA methods had high agreement and yielded similar spatial clustering patterns. Previous studies evaluating access to mammography screening have also shown high agreement between spatial accessibility scores using

TABLE 3 Association between spatial access to colonoscopy and late-stage colorectal cancer

	Univariate Model	Model I (gender, age, race/ethnicity, spatial accessibility)	Model II (gender, age, race/ethnicity, rurality, spatial accessibility)	Model III (gender, age, race/ethnicity, rurality, SES, spatial accessibility)
2SFCA				
2SFCA				
High	1.00	1.00	1.00	1.00
Medium	1.07 (0.93-1.22)	0.99 (0.86-1.24)	1.00 (0.87-1.14)	1.00 (0.87-1.14)
Low	1.10 (0.96-1.25)	0.92 (0.80-1.05)	0.93 (0.81-1.06)	0.93 (0.82-1.07)
Gender				
Male		1.00	1.00	1.00
Female		**0.89 (0.81-0.97)**	**0.89 (0.81-0.97)**	**0.89 (0.81-0.97)**
Age				
<50		1.00	1.00	1.00
50-64		**0.73 (0.63-0.85)**	**0.73 (0.63-0.85)**	**0.73 (0.63-0.85)**
65-74		**0.66 (0.56-0.77)**	**0.66 (0.56-0.77)**	**0.66 (0.56-0.77)**
75+		**0.69 (0.58-0.81)**	**0.69 (0.58-0.81)**	**0.68 (0.58-0.81)**
Race/Ethnicity				
White		1.00	1.00	1.00
Black		**1.16 (1.04-1.28)**	**1.15 (1.04-1.28)**	**1.15 (1.03-1.28)**
Other		0.83 (0.55-1.25)	0.83 (0.55-1.25)	0.83 (0.55-1.25)
Rural-Urban Status				
Urban			1.00	1.00
Rural			0.89 (0.75-1.06)	0.90 (0.75-1.07)
% in Poverty				1.00 (1.00-1.01)
Intercept	0.4024	0.8345	0.9245	0.9224
AIC	10 884.89	10 813.97	10 814.33	10 815.50
ICC	0.0160			
E2SFCA				
ESFCA				
High	1.00	1.00	1.00	1.00
Medium	0.94 (0.83-1.08)	0.88 (0.77-1.00)	0.89 (0.78-1.02)	0.89 (0.78-1.02)
Low	1.09 (0.95-1.24)	0.93 (0.81-1.06)	0.94 (0.82-1.08)	0.94 (0.82-1.08)
Gender				
Male		1.00	1.00	1.00
Female		**0.89 (0.81-0.97)**	**0.89 (0.81-0.97)**	**0.89 (0.81-0.97)**

(Continues)

TABLE 3 (Continued)

	Univariate Model	Model I (gender, age, race/ethnicity, spatial accessibility)	Model II (gender, age, race/ethnicity, rurality, spatial accessibility)	Model III (gender, age, race/ethnicity, rurality, SES, spatial accessibility)
Age				
<50		1.00	1.00	1.00
50-64		**0.73 (0.63-0.85)**	**0.73 (0.63-0.86)**	**0.73 (0.63-0.86)**
65-74		**0.66 (0.56-0.77)**	**0.66 (0.56-0.77)**	**0.66 (0.56-0.77)**
75+		**0.69 (0.58-0.81)**	**0.69 (0.58-0.81)**	**0.69 (0.58-0.81)**
Race/Ethnicity				
White		1.00	1.00	1.00
Black		**1.15 (1.04-1.28)**	**1.15 (1.03-1.28)**	**1.15 (1.03-1.28)**
Other		0.83 (0.55-1.25)	0.83 (0.55-1.25)	0.83 (0.55-1.25)
Rural-Urban Status				
Rural			0.91 (0.76-1.08)	0.91 (0.76-1.08)
Urban			1.00	1.00
% in Poverty				1.00 (0.99-1.01)
Intercept	0.4457	0.8677	0.9434	0.9532
AIC	10 882.39	10 812.02	10 812.82	10 813.99
ICC	0.0153			
V2SFCA Models				
VSFCA				
High	1.00	1.00	1.00	1.00
Medium	0.96 (0.84-1.10)	0.92 (0.81-1.05)	0.93 (0.82-1.06)	0.93 (0.82-1.06)
Low	1.05 (0.92-1.20)	0.97 (0.85-1.11)	0.99 (0.82-1.06)	0.99 (0.86-1.13)
Gender				
Male		1.00	1.00	1.00
Female		**0.89 (0.81-0.97)**	**0.89 (0.81-0.97)**	0.89 (0.74-1.06)
Age				
<50		1.00	1.00	1.00
50-64		**0.73 (0.63-0.85)**	**0.73 (0.63-0.85)**	**0.73 (0.63-0.85)**
65-74		**0.66 (0.56-0.77)**	**0.66 (0.56-0.77)**	**0.66 (0.56-0.77)**
75+		**0.69 (0.58-0.81)**	**0.69 (0.58-0.81)**	**0.69 (0.58-0.81)**
Race/Ethnicity				
White		1.00	1.00	1.00

(Continues)

TABLE 3 (Continued)

	Univariate Model	Model I (gender, age, race/ethnicity, spatial accessibility)	Model II (gender, age, race/ethnicity, rurality, spatial accessibility)	Model III (gender, age, race/ethnicity, rurality, SES, spatial accessibility)
Black		**1.16 (1.04-1.28)**	**1.15 (1.04-1.28)**	**1.15 (1.03-1.28)**
Other		0.83 (0.55-1.24)	0.83 (0.55-1.25)	0.83 (0.55-1.25)
Rural				
Rural			0.88 (0.74-1.05)	0.89 (0.74-1.06)
Urban			1.00	1.00
% in Poverty				1.00 (0.99-1.01)
Intercept	0.4522	0.8374	0.9386	0.9370
AIC	10 885.22	10 814.39	10 814.40	10 815.58
ICC	0.0160			

Note: Items in bold are statistically significant at $P < .05$.

Abbreviations: 2SFCA, two-step floating catchment area; AIC, Akaike information criterion; E2FCA, enhanced two-step floating catchment area; ICC, intraclass correlation coefficient; V2SFCA, variable two-step floating catchment area.

both the classic 2SFCA method and 2SFCA methods that account for distance decay.[14,15] The corroboration of our study findings with previous studies on mammography access suggests that the 2SFCA and E2SFCA methods are comparable. The added technical complexity of the E2SFCA method may be unnecessary—at least applied to studies on spatial accessibility to cancer screening—as results are largely similar to the 2SFCA method. However, we found that our patterns, correlations, and agreements with the V2SFCA method were not as similar as the more established 2SFCA methods. Most previous studies that have varied their catchment area size capped the number of accessible locations and applied different weights dependent upon population size of a town or city.[14,22] These previous studies showed stronger correlations between their variable methods and the classic 2SFCA than we found in our study, but similarly found weaker correlation between the V2SFCA and classic 2SFCA than between the classic 2SFCA and methods that only consider distance decay (eg, E2SFCA).[14] However, our study is the first, to our knowledge, to apply the V2SFCA method guided by ratios of providers rather than facilities accessed, to examine access to cancer screening. In the development and application of the V2SFCA method to evaluate access to primary care providers, Luo and Whippo used 1 physician:3500 patients, a common ratio for healthcare shortage designations, to determine the threshold in step 2 to guide the development of varied catchment sizes.[17] This is the strength of the V2FCA method is that it allows for varying the catchment area based upon meaningful, policy-relevant thresholds. The varied catchment size is the likely contributor to the large differences in the V2SFCA's concordance and spatial clustering with the 2SFCA and E2SFCA methods. No such ratio has been determined for optimal access to colonoscopy providers (a specialty vs primary care setting); thus, we used the statewide colonoscopy provider-to-patient ratio. Further, because this study was conducted with data from a single, geographically small state, results may vary from those in larger geographical settings (eg, multi-state studies or those from geographically larger states) as thresholds were bound, in part, by state boundaries. Future research should examine the optimal threshold for access to colonoscopy providers or specialists more broadly.

Our goal was to apply 2SFCA methods to colonoscopy access, which has not been examined in previous studies that have only examined travel time to colonoscopy providers without accounting for supply and demand.[5,7-9] In keeping with previous studies that employed 2SFCA method, we characterized "supply" as the location and/or number of providers or screening equipment (eg, mammography machines) at a given location.[11-18] However, these methods could be enhanced by considering more nuanced characterizations of supply of colonoscopy services. For example, studies suggest that volume of procedures may be more meaningful than number of providers to characterize access and may be more strongly associated with CRC outcomes compared to provider-based measures.[30] Additionally, volume varies by provider specialty and rural-urban location of the provider, as gastroenterologists and providers in urban areas perform higher volumes of procedures.[19] Further, with appropriate available data, an additional nuance that could be considered in "supply" of colonoscopy providers is that of

insurance coverage.[19] While a provider may be spatially accessible to a patient, insurance markets may affect the realized access to that provider or preferred modality of CRC screening. For example, previous research from the pre-Affordable Care Act era has shown that state-level adoption rates of managed care Medicare has had a mixed effect on CRC screening utilization.[31] Future studies should examine volume-weighted and/or spatial accessibility measures that account for variation in what insurance plans an endoscopist accepts (and whether new patients are being accepted) to more completely characterize the accessibility of screening services.

4.1 | Limitations and strengths

Our study was not without limitations. First, as our study considered only endoscopists in South Carolina, the estimation of spatial accessibility scores for ZCTAs closer to the Georgia and North Carolina may be underestimated or overestimated due to edge effects, as residents of neighboring states may use services in South Carolina or South Carolinians may use resources in neighboring states. Also, our study assumed that individuals of screening age had equal access to providers (eg, that insurance status had no effect on access). There are also limitations to using ZCTAs as our area-level unit, such as potential spatial mismatch between cancer case ZIP codes and area-level ZCTA data on sociodemographic factors.[32] However, ZIP code/ZCTAs were the most granular geographic unit available in the cancer registry data and have been used extensively as the geographic unit for calculating area-level spatial access to healthcare services in association with cancer outcomes.[33,34] In a similar vein, we recognize the scale effect—one type of modifiable area unit problem—which indicates that results may vary by the scale of the geographic unit used.[35] Had census tract been an available linkage and thus our unit for spatial analysis, results may have differed from our ZCTA-level analysis. Additionally, due to considerable missingness of insurance status (~30 percent of all cases), we did not account for insurance status in our multilevel models. Insurance status should be considered in future studies if such data become more complete in cancer registries. Previous studies have identified a relationship between insurance status and stage at diagnosis, but none have examined this relationship intersecting with spatial access to screening.[36] However, there were several strengths to our study. Our analysis was the first to apply multiple 2SFCA methods to determine spatial access to colonoscopy services. Additionally, we used population-based databases to obtain information on colonoscopy providers and colorectal cancer cases, inclusive of all colonoscopy providers and colorectal cancer patients in South Carolina. Most previous studies used claims data from one insurance payer to identify CRC patients, or used cancer registry but only used travel time to assess access to colonoscopy providers.[5,8,9] Another strength of our study is that we considered that endoscopists may provide services at different locations and determined their accessibility based upon the proportion of procedures they performed at a given location.

5 | CONCLUSIONS

The 2SFCA methods consider the three key elements of evaluating spatial access to care—supply, demand, and impedance. We found that the classic 2SFCA and E2FCA methods applied to access to colonoscopy services were very similar in their spatial patterns, correlation, and agreement. None of the three 2SFCA methods we tested were associated with late-stage CRC diagnosis. Future studies should consider additional nuances of "supply" and "demand," including using procedure volume-weighted supply measures and considering insurance and racial/ethnic composition more completely in assessing the "demand" for colonoscopy services.

ACKNOWLEDGMENT

Joint Acknowledgment/Disclosure Statement: This study was supported by the American Cancer Society (JME; MRSG-15-148-01-CPHPS) and the National Institute of General Medical Sciences (MJJ; T32-GM081740). The authors have nothing else to disclose.

ORCID

Whitney E. Zahnd https://orcid.org/0000-0001-5174-8666
Michele J. Josey https://orcid.org/0000-0003-0484-5476
Jan M. Eberth https://orcid.org/0000-0001-9500-4212

REFERENCES

1. American Cancer Society. *Cancer Facts & Figures 2019*. Atlanta, GA: American Cancer Society; 2019.
2. United States Preventive Services Task Force. USPSTF Recommendation Statement: Screening for Colorectal Cancer USPSTF Recommendation Statement: Screening for Colorectal Cancer. *JAMA*. 2016;315(23):2564-2575.
3. Centers for Disease Control and Prevention. Vital Signs: colorectal cancer screening test use — United States, 2012. *MMWR*. 2013;62(44):881-888.
4. Dinh T, Ladabaum U, Alperin P, Caldwell C, Smith R, Levin TR. Health benefits and cost-effectiveness of a hybrid screening strategy for colorectal cancer. *Clin Gastroenterol Hepatol*. 2013;11(9):1158-1166.
5. Charlton ME, Matthews KA, Gaglioti A, et al. is travel time to colonoscopy associated with late-stage colorectal cancer among medicare beneficiaries in Iowa? *J Rural Health*. 2016;32(4):363-373.
6. Anderson AE, Henry KA, Samadder NJ, Merrill RM, Kinney AY. Rural vs urban residence affects risk-appropriate colorectal cancer screening. *Clin Gastroenterol Hepatol*. 2013;11(5):526-533.
7. Lin Y, Wimberly MC. Geographic variations of colorectal and breast cancer late-stage diagnosis and the effects of neighborhood-level factors. *J Rural Health*. 2017;33(2):146-157.
8. Alyabsi M, Charlton M, Meza J, Islam KMM, Soliman A, Watanabe-Galloway S. The impact of travel time on colorectal cancer stage at diagnosis in a privately insured population. *BMC Health Serv Res*. 2019;19(1).172.
9. Wan N, Zhan FB, Zou B, Wilson JG. Spatial access to health care services and disparities in colorectal cancer stage at diagnosis in Texas. *Prof Geogr*. 2013;65(3):527-541.
10. Ma L, Luo N, Wan T, Hu C, Peng M. An improved healthcare accessibility measure considering the temporal dimension and population demand of different ages. *Int J Environ Res Public Health*. 2018;15(11): 2421.

11. Wei L, Fanui LWW. Measures of spatial accessibility to health care in a GIS Environment: synthesis and a case study in the Chicago Region. *Env Plann B Plann Des*. 2003;30:865-884.
12. Eberth JM, Eschbach K, Morris JS, Nguyen HT, Hossain MM, Elting LS. Geographic disparities in mammography capacity in the South: a longitudinal assessment of supply and demand. *Health Serv Res*. 2014;49(1):171-185.
13. Zahnd WE, McLafferty SL, Sherman RL, et al. Spatial accessibility to mammography services in the Lower Mississippi Delta Region States. *J Rural Health*. 2019;35(4):550-559.
14. Donohoe J, Marshall V, Tan X, Camacho FT, Anderson R, Balkrishnan R. Evaluating and comparing methods for measuring spatial access to Mammography Centers in Appalachia (Re-Revised). *Heal Serv Outcomes Res Methodol*. 2016;16(1):22-40.
15. Lian M, Struthers J, Schootman M. Comparing GIS-based measures in access to mammography and their validity in predicting neighborhood risk of late-stage breast cancer. *PLoS One*. 2012;7(8):e43000.
16. Luo W, Qi Y. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health Place*. 2009;15(4):1100-1107.
17. Luo W, Whippo T. Variable catchment sizes for the two-step floating catchment area (2SFCA) method. *Health Place*. 2012;18(4):789-795.
18. Donohoe J, Marshall V, Tan X, Camacho FT, Anderson R, Balkrishnan R. Predicting late-stage breast cancer diagnosis and receipt of adjuvant therapy: applying current spatial access to care methods in Appalachia. *Med Care*. 2015;53(11):980-988.
19. Eberth JM, Josey MJ, Mobley LR, et al. Who performs colonoscopy? Workforce trends over space and time. *J Rural Health*. 2018;34(2):138-147.
20. United States Census Bureau. American Community Survey Data. https://www.census.gov/programs-surveys/acs/data.html. Accessed August 12, 2019.
21. Wang F, Luo W. Assessing spatial and nonspatial factors for healthcare access: towards an integrated approach to defining health professional shortage areas. *Health Place*. 2005;11(2):131-146.
22. McGrail MR. Spatial accessibility of primary health care utilising the two step floating catchment area method: an assessment of recent improvements. *Int J Heal Geogr*. 2012;11:50.
23. Landis JR, Koch GG. Agreement of categorical data. *Biometrics*. 1977;33(1):159-174.
24. ESRI. Cluster and Outlier Analysis (Anselin Local Moran's I). http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/cluster-and-outlier-analysis-anselin-local-moran-s.htm. Accessed November 27, 2016.
25. United States Department of Agriculture. Rural-Urban Commuting Area codes. http://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes/documentation/
26. Zahnd WE, Fogleman AJ, Jenkins WD. Rural-urban disparities in stage of diagnosis among cancers with preventive opportunities. *Am J Prev Med*. 2018;54(5):688-698.
27. Boscoe FP, Henry KA, Sherman RL, Johnson CJ. The relationship between cancer incidence, stage, and poverty in the United States. *Int J Cancer*. 2016;139(3):607-612.
28. Siegel RL, Miller KD, Fedewa SA, et al. Colorectal cancer statistics, 2017. *CA Cancer J Clin*. 2017;67(3):177-193.
29. Dai D. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. *Health Place*. 2010;16(5):1038-1052.
30. Josey MJ, Eberth JM, Mobley LR, et al. Should measures of health care availability be based on the providers or the procedures? A case study with implications for rural colorectal cancer disparities. *J Rural Health*. 2019;35(2):236-243.
31. Mobley LR, Kuo TM, Urato M, Subramanian S. Community contextual predictors of endoscopic colorectal cancer screening in the USA: spatial multilevel regression analysis. *Int J Health Geogr*. 2010;9:44.
32. Grubesic TH, Matisziw TC. On the use of ZIP codes and ZIP code tabulation areas (ZCTAs) for the spatial analysis of epidemiological data. *Int J Health Geogr*. 2006;5(58). https://doi.org/10.1186/1476-072X-5-58
33. Wang F, McLafferty S, Escamilla V, Luo L. Late-stage breast cancer diagnosis and health care access in Illinois. *Prof Geogr*. 2008;60(1):54-69.
34. McLafferty S, Wang F, Luo L, Butler J. Rural - urban inequalities in late-stage breast cancer: spatial and social dimensions of risk and access. *Env Plann B Plann Des*. 2011;38(4):726-740.
35. Scale MD. Aggregation, and the modifiable areal unit problem. In: Fischer M, Nijkamp P, eds. *Handbook of Regional Science*. Berlin, Heidelberg: Springer; 2014.
36. Tawk R, Abner A, Ashford A, Brown CP. Differences in colorectal cancer outcomes by race and insurance. *Int J Environ Res Public Health*. 2016;13(1):48.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Zahnd WE, Josey MJ, Schootman M, Eberth JM. Spatial accessibility to colonoscopy and its role in predicting late-stage colorectal cancer. *Health Serv Res*. 2021;56:73–83. https://doi.org/10.1111/1475-6773.13562