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Investigating the Effects of Racial Residential Segregation, Area-level Socioeconomic Status and Physician Composition on Colorectal Cancer Screening

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

by

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Table of Contents

List of Tables and Figures

Abstract

INVESTIGATING THE EFFECTS OF RACIAL RESIDENTIAL SEGREGATION, AREA-LEVEL SOCIECONOMIC STATUS AND PYSIICIAN COMPOSITION ON COLORECTAL CANCER SCREENING

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Background: Colorectal cancer screening (CRCS) is nationally recommended to prevent colorectal cancer related deaths, yet adherence to CRCS guidelines is suboptimal. Neighborhood characteristics can impact CRCS adherence. To date, how racial residential segregation (RRS), area-level socioeconomic status (SES) and physician composition are associated with CRCS adherence are not fully understood.

Objectives: The main objectives of this dissertation project were: 1) To assess the association between facility proximity to RRS areas and facility-level CRCS adherence; 2) To evaluate associations between area-level SES indicators and individual-level CRCS adherence; 3) To evaluate the association between county-level physician composition and individual-level CRCS adherence among general U.S. population.

Methods: Multiple data sources at the state-and national-level were used, including 2013 Minnesota Community Measurement, 2009-2013 American Community Survey, 2012 U.S. and 2012-2013 Washington State Behavioral Risk Factor Surveillance System data, and 2013-2014 Area Health Resource File. Logistic regressions were used to assess the association between facility proximity to RRS areas and CRCS adherence. Weighted multilevel logistic regressions were used to evaluate the association between area-level SES, physician composition, and CRCS adherence. Odds ratios (ORs) and 95% confidence intervals (CIs) were reported.

Results: In general, facilities located closer to RRS areas were more likely to have low CRCS performance. For instance, facilities located less than 2 miles away from Asian and Hispanic segregated areas were > 2 times more likely to have CRCS adherence below state average than those at ≥5 miles away (Asian OR: 2.06, 95% CI: 1.00, 4.24; Hispanic OR: 2.83, 95% CI: 1.29, 6.24). Most area-level SES measures showed negative bivariate associations between deprivation and colonoscopy/overall adherence, and measures such as education and area SES summary score had relatively strong associations, although few of fully-adjusted associations remained statistically significant. For physician composition, a one-unit increase in the percentage of gastroenterologists among physicians was associated with about 3% increase in the odds of colonoscopy (OR: 1.03, 95% CI: 1.01-1.04) and overall adherence (OR: 1.03, 95% CI: 1.01-1.04) in the rural-metropolitan areas.

Conclusions: Developing culturally tailored CRCS programs and increasing percentage of gastroenterologists may improve CRCS adherence. CRCS interventions should also target deprived communities.

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CHAPTER 1: Specific Aims

Colorectal cancer (CRC) remains an important public health problem as it is the second leading cause of cancer-related deaths in the U.S.[1] In 2015, there were an estimated 49,700 CRC-related deaths.[1] Regular screening for CRC can reduce CRC mortality.[2-8] The national colorectal cancer screening (CRCS) guidelines recommend that average-risk adults, aged 50-75 years, should have CRCS by having a stool test every year, sigmoidoscopy every five years, or colonoscopy every ten years.[9] However, CRCS prevalence is suboptimal with 65.1% of the age-eligible population adherent to the national CRCS guidelines.[10] The current CRCS adherence is below Healthy People 2020's goal of 70.5%[11] and the National Colorectal Cancer Roundtable target of 80% by 2018.[12]

CRCS adherence is multifactorial. In addition to individual-level factors (e.g., age, usual source of care, health insurance coverage, and perceived barriers),[10, 13-42] contextual factors can impact CRCS adherence. These factors include area -level socioeconomic status (SES),[22, 25, 36, 42-50] racial residential segregation (RRS),[47, 48, 50] and physician composition.[23, 25]

A number of studies have examined cancer screening and area-level SES;[22, 25, 36, 42-59] however, the relationship between area-level SES and cancer screening, especially CRCS,[22, 25, 36, 42-50] is not clear for several reasons. For example, previous CRCS studies examined limited sets of SES measures in limited categories of SES.[22, 25, 36, 44-50] Given that area-level SES is complex and multidimensional,[60-62] some indicators that are important for CRCS may have been missed. Identifying area-level SES predictors of CRCS among a comprehensive list of SES measures would be useful not only for monitoring socioeconomic inequalities in CRCS adherence, but for understanding the impact of neighborhood SES on CRCS.

RRS, which describes the extent of residential separation of a racial group from another group,[63] could impact CRCS ahderence.[47, 48, 50] For instance, RRS is often viewed as a harmful factor because it adversely affects the segregated minorities' individual-level SES as well as the neighborhood socioeconomic environment,[64, 65] which could negatively impact cancer screening adherence. To date, only a few studies have examined RRS in the context of CRCS and findings are mixed.[47, 48, 50]

In addition to area-level SES and RRS, physician composition could play a role in CRCS adherence. In the CRCS physician workforce, while primary care physicians (PCPs) can provide the patient with the stool test kit, they refer patients to gastroenterologists (GIs) who perform colonoscopies (the most common CRCS test[10]). How PCPs and GIs are balanced in the CRCS physician workforce can influence the effectiveness and efficiency of CRCS service delivery. Few studies have examined physician composition on CRCS,[23, 25] and limitations exist. For example, composition was measured by ratio of PCPs among total physician population as a way to account for the balance of PCPs and all specialists.[23, 25] Using the CRCS related physicians as the denominator (i.e., PCPs and GIs), which excludes specialists that are not relevant to CRCS, may be more accurate in determining the effect of physician composition on CRCS. Also, previous studies were conducted among the Medicare population (age $\geq$ 65) with CRCS adherence assessed only within a one-year period.[23, 25] The investigation of how physician composition impacts CRCS adherence among all people aged 50-75 for whom CRCS is recommended could have important implications for resource planning and workforce policy.

By utilizing multiple state- and national-level data and involving secondary data analyses, the purpose of this dissertation project was to close some of the gaps existing in research on the impact of area-level SES, RRS, and physician composition on CRCS adherence. The specific aims of the study were to:

Aim 1: Assess the association between facility proximity to RRS areas and facility-level overall CRCS adherence in the 7-county metropolitan area in Minnesota

a. Assess the association between facility proximity to minority segregated areas and facility-level overall CRCS adherence

b. Assess the association between facility proximity to race-specific (i.e., Asian, Hispanic, non-Hispanic African American) segregated areas and facility-level overall CRCS adherence

Aim 2: Evaluate the association between area-level SES indicators and individual-level CRCS adherence in Washington State

a. Assess the association between area-level SES indicators and individual-level stool test adherence

b. Assess the association between area-level SES indicators and individual-level colonoscopy adherence

c. Assess the association between area-level SES indicators and individual-level overall CRCS adherence

Aim 3: Evaluate the association between county-level physician composition and individual-level CRCS adherence among the general U.S. population

a. Evaluate the association between county-level PCP composition and individual-level stool test adherence

b. Evaluate the association between county-level GI composition and individual-level colonoscopy adherence

c. Determine the association between county-level GI composition and individual-level overall CRCS adherence

CHAPTER 2: Background

Colorectal cancer and screening. Colorectal cancer (CRC) is the third most common cancer for both men and women and the second leading cause of cancer-related death in the U.S.[1] Approximately 136,830 new CRC cases were estimated to be diagnosed, and 49,700 people were estimated to die from CRC in 2015.[1] Early detection via screening reduces CRC incidence and mortality.[2-8] Regular colorectal cancer screening (CRCS) (i.e., having a stool test every year, flexible sigmoidoscopy every five years, or colonoscopy every ten years) is recommended for U.S. adults, aged 50-75 years, who are at average-risk of CRC.[9] The majority of people are at average-risk (i.e., no personal history of CRC, adenomatous polyps, ulcerative colitis, or Crohn's disease; no high-risk family history of CRC; no hereditary colorectal cancer syndrome).[66] However, CRCS is underutilized, with only 65% of age-eligible adults (50-75 years) adhering to CRCS recommendations.[10] The prevalence of CRCS adherence is below the national goal of increasing adherence to 80% by 2018.[12] Multiple factors are associated with low CRCS adherence, including not only individual-level factors[10, 13-42] but also area-level factors.[22, 23, 25, 36-38, 42-50, 67-71]

Individual-level factors associated with CRCS adherence. Individual-level factors associated with CRCS behaviors are well-documented. People who are < 65 years,[10, 17, 18, 26, 36] have lower education and income,[10, 14, 19, 31, 34, 36, 40] or are unmarried[14, 17, 28, 31, 40, 41] are less likely to be adherent to CRCS recommendations. Cognitive and psychosocial factors such as confusion about CRCS tests,[34] lack of social support,[28] and barriers to CRCS (e.g. fear of test, dislike of test logistics, not thinking screening is needed because they feeling fine)[14-16, 20, 21, 31-33] can influence individuals' decision to have CRCS. Lifestyle and health-related factors such as smoking status[14, 37] and family history of cancer[14, 17, 28] are associated with CRCS uptake. As for healthcare access factors, lack of physician recommendation[16, 17, 32, 33] and lack of health insurance coverage[10, 14, 17-19, 37, 41] are major barriers to screening, and having a usual source of care facilitates CRCS adherence.[14, 17, 26, 31, 36]

<u>Area-level factors associated with CRCS adherence.</u> In addition to individual-level factors, the contextual environment where people live can shape their health and behaviors.[72,73-75] The area characteristics that could impact CRCS adherence include: prevalence of health insurance plans such as Medicare[47, 50, 68] or Health Maintenance Organization plans,[50] area-level population characteristics like racial composition,[67, 68] age and gender distribution,[68] area-level socioeconomic status (SES),[22, 25, 36, 42-50] rural-urban residence,[36, 69-71] racial residential segregation (RRS), [47, 48, 50] number of available physicians,[23, 25, 36-38, 48, 67, 69, 70] and physician composition.[23, 25] Among the area-level factors, three in particular are the focus of the proposed study: area-level SES, RRS, and physician composition. The next sections provide more details about these three area-level factors first explaining the general idea of each followed by a summary of the research on the area-level measure and CRCS.

Racial Residential Segregation (RRS)

<u>General information about RRS.</u> RRS refers to the residential separation of a racial group from another group.[63] Commonly, RRS measures how the minority group is residentially separated from whites.[47, 48, 50, 63, 65, 76-80] The effects of RRS on cancer screening adherence is complex. On one hand, RRS is often regarded as a harmful factor because it encourages the uneven spreading of wealth, resources, opportunities, and political influence in favor of the majority.[64, 65]As a result, RRS is likely to concentrate poor people (especially poor minorities) in a single area, and cultivate a negative neighborhood environment,[64] characterized by having less accessible health providers[81-83]and screening facilities,[78] which ultimately could adversely impact screening adherence. Also, group attitudes towards cancer (e.g. fatalism)[84, 85] and group norm regarding

health system (e.g. mistrust)[85-87] may shape the belief of individuals, which further negatively affect cancer screening adherence. However, on the other hand, RRS may increase the probability of minorities interacting with their peers of same race within enclaves. The local networks may facilitate transmission of health information, which further leads to an increased awareness of preventive service,[88] such as cancer screening. Also, RRS may offer enhanced social cohesion or support to segregated minorities,[65, 76-80] which could positively impact cancer screening adherence.

Research on RRS and CRCS. Although a growing number of studies have examined the effects of RRS on cancer and cancer screening,[47, 48, 50, 63, 65, 76-80] limited studies have examined RRS in the context of CRCS and the effect is unclear.[47, 48, 50] A study conducted in California found that higher RRS in a Medical Service Study area was associated with lower odds of being adherent to CRCS; however, this relationship was not significant after adjustment for individual-level factors (e.g., age, race, marital status, education, income, and health insurance coverage).[50] One possible explanation was that individual-level factors may mediate the effects of RRS on CRCS.[50] Another possible reason was that the study measured RRS for minorities combined at the Medical Service Study area level, which could possibly mask effects of RRS if the effects of RRS differed by race or RRS was more salient in smaller geographic units. Another study that measured RRS by race in multiple states found the direction and magnitude of the association between RRS and CRCS varied by states and race.[48] Using African American segregation as an example, the African American segregation was negatively associated with CRCS adherence in Iowa, but had positive impacts in Louisiana, and no significant effects in Georgia.[48] Further within a state, RRS for one minority group may had statistically significant effects, while RRS for another minority group had no effects.[48] Thus, it is important to consider the context of state as well as race in RRS research.[48]

In Minnesota (MN), although non-Hispanic whites are the majority of the population, the minority population is increasing in the Twin Cities 7-county metropolitan area (Twin Cities are Minneapolis, St.Paul; 7-county metro is: Anoka, Carver, Dakota, Hennepin (where Minneapolis is located), Ramsey (where St. Paul is located), Scott, and Washington).[89] In 2010, about 24% of the 7-county metropolitan area were minorities, whereas < 10% of the population were minorities in 1990.[89] RRS exists in the 7-county metropolitan area[90, 91] e.g., Hispanic population is segregated in West Side of St. Paul.[90] A large number of Hmong live in certain census tracts of St. Paul City.[92] Four American Indian reservations are located in Dakota County.[93] Also, according to the American Community Survey, MN has the largest Somali population (more than 32,000) in the U.S., and the majority live in Minneapolis and St. Paul.[94]

Furthermore, the shortest life expectancy was observed in communities with highest concentration of minorities, mostly located in the central cities of Minneapolis and St.Paul.[89] As CRC remains the second leading cause of cancer-related death in MN, and minorities (except Asian/Pacific Islander) are more likely to be diagnosed with late stage of CRC relative to non-Hispanic white,[95] examining the impact of RRS on CRCS can provide a better understanding of how RRS as a social and cultural factor contributes to cancer screening adherence, which could further affect the poor health of the population who are living in racially segregated areas.

Area-level SES

<u>General information.</u> Area-level SES in this study refers to the social and economic environment where people live. Specifically, area-level SES describes the economic (e.g. income, poverty, wealth), educational, and occupational status in an area.[51] Even though people may have similar

individual and household incomes, the social and economic environment where they live may be very different.[96] Therefore, it is important to investigate how area-level SES impacts individuals' health and health behaviors,[96-98] including CRCS, as area-level SES could influence CRCS in multiple ways. For example, while individual income does not necessarily equate to area-level SES, area-level SES can nonetheless negatively affect individual SES, which could further reduce the probability of individual CRCS adherence. Evidence showed that individuals living in a high poverty area (e.g. poverty rate $\geq$ 20%) are more likely to have low household income and low education,[46] both of which are predictors of non-adherence to CRCS.[14, 19, 31, 34] Additionally, low SES neighborhoods may offer limited medical resources such as few available physicians,[36] which may contribute to the low CRCS adherence.

Research on area-level SES and CRCS. Although a growing body of studies have examined the effects of area-level SES on cancer screening,[22, 25, 36, 42-59] the relationship between area-level SES and CRCS[22, 25, 36, 42-50] is not completely understood. Among the three cancer screenings that are recommended to the general population, (i.e., mammogram, cervical cancer screening, and CRCS) the impact of area SES on CRCS is least studied.[51] A review published in 2009 found that only five studies examined the area-level SES in the context of CRCS as of 2007.[51] These five studies, however, did not come to a conclusive agreement regarding the effects of area-level SES on CRCS adherence.[22, 25, 43-45] Since 2007, a few subsequent studies have examined area-level SES and CRCS, and the findings remain inconclusive.[36, 46-50] For example, studies found that people living in high poverty areas were 19% – 46% less likely to be adherent to CRCS compared with residents from low poverty areas.[46, 49] Alternatively, other evidence suggested that area-level poverty did not have a significantly independent association with CRCS adherence.[42, 50]

An important limitation is shared by the current CRCS literature on area-level SES. That is, studies have used limited sets of SES measures under limited categories of SES.[22, 25, 36, 44-50] The area-level SES measure can be a single measure (e.g., percent of residents living below the poverty line within an area) to reflect a certain aspect of SES, or a composite measure (e.g., area-level SES score) that summarizes key single SES measures to reflect the overall SES. Using single SES measures and composite measures have both pros and cons. Using single SES measures can help us understand how a certain aspect of SES impacts health.[96] However, including multiple SES single measures may lead to collinearity, and single SES measures cannot fully reflect the whole concept of neighborhood SES.[98] Using SES composite measures can overcome the aforementioned problems; however, using SES composite measures may obscure variations because for areas that have same SES score, specific values in certain aspects of SES that contribute to the score may vary by area.[98] Also, using SES composite measures may introduce validity issues[60] as well as limited utility across time and space.[98] To date, previous CRCS studies commonly used up to three single SES measures to reflect the SES construct.[22, 25, 44-50, 69] Measures relating to income, poverty and/or education are commonly used,[22, 25, 36, 44-50] whereas measures capturing employment, occupation, housing, and wealth as well as a composite SES measure are rarely used.[36] Given area-level SES is complex and multidimensional,[60-62] without examining a comprehensive list of area-level SES measures, we may miss some area SES indicators that are important for CRCS.

Furthermore, because limited SES indicators were examined, previous studies have limited abilities to tell which indicators could be most important or strongest predictors of CRCS adherence. For example, a recent study found that patients living in high poverty neighborhoods were 30% less likely to undergo a screening colonoscopy than those from low poverty neighborhoods.[49] The study only used percent of residents living below the poverty line to measure area-level SES; thus, it is unknown whether other area-level SES indicators such as education are even more influential than area-level poverty. Area-level education could be an influential factor as it reflects residents' general knowledge about health, collective efficacy, social support about making screening decisions, and health literacy in the neighborhood. Identifying area-level SES indicators that have most influences on CRCS adherence will be helpful to guide the design and effective implementation of a CRCS intervention.

Physician Composition

General information about physician composition. Physician composition describes the mix between primary care physicians and specialists in the physician workforce.[99] For CRCS specifically, the physician workforce is mainly composed of primary care physicians (PCPs) and gastroenterologists (GIs). PCPs and GIs play different roles in CRCS. PCPs initiate CRCS conversations with patients, manage the ordering of CRCS tests, and distribute stool test kits, while GIs are not involved in ordering tests, but are responsible for performing colonoscopies. In short, PCPs' and GIs' involvement in CRCS varies by test. Given PCPs and GIs' roles and involvement in CRCS, the balance between PCPs and GIs is important to CRCS,[37] because the imbalance may affect the effective and efficient delivery of CRCS tests. For instance, if PCPs are excessive relative to GIs, it could lead to the scenario where patients receive CRCS recommendations from PCPs but have to endure long wait-times or drive long distances if they want a colonoscopy.[100]

Previous studies looking at CRC and healthcare access showed that physician composition is as important as total physician size, and also suggested that physician composition could play a role in CRCS.[101, 102] Specifically, the CRC study found that a greater representation of PCPs in the physician workforce was a significant predictor of lower colorectal cancer (CRC) incidence and mortality.[101] The observed effects were partially explained by PCPs' important role in promoting CRCS.[103] The healthcare access study found that individuals living in a county with a higher proportion of PCPs in the physician workforce were more likely to report having a usual source of care,[102] which could further impact people's cancer screening behaviors,[26, 36, 70] while the number of PCPs was found not to be a significant predictor of screening. Therefore, physician composition is an important dimension of physician workforce that needs to be considered in the study, beyond the size of physician workforce.[101, 102]

Research on physician composition and CRCS. Among studies that have investigated physician workforce and CRCS[23, 25, 36-38, 42, 48, 67, 69, 70] the majority only measured the size of PCPs, GIs and/or the overall physician population.[36-38, 42, 48, 67, 69, 70] Only two studies considered physician composition in their analyses, and more conclusive results on the effect of physician composition on CRCS are needed.[23, 25] Both studies found that higher proportions of PCPs in the physician workforce at the county-level were negatively associated with individuals' CRCS adherence.[23, 25] These findings, however, are contrary to the results of an aforementioned CRC study which found lower CRC incidence and mortality in areas with a higher proportion of PCPs,[101] possibly due to increased CRCS.

Furthermore, the studies examining physician composition and CRCS have several limitations. First, physician composition was measured by ratio of PCPs to all physicians to account for the balance of PCPs and all specialists.[23, 25] The ratio of PCPs to all physicians may not be an accurate measure of the balance in CRCS physician workforce because it includes specialists that are not involved in CRCS. Given that generally only GIs and PCPs are involved in CRCS services, the ratio of PCPs to CRCS physician workforce (i.e. total number of PCPs and

GIs) could be a more appropriate measure to be considered for workforce capacity and health policies. Second, the two studies only measured CRCS within a one-year study period,[23, 25] which did not fully capture individuals' CRCS adherence status.[9] Third, previous physician composition studies focused on the Medicare population exclusively.[23, 25] Their findings have limited generalizability to the general population aged 50-75 for which CRCS is recommended.

Given the conflicting evidence between the aforementioned CRCS[23, 25] and CRC studies[101] as well as limitations in the current CRCS studies on physician composition,[23, 25] more studies are warranted to better understand how the balance of PCPs and notably GIs contributes to CRCS[25] particularly among a diverse general population-based sample aged 50-75. Study findings could inform health resource planning and workforce policies.

CHAPTER 3: Description of Datasets

Multiple data sources at the state- and national-level were used to accomplish the Specific Aims of the proposed research. The datasets included: (1) 2013 Minnesota Community Measurement (MNCM), (2) 2009-2013 American Community Survey (ACS), (3) 2012 U.S. Behavioral Risk Factor Surveillance System (BRFSS), (4) 2012 and 2013 Washington state BRFSS data and (5) 2013-2014 Area Health Resource File.

Table 1 provides a summary of the data sources that were used for each paper. Also, a description of each dataset is provided below.

Table 1. Data Sources Used for Dissertation Chapter 4-6

	Minnesota Community Measurement	**American Community Survey**	**Nationwide BRFSS**	**Washington BRFSS**	**Area Health Resource File**
Chapter 4	X	X			
Chapter 5		X		X	
Chapter 6		X	X		X

Minnesota Community Measurement (MNCM). Facility-level CRCS adherence in the 7-county metropolitan area in MN were obtained from the 2013 MNCM data. As a state mandate, all facilities in MN are required to annually report health care data, including CRCS adherence, to MNCM. The 2013 CRCS adherence data was collected from July 1, 2012 to June 30, 2013.[104] Facility-level CRCS adherence refers to the percentage of patients who are adherent to CRCS among the eligible patient population in each facility. The eligible patient population is patients who had at least two doctor visits during the last two years and at least one visit during the last 12 months, and are aged 51-75 years by the end of the measurement period, identified using a query on a practice management system or Electronic Medical Recode (EMR). Once the eligible patients are identified, data on their CRCS tests are extracted from an EMR system or abstraction by medical record review abstraction if an EMR does not exist. Internal quality checks are conducted by medical groups that facilities are affiliated to. MNCM auditor validate the submitted data by comparing them with the source data in the patient medical record.[104] Facility-level crude CRCS and CRCS adjusted for patient health insurance status (to account for possible differences in patient characteristics across different facilities) are generated by MNCM, and linked to facilities' names.

American Community Survey (ACS). The 2009-2013 area-level SES information was obtained from the publically available ACS dataset. ACS data are used because unlike the 2010 decennial data, the ACS provides area-level (e.g., county-level, ZIP Code-level, and census tract-level) SES information. Every year the ACS randomly selects a nationally representative sample of about three million American households across all counties in the U.S. for the ACS.[105] Residents from the selected households are required to complete an online or paper-based questionnaire for their household. Households with incomplete questionnaire receive a phone call or personal visit from ACS staff to ensure complete data collection. The questionnaire collects social and economic information such as age, gender, race, income, education, housing, employment and occupations.[105]

U.S. Behavioral Risk Factor Surveillance System (BRFSS). Individual-level CRCS adherence in the U.S. was obtained from the BRFSS. BRFSS is a cross-sectional, state-based, random-digit-dialed telephone survey among non-institutionalized adults aged 18 years or older in the U.S.[106] A complex, probabilistic sampling method is used in BRFSS to obtain cellular and landline telephone samples. BRFSS collects information on cancer screening behaviors, other health-related issues, and healthcare utilization as well as demographics (e.g, age, gender, race, county of residence).[107] The BRFSS survey is conducted annually, but CRCS questions are only included in even years of the survey and only asked to people who are aged at 50 or older.[106] This study used BRFSS participants' county of residence to link BRFSS data with AHRF so that the BRFSS participants had information about county-level physician composition. Regarding county of residence information, BRFSS suppresses respondents' county of residence if respondents are from a county with < 50 respondents or with an adult population ≤ 10,000 because estimates (e.g., percentages) based on a denominator < 50 respondents (unweighted sample) are not reliable.[108] In 2012 BRFSS, median response rate was 45.2% (49.1% landline telephone; 35.5% cellular telephones) among the all 50 states, the District of Columbia, the Commonwealth of Puerto Rico, and Guam,[109] and 240,800 respondents were age-eligible (ages 50-75 years) for CRCS.

Washington State BRFSS. The Chapter 5 in this dissertation used the 2012 and 2013 Washington State BRFSS data.[110] Data collection methods are the same as that of U.S. BRFSS data (see details in "U.S. BRFSS" section). Different from the national BRFSS, Washington State BRFSS collects colorectal cancer screening every year instead of every even year, and collects participants' residential information down to the zip code level instead of the county level. To increase the sample size within each zip code to provide reliable estimates, this study combined Washington BRFSS 2012 and 2013 data instead of using a single year data.

Area Health Resource File (AHRF). The 2013-2014 AHRF provided the county-level counts of physicians by specialty in 2012 in the U.S., which was used to compute county-level physician composition. The AHRF is a comprehensive health resource database that integrates a broad range of information, such as counts of physicians by detailed specialty as well as population and economic data. Data for each county in the U.S. are pulled from more than 50 data sources (e.g., American Medical Association, U.S. Census Bureau).[111] The AHRF is publicly available, and released every year by the Health Resources and Services Administration in the U.S. Department of Health and Human Services.[111]

CHAPTER 4: The Association between Facility Proximity to Racial Residential Segregation Areas and Facility-level Colorectal Cancer Screening Adherence

Abstract

Purpose: How racial residential segregation (RRS) as a social and cultural factor influences colorectal cancer screening (CRCS) adherence is not fully understood. This study investigated the association between healthcare facility proximity to RRS areas and facility-level CRCS adherence in 7-county metropolitan areas in Minnesota.

Methods: Data from the 2013 Minnesota Community Measurement and the 2009-2013 American Community Survey were used. RRS areas were defined as census tracts with isolation index ≥0.3. Facility proximity was measured by the distance from facility location to the centroid of the closest minority or race/ethnicity specific RRS areas. Facility-level CRCS adherence, referring to percentage of eligible patients adhering to CRCS guidelines, were categorized into high and low groups given the state average CRCS. Odds ratios (OR) and 95% confidence intervals (CI) from logistic regression models were reported.

Results: Facilities less than 2 miles away from Asian and Hispanic segregated areas were >2 times more likely to have low CRCS adherence performance than those with ≥5 miles proximity (Asian OR: 2.06, 95% CI: 1.00, 4.24; Hispanic OR: 2.83, 95% CI: 1.29, 6.24). The associations between proximity to minority and African American segregated areas and facility CRCS performance were significant in bivariate analysis (minority OR: 3.35, 95% CI: 1.77-6.32; African American OR: 3.10, 95% CI: 1.68-5.71), and nonsignificant but trended positively in adjusted models.

Conclusion: A facility located closer to RRS areas (especially Asian and Hispanic segregated areas) was associated with low facility-level CRCS adherence. This suggests that RRS may play a negative role in residents obtaining CRCS. Further investigation using patient level data in

other geographic areas is warranted to validate the study results and better understand the relationship between RRS and CRCS adherence

Introduction

Colorectal cancer (CRC) remains an important public health concern in the U.S,[1] resulting in an estimated 49,700 deaths in 2015.[1] It is considered the second leading cause of death due to cancer in the U.S. Although considerable evidence has shown the effectiveness of colorectal cancer screening (CRCS) in CRC prevention,[2-8] about one in three age-eligible (aged 50-75) adults did not get screened for CRC as recommended by national guidelines.[10] In general, racial or ethnic minorities were less likely to adhere to CRCS compared to whites.[10] Individual-level factors such as age ≥ 65 and higher levels of education are positively associated with CRCS adherence.[13, 14, 17, 18, 26] Recent studies suggested that contextual, place-based factors could also influence the adherence to CRCS guidelines. [36, 37, 42, 47, 48, 112] One of the contextual factors was racial residential segregation.[47, 48, 50]

Racial residential segregation (RRS) refers to the residential separation of one racial group from another racial group.[63] RRS was associated with increased risk of various adverse health outcomes, such as cardiovascular disease,[113, 114] late stage cancer diagnosis,[78, 115] all-cause and cancer mortality.[116, 117] RRS could affect cancer screening in complex ways. For example, low neighborhood and individual socioeconomic status (SES) resulting from RRS,[64] as well as psychosocial factors relating to cancer such as cancer fatalism[85, 118] (e.g., cancer is incurable therefore there is no purpose in getting screened for CRC) shared by segregated minority members may adversely affect cancer screening adherence. However, networks between segregated minorities may also offer enhanced social cohesion or support to segregated minorities,[65, 76-80] potentially positively impacting screening adherence. To date, limited studies have examined RRS in the context of CRCS, and the relationship between RRS and CRCS is not fully understood.[47, 48, 50]

In Minnesota (MN), about 25% of the Twin Cities (i.e., Minneapolis and Saint Paul) 7-county metropolitan area are minorities[119] and RRS exists.[90-92] Minorities (except Asian/Pacific Islander) were more likely to be diagnosed with late stage CRC relative to non-Hispanic whites in MN,[95] and shorter life expectancy was reported in communities with a high concentration of minorities in the 7-county area.[89] Examining the impact of RRS on CRCS could inform future interventions that aim to improve population health. Thus, this study evaluated the association between facility proximity to RRS areas (i.e., minority segregated areas, and race-specific segregated areas) and facility-level CRCS adherence performance.

Materials and Methods

Setting

The present study explored the association between area-level RRS and facility-level CRCS adherence among patients, ages 50-75 years, in the Twin Cities 7-county Metropolitan area in MN. This metropolitan area included Anoka, Carver, Dakota, Hennepin, Scott, Ramsey, and Washington counties, and was Minnesota's largest urban area. The 7-county metropolitan area had a population of 2,849,567 in 2013, consisting of 75.2% non-Hispanic whites, 8.4% non-Hispanic black/African Americans (AA), 6.8% Asians 6.0% Hispanics, and 3.6% of other race/ethnicity.[119]

Data Sources

This study utilized two data sources: 2013 Minnesota Community Measurement (MNCM) data and 2009-2013 American Community Survey (ACS). As a state mandate, all facilities in MN were required to annually report health care data, including CRCS adherence, to MNCM.[104] The ACS was conducted by U.S. Census Bureau annually which provided information about the population characteristics aggregated at the area level such as census tract and block group. This study was approved by the Virginia Commonwealth University Institutional Review Board.

Sample

This study included all available 254 facilities that offered CRCS (i.e., primary care practices, colonoscopy facilities or other kinds of clinics that provide CRCS services) in the Twin Cities, 7-county metropolitan area in MN in 2013.

Outcomes

The primary outcome was facility-level CRCS adherence, defined as the percentage of patients adherent to the CRCS national guidelines [9] among the eligible patient population in a facility during the study period (i.e., July 1, 2012 to June 30, 2013).[104] The eligible patients were those who had at least two doctor visits during the last two years, at least one visit during the last twelve months, and were aged 51-75 years by the end of the measurement period, which were identified using a query on a practice management system or Electronic Medical Record. The publicly available 2013 MNCM data had facility-level crude CRCS, and CRCS adjusted for patient health insurance (to account for the potential difference in patient population across facilities).[120]

Main Covariate of Interest

The primary covariate variable of interest was the facility proximity to RRS areas, which indirectly measures the extent to which the patient population may be influenced by RRS within a facility. The facility proximity was measured by the distance from a facility location to the centroid of the nearest minority segregated areas as well as the race-specific (Asian, Hispanic, and AA) segregated areas. RRS is a comparison of a population's racial distribution in subareas relative to the larger geographic areas.[64] Because minority groups in the 7-county area were relatively small in terms of population and geographic area, we used minority population counts in block groups (i.e., subarea) as well as minority population counts in the corresponding census tract (i.e., larger overall geographic area) to construct census tract-level RRS. The population counts were age inclusive instead of ages 50-75 only (i.e., eligible age for CRCS) because RRS was a neighborhood contextual factor, and thus all residents needed to be taken into account. Among multiple indices that have been proposed to measure RRS,[121] we chose one of the most commonly used RRS indices, i.e., isolation index, which reflected the probability of a minority member being exposed to another minority member of the same race within an area (range: 0 to 1, where higher values indicate higher RRS). Methods proposed by Massey & Denton[121] were used to construct the isolation index (See *Appendix 1* for details). An isolation index $\geqslant$0.3 indicated that the area had moderate to high RRS.[122] In addition to isolation index for minority combined, race-specific isolation index was constructed with consideration that the culture and influence of RRS may vary by individual racial and ethnic groups.

Other Covariates

This study included some characteristics of facilities, i.e., SES of the neighborhood where the facility was located, and whether or not a facility participated in the Sage Scope program, a program which provided free colonoscopies as well as screening-related services (e.g., interpreter service) to MN residents aged 50-64 with low income and no insurance[123]. The neighborhood SES was measured by the socioeconomic position (SEP) index at the census tract level, which was proposed by Krieger.[61] The SEP index was a summary deprivation measure, using a standardized z score combining data (with equal weights) on six SES variables, i.e., median household income, percentage of homes worth ≥400% of median value of owned homes, percentage of persons employed in working-class occupations, percentage of unemployment, percentage of persons living below the federal poverty line, and percentage of ≤ high school graduate. The SEP index was categorized into quintiles (Q1: least deprived - Q5: most deprived census tracts).[61]

Statistical Analysis

Mapping was conducted in ArcGIS 10.3.1[124] and other analyses were performed in R version 3.2.2.[125] Firstly, we did exploratory analysis on how the facility-level CRCS adherence distributed with increasing facility distance to RRS areas by performing generalized additive models with facility-level CRCS adherence (continuous variable) as outcome, and facility proximity to RRS areas (continuous variable) in the smoothing function. As the plot of generalized additive models (See *Appendix 2*) showed non-linear associations between facility proximity and CRCS adherence, we categorized facility proximity to RRS areas into several groups, where cut-offs were mainly informed by the plot of generalized additive models. Specifically, the plots for facility proximity to race-specific (i.e., Asian, Hispanic, AA) segregated areas had similar curves. Therefore, same cut-offs (i.e., 2 miles and 5 miles) were used for facility proximity to race-specific segregated areas. The plot for minority segregated areas showed a wavy curve. Thus, we started with multiple categories (5 categories) with cut-offs of 0.5 miles, 1 miles, 2 miles, and 5 miles, where the 1 miles, 2 miles, and 5 miles were suggested by the plot of generalized additive model. Cut-off greater than 5 miles was not chosen because of concerns about the insufficient sample size in the category. The 0.5 mile was chosen because about one third of the facilities (81/254) were located < 0.5 miles away from minority segregated areas, and we were interested in exploring whether there was a "dose response" regarding the association between facility proximity to minority segregated areas and facility-level CRCS adherence. Since the logistic regression model (as described in the following two paragraphs) results showed that the categories of "0.50-0.99" and "1.00-1.99" had similar estimates, and so do the categories of "2.00-4.99" and "5.00-", we collapsed the categories correspondingly. As a result, facility proximity to minority segregated areas had 3 categories, i.e.,< 0.50, 0.50-1.99, 2.00- (miles). Then, using Akaike information criterion (AIC), we compared goodness of fit between the models that included the 5-category and 3-category variables of facility proximity to minority segregated areas. Since the model with 3-category variable had a better model fit than the one with 5-category variable (AIC: 316.7 vs. 320.6), we used the 3-category variable of facility proximity to minority segregated areas (i.e., < 0.50, 0.50-1.99, 2.00-) in the analysis.

Regarding the outcome, given statewide interests in how the facility CRCS adherence compares to the statewide average,[120, 126] the current study further categorized both crude and health insurance-adjusted facility-level CRCS adherence into binary variables: high CRCS performance (equal to or above state average of 68.8% in 2013), and low CRCS performance (below the state average). However, considering that using the original facility-level CRCS adherence as a continuous variable may be able to utilize full information of the data, sensitivity analysis (which modeled CRCS adherence as a continuous variable) was also performed to see whether the results were consistent compared with results for binary CRCS adherence outcomes.

CRCS facilities, facility-level CRCS adherence, and RRS areas were mapped. Spatial distributions of CRCS facilities and RRS areas in the 7- county metropolitan areas, as well as characteristics of the CRCS facilities were provided. The chi-square test was used to test different distributions of facility characteristics by CRCS performance. Logistic regressions were conducted with facility-level CRCS adherence as the outcome and the proximity of facilities to RRS areas as the main covariate variable. Facility proximity to minority segregated areas, and race-specific segregated areas were included in separate models. For each facility proximity variable, two models were performed. A crude model included the main covariate variable and outcome of interest. An adjusted model further added other covariates given their significant associations with the outcome in bivariate analysis. Furthermore, the adjusted model used health insurance-adjusted CRCS adherence as the outcome in order to adjust for patient population characteristics across facilities. Also, sensitivity analysis was performed by modeling CRCS adherence as a continuous variable. Odds ratios (ORs) and 95% confidence intervals (CIs) of model estimates were provided.

Results

Descriptive results

Figures 1a-1d show maps of facilities, facility-level CRCS adherence, and minority/race-specific segregated areas. Of the 254 total CRCS facilities in the 7-county metropolitan area, 40.2% (n=102) of the facilities had CRCS adherence below the state average (i.e., low performance). The low-performance facilities clustered in the center of 7-county metropolitan areas, largely in Hennepin County. For RRS areas, minority segregated areas were found primarily in the middle of metropolitan areas, most of which were located in Hennepin and Ramsey Counties. For race-specific segregated areas, Asian-segregated areas were mainly located in Ramsey County. The non-Hispanic AA- and Hispanic-segregated areas spread out throughout the metropolitan area, and the majority of them were located in Hennepin County.

Table 2.1 shows the characteristics of CRCS facilities in the 7-county metropolitan areas in MN. Overall, over 66% of facilities were located less than 2 miles away from the centroid of minority segregated areas, and the majority of facilities had distance <5 miles away from race-specific segregated areas. About 40% of the facilities were located in more deprived census tracts (i.e., lowest two quintiles). Low and high CRCS performance facilities had significantly different distributions of geographic proximity to RRS areas. The socioeconomic status of where facilities were located as well as participation in Sage Scope programs also differed by CRCS performance. Low CRCS performance facilities tended to be located closer to the RRS areas and in more deprived census tracts, compared with high CRCS performance facilities. Low CRCS performance facilities had a significantly higher percentage of participation in Sage Scope program than high performance facilities.

Modeling results

Table 2.2 shows the model estimates of associations between proximity to RRS areas and facility-level CRCS adherence. Compared with facilities that were located at least 2 miles away (i.e., reference category) from the centroid of minority segregated areas, facilities located less than 0.5 miles away were 3.35 times more likely to have low CRCS performance (OR: 3.35, 95% CI: 1.77-6.32). The association was not significant when it was adjusted for covariates, but still trended positively (OR: 2.06, 95% CI: 0.92-4.62). Similar positive associations were also observed when RRS was examined by individual racial and ethnic groups. Specifically, when compared with facilities at least 5 miles from Asian and Hispanic segregated areas, facilities less than 2 miles away were more likely to have low CRCS performance for both Asians (OR: 3.90, 95% CI: 2.09-7.30) and Hispanics (OR: 4.62, 95% CI: 2.38-8.94). The association was significant when it was adjusted for covariates (Asian OR: 2.06, 95% CI: 1.00-4.24; Hispanic

OR: 2.83, 95% CI: 1.29-6.24). Additionally, facilities with less than 2 miles proximity to AA segregated areas were 3.10 times more likely to have low CRCS performance than facilities with at least 5 miles proximity (OR: 3.10, 95% CI: 1.68-5.71). The adjusted association was not significant but trended positively (OR: 1.67, 95% CI: 0.81-3.43). Other covariate variables, such as participation in the Sage Scope program, and SEP, were not significantly associated with facility-level CRCS performance in any of the adjusted models.

Sensitivity Analysis Results

Appendix 3 shows results from sensitivity analysis which assessed the association between facility proximity to RRS areas and facility-level CRCS adherence by modeling facility-level CRCS adherence as a continuous outcome. Results for facility proximity to minority, Hispanic, and African American segregated areas had the same pattern as the formal analysis results (shown in Table 2.2). For instance, the crude analysis in *Appendix 3* showed that facilities located less than 0.5 miles away from minority segregated areas was associated with about 12-point lower in percentage of adherent to CRCS, compared with facilities located at least 2 miles away. The adjusted estimate was not statistically significant, but still trended negatively. This was similar to what was reported in Table 2.2. For Asian segregated areas, the adjusted estimates for facility proximity to Asian segregated areas were not statistically significant, which was different from formal analysis; nonetheless, the estimates still trended negatively. Another difference was that facility participation in the Sage Scope program and neighborhood SEP were significantly associated with facility-level CRCS adherence in some of the adjusted models in the sensitivity analysis, whereas none of the associations were statistically significant in the formal analysis in Table 2.2.

Discussion

The current study advanced the literature on neighborhood contributors to CRCS by examining the association between facility proximity to RRS and facility-level CRCS adherence performance. We found that facilities located closer to the RRS areas (especially the Asian and Hispanic segregated areas) were more likely to have low CRCS performance. Moreover, these low performance facilities had higher percentages of participation in the Sage Scope program, and tended to be located in relatively low SES neighborhoods. However, participation in the Sage Scope program and neighborhood SES were not significantly associated with low CRCS performance in adjusted models.

In general, we found that facilities located closer to RRS areas were more likely to perform low CRCS adherence, indicating that RRS may have negative impacts on cancer screening use. This is consistent with findings from a large body of studies which documented worse cancer outcomes[78, 115, 117]and less healthcare utilization[81] among residents from high RRS areas, or communities with a high concentration of minorities.

For race-specific segregation, we found that a facility being located closer to Hispanic and Asian segregated areas was associated with low facility CRCS performance. Our results relating to Hispanic segregation are consistent with previous findings which reported a lower probability of endoscopy and mammogram use for residents living in Hispanic segregated neighborhoods in some U.S. states.[48, 65, 77] Our study results relating to Asian segregation were different from previous evidence which showed that the Asian segregation had neither significant nor beneficial effects on cancer screening use.[48, 65, 77] These discrepancies could be due to different characteristics of Asian population in our study in comparison with previous studies. Two of the previous studies were conducted in California, where Asian communities were established centuries ago, and the Asian population is mainly composed of Filipinos, Chinese, and Vietnamese people. However, MN had a relatively short history of Asian immigration, which began in the 1970s, and the Asian population in the 7-county metropolitan area had relatively high composition of Hmong and Asian Indian people [127]. Hence, the different culture held by Asian subgroups and the number of years which the RRS had been established in respective areas may influence how RRS is related to residents' screening behaviors.

With regard to AA segregation, previous evidence has shown that residents from the AA segregation community had a lower probability of mammogram and endoscopy use.[48, 65] In the present study, we found that the association between facility proximity to AA segregated areas and low facility-level CRCS adherence trended positively but was not statistically significant. Although our results are similar to the previous evidence, consideration should be given to the fact that 27.5% of AA were foreign-born in the 7-county metropolitan areas, the majority of which were new immigrants or refugees from Somalia, Liberia, and Ethiopia.[127] Therefore, the AA segregation in the 7-county metropolitan areas may not be comparable to other places where there is historical AA segregation.

When using spatially aggregated data, it is important to be aware that the association between contextual, place-based factors and health outcomes could depend upon the geographic unit of analysis.[61, 65, 128, 129] For the relationship of RRS and cancer screening specifically, Mobley et al. measured RRS at 4 different geographic levels (ranging from the ZIP Code to county level), and found that the significance levels of estimates of the association between RRS and mammogram use were higher when RRS was measured at the smaller geographic unit.[65] In our study, as the minorities in the 7-county metropolitan area were relatively small in terms of population and geographic area, we measured RRS at the census tract level. Therefore, the results obtained may be specific to the influence of RRS on CRCS at the census tract level.

Also, the geographic scales employed for RRS may affect interpretation of the RRS. RRS (measured by isolation index) at the smaller geographic unit could be considered an indication of local community factors such as social support, social cohesion, and culture. RRS at a larger geographic scale (e.g., county) suggests that there was a larger degree of the spatial clustering. This may reflect political influence held by minorities (e.g., political empowerment) as a broader demonstration of social support and social cohesion.[65, 80] RRS in our study were measured at the census tract level, which may indicate local community influence rather than political influence held by minorities.

There are several possible explanations for our findings about potential negative impacts of RRS on CRCS adherence. First, the relationship between RRS and CRCS adherence could be mediated by SES. RRS can create social-cultural barriers to residents' employment and education opportunities. In some cases, this may adversely impact the individual and neighborhood SES,[64] which further limits residents' opportunities to access healthcare. Second, living in a RRS area could likely delay immigrants' assimilation process into U.S. society. As a result, the RRS residents may have greater barriers in communicating with health providers[118] and navigating the U.S. health system. Third, the culture shared by RRS members could shape the residents' healthcare preferences.[81] For instance, CRCS may be perceived as unnecessary in the immigrant community since CRCS was not common in the original countries.[130] Also, the group beliefs may hold back the individuals from getting screened for CRC. Some minority groups believed that cancer is incurable [85, 118] or cancer can be protected by religious beliefs.[118]

In addition to facility proximity to RRS areas, other covariates such as facility participation in Sage Scope program and SES of the neighborhood where facilities were located were examined. Neighborhoods with low SES may be more likely to also have high crime rates.

Previous evidence suggested that when a screening facility was located in such neighborhood environments, patients may become discouraged from getting cancer screenings.[131] The Chi-square tests in Table 2.1 suggested that low neighborhood SES was associated with low facility-level CRCS adherence. However, the association was not statistically significant in the fully-adjusted model. It is possible that other factors such as RRS play a more significant role than SES in CRCS. For the Sage Scope program, which offered free colonoscopies and screening related services (e.g., interpreter for non-English speaking patients), we expected a higher CRCS adherence for facilities participating in this program. However, we found the association was not statistically significant in the adjusted model. One possible explanation is that we cannot rule out the potential for residual confounding since we were unable to take into account other characteristics of the patient population (e.g., distribution of non-English speaking patients) and facilities (e.g., physician workforce in the facility). Also, we did not examine how often the Sage Scope program was utilized by participants. A study conducted in MN Somali men found that participants were unwilling to use interpreters because interpreters usually were also members of their community, which created concerns among participants about privacy regarding potential cancer diagnoses.[118]

Our main findings about the association between facility proximity to RRS areas and facility-level CRCS adherence have potentially important implications for policy and practice. Facility-level CRCS adherence is one of the important healthcare quality indicators used to evaluate clinic performance in MN.[120] The actual CRCS rates and rankings relative to the state average are publically available on MNCM [120] as well as the MN HealthScore website[126]. Our study investigated factors that existed outside the screening facility but could possibly affect facility-level CRCS adherence. Findings from our study suggest that the social and cultural environment where the potential service population reside could affect the CRCS adherence. Culturally tailored programs and interventions within the facility, as well as in the RRS community, are needed to promote CRCS. Further, leveraging resources in the RRS communities, as well as in facilities that are closer to RRS areas, could be beneficial to increase CRCS use among minorities, which can further improve CRC outcomes.

Our study findings may be subject to several potential limitations. First, it was a cross-sectional study; thus, the temporal sequence between facility proximity to RRS areas and facility-level CRCS adherence cannot be inferred. Second, because relevant information was not publically available, this study examined overall CRCS adherence as the outcome. Future studies are warranted to examine how RRS is associated with test-specific CRCS adherences. Third, variations in RRS may exist for racial subgroups used in the current study, e.g., the Asian subgroups, such as Hmong and Asian Indian, likely differ. However, data at the small geographic scale were not available to analyze RRS for racial subgroups. Similarly, residents born in the U.S. may differ from the foreign-born population.[132] This study was not able to capture how nationality in RRS areas could affect facility-level CRCS performance. Fourth, because patient-level data were not publically available, the impact of RRS on individual-level CRCS adherence could not be assessed. Future studies are needed to investigate the association between residence in RRS areas and individual-level CRCS adherence. Fifth, other important characteristics of patient population and facilities were not included in the analysis, due to inability to access the data; thus, residual confounding cannot be ruled out. Sixth, the study results might be biased due to spatial correlations among the high- and low-performance facilities as significant spatial clustering was found among the low-and high- performace facilities (maximum absolute deviation test p-value <0.001), and the model residuals tended to cluster over space even after the adjustment of covariates.Lastly, the area-level estimates provided by the American Community Survey had uncertainty (i.e., the estimates were associated with a margin of error), which may not necessarily represent the exact true value in the population.

In conclusion, the present study revealed that facilities located closer to the RRS areas (especially Asian and Hispanic segregated areas) were associated with low facility-level CRCS adherence, suggesting that RRS may play a role in residents' obtaining CRCS. Future studies analyzing patient-level data in states with greater numbers and variety of minority populations as well as accounting for number of facility characteristics (i.e. physician supply) and patient characteristics are needed to validate the results of our study and provide more specific evidence about the impacts of RRS on individual-level CRCS adherence. Our findings suggest that culturally tailored CRCS programs within facilities located closer to RRS areas, as well as community-based CRCS interventions in RRS areas, are needed. These interventions can further contribute to improving the health of minorities in RRS areas.

Figure 1a. Map of CRCS Facilities, Facility-level CRCS Adherence, and Minority Segregated Areas

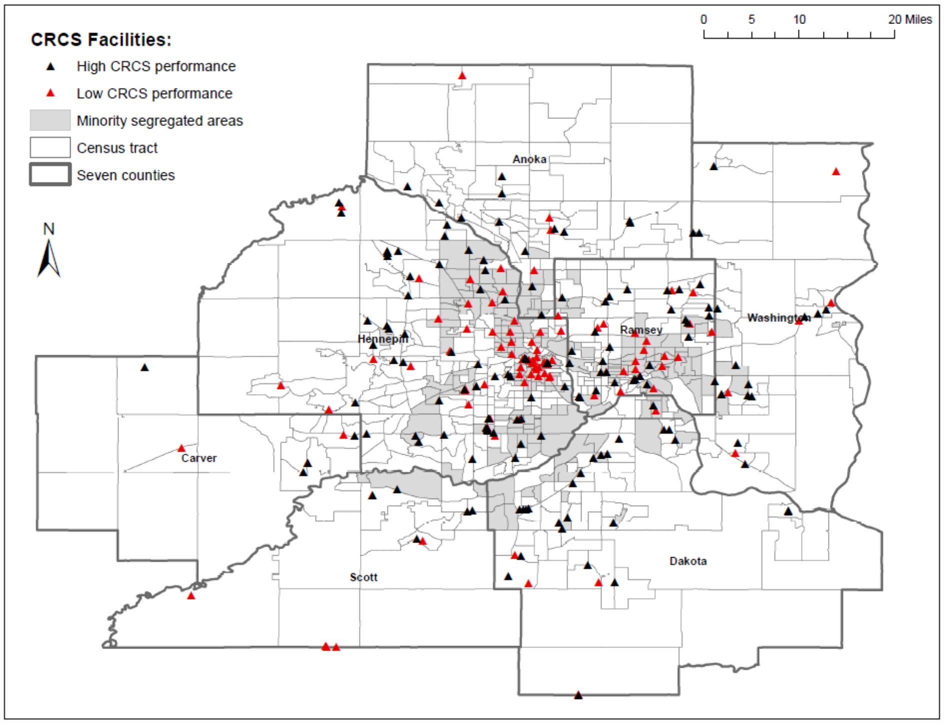

Figure 1b. Map of CRCS Facilities, Facility-level CRCS Adherence, and Asian Segregated Areas

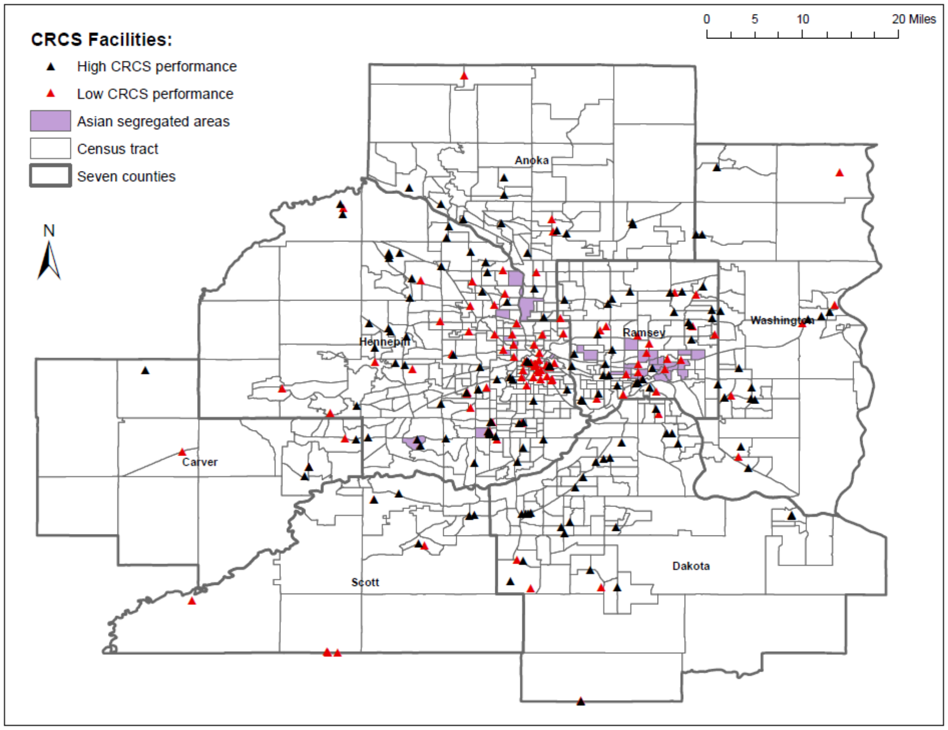

Figure 1c. Map of CRCS Facilities, Facility-level CRCS Adherence, and Hispanic Segregated Areas

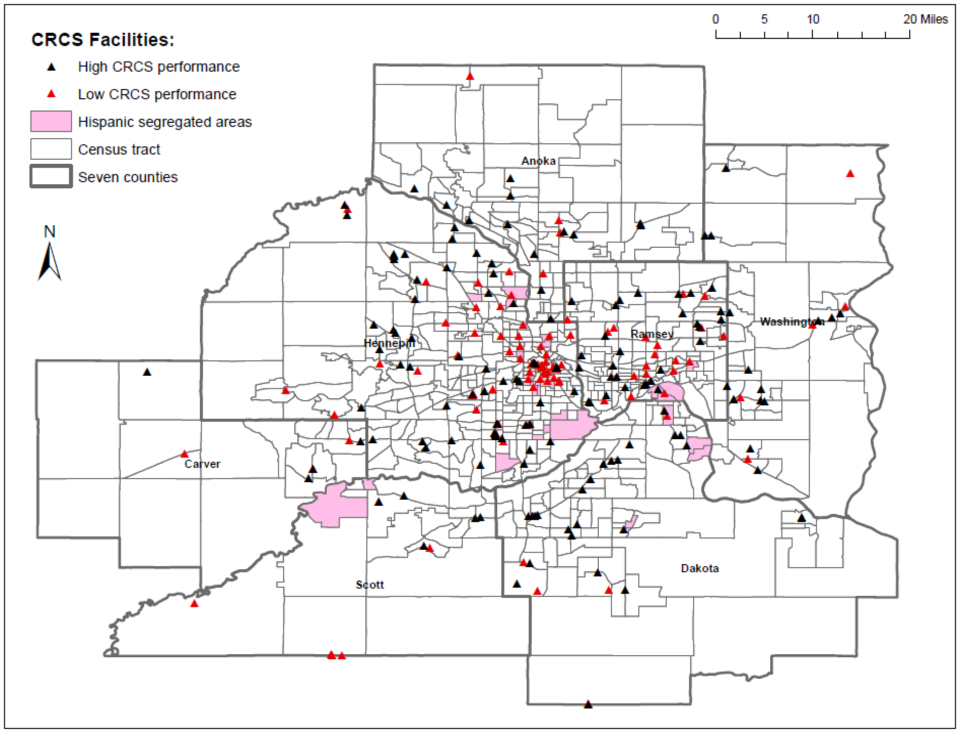

Figure 1d. Map of CRCS Facilities, Facility-level CRCS Adherence, and AA Segregated Areas

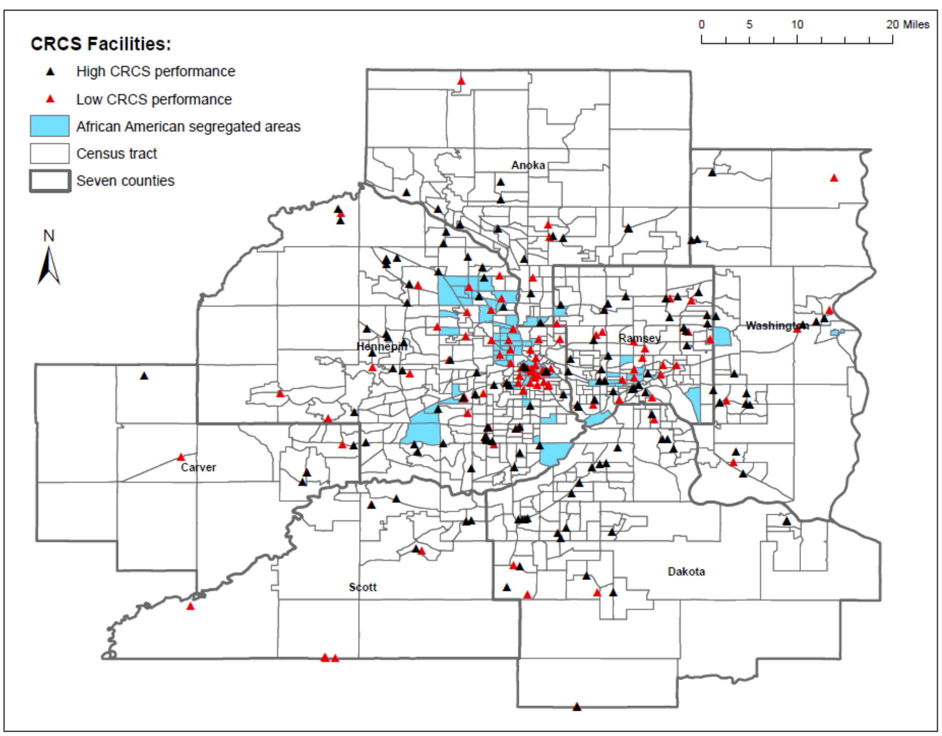

Table 2.1 Characteristics of CRCS Facilities in 7-County Metropolitan Areas in Minnesota

Characteristics	All CRCS Facilities (N=254)		Low CRCS Performance (n=102)		High CRCS Performance (n=152)		P-value from χ2 Test
	n	%	n	%	n	%	
Facility proximity to minority segregated areas (miles)							
< 0.50	81	31.9	52	51.0	29	19.1	
0.50-1.99	87	34.2	20	19.6	67	44.1	<0.001
2.00-	86	33.9	30	29.4	56	36.8	
Facility proximity to Asian segregated areas (miles)							
<2.00	76	29.9	45	44.1	31	20.4	
2.00-4.99	71	28.0	28	27.5	43	28.3	<0.001
5.00-	107	42.1	29	28.4	78	51.3	
Facility proximity to Hispanic segregated areas (miles)							
<2.00	75	29.5	47	46.1	28	18.4	
2.00-4.99	89	29.1	31	30.4	58	38.2	<0.001
5.00-	90	35.4	24	23.5	66	43.4	
Facility proximity to AA segregated areas (miles)							
<2.00	106	41.7	60	58.8	46	30.3	
2.00-4.99	67	26.4	18	17.6	49	32.2	<0.001
5.00-	81	31.9	24	23.5	57	37.5	
Socioeconomic position index[a]							
Q1: least deprived	50	19.7	17	16.7	33	21.7	
Q2	53	20.9	13	12.7	40	26.3	
Q3	49	19.3	17	16.7	32	21.1	<0.001
Q4	55	21.7	23	22.5	32	21.1	
Q5: most deprived	47	18.5	32	31.4	15	9.9	
Participation in Sage Scope program							
Yes	72	28.3	38	37.3	34	22.4	0.0147

[a] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived census tracts, and Q5 stands for quintile 5 the most deprived census tracts

AA: Non-Hispanic African American

Table 2.2 Associations between Facilities' Proximity to RRS Areas and Facility-level CRCS Adherence

	Minorities Combined OR (95% CI)		**Asian** OR (95% CI)	
	Crude	Adjusted[a]	Crude	Adjusted[a]
Facility proximity to minority segregated areas (miles)				
< 0.50	**3.35 (1.77,6.32)**	2.06 (0.92,4.62)	–	–
0.50-1.99	0.56 (0.29,1.09)	0.50 (0.25,1.00)	–	–
2.00-	REF	REF	–	–
Facility proximity to race-specific segregated areas (miles)				
< 2.00	–	–	**3.90 (2.09,7.30)**	**2.06 (1.00,4.24)**
2.00-4.99	–	–	1.75 (0.92,3.32)	1.22 (0.62,2.37)
5.00-	–	–	REF	REF
Socioeconomic position index[b]				
Q1: least deprived	–	REF	–	REF
Q2	–	0.65 (0.28,1.52)	–	0.65 (0.28,1.49)
Q3	–	0.90 (0.38,2.14)	–	0.84 (0.36,1.95)
Q4	–	0.88 (0.36,2.15)	–	0.78 (0.34,1.82)
Q5: most deprived	–	1.29 (0.45,3.71)	–	1.58 (0.60,4.12)
Participation in Sage Scope program				
Yes	–	1.42 (0.77,2.60)	–	1.59 (0.88,2.86)
No	–	REF	–	REF

(To be continued)

[a] Outcome was CRCS adherence (binary variable) adjusted for patient health insurance. Facilities' neighborhood SES and participation in the Sage Scope program were included in the model

[b] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived census tracts, and Q5 stands for quintile 5 the most deprived census tracts

RRS: Racial residential segregation; CRCS: Colorectal cancer screening

Table 2.2 Associations between Facilities' Proximity to RRS Areas and Facility-level CRCS Adherence *(Continued)*

	Hispanic OR (95% CI)		AA OR (95% CI)	
	Crude	Adjusted[a]	Crude	Adjusted[a]
Facility proximity to minority segregated areas (miles)				
< 0.50	–	–	–	–
0.50-1.99	–	–	–	–
2.00-	–	–	–	–
Facility proximity to race-specific segregated areas (miles)				
< 2.00	**4.62 (2.38,8.94)**	**2.83 (1.29,6.24)**	**3.10 (1.68,5.71)**	1.67 (0.81,3.43)
2.00-4.99	1.47 (0.78,2.79)	0.92 (0.48,1.74)	0.87 (0.42,1.79)	0.62 (0.30,1.26)
5.00-	REF	REF	REF	REF
Socioeconomic position index[b]				
Q1: least deprived	–	REF	–	REF
Q2	–	0.80 (0.35,1.83)	–	0.77 (0.33,1.77)
Q3	–	0.90 (0.39,2.09)	–	0.94 (0.40,2.19)
Q4	–	0.72 (0.31,1.69)	–	0.79 (0.34,1.87)
Q5: most deprived	–	1.26 (0.47,3.39)	–	1.54 (0.57,4.12)
Participation in Sage Scope program				
Yes	–	1.42 (0.78,2.58)	–	1.55 (0.86,2.80)
No	–	REF	–	REF

[a] Outcome was CRCS adherence (binary variable) adjusted for patient health insurance. Facilities' neighborhood SES and participation in the Sage Scope program were included in the model

[b] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived census tracts, and Q5 stands for quintile 5 the most deprived census tracts

RRS: Racial residential segregation; CRCS: Colorectal cancer screening; AA: Non-Hispanic African American

CHAPTER 5: The Association between Area-level Socioeconomic Status and Colorectal Cancer Screening Adherence

Abstract

Purpose: Existing evidence regarding the relationship between area-level socioeconomic (SES) and colorectal cancer screening (CRCS) adherence is mixed, partly due to the use of different SES measurements. We evaluated the effects of area-level SES on CRCS adherence using a comprehensive list of SES measures, and identified robust SES measures for detecting social inequalities in CRCS adherence.

Methods: The 2012-2013 Washington Behavioral Risk Factor Surveillance System data were used, and linked with the 2009-2013 American Community Survey data. The eligible sample included 12,711 respondents aged 50-75 years with CRCS and residential ZIP Code information. The exposure was ZIP Code-level SES (i.e., 19 single and five composite SES measures), categorized into quintiles (Q1: least deprived – Q5: most deprived). The outcomes were prevalence of self-reported stool test, colonoscopy, and overall CRCS adherence, defined according to national guidelines. Odds ratios (ORs) and 95% confidence interval (CIs) from multilevel logistic regression models were reported.

Results: Of the SES measures, percentage of people below poverty was positively associated with stool test adherence (Q4 vs. Q1 OR: 1.33, 95% CI: 1.01-1.75), even after adjustment for individual factors (OR:1.43, 95% CI: 1.08-1.88). Most SES measures showed negative bivariate associations with colonoscopy adherence. Income measures such as per capital income (Q5 vs. Q1 OR: 0.50, 95% CI: 0.41-0.61), education measures such as percentage of ≥ college education (Q5 vs. Q1 OR: 0.53, 95% CI: 0.43-0.65), and composite measures such as SES summary score (Q5 vs Q1 OR: 0.51, 95% CI: 0.42-0.61) showed relatively strong associations. However, few associations remained statistically significant after adjustment for individual factors. Results for overall CRCS adherence were similar to colonoscopy adherence.

Conclusion: The majority of area-level SES measures indicated negative bivariate associations between deprivation and colonoscopy/overall adherences. Given the strength of associations, measures such as per capital income, education, and area SES summary score can be good candidate SES measures for detecting socioeconomically disadvantaged areas that need CRCS intervention.

Introduction

Colorectal cancer (CRC) is one of the predominant cancers in both men and women in the U.S,[1] but it can be largely prevented through effective screening methods.[2-8] Although national guidelines recommend regular colorectal cancer screening (CRCS) for adults at age 50-75,[9] the current CRCS rates are lower than optimal. One in three adults aged 50-75 are not adherent to the national guidelines (i.e., a stool test within a year, or sigmoidoscopy within five years, or colonoscopy within ten years), and CRCS adherence varies geographically.[10, 45, 46]

Individual characteristics such as age < 65, low education, no health insurance coverage, and having barriers to CRCS were associated with nonadherence to CRCS.[13, 14, 18, 26, 32, 40] Area-level characteristics (i.e., characteristics of where people live) could also play a role in individuals' obtaining CRCS. [22, 23, 25, 36, 37, 42, 44-50, 67, 69, 71] Among area-level characteristics, socioeconomic status (SES) has received growing attention in CRCS research. [22, 23, 25, 36, 42, 44-50, 67, 112] The area-level SES could influence CRCS in multiple ways. For instance, low area-level SES may be associated with low individual SES,[46] which could further impact the probability of individual CRCS adherence.[14, 19, 31, 34] Also, low SES neighborhoods may offer limited medical resources such as few available physicians,[36] which may contribute to low CRCS adherence. The current findings about the relationship between area-level SES and CRCS adherence are mixed.

Some studies found that people living in low SES areas were 19% – 24% less likely to be adherent to CRCS compared with residents from high SES areas,[44, 46] whereas other evidence suggested that area-level SES was not associated with CRCS adherence.[42, 50] Furthermore, an important limitation exists in the current CRCS literature on area-level SES with examination of limited sets of area-level SES measures.[22, 23, 25, 36, 42, 44-50, 67] However, SES is a complex and multidimensional construct [60, 96]. Measures of area-level SES that have been proposed in seminal SES-related studies focusing on other health outcomes[61, 133-135] would be important to assess in relation to CRCS. Also, due to limited examination of SES measures, there is a lack of knowledge about which individual and/or composite SES measures would be most appropriate for monitoring social inequalities in CRCS adherence.

To address the aforementioned gaps, the present study evaluated the association between area-level SES and CRCS adherence using a comprehensive list of individual and composite SES measures, and identified robust SES measures for detecting social inequalities in CRCS adherence.

Materials and Methods

Setting

The current study was conducted in Washington state (WA). The population characteristics of WA are similar to the national level, except WA has a slightly higher proportion of whites.[136] Large variations of area-level SES [137] and significantly higher CRC incidence rates have been reported in low SES areas.[138] Examining the effects of area-level SES on CRCS adherence could help to reduce socioeconomic inequalities in CRC outcomes. Another reason for choosing WA was data availability. We were able to access participants' ZIP Code of residence information in the WA Behavioral Risk Factor Surveillance System (BRFSS) data.

Data sources

This study used data from the 2012-2013 WA BRFSS and 2009-2013 American Community Survey (ACS). The BRFSS is a state-based surveillance program that collects self-reported information regarding health-related behaviors, preventive health practices, health care access, and residence from probabilistically sampled, non-institutionalized adults in the U.S. The ACS is conducted by U.S. Census Bureau annually to provide estimates of area-level population characteristics and socioeconomic status. The self-reported five-digit ZIP Codes from the BRFSS were linked to ZIP Code Tabulation Areas in the ACS (an areal feature developed by U.S. Census to approximate the geographic boundaries for ZIP Code Service areas). This study was approved by the Virginia Commonwealth University Institutional Review Board.

Study population

Eligibility for this study included respondents aged 50-75 at the time of the 2012-2013 WA BRFSS survey who provided responses to the CRCS questions, and reported ZIP Code of residence in WA. A total of 12,711 individuals from 534 ZIP Codes were included in the analyses.

Outcomes

Our primary outcome was individual-level CRCS adherence. In the WA BRFSS, participants aged ≥50 were asked about ever having had a stool test, and sigmoidoscopy/ colonoscopy, and the time when each of the CRCS tests were most recently obtained,[106] which was used to create three binary CRCS adherence outcomes (adherent vs. non-adherent). The three outcomes were a) stool test adherence: respondent reported having had a stool test within the last year; b) colonoscopy adherence: respondent reported having had a colonoscopy within past 10 years; and c) overall CRCS adherence: respondent reported having had a stool test, or colonoscopy, or flexible sigmoidoscopy within the nationally recommended timeframe.[9] Because of limited use (prevalence: 6.5%), flexible sigmoidoscopy was not assessed as a separate outcome.

Main Covariate of Interest

The main covariate of interest was ZIP Code-level SES. The area-level SES measures were selected using the following criteria: a) measures were used in previous studies focusing on area-level SES and cancer screening in the U.S. [22, 25, 36, 42, 44-57, 59], or consistently used in seminal area-level SES studies for other health outcomes,[61, 133-135] b) the measures were clearly defined, and c) relevant information was available in the ACS data. A total of 19 single item SES measures in seven categories and five composite indices were included in this study. Table 3.1a and 3.1b provides a brief description of single and composite SES measures, respectively.

Table 3. 1a Area-level SES Single Measures

Aspects Categories		Description of items in each category
Occupation/employment		
Working class	-	Percent of people in working class occupation.[57, 61] The working-class occupations are defined as follows: food preparation and food service; building and grounds cleaning and maintenance; personal care and service; office work and administrative support; construction trades; installation and repair work; production, transportation, and material moving occupations, except aircraft and traffic control occupations; construction, extraction, and maintenance occupations; and health-care support occupations[139]
Unemployment	-	Percent of unemployed people among population aged 16 years and over [36, 42, 57, 61, 112]
White collar	-	Percent of people in white-collar employment.[36, 56] White collar occupations include management, professional, and related occupations, except farming and farm management
Income		

	Median household income	-	Median household income ($) [22, 54, 55, 57, 61]
	Low income	-	Percent of households with income < 50% of median household income [61]
	High income	-	Percent of households with incomes > 400% of median household income [61]
	Gini coefficient	-	Gini coefficient. [61, 112]A statistical measure of income inequality with regard to income distribution across the population. Gini coefficient ranges from 0 to 1 where 1 indicates complete inequality (only one household has income), and 0 indicates no inequality (all households have equal income).
	Per capita income	-	Per capita income ($)[22]
	Non-salary income	-	Percent of households with dividend, rental, or interest income[56]
Poverty			
	Below poverty	-	Percent of people living below federal poverty line [22, 42, 45-47, 49, 50, 57, 61, 88, 102, 112]
	Female-headed households	-	Percent of female-headed households[140]
Wealth			
	Expensive homes	-	Percent of homes worth $\geq$400% of the median value of owned homes [57, 61]
	Median housing value	-	Median housing value ($)[56]
Education			
	Low education	-	Percent of people with education < high school[42, 57, 61, 112]
	High school or higher	-	Percent of people who completed high school [25, 36, 141]
	High education	-	Percent of people with education $\geq$ college [52, 56, 61]
Crowding			
	Crowded households	-	Percent of households with > 1 person per room [57, 61]
Housing			
	Rented houses	-	Percent of house units rented [57]
	Households with no car	-	Percent of households with no car [57]

Table 3. 1b Area-level SES Composite Measures

Description of SES composite measures
- Socioeconomic position (SEP) index.[57, 59, 61] A summary deprivation measure composed of a standardized z score that combines data (with equal weights) on percentage of working class, unemployment, poverty, low education (less than high school), expensive homes, and median household income
- Area SES summary score.[133-135] A summary area SES measure of consisting of z score combining data (with equal weights) on wealth/income (log median household income, log median value of housing units, and % of households receiving interest, dividend, or net rental income), education (% of adults with complete high school education, % of adults with complete college education), and occupation (% of persons in executive, managerial, or professional specialty occupations)
- Index of Local Economic Resources.[61] A summary index based on white collar occupation, unemployment, and family income
- SEP1.[61]A composite categorical variable based on % of below poverty, working class, and expensive homes. (See Krieger et al., 2002 [61] for detailed categorization methods)
- SEP2.[61] A composite categorical variable based on % of below poverty, working class, and high income. (See Krieger et al., 2002 [61] for detailed categorization methods)

Other Covariates

Individual-level covariates were age (as measured in 5-year age groups between 50 and 75), gender, race/ethnicity (non-Hispanic white, non-Hispanic black, other non-Hispanic, and Hispanic), education (< high school graduate, high school graduate, some college/technical school, and ≥college graduate), household income (< $15,000, $15,000-$34,999, $35,000-$49,999, $50,000-$74,999, and ≥ $75,000), employed for wages (yes, no), marital status (married/partnered, not married), health insurance coverage (yes, no), smoking status (previous smoker, current smoker, never smoked), having usual source of care (yes, no), and delayed health care due to cost (yes, no). The ZIP Code-level covariates included the percentage of age 50-75 in the ZIP Code population, and percent of minorities among the ZIP Code population.

Statistical analysis

Data analysis was performed in SAS.9.4 software (SAS Institute, Inc., Cary, NC, version 9.4). All the SES measures were categorized into quintiles (Q1: least deprived - Q5: most deprived ZIP Codes),[61] except socioeconomic position (SEP)1 and SEP2. The SEP1 and SEP2 were initially classified into 7 categories given the cut-offs proposed by Krieger et al.;[61] however, due to small subgroup samples, two categories (i.e., category 5 and 7 as listed in Krieger et al. paper [61]) were collapsed with category 4 and 6, respectively. Therefore, SEP1 and SEP2 had 5 categories (See *Appendix 4* for the cut-offs for all SES measures).

Given the probabilistic sampling, eligible respondent characteristics were described by frequencies and weighted percentages. To evaluate the association between area-level SES and CRCS adherence, multilevel logistic regression models were performed using the GLIMMIX procedure. Scaled weights[142],[143] were included in the GLIMMIX WEIGHT statement to reduce the bias in the estimator of variance (See *Appendix 5* for methods of scaling weights and *Appendix 6* for the multilevel model).

Pairwise Pearson correlations between area-level SES measures were generated. Also, the multicollinearity between multiple area-level SES measures was assessed by the variance inflation factors (VIFs) in regression models with all the SES measures included simultaneously. The multicollinearity was considered acceptable if the VIF was less than 2.5.[144] In our study, VIF exceeded the acceptable value (i.e., 2.5), thus the area-level SES measures were included in separate models. Effect modification by race and age were tested by examining the significance of interaction term (i.e., race*area-level SES measure, age*area-level SES measure). Because the majority of the interaction terms were not significant, results were not stratified by race or age. Covariates were included in the final model if bivariate analyses indicated that the covariate had a statistically significant relationship ($\alpha < 0.05$) with the outcome or the covariate was a historical confounder (i.e., age, gender, and race). The crude and fully-adjusted associations between ZIP Code-level SES and CRCS adherence were reported through odds ratios (ORs) and 95% confidence intervals (CIs). Further, the robust SES measures for CRCS adherence were identified according to the strength of their associations with CRCS adherence outcomes (i.e., magnitude of OR).

Results

Characteristics of sample

Table 3.2 shows the characteristics of the study population. Overall, 71.5% were aged < 65 years old, 48.6% were female, 84.0% were non-Hispanic white, and 30.7% obtained a high school education or less. The majority of the population had health insurance (89.7%), and had a usual source of care (87.8%). The prevalence of stool test, colonoscopy, and overall CRCS adherence was 10.3%, 64.4%, and 70.7%, respectively.

Associations between SES single measures and CRCS adherence

Table 3.3 shows the crude and adjusted associations between SES single measures and CRCS adherence. None of the 19 SES single measures were significantly associated with stool test adherence in both crude and adjusted models, with the exception of the percentage of people living below the poverty line, which had a significant positive association with stool test adherence (Q4 vs. Q1: crude OR: 1.33, 95% CI: 1.01-1.75; adjusted OR: 1.42, 95% CI: 1.08-1.88). For colonoscopy adherence, the majority of the results from bivariate analyses were significant. Specifically, seventeen SES single measures were significantly associated with colonoscopy adherence in the crude models. Compared with individuals living in the least deprived areas (Q1), those living in more deprived areas were less likely to adhere to colonoscopy (e.g., working class: Q3 OR: 0.78, 95% CI: 0.65-0.94, Q4 OR: 0.64, 95% CI: 0.53-

0.77; Q5 OR: 0.55, 95% CI: 0.45-0.68). Furthermore, indicators such as percentage of working class, percentage of white collar occupations, per capita income, and all three education indicators (percentage of < high school, ≥ high school, and≥ college education) had relatively strong associations. However, few of the associations remained statistically significant after adjustment for individual-level characteristics. Results for overall CRCS adherence were similar to colonoscopy adherence.

Associations between SES composite measures and CRCS adherence

Table 3.4 shows the crude and adjusted association between SES composite measures and CRCS adherence. None of the composite measures were significantly associated with stool test adherence in both crude and adjusted models. All five composite measures had negative bivariate associations with CRCS adherence, i.e., residents from more deprived areas were less likely to adhere to colonoscopy (e.g., index of local economic resources: Q4 vs. Q1 OR=0.75, 95% CI: 0.62-0.90). The SEP index (Q5 vs. Q1 OR=0.52, 95% CI: 0.43-0.63) and area SES summary score (Q5 vs. Q1 OR=0.50, 95% CI: 0.42-0.61) had relatively strong associations with colonoscopy adherence in the crude analysis. However, few of the associations were statistically significant after adjustment for individual-level characteristics. Results for the outcome of overall CRCS adherence were similar to colonoscopy adherence.

Discussion

The present study involved the use of a comprehensive list of area-level SES measures to evaluate the association between area-level SES and CRCS adherence. We found that the percentage of people living below the poverty line was the only measure that showed a significantly positive association with stool test adherence in both crude and adjusted models. The majority of area-level SES measures were negatively associated with colonoscopy and overall adherence in the crude analysis, where single SES measures such as per capita income, percentage of working class and white collar occupations, and three education indicators, as well as composite SES measures such as SEP index and area SES summary score, had comparatively strong associations. However, few of the associations were statistically significant in the adjusted models. Additionally, we observed a high percentage of people < 65 in the study population. This population tended to be less likely to adhere to CRCS than those aged 65 or over;[10, 17, 18, 26, 36] therefore, more CRCS intervention attention needs to be paid to this population.

Area-level SES and CRCS adherence

For stool test adherence, we found its association with area-level deprivation was not statistically significant in general. This is consistent with findings suggested by a previous study.[46] However, some other studies reported negative associations.[23, 25, 45] These discrepancies could be due to different geographic scales employed for area SES measurement. Unexpectedly, the percentage of people living below the poverty line was the only measure that was positively associated with stool test adherence. This could be due to CRCS programs in WA, which are available to residents with low income.[145, 146] Alternatively, residents in low SES communities may prefer stool tests over other CRCS tests,[147] due to the fact that stool tests are relatively cheap and flexible (i.e., does not require taking time off from work).

Our findings of negative associations of area-level deprivation on colonoscopy and overall adherence in crude analysis are consistent with findings reported by previous studies.[44, 46, 49, 50, 112, 148] Additionally, similar to some of the previous studies, [22, 23, 25, 42, 50, 112] we observed that the relationship between area-level SES and colonoscopy/overall adherence was generally not statistically significant with adjustment for individual-level factors. This suggests that individual-level factors may play a greater role than area-level factors when it comes to personal health decisions, or individual-level factors may possibly play mediation roles in the pathway between area-level SES and colonoscopy/overall adherence,[46, 50] which deserves future investigation. The non-significant adjusted results could also be explained by unmeasured confounders such as colonoscopy accessibility.[149] Nonetheless, our bivariate findings underscore the need for CRCS interventions in deprived areas, as residents living in low SES areas were less likely to adhere to CRCS. Further, building up the economic and social resources in the deprived communities may possibly contribute to an increased use of preventive services.

Choosing appropriate area-level SES indicators

Choosing appropriate area-level SES measures to investigate social inequalities is a challenge, as SES is complex and multidimensional.[60, 96] Previous CRCS research may lack the power to identify appropriate SES measures for CRCS because limited SES measures were studied.[22, 23, 25, 36, 42, 44-50, 67] The present study evaluated the association between area-level SES and CRCS adherence among a comprehensive list of SES measures. Although few of the adjusted associations were significant, our results from the crude analysis could also provide some useful evidence with regard to choice of appropriate area-level SES indicators for investigation on socioeconomic disparities in CRCS.

In previous studies, the indicator “percentage of people living below the poverty line” was most commonly examined.[22, 23, 25, 36, 42, 44-50] Only a few studies have investigated area-level education,[23, 25, 36, 42] or per capita income,[22] or percentage of white collar occupations.[36] To the best of our knowledge, no previous CRCS study has examined percentage of working class occupations. Our crude analysis on colonoscopy and overall adherence showed that single SES measures such as per capita income, percentage of working class and white collar, and all three education measures (i.e., percentage of < high school, ≥ high school, and ≥ college education) consistently detected a sharper socioeconomic gradient than percentage below the poverty line did. Furthermore, our Pearson correlation results showed that the identified six robust SES single measures had high correlations (Pearson correlation ≥ 0.6) with ≥ 11 other SES measures respectively, whereas the below-poverty indicator was strongly correlated with only five other SES measures (See details in *Appendix 7*).

The bivariate results, along with correlation results, highlight the importance of examining area-level SES from the dimensions of per capita income, percentage of working class and white collar occupations, and education in CRCS research, in addition to percentage below poverty. This is particularly useful for the CRCS research where data do not have much individual SES information, and area-level SES intends to approximate the individual SES (like Dailey et al.[35] did). The aforementioned SES single measures could be good options for such CRCS research. Further, composite measures such as SEP index and area SES summary score can be considered, since they also had relatively strong bivariate associations with colonoscopy and overall adherence. Finally, another important implication of our results is that the identified robust area-level SES measures, i.e., per capita income, percentage of working class and white collar occupations, and education measures (percentage of < high school, ≥ high school, and ≥ college education) as well as SEP index and area SES summary score can be used to identify geographic targets of CRCS interventions, and facilitate allocation of screening resources locally.[45]

Our study findings should be interpreted with consideration of several important limitations. First, the causality of associations between area-level SES and CRCS adherence cannot be inferred since the current study was a cross-sectional study. Second, due to lack of relevant information, individuals at increased risk of CRC cannot be excluded from study. This may introduce misclassification of screening adherence among the increased risk population because this population commonly needs to be screened more frequently than the average-risk population.[150] Third, CRCS information relying on self-reporting may introduce recall bias. However, previous evidence has shown that self-reported CRCS were similar to medical record data.[151] Fourth, the cut-offs of SEP1 and SEP2 variables were based on a seminal SES study conducted in other states.[61] It is possible that these cut-offs may not be applicable in the WA state. Fifth, due to lack of longitude and latitude information of individual residence, we were not able to assess possible spatial correlations among individual participants. If the spatial correlations exist, the study results may be biased. Next, the study findings have limited generalizability to other U.S. states which have different characteristics than WA.

Another important potential limitation of this study is that ZIP Code was used as a proxy of neighborhood, which may not reflect meaningful neighborhoods or communities. However, using census data may have several advantages, such as the systematic collection of data for the population and good accessibility. Census data is now widely used in area-level SES research.[22, 23, 25, 36, 42, 44-50, 67] Furthermore, some scholars suggest using smaller geographic scales, such as the census tract and block group, to better represent the heterogeneity in SES.[50, 61] However, ZIP Code is the smallest geographic scale available in WA BRFSS. Examining ZIP Code level may be more feasible in some circumstances because using a smaller geographic scale (e.g., census tract and block group) requires extensive efforts in collecting full addresses which sometimes people may refuse to provide, and additional efforts are needed to geocode health data, which could introduce geocoding bias.

In summary, our study found that the majority of area-level SES measures showed a negative bivariate relationship between area-level deprivation and colonoscopy/overall CRCS adherence. CRCS promotions and interventions should target highly deprived areas. Several SES measures at the ZIP Code level (i.e., per capita income, percentage of working class and white collar, percentage < high school, ≥ high school, ≥ college education, SEP index and area SES summary score) can be candidates for describing social inequalities in colonoscopy and overall CRCS adherence, and for detecting socioeconomically disadvantaged areas that are in need of CRCS interventions. Further, improving the economic and social environment in the deprived community may help to increase uptake of CRCS, and further lead to reduction of socioeconomic disparities in CRC. Future studies analyzing national data are warranted to ensure the generalizability of the study results. Also, studies using smaller geographic areas of aggregation such as the census tract may be needed in order to better measure area-level SES.

Table 3.2 Characteristics of the Eligible Respondents from 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711)

Characteristics	n[a]	Weighted %
<u>**Individual-level Characteristics**</u>		
Age		
50-54	2,306	27.5
55-59	2,627	23.2
60-64	2,852	20.8
65-69	2,684	15.9
70-75	2,242	12.6
Gender		
Female	7,334	51.4
Male	5,377	48.6
Race/Ethnicity		
Non-Hispanic white	11,412	84.0
Non-Hispanic black	166	2.7
Other non-Hispanic	667	8.9
Hispanic	318	4.4
Education		
< High school	447	7.3
High school/GED	2,686	23.4
Some college/Technical school	4,014	37.6
College graduate	5,549	31.7
Household income		
< $15,000	965	7.7
$15,000-$34,999	2,484	20.5
$35,000-$49,999	1,808	15.1
$50,000-$74,999	2,271	19.9
≥ $75,000	3,883	36.8
Employed for wages		
Yes	4,562	42.4
Marital status		
Not married	5,074	35.1
Married	7,601	64.9
Have health insurance?		
Yes	11,728	89.7

(To be continued)

[a] Unweighted sample size, may not sum to total due to missing.
CRCS: Colorectal cancer screening

Table 3.2 Characteristics of the Eligible Respondents from 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Characteristics	n[a]	Weighted %
Smoking status		
Current smoker	1,615	14.6
Previous smoker	4,637	35.9
Never smoked	6,407	49.5
Have a usual source of care		
Yes	11,390	87.8
Delayed health care due to cost		
Yes	1,249	12.1
Stool test status[b]		
Adherent	1,395	10.3
Colonoscopy status[c]		
Adherent	8,173	64.4
Overall CRCS status[d]		
Adherent	8,966	70.7

[a] Unweighted sample size, may not sum to total due to missing.
[b] Adherent to stool test = self-reported having a stool test in last year
[c] Adherent to colonoscopy = self-reported having a colonoscopy in last 10 years
[d] Adherent to overall CRCS = self-reported having a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years
CRCS: Colorectal cancer screening

Table 3.3 Associations between Area-level SES Single Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711)

Area-level SES Single Measures[a] (ref: Q1 least deprived)		Adherence to CRCS Recommendations OR (95% CI)[b]					
		Stool Test in Last Year		Colonoscopy in Last 10 Years		Adherent to Overall CRCS[c]	
		Crude	Adjusted[d]	Crude	Adjusted[e]	Crude	Adjusted[e]
<u>Occupation/employment</u>							
Working class % of people in working class occupation	Q2	1.00 (0.76,1.31)	1.04 (0.79,1.37)	0.83 (0.69,1.01)	0.93 (0.75,1.15)	0.89 (0.72,1.10)	1.01 (0.80,1.28)
	Q3	1.13 (0.87,1.46)	1.20 (0.92,1.57)	**0.78 (0.65,0.94)**	0.99 (0.80,1.23)	**0.77 (0.63,0.95)**	0.99 (0.78,1.25)
	Q4	1.00 (0.77,1.29)	1.07 (0.82,1.39)	**0.64 (0.53,0.77)**	0.86 (0.70,1.06)	**0.64 (0.52,0.78)**	0.87 (0.69,1.09)
	Q5	0.99 (0.74,1.32)	1.12 (0.83,1.51)	**0.55 (0.45,0.68)**	0.88 (0.69,1.11)	**0.57 (0.46,0.72)**	0.98 (0.76,1.27)
Unemployment % of unemployed persons aged ≥ 16	Q2	0.95 (0.69,1.30)	0.96 (0.70,1.33)	0.93 (0.74,1.17)	1.00 (0.78,1.29)	0.93 (0.73,1.20)	0.99 (0.75,1.30)
	Q3	1.01 (0.75,1.38)	1.08 (0.79,1.47)	**0.77 (0.62,0.96)**	0.92 (0.72,1.18)	0.79 (0.62,1.01)	0.95 (0.72,1.25)
	Q4	1.04 (0.76,1.42)	1.11 (0.81,1.52)	**0.71 (0.57,0.89)**	1.01 (0.79,1.30)	**0.70 (0.55,0.90)**	1.00 (0.76,1.32)
	Q5	0.97 (0.68,1.39)	1.06 (0.73,1.52)	**0.65 (0.50,0.83)**	1.10 (0.83,1.46)	**0.64 (0.49,0.85)**	1.11 (0.81,1.51)
White collar % of people in white-collar employment	Q2	1.03 (0.80,1.32)	1.07 (0.83,1.39)	**0.83 (0.69,0.99)**	0.99 (0.80,1.21)	**0.82 (0.67,1.00)**	0.97 (0.77,1.22)
	Q3	0.98 (0.77,1.25)	1.02 (0.79,1.31)	**0.75 (0.63,0.90)**	0.95 (0.78,1.17)	**0.78 (0.64,0.94)**	1.01 (0.81,1.26)
	Q4	0.85 (0.66,1.10)	0.92 (0.71,1.20)	**0.62 (0.52,0.74)**	0.89 (0.73,1.10)	**0.60 (0.49,0.73)**	0.86 (0.69,1.08)
	Q5	0.87 (0.64,1.18)	0.99 (0.72,1.36)	**0.54 (0.44,0.67)**	0.96 (0.75,1.23)	**0.55 (0.44,0.69)**	1.03 (0.79,1.35)

(To be continued)

[a] Categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes
[b] OR and 95% CI are bold if the estimates were significant at α=0.05
[c] Adherent to overall CRCS = self-reported having a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years
[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care
[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.3 Associations between Area-level SES Single Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Area-level SES Single Measures[a] (ref: Q1 least deprived)		Adherence to CRCS Recommendations OR (95% CI)[b]					
		Stool Test in Last Year		Colonoscopy in Last 10 Years		Adherent to Overall CRCS[c]	
		Crude	Adjusted[d]	Crude	Adjusted[e]	Crude	Adjusted[e]
<u>**Income**</u>							
Median household income ($)	Q2	0.91 (0.72,1.15)	0.93 (0.74,1.17)	**0.84 (0.71,0.99)**	0.96 (0.80,1.16)	0.85 (0.71,1.02)	0.97 (0.79,1.19)
	Q3	1.00 (0.78,1.27)	1.03 (0.81,1.32)	**0.81 (0.68,0.96)**	1.09 (0.89,1.33)	**0.78 (0.64,0.94)**	1.05 (0.85,1.31)
	Q4	0.91 (0.70,1.19)	0.97 (0.74,1.28)	**0.63 (0.52,0.76)**	0.93 (0.75,1.15)	**0.62 (0.51,0.76)**	0.95 (0.75,1.20)
	Q5	0.92 (0.68,1.25)	0.95 (0.70,1.30)	**0.61 (0.49,0.75)**	0.91 (0.72,1.16)	**0.58 (0.46,0.72)**	0.84 (0.65,1.09)
Low income % of households with income < 50% of median income	Q2	1.03 (0.81,1.31)	1.04 (0.82,1.33)	0.90 (0.76,1.08)	1.00 (0.82,1.21)	0.90 (0.74,1.09)	0.97 (0.79,1.20)
	Q3	1.03 (0.80,1.33)	1.09 (0.85,1.41)	**0.79 (0.66,0.95)**	1.02 (0.83,1.25)	**0.77 (0.63,0.94)**	0.97 (0.78,1.22)
	Q4	1.00 (0.77,1.29)	1.01 (0.78,1.32)	**0.71 (0.59,0.86)**	0.99 (0.81,1.22)	**0.71 (0.58,0.87)**	1.00 (0.80,1.26)
	Q5	1.07 (0.80,1.45)	1.16 (0.85,1.57)	**0.65 (0.52,0.80)**	0.91 (0.72,1.15)	**0.62 (0.49,0.78)**	0.83 (0.64,1.07)
High income % of households with income > 400% median income	Q2	1.13 (0.90,1.43)	1.14 (0.90,1.45)	0.84 (0.71,0.99)	0.98 (0.81,1.18)	0.86 (0.71,1.03)	1.01 (0.82,1.25)
	Q3	0.97 (0.77,1.23)	1.04 (0.82,1.32)	**0.66 (0.56,0.78)**	0.87 (0.72,1.04)	**0.65 (0.54,0.78)**	0.87 (0.70,1.07)
	Q4	0.98 (0.76,1.26)	1.07 (0.83,1.39)	**0.62 (0.52,0.74)**	0.98 (0.80,1.20)	**0.59 (0.49,0.72)**	0.94 (0.75,1.18)
	Q5	1.02 (0.64,1.61)	0.99 (0.62,1.60)	0.76 (0.56,1.03)	0.98 (0.69,1.40)	0.74 (0.53,1.02)	0.97 (0.66,1.42)

(To be continued)

[a] Categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes
[b] OR and 95% CI are bold if the estimates were significant at α=0.05
[c] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years
[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care
[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.3 Associations between Area-level SES Single Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Area-level SES Single Measures[a] (ref: Q1 least deprived)		**Adherence to CRCS Recommendations OR (95% CI)**[b]					
		Stool Test in Last Year		**Colonoscopy in Last 10 Years**		**Adherent to Overall CRCS**[c]	
		Crude	**Adjusted**[d]	**Crude**	**Adjusted**[e]	**Crude**	**Adjusted**[e]
<u>**Income**</u>							
Gini coefficient	Q2	0.88 (0.65,1.18)	0.85 (0.63,1.15)	0.89 (0.72,1.11)	0.92 (0.72,1.16)	0.89 (0.70,1.13)	0.91 (0.71,1.18)
	Q3	0.97 (0.73,1.30)	0.97 (0.72,1.29)	**0.80 (0.65,0.99)**	0.85 (0.67,1.07)	0.85 (0.68,1.08)	0.91 (0.70,1.17)
	Q4	1.01 (0.76,1.35)	0.97 (0.72,1.30)	0.99 (0.80,1.22)	1.01 (0.80,1.27)	0.96 (0.76,1.21)	0.97 (0.75,1.25)
	Q5	1.00 (0.73,1.37)	0.96 (0.70,1.32)	0.95 (0.76,1.20)	0.95 (0.74,1.22)	0.97 (0.75,1.25)	0.94 (0.72,1.24)
Per capita income ($)	Q2	1.13 (0.89,1.42)	1.19 (0.94,1.51)	**0.78 (0.66,0.92)**	0.95 (0.78,1.15)	**0.81 (0.68,0.97)**	1.01 (0.82,1.25)
	Q3	1.02 (0.80,1.31)	1.09 (0.84,1.40)	**0.67 (0.56,0.79)**	0.95 (0.78,1.16)	**0.65 (0.54,0.78)**	0.95 (0.76,1.19)
	Q4	1.06 (0.82,1.37)	1.13 (0.87,1.47)	**0.65 (0.55,0.78)**	0.99 (0.80,1.22)	**0.65 (0.54,0.79)**	1.02 (0.81,1.28)
	Q5	0.80 (0.58,1.10)	0.95 (0.68,1.31)	**0.50 (0.41,0.61)**	0.87 (0.68,1.11)	**0.48 (0.38,0.59)**	0.83 (0.64,1.08)
Non-salary income % households with dividend, rental/interest income	Q2	1.11 (0.86,1.42)	1.14 (0.88,1.46)	0.88 (0.74,1.06)	1.02 (0.83,1.25)	**0.89 (0.73,1.09)**	1.02 (0.82,1.28)
	Q3	0.97 (0.75,1.26)	1.04 (0.80,1.35)	**0.70 (0.59,0.84)**	0.92 (0.74,1.13)	**0.70 (0.57,0.85)**	0.92 (0.74,1.16)
	Q4	1.17 (0.90,1.53)	1.27 (0.97,1.66)	**0.70 (0.58,0.85)**	1.02 (0.83,1.27)	**0.70 (0.57,0.86)**	1.07 (0.84,1.36)
	Q5	0.90 (0.67,1.21)	1.03 (0.76,1.40)	**0.59 (0.49,0.73)**	1.01 (0.80,1.28)	**0.58 (0.47,0.73)**	1.03 (0.80,1.33)

(To be continued)

[a] Categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes
[b] OR and 95% CI are bold if the estimates were significant at α=0.05
[c] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years
[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care
[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.3 Associations between Area-level SES Single Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Area-level SES Single Measures[a] (ref: Q1 least deprived)		Adherence to CRCS Recommendations OR (95% CI)[b]					
		Stool Test in Last Year		Colonoscopy in Last 10 Years		Adherent to Overall CRCS[c]	
		Crude	Adjusted[d]	Crude	Adjusted[e]	Crude	Adjusted[e]
Poverty							
Below poverty	Q2	1.26 (0.98,1.62)	**1.29 (1.00,1.67)**	1.03 (0.86,1.22)	1.18 (0.97,1.44)	1.13 (0.93,1.37)	**1.32 (1.06,1.64)**
% of people	Q3	1.19 (0.91,1.55)	1.22 (0.93,1.60)	0.89 (0.73,1.07)	1.11 (0.89,1.37)	0.93 (0.76,1.15)	1.17 (0.93,1.48)
living below federal poverty	Q4	**1.33 (1.01,1.75)**	**1.42 (1.08,1.88)**	**0.69 (0.57,0.84)**	1.04 (0.83,1.29)	**0.70 (0.57,0.86)**	1.08 (0.85,1.37)
line	Q5	1.03 (0.76,1.39)	1.13 (0.83,1.54)	**0.59 (0.48,0.72)**	0.95 (0.75,1.20)	**0.58 (0.47,0.73)**	0.96 (0.74,1.23)
Female-headed	Q2	0.93 (0.62,1.39)	0.92 (0.61,1.39)	1.16 (0.88,1.52)	1.24 (0.91,1.68)	1.04 (0.77,1.40)	1.06 (0.76,1.49)
households	Q3	0.96 (0.65,1.42)	0.98 (0.66,1.45)	1.20 (0.92,1.57)	1.21 (0.90,1.64)	1.10 (0.82,1.47)	1.07 (0.77,1.49)
% of female-headed	Q4	1.27 (0.86,1.86)	1.33 (0.90,1.97)	1.00 (0.77,1.31)	1.17 (0.87,1.58)	0.98 (0.73,1.31)	1.11 (0.80,1.55)
households	Q5	1.12 (0.75,1.66)	1.20 (0.80,1.79)	0.91 (0.70,1.19)	1.24 (0.92,1.68)	0.86 (0.64,1.15)	1.16 (0.83,1.62)
Wealth							
Expensive homes	Q2	0.99 (0.77,1.28)	1.04 (0.80,1.34)	0.93 (0.77,1.12)	1.14 (0.93,1.40)	0.89 (0.73,1.09)	1.10 (0.88,1.38)
% homes worth	Q3	1.10 (0.86,1.40)	1.19 (0.93,1.53)	**0.74 (0.62,0.89)**	0.95 (0.78,1.16)	**0.71 (0.58,0.86)**	0.91 (0.73,1.13)
≥400% median value owned	Q4	1.12 (0.87,1.45)	1.27 (0.98,1.65)	**0.70 (0.58,0.84)**	1.01 (0.83,1.25)	**0.69 (0.57,0.85)**	1.06 (0.84,1.33)
homes	Q5	1.25 (0.88,1.79)	1.24 (0.86,1.80)	**0.80 (0.62,1.03)**	1.11 (0.83,1.49)	**0.75 (0.57,0.99)**	1.06 (0.77,1.46)

(To be continued)

[a] Categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes

[b] OR and 95% CI are bold if the estimates were significant at α=0.05

[c] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years

[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.3 Associations between Area-level SES Single Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Area-level SES Single Measures[a] (ref: Q1 least deprived)		Adherence to CRCS Recommendations OR (95% CI)[b]					
		Stool Test in Last Year		Colonoscopy in Last 10 Years		Adherent to Overall CRCS[c]	
		Crude	Adjusted[d]	Crude	Adjusted[e]	Crude	Adjusted[e]
Wealth							
Median housing value ($)	Q2	1.07 (0.85,1.34)	1.11 (0.88,1.40)	0.87 (0.74,1.02)	1.06 (0.88,1.28)	0.87 (0.73,1.05)	1.08 (0.88,1.33)
	Q3	1.18 (0.93,1.50)	1.27 (1.00,1.61)	**0.79 (0.66,0.93)**	1.03 (0.85,1.26)	**0.79 (0.66,0.96)**	1.06 (0.86,1.32)
	Q4	1.15 (0.88,1.51)	1.20 (0.90,1.58)	**0.65 (0.54,0.79)**	0.92 (0.73,1.14)	**0.68 (0.55,0.84)**	0.95 (0.74,1.21)
	Q5	0.74 (0.52,1.04)	0.85 (0.59,1.21)	**0.58 (0.47,0.73)**	0.96 (0.74,1.24)	**0.53 (0.42,0.67)**	0.87 (0.66,1.16)
Education							
Low education % of people with education < high school	Q2	1.20 (0.92,1.57)	1.24 (0.94,1.62)	0.93 (0.77,1.13)	1.15 (0.93,1.43)	0.96 (0.78,1.18)	1.22 (0.96,1.54)
	Q3	1.13 (0.86,1.48)	1.17 (0.89,1.55)	0.71 (0.59,0.86)	0.88 (0.71,1.09)	0.72 (0.58,0.89)	0.91 (0.72,1.15)
	Q4	1.09 (0.83,1.45)	1.18 (0.88,1.58)	0.70 (0.58,0.85)	1.05 (0.84,1.32)	0.73 (0.58,0.90)	1.14 (0.89,1.46)
	Q5	1.00 (0.75,1.34)	1.16 (0.85,1.57)	0.54 (0.45,0.66)	1.04 (0.82,1.31)	0.54 (0.43,0.67)	1.11 (0.86,1.44)
High education % of people with education ≥ college	Q2	1.06 (0.85,1.34)	1.08 (0.85,1.36)	0.89 (0.75,1.04)	1.05 (0.87,1.27)	0.94 (0.78,1.12)	1.14 (0.93,1.41)
	Q3	1.06 (0.83,1.35)	1.12 (0.88,1.44)	0.71 (0.60,0.84)	0.97 (0.79,1.18)	0.72 (0.59,0.86)	1.03 (0.82,1.28)
	Q4	0.85 (0.65,1.12)	0.93 (0.71,1.22)	0.61 (0.51,0.73)	0.90 (0.73,1.11)	0.58 (0.48,0.71)	0.86 (0.68,1.08)
	Q5	1.10 (0.81,1.50)	1.26 (0.92,1.73)	0.53 (0.43,0.65)	0.97 (0.75,1.25)	0.55 (0.43,0.68)	1.07 (0.81,1.40)

(To be continued)

[a] Categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes
[b] OR and 95% CI are bold if the estimates were significant at α=0.05
[c] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years
[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care
[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.3 Associations between Area-level SES Single Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Area-level SES Single Measures[a] (ref: Q1 least deprived)		**Adherence to CRCS Recommendations OR (95% CI)**[b]					
		Stool Test in Last Year		**Colonoscopy in Last 10 Years**		**Adherent to Overall CRCS**[c]	
		Crude	**Adjusted**[d]	**Crude**	**Adjusted**[e]	**Crude**	**Adjusted**[e]
Education							
High school or higher	Q2	1.20 (0.92,1.57)	1.23 (0.94,1.62)	0.94 (0.78,1.13)	1.16 (0.93,1.43)	0.96 (0.78,1.19)	1.22 (0.96,1.54)
% of people who completed	Q3	1.13 (0.86,1.48)	1.17 (0.89,1.55)	**0.70 (0.58,0.85)**	0.88 (0.71,1.09)	**0.71 (0.58,0.88)**	0.90 (0.71,1.14)
high school	Q4	1.10 (0.83,1.46)	1.18 (0.89,1.58)	**0.70 (0.58,0.86)**	1.06 (0.85,1.33)	**0.73 (0.59,0.90)**	1.14 (0.89,1.47)
	Q5	1.00 (0.75,1.34)	1.16 (0.85,1.57)	**0.54 (0.45,0.66)**	1.04 (0.82,1.31)	**0.54 (0.43,0.67)**	1.12 (0.86,1.44)
Crowding							
Crowded households	Q2	0.97 (0.67,1.41)	1.06 (0.72,1.55)	0.87 (0.67,1.12)	0.95 (0.71,1.27)	0.96 (0.72,1.27)	1.07 (0.78,1.48)
% of households	Q3	1.10 (0.76,1.60)	1.22 (0.83,1.78)	0.85 (0.65,1.10)	1.02 (0.76,1.36)	0.92 (0.70,1.23)	1.11 (0.81,1.53)
with > 1 person	Q4	1.05 (0.72,1.52)	1.16 (0.79,1.70)	**0.69 (0.53,0.89)**	0.88 (0.66,1.19)	**0.71 (0.54,0.95)**	0.93 (0.67,1.28)
per room	Q5	1.01 (0.68,1.50)	1.20 (0.80,1.81)	**0.57 (0.44,0.75)**	0.93 (0.68,1.26)	**0.62 (0.46,0.84)**	1.09 (0.78,1.53)
Housing							
Rented houses	Q2	0.99 (0.73,1.35)	0.99 (0.73,1.36)	1.12 (0.89,1.41)	1.22 (0.95,1.56)	1.08 (0.84,1.39)	1.18 (0.90,1.55)
% of house	Q3	0.79 (0.58,1.06)	0.80 (0.59,1.08)	0.97 (0.78,1.21)	1.07 (0.85,1.36)	0.91 (0.72,1.16)	0.99 (0.77,1.28)
units rented	Q4	1.09 (0.82,1.45)	1.13 (0.84,1.52)	0.98 (0.79,1.21)	1.15 (0.91,1.46)	0.97 (0.77,1.23)	1.16 (0.89,1.50)
	Q5	0.97 (0.73,1.30)	1.00 (0.75,1.35)	0.98 (0.79,1.21)	1.14 (0.90,1.44)	0.94 (0.74,1.19)	1.11 (0.86,1.44)

(To be continued)

[a] Categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes

[b] OR and 95% CI are bold if the estimates were significant at α=0.05

[c] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years

[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.3 Associations between Area-level SES Single Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Area-level SES Single Measures[a] (ref: Q1 least deprived)		**Adherence to CRCS Recommendations OR (95% CI)**[b]					
		Stool Test in Last Year		**Colonoscopy in Last 10 Years**		**Adherent to Overall CRCS**[c]	
		Crude	**Adjusted**[d]	**Crude**	**Adjusted**[e]	**Crude**	**Adjusted**[e]
Housing							
Households	Q2	0.92 (0.69,1.23)	0.95 (0.70,1.27)	1.09 (0.89,1.34)	1.13 (0.90,1.42)	1.07 (0.85,1.35)	1.10 (0.86,1.42)
with no car	Q3	1.14 (0.86,1.51)	1.20 (0.90,1.59)	0.96 (0.79,1.18)	1.08 (0.86,1.35)	0.96 (0.77,1.20)	1.06 (0.83,1.36)
% of households	Q4	0.94 (0.70,1.27)	1.02 (0.75,1.38)	0.87 (0.70,1.07)	1.09 (0.86,1.38)	0.82 (0.65,1.03)	1.03 (0.80,1.34)
with no car	Q5	1.05 (0.75,1.48)	1.18 (0.83,1.67)	**0.70 (0.55,0.89)**	1.01 (0.77,1.33)	**0.69 (0.53,0.89)**	0.99 (0.74,1.34)

[a] Categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes
[b] OR and 95% CI are bold if the estimates were significant at α=0.05
[c] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years
[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care
[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.4 Associations between Area-level SES Composite Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711)

Area-level SES Composite Measures [a] (ref: Q1 least deprived)		Adherence to CRCS Recommendations OR (95% CI)[b]					
		Stool Test in Last Year		Colonoscopy in Last 10 Years		Adherent to Overall CRCS[c]	
		Crude	Adjusted[d]	Crude	Adjusted[e]	Crude	Adjusted[e]
SEP index	Q2	1.24 (0.98,1.58)	1.27 (0.99,1.62)	**0.82 (0.69,0.97)**	0.92 (0.76,1.12)	0.89 (0.74,1.08)	1.01 (0.82,1.26)
	Q3	1.07 (0.83,1.38)	1.14 (0.88,1.47)	**0.74 (0.62,0.88)**	0.96 (0.79,1.18)	**0.75 (0.62,0.91)**	1.00 (0.80,1.24)
	Q4	1.05 (0.80,1.36)	1.12 (0.85,1.46)	**0.59 (0.49,0.71)**	0.87 (0.71,1.08)	**0.56 (0.46,0.68)**	0.83 (0.65,1.04)
	Q5	1.08 (0.81,1.43)	1.23 (0.91,1.65)	**0.52 (0.43,0.63)**	0.93 (0.74,1.17)	**0.54 (0.44,0.66)**	1.01 (0.79,1.30)
Area SES summary score	Q2	1.02 (0.81,1.29)	1.07 (0.84,1.35)	**0.82 (0.70,0.96)**	0.97 (0.81,1.17)	0.85 (0.71,1.01)	1.01 (0.82,1.25)
	Q3	1.13 (0.88,1.45)	1.22 (0.95,1.58)	**0.68 (0.57,0.81)**	0.90 (0.73,1.11)	**0.67 (0.55,0.82)**	0.93 (0.74,1.16)
	Q4	0.93 (0.71,1.21)	1.01 (0.77,1.32)	**0.67 (0.56,0.81)**	1.02 (0.82,1.26)	**0.65 (0.53,0.79)**	1.01 (0.80,1.28)
	Q5	0.90 (0.67,1.21)	1.05 (0.77,1.42)	**0.50 (0.42,0.61)**	0.94 (0.75,1.19)	**0.51 (0.41,0.63)**	0.98 (0.76,1.26)
Index of local economic resources	Q2	0.86 (0.70,1.06)	0.88 (0.71,1.09)	1.01 (0.87,1.18)	1.08 (0.91,1.28)	1.02 (0.86,1.21)	1.11 (0.92,1.34)
	Q3	1.05 (0.82,1.34)	1.07 (0.83,1.37)	0.94 (0.79,1.14)	1.03 (0.84,1.26)	0.94 (0.77,1.15)	1.00 (0.80,1.25)
	Q4	0.97 (0.75,1.26)	0.97 (0.74,1.27)	**0.75 (0.62,0.90)**	0.87 (0.71,1.08)	**0.75 (0.61,0.91)**	0.86 (0.69,1.08)
	Q5	0.86 (0.60,1.24)	0.90 (0.62,1.31)	0.80 (0.63,1.03)	1.24 (0.93,1.64)	**0.73 (0.56,0.95)**	1.12 (0.82,1.53)

(To be continued)

[a] Area-level SES measures (except SEP1 and SEP2) were categorized into quintiles where Q1 stands for the least deprived ZIP Codes, and Q5 stands for the highest deprived ZIP Codes

[b] OR and 95% CI are bold if the estimates were significant at α=0.05

[c] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years

[d] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

[e] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

Table 3.4 Associations between Area-level SES Composite Measures and Individual-level Adherence to Colorectal Cancer Screening, 2012-2013 Washington State Behavioral Risk Factor Surveillance System Data (N= 12,711) *(Continued)*

Area-level SES Composite Measures		**Adherence to CRCS Recommendations OR (95% CI)[a]**					
		Stool Test in Last Year		**Colonoscopy in Last 10 Years**		**Adherent to Overall CRCS[b]**	
		Crude	**Adjusted[c]**	**Crude**	**Adjusted[d]**	**Crude**	**Adjusted[d]**
SEP1[e] (ref: C1)	C2	0.95 (0.30,2.98)	1.08 (0.34,3.41)	0.51 (0.25,1.03)	0.90 (0.39,2.09)	0.49 (0.23,1.05)	0.99 (0.39,2.48)
	C3	1.29 (0.97,1.71)	1.37 (1.02,1.82)	0.94 (0.77,1.14)	1.14 (0.92,1.43)	0.96 (0.77,1.20)	1.21 (0.94,1.55)
	C4	1.20 (0.91,1.59)	1.31 (0.98,1.75)	**0.71 (0.58,0.86)**	0.98 (0.79,1.23)	**0.71 (0.57,0.88)**	1.03 (0.80,1.31)
	C5	1.25 (0.88,1.77)	1.41 (0.98,2.03)	**0.61 (0.47,0.77)**	1.07 (0.81,1.41)	**0.61 (0.47,0.80)**	1.13 (0.83,1.53)
SEP2[e] (ref: C1)	C2	1.29 (0.93,1.78)	1.32 (0.95,1.84)	**0.72 (0.57,0.92)**	0.92 (0.70,1.21)	0.77 (0.59,1.00)	1.04 (0.77,1.42)
	C3	0.95 (0.73,1.24)	1.01 (0.77,1.32)	**0.69 (0.58,0.83)**	0.86 (0.70,1.07)	**0.70 (0.57,0.86)**	0.89 (0.71,1.13)
	C4	0.93 (0.76,1.15)	0.99 (0.81,1.23)	**0.64 (0.55,0.74)**	**0.83 (0.70,0.98)**	**0.63 (0.53,0.73)**	**0.83 (0.69,1.00)**
	C5	0.94 (0.70,1.27)	1.03 (0.76,1.40)	**0.57 (0.47,0.70)**	0.93 (0.74,1.18)	**0.56 (0.44,0.69)**	0.92 (0.71,1.19)

[a] OR and 95% CI are bold if the estimates were significant at α=0.05

[b] Adherent to overall CRCS = Had a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years

[c] Adjusted for age, female, race/ethnicity, education, smoking status, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

[d] Adjusted for age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost, and having a usual source of care

[e] See "*Appendix 4: Cut-offs of area-level SES measures*" for definition for C1-C5

CHAPTER 6: The Association between Physician Composition and Colorectal Cancer Screening Adherence

Abstract

Purpose: Number of gastroenterologists per population was positively associated with colorectal cancer screening (CRCS) adherence, however, how the composition of physician population affects screening adherence is unclear. Investigating this holds important implications for health workforce policies. We evaluated the effect of physician composition on CRCS adherence.

Methods: Three linked U.S. national datasets were used, including 2012 Behavioral Risk Factor Surveillance System, 2013-2014 Area Health Resource File and 2009-2013 American Community Survey. Respondents aged 50-75 with complete information about CRCS and residential county were included (N=194,940). Outcomes were rates of stool test, colonoscopy, and overall CRCS adherence, as defined by national guidelines. The exposure was county-level physician composition, i.e., percentage of primary care physicians (PCPs) or gastroenterologists among physicians involved in CRCS. Weighted multilevel models were performed, controlling for individual- and county-level covariates.

Results: A one-unit increase in the percentage of gastroenterologists among CRCS physicians was associated with a 2.5% increase in the odds of colonoscopy (odds ratio: 1.025, 95% confidence interval: 1.008-1.042) and overall adherence (odds ratio: 1.025, 95% confidence interval: 1.007-1.043) in the rural-metropolitan areas. The association was not significant in the metropolitan and rural areas. People from more deprived counties were less likely to adhere to colonoscopy/overall CRCS compared with those from less deprived counties.

Conclusion: Physician composition impacts CRCS adherence in the rural-metropolitan areas. Increasing the percentage of gastroenterologists to achieve a balance of PCPs and gastroenterologists could benefit the uptake of CRCS. CRCS interventions should also pay attention to geographic characteristics such as area-level socioeconomic status.

Keywords: Colorectal cancer screening · Primary care physician · Gastroenterologist · Physician composition

Introduction

Colorectal cancer (CRC) is the second leading cause of cancer-related death in the U.S.[1] CRC mortality can be reduced by having a regular colorectal cancer screening (CRCS) test such as stool test, sigmoidoscopy, or colonoscopy.[2-8] The U.S. Preventive Services Task Force recommends that adults aged 50-75 years should obtain a stool test every year, sigmoidoscopy every five years, or colonoscopy every ten years.[9] However, in a 2012 CDC report,[10] only 65% of age-eligible (aged 50-75 years) adults were adherent to the guidelines, substantially below the National Colorectal Cancer Roundtable target of 80% by 2018.[12] Multiple factors affect CRCS adherence, including not only individual-level factors such as age, [26, 152] education,[18, 40] and perceived barriers to CRCS,[20, 32] but also area-level factors such as physician composition.[23, 25]

Physician composition describes the mix between primary care physicians and specialists in the physician workforce.[99] Primary care physicians (PCPs) and gastroenterologists (GIs) comprise the majority of the CRCS physician workforce. PCPs are responsible for initiating and overseeing the ordering of CRCS, as well as distributing stool tests. GIs are mainly involved in performing colonoscopies,[153] the most common CRCS test.[10] Since PCPs and GIs have different roles and involvement in CRCS tests, the balance between PCPs and GIs in an area could have important implications for CRCS,[37] especially for the test-specific CRCS adherence.

The importance of physician composition in CRCS has also been suggested by previous studies,[101, 102] which found that an increased proportion of PCPs among physicians at the county level was associated with decreased colorectal cancer incidence and mortality [101] (partially attributable to PCPs' role in promoting CRCS), as well as higher odds of individuals having a usual source of care,[102] which could further increase CRCS adherence.[26, 36, 70] Moreover, the reported associations were independent from the number of physicians available per population, suggesting that physician composition could affect CRCS adherence in addition to the size of physician workforce.

To date, CRCS research has focused primarily on the size of physician workforce,[36-38, 42, 48, 67, 69, 70]and found that an increased number of GIs per population was associated with higher odds of CRCS adherence.[23, 37, 38, 48] A few studies have considered physician composition, suggesting that a higher PCP composition at the county level was negatively associated with the CRCS utilization.[23, 25] These findings are contrary to the results of the aforementioned study, which observed beneficial effects from a higher proportion of PCPs on CRC incidence and mortality,[101] possibly due to increased cancer screening. Therefore, further research is needed to better understand the relation between the physician composition and CRCS.

Additionally, important gaps exist in the previous physician composition studies. First, physician composition was measured by the ratio of PCPs to all physicians.[23, 25] Because not all physicians are involved in CRCS, it may be more appropriate to change the denominator to "CRCS physicians" (i.e. total number of PCPs and GIs). Second, previous studies assessed CRCS adherence given tests completed in a one-year period,[23, 25] which might not fully reflect individuals' CRCS adherence status given national guidelines.[9] Third, while studies have examined how the size of physician supply affects CRCS among the general population, (i.e., number of physicians per population),[37, 67, 70] the effect of physician composition on CRCS among the general population has not been studied. A couple of previous physician composition studies focused on the Medicare population aged 65 years and older.[23, 25] Inclusion of people 50-

75 years is important to understand the implications for all people for whom CRCS is recommended.[9]

Currently, over 82 million people in the U.S. are aged 50-75, representing 27% of the U.S. population.[154] This population is projected to grow in the coming decades,[155] posing challenges to health policy makers and programs in meeting the increasing needs of preventive care for this population. Understanding how physician composition potentially impacts CRCS holds important implications for health resource planning and health workforce policies. Therefore, the objective of this study was to assess the association between county-level physician composition and individual-level CRCS adherence among the U.S. population aged 50-75.

Materials and Methods

Data sources

To address the study objective, three data sources were used in this analysis: 2012 Behavioral Risk Factor Surveillance System (BRFSS) data, 2013-2014 Area Health Resource File (AHRF), and 2009-2013 American Community Survey. BRFSS is a nationwide, state-based, phone survey among the non-institutionalized U.S. population ≥ aged 18, which provides individuals' health service utilization such as CRCS as well as demographic information.[106] AHRF is a comprehensive health resource database that contains count-level physician counts in the U.S.[111] The American Community Survey provides county-level population characteristics and socioeconomic status.[105] County federal information processing standard (FIPS) code was used to link the three datasets. The current study was approved by the Virginia Commonwealth University Institutional Review Board.

Study population

This study included BRFSS respondents 50-75 years of age who provided responses to the CRCS questions, and had complete county of residence information. Given the unique characteristics of Hawaii and Puerto Rico, respondents from these areas were not included in analysis, yielding an analytic sample of 194,940 individuals from 2,227 U.S. counties.

Outcomes

The outcome of interest was individual-level CRCS adherence. Questions assessed CRCS history, including whether the respondent ever had a stool test, and sigmoidoscopy/colonoscopy and when each of the tests was most recently obtained.[106] This information was used to create three CRCS adherence outcomes: stool test adherence was defined as having a stool test within the past year, colonoscopy adherence was defined as having a colonoscopy within past 10 years, and overall CRCS adherence was defined as having stool test, colonoscopy, or flexible sigmoidoscopy in according to guidelines.[9] Based on these criteria, each outcome was dichotomized into adherent and non-adherent categories. Due to limited use, flexible sigmoidoscopy was not assessed individually.

Main Covariate of Interest

The main covariate of interest was the county-level physician composition. The role and involvement of PCPs and GIs in CRCS varies by the CRCS tests;[153, 156] thus to account for their different roles, the operationalization of physician composition as the main exposure variable differed by the specific screening test used as the outcome. For stool test adherence, PCP composition was used, which was defined as the percentage of PCPs among the CRCS physicians at the county level (i.e., the number of PCPs divided by the total number of PCPs and GIs in a county). For colonoscopy and overall CRCS adherence, GI composition was used, which was defined as the percentage of GIs among the CRCS physicians at the county level (i.e., the number of GIs divided by the total number of PCPs and GIs in a county). We did not include PCP composition for colonoscopy and overall adherence because of its high correlation with GI composition. Moreover, PCPs referred to physicians who had an office-based specialty in general internal medicine, family medicine, general practice, and gerontology/obstetrics.[67, 101, 157] GIs referred to physicians who had office-based specialty in gastroenterology. We used the county or county-equivalent level as the geographic scale for two reasons. First, public health is typically organized at the administrative level such as county level.[51] The county level was commonly used in previous physician workforce studies.[23, 25, 42, 48, 67, 69, 70] Second, the AHRF from which physician counts were obtained is a county-based database where the county level is the smallest geographic scale that is available.

Other Covariates

A priori selected covariates at the individual- and county-level were included based on previous studies of CRCS.[10, 25, 36, 37, 67, 69, 70] Individual-level covariates include age (measured in 5-year age groups between 50 and 75), gender, race /ethnicity (non-Hispanic white, non-Hispanic black, other non-Hispanic, and Hispanic), education (< high school graduate, high school graduate, some college/technical school, and college graduate), household income (< $15,000, $15,000-$34,999, $35,000-$49,999, $50,000-$74,999, and ≥ $75,000), marital status (married, not married), health insurance coverage (yes, no), smoking status (previous smoker, current smoker, never smoked), and delayed health care due to cost (yes, no).

County-level covariates included socioeconomic status (SES), percentage of individuals age 50-75 in county population, race/ethnicity composition (i.e., percentage of African American, percentage of Hispanic in the county population), rurality, and total number of PCPs and GIs per 10,000 residents aged 50-75 (as a measure of the size of the CRCS physician workforce).

SES was measured using a socioeconomic position index, which was a summary deprivation measure combining data on median household income, and percentage of working class, unemployment, residents below the U.S. poverty line, less than high school graduate, and owner-occupied homes worth ≥ 400% of the median value of homes.[61] The socioeconomic position index was categorized into quintiles, where quintile 1 (Q1) corresponded to the least deprived counties, and quintile 5 (Q5) corresponded to the most deprived counties. Counties were classified into metropolitan, rural-metropolitan and rural categories [158] based on counties' Index of Relative Rurality (IRR) values [159] and Urban Influence Code (UIC).[160] The IRR was used because it combined four of mostly commonly used factors together (i.e., population size, density, percentage of urban residents, and distance to the closest metropolitan area) to describe the degree of rurality in a continuous way (range from 0-lowest rurality to 1-highest rurality), which overcomes shortcomings in other existing rural-urban measures.[159] Then, the IRR was coupled with UIC (which has good information about accessibility to a metro area) to better measure rural and metropolitan interface.[158] The operational definitions of rurality categories were as follows: (1) metropolitan county: a county had low degree of rurality (i.e., IRR<0.4) and was located within a metro area as indicated by Urban Influence Code; (2) rural-metropolitan county: a county had low degree of rurality and was located adjacent to a metro area, or a county had high degree of rurality (i.e., IRR≥ 0.4) and was located within/adjacent to a metro area; (3) rural county: a county had high degree of rurality and was located remotely from a metro area.

Statistical analysis

Data analysis was performed using SAS.9.4 software (SAS Institute, Inc., Cary, NC, version 9.4). Characteristics of the eligible respondents were described by weighted frequencies and percentages. Characteristics of counties where eligible respondents lived were also described. Multilevel logistic regression models using PROC GLIMMIX, with weights given the probabilistic sampling, were used to assess the association between county-level physician composition and individual-level CRCS adherence. Specifically, the original BRFSS weights were scaled using "Method 2", as described by Pfefferman et al.[142] and Rabe-Hesketh et al.[143] (See *Appendix 5* for methods for scaling weights and *Appendix 8* for the multilevel model).

Rurality was assessed as a potential effect modifier. Covariates were included in the final model if they had a statistically significant association ($\alpha < 0.05$) with the outcome given bivariate analysis or the covariate was a historical confounder (i.e., age, gender, and race). To control for the size of CRCS physician workforce in a county, number of PCPs and GIs per 10,000 residents aged 50-75 was included in the final models regardless of the significance of its bivariate analysis results. For each outcome (i.e., stool test, colonoscopy, and overall CRCS adherence), three models were assessed. Model 1 included the main exposure of interest – physician composition; Model 2 added county-level covariates; and Model 3 included individual- and county-level covariates. The association between physician composition and CRCS adherence was reported using odds ratios (ORs) and 95% confidence intervals (CIs).

Results

Sample characteristics

Table 4.1 depicts the characteristics of eligible respondents. Of 194,940 eligible BRFSS respondents, a majority of the study population was younger than 65 years old (70.3%), non-Hispanic white (74.6%), acquired education more than high school (58.1%), and had health insurance (88.9%). The prevalence of being adherent to stool test, colonoscopy, and overall CRCS were 10.4%, 62.3%, and 67.7%, respectively. Overall, 63.0% of the respondents lived in less deprived counties (i.e., lowest two quintiles).

Table 4.2 shows the characteristics of county of residence among the eligible respondents. Overall, the mean number of CRCS physicians in a county was 24.9 per 10,000 residents aged 50-75. The mean percentages of PCPs and GIs among CRCS physicians in a county was 97.3%, and 1.8%, respectively. Compared with metropolitan counties, the rural-metropolitan and rural counties had lower mean percentages of GI composition (i.e., 3.6 vs. 0.8 and 1.0, respectively).

Multilevel analysis results

Table 4.3 provides the multilevel model estimates of the associations between physician composition and adherence to CRCS stool test. The PCP composition was not significantly associated with stool test adherence in both crude and adjusted models. Compared with residents from the least deprived counties (i.e. socioeconomic position index Q1), people living in more deprived counties were more likely to be adherent to stool test (Q3 OR: 1.110, 95% CI: 1.008-1.223, Q4 OR: 1.118, 95% CI: 1.010, 1.239) as shown in Model 2 adjusted for county-level covariates. The associations were not significant when fully adjusted for individual- and county-level covariates.

Table 4.4 provides the multilevel model estimates of the association between physician composition and adherence to CRCS colonoscopy. Because the residential counties' rurality was an effect modifier for the association, results were stratified by rurality. The GI composition was significantly associated with colonoscopy adherence for people living in rural-metropolitan areas but not for those living in the metropolitan and rural areas. Specifically, each one percentage-point increase in GIs among CRCS physicians at the county level was associated with a 2.5% increase in the odds of being adherent to colonoscopy (crude OR: 1.034, 95% CI: 1.018-1.050; adjusted OR: 1.027, 95% CI: 1.012-1.042; fully adjusted OR: 1.025, 95% CI: 1.008-1.042). Regardless of rurality, people living in more deprived counties were less likely to adhere to colonoscopy (e.g., Q2 OR: 0.876, 95% CI: 0.821-0.936 for metropolitan areas) than those from the least deprived counties (Q1), when adjusting for county-level covariates. Some of these associations persisted when controlling for both individual- and county-level covariates.

Table 4.5 provides the multilevel model estimates of the association between physician composition and adherence to overall CRCS measures. Similar to results of colonoscopy adherence, the GI composition was significantly associated with overall CRCS adherence in the rural-metropolitan areas (Crude OR: 1.032, 95% CI: 1.016-1.049; adjusted OR: 1.025, 95% CI: 1.010-1.041; fully adjusted OR: 1.025, 95% CI: 1.007-1.043), but the metropolitan and rural areas. Regardless of rurality, people living in the more deprived counties were less likely to adhere to overall CRCS (e.g., Q2 OR: 0.863, 95% CI: 0.808-0.921 for metropolitan areas), when adjusting for county-level covariates. Some of the associations were still significant with adjustment for both individual- and county-level covariates.

Discussion

The current study used a nationally representative sample to assess the association between county-level physician composition among CRCS providers and individual-level CRCS adherence. We found that PCP composition did not exert significant effects on stool test adherence; however, GI composition was associated with colonoscopy and overall CRCS adherence in rural-metropolitan areas but not in the metropolitan and rural areas.

County characteristics such as county-level socioeconomic status were significant predictors of CRCS adherence.

Physician composition and CRCS adherence

Over the past several decades, studies have suggested an imbalance between PCPs and specialists in the physician workforce.[99, 161, 162] The imbalanced physician composition could negatively impact health care access [102, 161] and health service efficacy, as well as increase health-related costs.[163, 164] The balance of PCPs and GIs is important for CRCS[37] since CRCS, especially colonoscopy, requires involvement of both PCPs and GIs. Previous studies have studied how the number of PCPs, GIs, and all physicians available to the population could impact CRCS utilization.[36-38, 42, 48, 67, 69, 70] Our study extended the literature by examining how the number of GIs relative to PCPs in the CRCS physician workforce impacts CRCS adherence, while controlling for the total number of GIs and PCPs per population.

The positive association observed between the percentage of GIs among CRCS physicians and colonoscopy adherence is consistent with results suggested by a previous study.[23] That study found an inverse association between the percentage of PCPs among all physicians and colonoscopy use, suggesting that a higher proportion of specialists (the counterparts of PCPs) in the physician workforce could be positively associated with colonoscopy screening. Our study findings further provide direct and specific evidence that the GI composition in the CRCS physician workforce matters to colonoscopy adherence. Interestingly, we found the significant association only in the rural-metropolitan areas, but not in the metropolitan and rural areas. The observed effects could be driven by the possible fact that the current physician capacity is not consistent with patients' test preference in the rural-metropolitan areas. Previous evidence showed that the urban and suburban residents preferred colonoscopy over stool test, and rural residents preferred stool test and colonoscopy equally.[165] In our study the suburban counties had the relative low GI composition. Given suburban residents' preference of colonoscopy but generally having limited GI capacity in the suburban area, it is reasonable to observe that individuals from higher GI composition counties had higher colonoscopy adherence compared to those from low GI composition counties. However, in the metropolitan and rural areas, maybe because the current level of physician capacity was relatively comparable to patients' test preference, no significant effect of GI composition was found.

For stool test adherence, previous studies reported a negative association between county-level PCP composition and stool test adherence.[23, 25] However, we did not observe such significant association. The discrepancies could be due to methodological differences. For instance, previous studies focused on the Medicare population, while our study population had varied health insurance status and broader age ranges. Also, for measurement of PCP composition, previous studies employed the ratio of PCPs to all physicians to account for the balance of PCPs and specialists. Our study refined this measure by changing the denominator into CRCS physicians (i.e., total number of PCPs and GIs) because PCPs and GIs are primarily involved in CRCS services. Nevertheless, the results of our study are reasonable given the fact that only a small proportion of people (about 10% in our sample) chose stool test for their CRCS, and the majority of the CRCS physicians in a county were PCPs (97% in our data). Therefore, the current level of representativeness of PCPs in the CRCS physician population may be sufficient to provide the stool test service.

Our study results concerning physician composition have potentially important public health implications. In light of calling for more PCPs[166-168] and more GIs[169] to meet the population demand of preventive care, our data suggest that achieving a functionally desirable mix of PCPs and specialists[162] (i.e., GIs) in the physician workforce is important to CRCS adherence, especially in rural-metropolitan areas. Specifically, while the increased number of GIs per served population was associated with higher CRCS rates [23, 37, 38, 48], our study results further show that the increased proportion of GIs in the CRCS physician workforce could give an additional boost in colonoscopy adherence. Moreover, given the previous evidence that over 30% of the population prefer stool test for their CRCS[165, 170] and the test preference varies geographically,[165] the population test preference may also be considered for future physician composition planning.

Area-level SES and CRCS adherence

In the current study, we found that county-level deprivation was positively associated with stool test adherence, which is in accordance with evidence suggested by a previous study [46], although some other studies reported a negative association.[23, 25] The observed positive effects may be due to the CRCS promotion targeting low SES population.[47] Meanwhile, we found that area-level deprivation was negatively associated with colonoscopy adherence, which is consistent with the results from previous studies.[44, 46, 49] Limited access to colonoscopy in low SES areas could partially explain this association. Alternatively, test preference may also drive the observed differential effects of deprivation on stool test and colonoscopy adherence. A study by DeBourcy et al. showed that residents from low SES neighborhoods were more likely to prefer stool test over colonoscopy,[147] which could be due to the fact that stool test seems more affordable and flexible (e.g.,, no need to take time off from work) to the low SES people. Despite the differential effects, we found individuals from more deprived counties were less likely to adhere to overall CRCS, suggesting that the design of CRCS interventions and programs should pay more attention in low SES areas to address the area specific preferences and demands.

The study findings should be interpreted in consideration of several limitations. First, this study was a cross-sectional study; thus temporality between physician composition among CRCS providers and CRCS adherence cannot be inferred. Second, the CRCS information was self-reported, and may be subject to recall bias. However, CRCS based on self-report has been found to be similar to medical record data.[151] Third, due to lack of information, individuals who were at increased risk of CRC cannot be excluded from analysis. Misclassification of screening adherence may exist for the increased risk population as they may need to screen more frequently than the average-risk population.[150] Lastly, potential spatial correlations among individual participants were not assessed due to that the longitude and latitude individual residence were not available. If the spatial correlations exist, the study results may be biased.

In summary, the results from our study suggest that physician composition plays an important role in CRCS adherence; and sufficient number of GI specialists relative to PCP in the physician workforce directly impacts the colonoscopy adherence in the rural- metropolitan areas. The study findings may be particularly relevant in underserved geographic areas, where access to colonoscopy is more limited. Health workforce policies that aim to achieve an appropriate mix of PCPs and GIs in the physician population could help increase the CRCS rate. Future interventions to improve CRCS adherence should be designed targeting the underserved geographic regions.

Table 4.1 Characteristics of the Eligible Respondents from 2012 U.S. Behavioral Risk Factor Surveillance System (N=194,940)

Characteristics	All (N= 194,940)		Metropolitan (n=132,204)		Rural-Metropolitan (n=41,747)		Rural (n=20,989)	
	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]
Individual-level characteristics								
Age*								
50-54	38,306	27.5	26,837	27.9	7,598	25.6	3,871	25.9
55-59	41,217	21.8	28,019	21.9	8,684	21.5	4,514	21.9
60-64	42,551	21.0	28,764	21.0	9,150	21.1	4,637	21.4
65-69	38,049	15.7	25,553	15.4	8,395	16.9	4,101	15.8
70-75	34,817	14.0	23,031	13.8	7,920	14.9	3,866	15.0
Gender								
Female	117,285	52.5	79,560	52.6	25,136	52.2	12,589	51.6
Male	77,655	47.5	52,644	47.4	16,611	47.8	8,400	48.4
Race/Ethnicity*								
Non-Hispanic white	161,091	74.6	106,585	71.6	36,088	85.8	18,418	86.9
Non-Hispanic black	16,608	10.5	130,36	11.4	2,655	7.1	917	5.3
Other non-Hispanic	7,332	5.7	4,925	6.3	1,647	3.7	760	3.8
Hispanic	7,849	9.2	6,203	10.7	946	3.4	700	4.0
Education*								
< High school	14,463	12.6	8,613	11.8	3,949	15.4	1,901	15.0
High school/GED	57,054	29.3	34,771	26.9	15,176	38.9	7,107	35.9
Some college /Technical school	52,856	30.5	35,936	31.0	11,136	28.7	5,784	29.5
College graduate	70,290	27.6	52,692	30.3	11,434	17.0	6,164	19.6
Household income*								
< $15,000	19,055	10.6	11,809	9..9	4,798	13.0	2,448	13.3
$15,000-$34,999	47,480	26.0	29,640	24.3	12,034	32.7	5,806	31.8
$35,000-$49,999	26,457	15.3	17,286	14.9	6,053	16.8	3,118	17.2
$50,000-$74,999	29,164	16.9	19,946	16.8	6,076	17.5	3,142	17.1
≥ $75,000	49,888	31.2	38,142	34.1	7,686	20.0	4,060	20.6
Employed for wages*								
Yes	71,968	39.7	50,788	40.9	13,729	35.0	7,451	36.0

(To be continued)

*Significantly different at α=0.05 among metropolitan, rural-metropolitan, and rural groups based on χ^2 tests

[a] Unweighted sample size may not sum to total due to missing

[b] Weighted percentages given the probabilistic sampling in BRFSS data

CRCS: Colorectal cancer screening

Table 4.1 Characteristics of the Eligible Respondents from 2012 U.S. Behavioral Risk Factor Surveillance System (N=194,940) *(Continued)*

Characteristics	All (N= 194,940)		Metropolitan (n=132,204)		Rural-Metropolitan (n=41,747)		Rural (n=20,989)	
	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]
Individual-level characteristics								
Marital status*								
Married	111,848	63.4	73,922	62.8	25,113	65.7	12,813	66.6
Have health insurance?*								
Yes	178,141	88.9	121,594	89.2	37,596	87.6	18,951	88.6
Smoking status*								
Current smoker	31,235	17.1	20,288	16.1	7,381	21.1	3,566	20.6
Previous smoker	67,807	34.4	46,374	34.4	14,373	34.6	7,060	33.8
Never smoked	95,001	48.5	64,951	49.5	19,775	44.3	10,275	45.6
Delayed health care due to cost*								
Yes	20,627	12.7	13,401	12.4	4,903	14.0	2,323	13.1
Stool test[c]*								
Adherent	18,922	10.4	13,321	10.9	3,706	8.7	1,895	8.7
Colonoscopy[d]*								
Adherent	124,585	62.3	86,731	63.2	25,578	59.4	12,276	57.4
Overall CRCS[e]*								
Adherent	133,445	67.7	92,991	68.8	27,310	64.2	13,144	62.3
County-level characteristics								
Socioeconomic position index*								
Q1: least deprived	78,957	39.1	66,300	46.5	7,853	10.6	4,804	12.6
Q2	46,262	23.9	32,201	25.4	9,436	18.6	4,625	16.2
Q3	30,076	17.4	18,599	15.9	7,138	23.0	4,339	23.6
Q4	21,118	11.4	9,950	8.0	7,828	24.1	3,340	23.8
Q5: most deprived	18,527	8.3	5,154	4.2	9,492	23.7	3,881	23.8

*Significantly different at α=0.05 among metropolitan, rural-metropolitan, and rural groups based on χ^2 tests

[a] Unweighted sample size may not sum to total due to missing

[b] Weighted percentages given the probabilistic sampling in BRFSS data

[c] Adherent to stool test = self-reported having a stool test in last year

[d] Adherent to colonoscopy = self-reported having a colonoscopy in last 10 years

[e] Adherent to overall CRCS = self-reported having a stool test in last year, flexible sigmoidoscopy in last 5 years, or colonoscopy in last 10 years

CRCS: Colorectal cancer screening

Table 4.2 Characteristics of County of Residence among the Eligible Respondents[a]

County-level Characteristics	All (N=2,227)		Metropolitan (n=780)		Rural-Metropolitan (n=1048)		Rural (n=399)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age distribution								
Percent of age 50-75 among whole population*	29.7	4.4	27.5	4.1	30.9	3.7	31.0	5.0
Race composition								
Percent of African American*	9.9	14.0	11.4	12.8	9.6	14.5	7.7	14.7
Percent of Hispanic*	8.4	12.4	11.0	13.2	6.6	11.1	7.8	12.9
Physician size								
Number of PCPs and GIs per 10,000 residents aged 50-75*	24.9	14.8	32.3	16.4	19.2	11.5	25.2	12.7
Physician composition								
Percent of PCP among CRCS physicians[b]*	97.3	9.6	96.2	5.4	97.6	12.4	98.5	7.4
Percent of GI among CRCS physicians[b]*	1.8	2.7	3.6	2.4	0.8	2.3	1.0	2.4

[*] Significantly different at α=0.05 among metropolitan, rural-metropolitan, and rural counties based on ANOVA tests

[a] Analysis were performed among N=2,227 counties where 194,940 individuals lived

[b] Not sum to 100 percent because 20 counties (2 metropolitan counties, 16 rural-metropolitan county, and 2 rural county) had zero percent of PCP and zero percent of GI among CRCS physicians due to zero counts for PCPs and GIs in these counties

CRCS: Colorectal cancer screening; PCP: Primary care physicians; GI: Gastroenterologist; SD: Standard deviation

Table 4.3 Associations between Physician Composition and Adherence to CRCS Stool Test (N= 194,940)

	Adherence to Stool Test OR (95% CI)[a]		
	Model 1[b]	**Model 2[c]**	**Model 3[d]**
PCP composition			
% of PCP among CRCS physicians	0.996 (0.992,1.001)	0.996 (0.992,1.001)	0.997 (0.992,1.001)
Other county characteristics			
Number of CRCS physicians per 10,000 residents aged 50-75	–	1.000 (0.998,1.002)	1.000 (0.997,1.002)
Socioeconomic position index[e] (ref:Q1: least deprived)			
Q2	–	1.012 (0.924,1.108)	1.010 (0.918,1.112)
Q3	–	**1.110 (1.008,1.223)**	1.108 (1.000,1.227)
Q4	–	**1.118 (1.010,1.239)**	1.100 (0.996,1.237)
Q5: most deprived	–	1.088 (0.969,1.221)	1.083 (0.956,1.225)
% of Hispanic	–	**1.003 (1.000,1.005)**	**1.003 (1.001,1.006)**
% of Non-Hispanic African American	–	**1.002 (1.000,1.005)**	1.000 (0.997,1.003)

[a] "–" means covariates were not included in the model. Estimates were bold if significant at α=0.05

[b] Model 1: Physician composition only

[c] Model 2: Physician composition + other county-level characteristics

[d] Model 3: Physician composition + other county-level characteristics + individual-level characteristics (i.e., age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost)

[e] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived counties, and Q5 stands for quintile 5 the most deprived counties

CRCS: Colorectal cancer screening; PCP: Primary care physicians; OR: Odds ratio; 95% CI: 95% Confidence interval

Table 4.4 Associations between Physician Composition and Adherence to CRCS Colonoscopy by Rurality of County of Residence (N= 194,940)

	Adherence to Colonoscopy OR (95% CI)[a]		
	Metropolitan		
	Model 1[b]	**Model 2[c]**	**Model 3[d]**
GI composition			
% of GI among CRCS physicians	1.007 (0.994, 1.020)	1.003 (0.991,1.015)	0.998 (0.985,1.011)
County covariates			
Number of CRCS physicians per 10,000 residents aged 50-75	–	1.002 (1.000,1.004)	1.001 (0.999,1.003)
Socioeconomic position index[e] (ref:Q1: least deprived)			
Q2	–	**0.876 (0.821,0.936)**	0.985 (0.918,1.058)
Q3	–	**0.830 (0.770,0.894)**	0.954 (0.878,1.035)
Q4	–	**0.729 (0.668,0.796)**	**0.870 (0.789,0.958)**
Q5: most deprived	–	**0.786 (0.685,0.902)**	0.975 (0.838,1.134)
% of Hispanic	–	**0.992 (0.990,0.994)**	**0.995 (0.992,0.997)**
% of age 50-75	–	–	–
% of Non-Hispanic African American	–	–	–

(To be continued)

[a] "–" means covariates were not included in the model. Estimates were bold if significant at α=0.05

[b] Model 1: Physician composition only

[c] Model 2: Physician composition + other county-level characteristics

[d] Model 3: Physician composition + other county-level characteristics + individual-level characteristics (i.e., age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost)

[e] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived counties, and Q5 stands for quintile 5 the most deprived counties

CRCS: Colorectal cancer screening; GI: Gastroenterologist; OR: Odds ratio; 95% CI: 95% Confidence interval

Table 4.4 Associations between Physician Composition and Adherence to CRCS Colonoscopy by Rurality of County of Residence (N= 194,940) *(Continued)*

	Adherence to Colonoscopy OR (95% CI)[a]		
	Rural-Metropolitan		
	Model 1[b]	**Model 2[c]**	**Model 3[d]**
GI composition			
% of GI among CRCS physicians	**1.034 (1.018, 1.050)**	**1.027 (1.012,1.042)**	**1.025 (1.008,1.042)**
County covariates			
Number of CRCS physicians per 10,000 residents aged 50-75	–	**1.004 (1.001,1.007)**	**1.004 (1.001,1.008)**
Socioeconomic position index[e] (ref:Q1: least deprived)			
Q2	–	**0.836 (0.738,0.948)**	0.912 (0.795,1.046)
Q3	–	**0.783 (0.691,0.887)**	0.874 (0.762,1.003)
Q4	–	**0.723 (0.639,0.817)**	**0.868 (0.757,0.995)**
Q5: most deprived	–	**0.694 (0.614,0.784)**	0.925 (0.806,1.061)
% of Hispanic	–	**0.994 (0.990,0.998)**	**0.995 (0.990,0.999)**
% of age 50-75	–	**1.015 (1.005,1.024)**	**1.014 (1.003,1.024)**
% of Non-Hispanic African American	–	–	–

(To be continued)

[a] "–" means covariates were not included in the model. Estimates were bold if significant at α=0.05

[b] Model 1: Physician composition only

[c] Model 2: Physician composition + other county-level characteristics

[d] Model 3: Physician composition + other county-level characteristics + individual-level characteristics (i.e., age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost)

[e] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived counties, and Q5 stands for quintile 5 the most deprived counties

CRCS: Colorectal cancer screening; GI: Gastroenterologist; OR: Odds ratio; 95% CI: 95% Confidence interval

Table 4.4 Associations between Physician Composition and Adherence to CRCS Colonoscopy by Rurality of County of Residence (N= 194,940) *(Continued)*

	Adherence to Colonoscopy OR (95% CI)[a]		
	Rural		
	Model 1[b]	**Model 2[c]**	**Model 3[d]**
GI composition			
% of GI among CRCS physicians	1.021 (0.999,1.044)	1.019 (0.999,1.040)	1.009 (0.987,1.030)
County covariates			
Number of CRCS physicians per 10,000 residents aged 50-75	–	1.001 (0.996,1.005)	1.000 (0.995,1.004)
Socioeconomic position index[e] (ref:Q1: least deprived)			
Q2	–	0.928 (0.786,1.095)	0.962 (0.807,1.148)
Q3	–	0.864 (0.731,1.021)	0.893 (0.747,1.068)
Q4	–	**0.779 (0.657,0.923)**	0.883 (0.734,1.062)
Q5: most deprived	–	**0.656 (0.546,0.788)**	**0.814 (0.666,0.994)**
% of Hispanic	–	**0.993 (0.988,0.997)**	**0.993 (0.988,0.998)**
% of age 50-75	–	**1.021 (1.010,1.032)**	**1.013 (1.001,1.025)**
% of Non-Hispanic African American	–	1.000 (0.996, 1.004)	1.000 (0.995,1.004)

[a] "–" means covariates were not included in the model. Estimates were bold if significant at α=0.05

[b] Model 1: Physician composition only

[c] Model 2: Physician composition + other county-level characteristics

[d] Model 3: Physician composition + other county-level characteristics + individual-level characteristics (i.e., age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost)

[e] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived counties, and Q5 stands for quintile 5 the most deprived counties

CRCS: Colorectal cancer screening; GI: Gastroenterologist; OR: Odds ratio; 95% CI: 95% Confidence interval

Table 4.5 Associations between Physician Composition and Adherence to Overall CRCS by Rurality of County of Residence (N= 194,940)

	Adherence to Overall CRCS OR (95% CI)[a]		
	Metropolitan		
	Model 1[b]	Model 2[c]	Model 3[d]
GI composition			
% of GI among CRCS physicians	1.004 (0.992,1.017)	0.999 (0.987,1.011)	0.992 (0.979,1.005)
County covariates			
Number of CRCS physicians 10,000 residents aged 50-75	–	**1.002 (1.000,1.004)**	1.002 (0.999,1.004)
Socioeconomic position index[e] (ref:Q1: least deprived)			
Q2	–	**0.863 (0.808,0.921)**	0.966 (0.899,1.039)
Q3	–	**0.840 (0.780,0.906)**	0.966 (0.888,1.050)
Q4	–	**0.750 (0.686,0.819)**	**0.884 (0.801,0.976)**
Q5: most deprived	–	**0.749 (0.652,0.860)**	0.872 (0.750,1.013)
% of Hispanic	–	**0.994 (0.992,0.996)**	**0.997 (0.994,0.999)**
% of age 50-75	–	–	–
% of Non-Hispanic African American	–	–	–

(To be continued)

[a] "–" means covariates were not included in the model. Estimates were bold if significant at α=0.05

[b] Model 1: Physician composition only

[c] Model 2: Physician composition + county-level characteristics

[d] Model 3: Physician composition + county-level characteristics + individual-level characteristics (i.e., age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost)

[e] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived counties, and Q5 stands for quintile 5 the most deprived counties

CRCS: Colorectal cancer screening; GI: Gastroenterologist; OR: Odds ratio; 95% CI: 95% Confidence interval

Table 4.5 Associations between Physician Composition and Adherence to Overall CRCS by Rurality of County of Residence (N= 194,940) *(Continued)*

	Adherence to Overall CRCS OR (95% CI)[a]		
	Rural-Metropolitan		
	Model 1[b]	Model 2[c]	Model 3[d]
GI composition			
% of GI among CRCS physicians	**1.032 (1.016, 1.049)**	**1.025 (1.010,1.041)**	**1.025 (1.007,1.043)**
County covariates			
Number of CRCS physicians 10,000 residents aged 50-75	–	**1.004 (1.001,1.008)**	**1.005 (1.001,1.008)**
Socioeconomic position index[e] (ref:Q1: least deprived)			
Q2	–	**0.812 (0.713,0.925)**	0.871 (0.753,1.009)
Q3	–	**0.784 (0.688,0.893)**	0.880 (0.760,1.019)
Q4	–	**0.715 (0.629,0.813)**	0.868 (0.750,1.004)
Q5: most deprived	–	**0.705 (0.620,0.801)**	0.939 (0.811,1.087)
% of Hispanic	–	**0.994 (0.990,0.998)**	**0.994 (0.989,0.998)**
% of age 50-75	–	**1.016 (1.007,1.026)**	**1.015 (1.004,1.026)**
% of Non-Hispanic African American	–	–	–

(To be continued)

[a] "–" means covariates were not included in the model. Estimates were bold if significant at α=0.05

[b] Model 1: Physician composition only

[c] Model 2: Physician composition + county-level characteristics

[d] Model 3: Physician composition + county-level characteristics + individual-level characteristics (i.e., age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost)

[e] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived counties, and Q5 stands for quintile 5 the most deprived counties

CRCS: Colorectal cancer screening; GI: Gastroenterologist; OR: Odds ratio; 95% CI: 95% Confidence interval

Table 4.5 Associations between Physician Composition and Adherence to Overall CRCS by Rurality of County of Residence (N= 194,940) *(Continued)*

	Adherence to Overall CRCS OR (95% CI)[a]		
	Rural		
	Model 1[b]	Model 2[c]	Model 3[d]
GI composition			
% of GI among CRCS physicians	1.018 (0.995,1.041)	1.016 (0.996,1.038)	1.003 (0.981,1.025)
County covariates			
Number of CRCS physicians 10,000 residents aged 50-75	–	0.999 (0.995,1.004)	0.998 (0.993,1.003)
Socioeconomic position index[e] (ref:Q1: least deprived)			
Q2	–	0.922 (0.776,1.095)	0.955 (0.795,1.148)
Q3	–	**0.837 (0.704,0.996)**	0.862 (0.715,1.039)
Q4	–	**0.755 (0.633,0.901)**	0.865 (0.714,1.049)
Q5: most deprived	–	**0.598 (0.495,0.723)**	**0.714 (0.580,0.878)**
% of Hispanic	–	**0.992 (0.988,0.997)**	**0.992 (0.987,0.997)**
% of age 50-75	–	**1.021* (1.009,1.033)**	1.010 (0.998,1.023)
% of Non-Hispanic African American	–	1.001 (0.997,1.005)	1.001 (0.996,1.005)

[a] "–" means covariates were not included in the model. Estimates were bold if significant at α=0.05

[b] Model 1: Physician composition only

[c] Model 2: Physician composition + county-level characteristics

[d] Model 3: Physician composition + county-level characteristics + individual-level characteristics (i.e., age, female, race/ethnicity, education, smoking status, household income, marital status, insurance coverage, employment, delayed health care due to cost)

[e] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived counties, and Q5 stands for quintile 5 the most deprived counties

CRCS: Colorectal cancer screening; GI: Gastroenterologist; OR: Odds ratio; 95% CI: 95% Confidence interval

CHAPTER 7: Summary

Colorectal cancer (CRC) remains an important public health issue in the U.S.[1] Although the incidence and mortality of CRC can be largely prevented by regular screening,[2-8] one in three adults aged 50-75 did not receive colorectal cancer screening (CRCS) as recommended by the national guidelines. Not only individual characteristics but also contextual, area-based characteristics could impact people's screening behaviors. The aim of this dissertation project was to investigate the association between racial residential segregation (RRS), area-level socioeconomic status (SES), physician composition, and CRCS adherence.

Chapter 4, entitled "*The Association between Facility Proximity to Racial Residential Segregation Areas and Facility-level Colorectal Cancer Screening Adherence*" assessed the association between facility proximity to RRS areas (i.e., minority segregated areas, and race-specific segregated areas) and facility-level CRCS adherence. Logistic regression models were used for analyses. We found that facilities being located closer to the RRS areas (especially Asian and Hispanic segregated areas) was associated with low facility-level CRCS adherence. Results suggest that RRS may play a negative role in residents obtaining CRCS.

Chapter 5, entitled "*The Association between Area-level Socioeconomic Status and Colorectal Cancer Screening Adherence*" evaluated the association between area-level SES and individual-level CRCS adherence using a comprehensive list of single and composite SES measures. Weighted multilevel logistic regression models were used for analyses. We found that the majority of the area-level SES measures have significant bivariate associations with colonoscopy and overall CRCS adherence, where measures such as per capita income, education, area SES summary score had relatively strong associations. However, few of the associations remained significant after adjustment for individual characteristics. Although area-level SES was not associated with CRCS adherence in the fully adjusted model, results from our bivariate analyses underscore the need of CRCS interventions in highly deprived areas since low prevalence of CRCS adherence was observed in low SES areas. Also, the area-level SES measures that had relatively strong bivariate associations with CRCS adherence (e.g., per capita income, education, and area SES summary score) could be good candidate measures to detect socioeconomically disadvantaged areas that need special attention from CRCS interventions.

Chapter 6, entitled "*The Association between Physician Composition and Colorectal Cancer Screening Adherence*" examined the association between county-level physician composition and individual-level CRCS adherence among the general U.S. population aged 50-75. Weighted multilevel logistic regression models were used for analyses. We found that a higher percentage of gastroenterologists among CRCS physicians at the county level was associated with higher odds of individuals adhering to colonoscopy and overall CRCS in the rural-metropolitan areas, but not in metropolitan and rural areas. These results suggest the number of gastroenterologist (GI) specialists relative to primary care physicians (PCPs) in the physician workforce may have impacts on CRCS adherence, especially colonoscopy adherence. This is particularly relevant in underserved geographic areas, where access to colonoscopy is limited.

Implications for Public Health

In general, the findings of this dissertation project highlight the importance of neighborhood factors such as neighborhood culture, socioeconomics, and healthcare workforce composition in shaping residents' adherence to CRCS. RRS, area-level SES, and physician composition were examined separately in this project to understand how each factor was associated with CRCS adherence. The following paragraphs discuss the important public health implications of the research findings relating to each of the three factors. However, neighborhood factors are complex and sometimes interrelated.[64] If possible, these three factors can be all focused on in order to maximize the effects of multilevel interventions that aim to increase CRCS use.

Findings with regard to RRS (See *Chapter 4*) imply the need for culturally tailored CRCS programs within facilities located closer to the RRS areas, as well as community-based CRCS interventions in the RRS areas, which further contribute to improving the health of minorities in the RRS areas. One of the interventions could be utilizing social connectedness/within-group support networks [89] in the RRS community to disseminate CRCS information and reinforce residents' attitude towards CRCS in a positive way.

Findings with regard to area-level SES (See *Chapter 5*) underscore the need for CRCS interventions in highly deprived areas. Area-level SES measures such as per capita income, education, and area SES summary score could be useful indicators to identify geographic targets of CRCS interventions and allocate screening resources. Further, the CRCS interventions need to identify the CRCS barriers that residents from low SES areas have. Improving economic and social environments in deprived communities might help to increase uptake of CRCS, and further lead to reduction of socioeconomic disparities in CRC.

Findings with regard to physician composition (See *Chapter 6*) suggest that health workforce policies that aim to increase the number of GI specialists to achieve an appropriate mix of PCPs and GIs in the physician population could help increase the CRCS rate. Meanwhile, given the current population's great needs for colonoscopies but comparatively long training period of GI specialists, it may be feasible to train non-physician health providers to do some of the colonoscopy procedures.[171]

Future Research

Regarding RRS, future studies analyzing the patient level data in other geographic areas with greater numbers and variety of minority population are needed to validate the results of our study and better understand how RRS is associated with individual-level CRCS adherence. Patients' detailed race/ethnicity, residence location, education obtainment, country of origin, preferred language, and duration of stay in the U.S. should be collected in the Electronic Health Record data, and be taken into account in the analysis. Also, the characteristics of facilities such as CRCS physician capacities, and whether or not the facility provides certain services/programs for RRS residents, should be considered in the future analysis.

Regarding area-level SES, future studies analyzing national data are warranted to ensure the generalizability of study results. Studies using smaller geographic areas of aggregation such as the census tract and block group may be needed in order to better measure area-level SES. Also, future research is warranted to investigate how individual-level factors play a role in the association between area-level SES and CRCS adherence.

Also, previous evidence has shown that RRS and area-level SES was interrelated,[64] and these two factors could likely affect the geographic distribution of physicians. How RRS, area-level SES, and physician composition interplay in CRCS adherence needs future investigation. Advanced analytical methods such as geospatial analysis are needed in future analysis on the associations between area-based factors and CRCS adherence to address possible spatial correlations among units of analysis.

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Appendices

Appendix 1: The Isolation index (P) calculation

The isolation index for a minority group k within a census tract j will be:

$$P_{kj} = \sum_{i=1}^{n} \frac{k_{ij}}{k_{totalj}} \times \frac{k_{ij}}{T_{ij}}$$

Where:

P_{jk} is isolation index for a minority group k in census tract j, where k = all minority combined, Asian, Non-Hispanic African American, or Hispanic

i is the ith block group in census tract j, and there are a total of n block groups in census tract j

k_{ij} is population counts for a minority group k in block group i in census tract j

k_{totalj} is total population counts for a minority group k in census tract j

T_{ii} is total population counts in block group i in a census tract j

Appendix 2: Plots of generalized additive models (GAMs)

GAM equation: y_i= α +s (x_{dist}) +ε_i

Where *i* refers to *i* th CRCS facility; y_i is CRCS adherence for a facility *i* (continuous variable); α is intercept; s(·) is a smooth function; x_{dist} is facility proximity to RRS areas (continuous variable); ε_i are residuals.

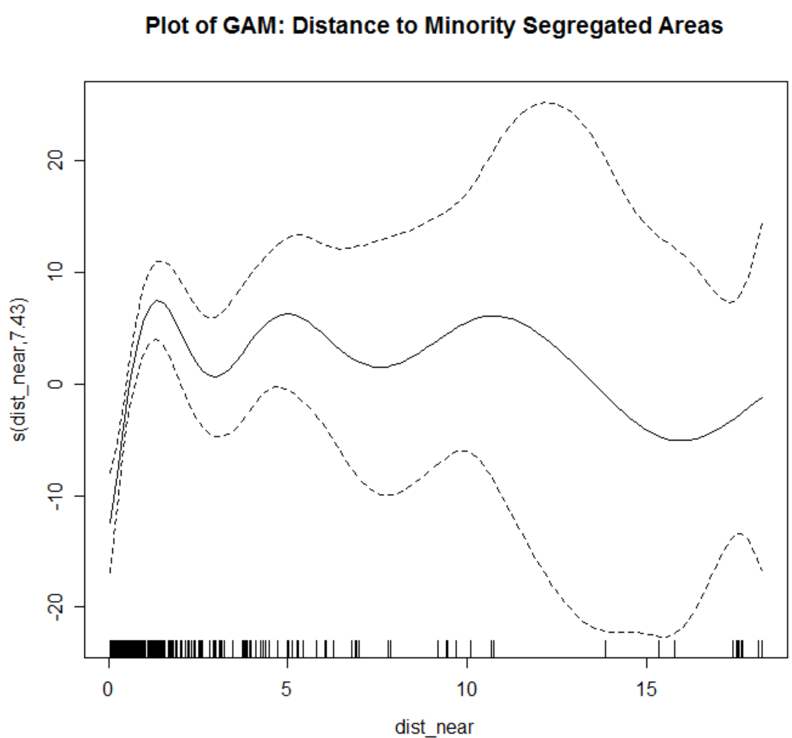
In GAM plots below, X-axis is x_{dist} (i.e., facility proximity to RRS areas), and Y- axis is s (x_{dist}, λ), where λ is a constant parameter that controls the degree of smoothing, with larger value indicating more maximal smoothness. "Dist_near", "Dist_near.AA", "Dist_near.Asi", and "Dist_near.hsp" are facility proximity to RRS areas variables.

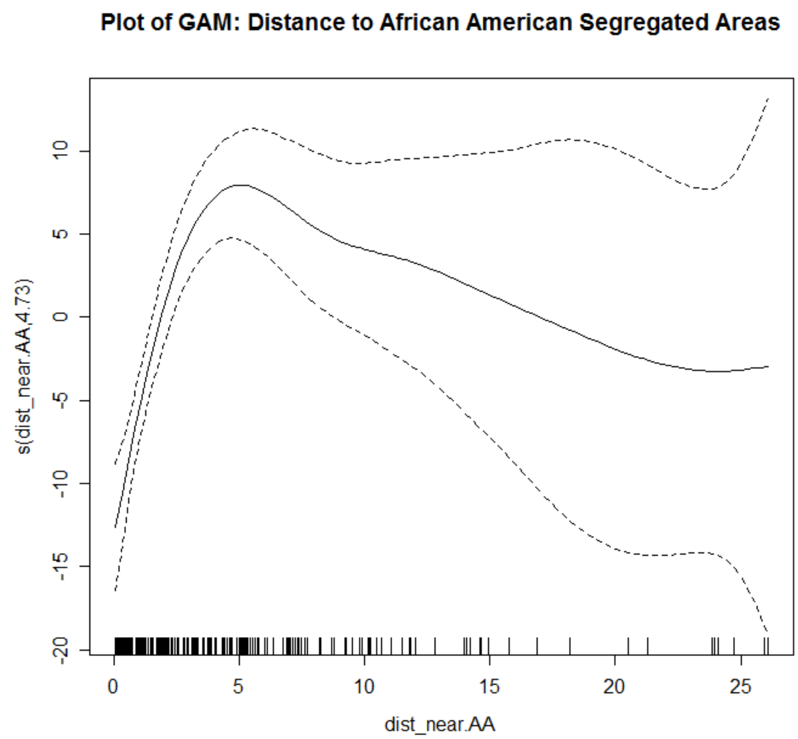
Dist_near = Facility proximity to minority segregated areas

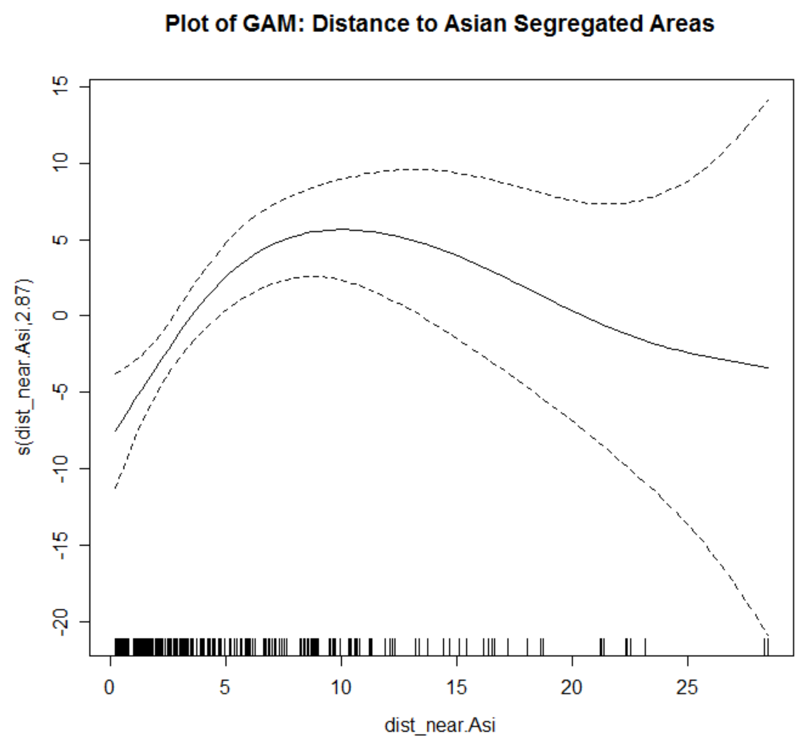
Dist_near.AA = Facility proximity to African American-segregated areas

Dist_near.Asi = Facility proximity to Asian-segregated areas

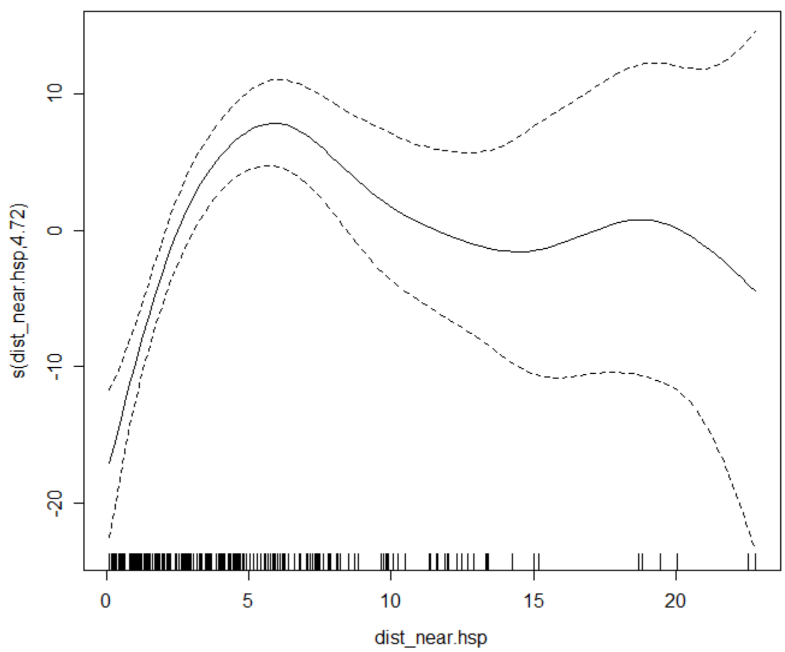
Dist_near.hsp = Facility proximity to Hispanic-segregated areas




Plot of GAM: Distance to African American Segregated Areas
s(dist_near.AA,4.73)
dist_near.AA
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25


Plot of GAM: Distance to Asian Segregated Areas
s(dist_near.Asi,2.87)
dist_near.Asi
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25

Plot of GAM: Distance to Hispanic Segregated Areas



Appendix 3: Results when facility-level CRCS adherence was modeled as a continuous outcome

Appendix 3. Associations between Facility Proximity to RRS Areas and Facility-level CRCS Adherence

	Minorities Combined		Asian	
	Crude	Adjusted[a]	Crude	Adjusted[a]
Facility proximity to minority segregated areas (miles)				
< 0.50	**-11.83 (-16.63,-7.04)**	-5.05 (-10.51,0.40)	–	–
0.50-1.99	3.69 (-1.02,8.40)	3.77 (-0.68,8.23)	–	–
2.00-	REF	REF	–	–
Facility proximity to race-specific segregated areas (miles)				
< 2.00	–	–	**-10.70 (-15.55,-5.86)**	-3.61 (-8.56,1.35)
2.00-4.99	–	–	-2.02 (-6.97,2.92)	0.71 (-3.8,5.22)
5.00-	–	–	REF	REF
Socioeconomic position index[b]				
Q1: least deprived	–	REF	–	REF
Q2	–	5.07 (-0.44,10.58)	–	4.90 (-0.69,10.48)
Q3	–	1.39 (-4.31,7.10)	–	1.47 (-4.27,7.21)
Q4	–	1.76 (-4.14,7.66)	–	1.92 (-3.88,7.72)
Q5: most deprived	–	-6.25 (-13.28,0.78)	–	**-8.77 (-15.39,-2.15)**
Participation in Sage Scope program				
Yes	–	**-5.48 (-9.50,-1.46)**	–	**-6.06 (-10.13,-2.00)**
No	–	REF	–	REF

(To be continued)

[a] Outcome was CRCS adherence (continuous variable) adjusted for patient health insurance. Facilities' neighborhood SES and participation in the Sage Scope program were included in the model

[b] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived census tracts, and Q5 stands for quintile 5 the most deprived census tracts

RRS: Racial residential segregation; CRCS: Colorectal cancer screening

Appendix 3. Associations between Facility Proximity to RRS Areas and Facility-level CRCS Adherence (As continuous variable) *(Continued)*

	Hispanic		AA	
	Crude	Adjusted[a]	Crude	Adjusted[a]
Facility proximity to minority segregated areas (miles)				
< 0.50	–	–	–	–
0.50-1.99	–	–	–	–
2.00-	–	–	–	–
Facility proximity to race-specific segregated areas (miles)				
< 2.00	**-14.12 (-18.98,-9.26)**	**-6.87 (-12.22,-1.53)**	**-10.21 (-14.93,-5.50)**	-3.68 (-8.69,1.33)
2.00-4.99	-0.23 (-4.88,4.42)	0.75 (-3.49,4.99)	0.62 (-4.65,5.90)	0.67 (-4.04,5.37)
5.00-	REF	REF	REF	REF
Socioeconomic position index[b]				
Q1: least deprived	–	REF	–	REF
Q2	–	3.77 (-1.75,9.30)	–	4.36 (-1.22,9.95)
Q3	–	1.31 (-4.36,6.98)	–	1.37 (-4.39,7.13)
Q4	–	2.87 (-2.79,8.53)	–	2.25 (-3.61,8.10)
Q5: most deprived	–	-6.24 (-12.87,0.39)	–	**-7.86 (-14.66,-1.06)**
Participation in Sage Scope program				
Yes	–	**-5.41 (-9.43,-1.39)**	–	**-6.16 (-10.22,-2.09)**
No	–	REF	–	REF

[a] Outcome was CRCS adherence (continuous variable) adjusted for patient health insurance. Facilities' neighborhood SES and participation in the Sage Scope program were included in the model
[b] Socioeconomic position index was categorized into quintiles, where Q1 stands for quintile 1 the least deprived census tracts, and Q5 stands for quintile 5 the most deprived census tracts
RRS: Racial residential segregation; CRCS: Colorectal cancer screening

Appendix 4: Cut-offs for area-level SES measures

Appendix 4. Cut-off Points for Area-level SES Single and Composite Measures

Area-level SES Variables	**Q1: least deprived**	**Q2**	**Q3**	**Q4**	**Q5: most deprived**
	"["or "]" means containing the cut-off point; "("or ")' means not containing the cut-off point				
SES SINGLE MEASURES					
<u>Occupation/employment</u>					
Working class % of people in working class occupation	[0, 38.8457)	[38.8457, 47.6067)	[47.6067, 53.6246)	[53.6246, 58.7601)	[58.7601,100]
Unemployment % of unemployed persons	[0, 6.1)	[6.1, 8.0)	[8.0, 10.35)	[10.35, 13.55)	[13.55, 66.4]
White collar % of people in white-collar employment	[45.0005, 100]	[36.1165, 45.0005)	[30.2326, 36.1165)	[24.1884, 30.2326)	[0, 24.1884)
<u>Income</u>					
Median household income ($)	[66833, 183833]	[56893, 66833)	[47813, 56893)	[40741, 47813)	[13750, 40741)
Low income % of households with income < 50% of median income	[0, 13.1128)	[13.1128, 18.4651)	[18.4651, 23.3187)	[23.3187, 30.7293)	[30.7293, 100]
High income % of households with incomes > 400% of median income	[5.40875, 47.5143]	[2.87879, 5.40875)	[1.53161, 2.87879)	(0, 1.53161)	0
Gini coefficient	[0.0339, 0.3653)	[0.3653,0.3946)	[0.3946, 0.4214)	[0.4214, 0.4555)	[0.4555, 0.6268]
Per capita income($)	[33580,99911]	[27973, 33580)	[24249, 27973)	[20736, 24249)	[4459, 20736)

(To be continued)

SES: Socioeconomic status

Appendix 4. Cut-off Points for Area-level SES Single and Composite Measures *(Continued)*

Area-level SES Variables	**Q1: least deprived**	**Q2**	**Q3**	**Q4**	**Q5: most deprived**
	"["or "]" means containing the cut-off point; "("or ")' means not containing the cut-off point				
SES SINGLE MEASURES					
Income					
Non-salary income % of households with dividend, rental, or interest income	[32.0148, 69.3878]	[26.1538, 32.0148)	[21.7746, 26.1538)	[16.46, 21.7746)	[0, 16.46)
Poverty					
Below poverty % of people living below the poverty line	[0, 7.4)	[7.4, 11.2)	[11.2, 15.2)	[15.2, 21)	[21, 84.7]
Female-headed households % of female-headed households	[0, 3.16484)	[3.16484, 5.96855)	[5.96855, 8.58837)	[8.58837, 11.8684)	[11.8684, 61.5894]
Wealth					
Expensive homes % of homes worth ≥400% of median value of owned homes	[5.14936, 90]	[2.2245, 5.14936)	[0.86784, 2.2245)	(0, 0.86784)	0
Median housing value ($)	≤306000	[238800, 306000)	[188800, 238800)	[151300, 188800)	[151300, 10200)
Education					
Low education % of people with education < high school	[0, 4.53083)	[4.53083, 7.32127)	[7.32127, 10.5)	[10.5, 15.1111)	[15.1111, 100]
High school or higher % of people who completed high school	[95.4692, 100]	[92.6787, 95.4692)	[89.5, 92.6787)	[84.8889, 89.5)	[0, 84.8889)

(To be continued)

SES: Socioeconomic status

Appendix 4. Cut-off Points for Area-level SES Single and Composite Measures (continued)

SES Variables	**Q1:least deprived**	**Q2**	**Q3**	**Q4**	**Q5: most deprived**
	“[“ means containing the cut-off point; “(” means not containing the cut-off point				
SES SINGLE MEASURES					
Education					
High education (rev) % of people with education ≥ college	[37.242, 100]	[23.9694, 37.242)	[18.0527, 23.9694)	[13.6171, 18.0527)	[0, 13.6171)
Crowding					
Crowded households % of households with > 1 person per room	[0, 0.53667)	[0.53667,1.64654)	[1.64654, 2.66667)	[2.66667, 4.34749)	[4.34749, 38.4106]
Housing					
Rented houses % of house units rented	[0, 17.9329)	[17.9329, 25.8497)	[25.8497, 32.6087)	[32.6087, 42.0208)	[42.0208, 100]
Households with no car % of households with no car	0	(0, 0.64836)	[0.64836, 1.59467)	[1.59467, 3.50877)	[3.50877, 17.2414]
SES COMPOSITE MEASURES					
SEP index	[-18.8104, -0.21402)	[-0.21402, 1.39932)	[1.39932, 2.78743)	[2.78743, 4.3579)	[4.3579, 15.6302]
Area SES summary score	[3.48634, 16.3208)	[0.6404, 3.48634)	[-1.06398, 0.6404)	[-2.7342, -1.06398)	[-10.9664, -2.7342)
Index of Local Economic Resources	[24,25]	[17,24)	[15,17)	[7,15)	[2,7)

(To be continued)

SES: Socioeconomic status

Appendix 4. Cut-off Points for Area-level SES Single and Composite Measures *(Continued)*

SES Variables		*“[“ means containing the cut-off point; “(” means not containing the cut-off point*				
SES COMPOSITE MEASURES						
		% < poverty	% working class	% expensive homes		
SEP1	*C1*	Any value	[0,50)	≥ 10		
	C2	Any value	[50,75)	≥ 10		
	C3	Any value	[0,50)	< 10		
	C4	[0,20)	[50,75)	< 10		
	or	[0,20)	≥ 75	Any value		
	C5	≥ 20	[50,75)	< 10		
		% < poverty	% working class	% high income		
SEP2	*C1*	Any value	[0,50)	≥ 3.5		
	C2	Any value	[50,75)	≥ 3.5		
	C3	Any value	[0,50)	< 3.5		
	C4	[0,20)	[50,75)	< 3.5		
	or	[0,20)	≥ 75	Any value		
	C5	≥ 20	[50,75)	< 3.5		

SES: Socioeconomic status; SEP: Socioeconomic position

Appendix 5: Methods for scaling weights

Scaled weights were included in the GLIMMIX WEIGHT statement to reduce the bias in the estimator of variance. Because GLIMMIX WEIGHT statement treats the weight variable as a frequency weight, the original BRFSS weights cannot be directly applied. We will scale the BRFSS weights using what previous papers [142, 143] referred to as "Method 2". The formula is expressed as:

$$\text{Scaled weights}=\frac{Ns}{\sum_S w_{is}}\times w_{is}$$

Where *s* refers to a specific state *s*, *i* refers to *i* th respondent in a state s, w_{is} is the original BRFSS weight for *i* th respondent in a state s; $\sum_S w_{is}$ is the sum of total original weights in a state s; Ns is number of respondents in a state s. Weights were scaled by state because BRFSS was a state-based survey whose sampling and data collection were conducted independently among states.

Appendix 6: Multilevel models in Chapter 5

The multilevel logistic regressions used in this study were expressed as:

$$\text{Logit}(\Pr(y_{ij}=1)) = \alpha + \beta_{SES}\chi_{SESj} + \beta_q\chi_{qij} + u_j + \varepsilon_{ij}$$

Where $\Pr(y_{ij}=1)$ indicates the probability of self-reported being adherent to stool test, colonoscopy, or overall CRCS for respondent *i* in ZIP Code *j*; α is intercept; β_{SES} is the coefficient for area-level SES measure; χ_{SESj} is a specific area-level SES measure (e.g., percentage of people living below poverty) in ZIP Code *j*; β_q represents coefficients for individual-level characterisitcs; χ_{qij} refers to individual-level characteristics (e.g., age, gender) for respondent i in ZIP Code *j*, and the total number of individual-level characteristics is q; u_j are county-specific random intercepts; and ε_{ij} are residuals.

Appendix 7: Pearson Correlations between Area-level SES Measures

Appendix 7. Pearson Correlations between Area-level SES Measures						
	Working class	**Unemployment**	**White collar**	**Median household income**	**Low income**	**High income**
Working class	1.00					
Unemployment	0.54	1.00				
White collar	0.84	0.55	1.00			
Median household income	0.49	0.48	0.57	1.00		
Low income	0.44	0.46	0.49	0.91	1.00	
High income	0.67	0.55	0.72	0.66	0.57	1.00
Gini coefficient	-0.20	-0.07	-0.17	0.33	0.44	-0.21
Per capita income	0.65	0.59	0.76	0.78	0.70	0.81
Non-salary income	0.61	0.57	0.67	0.52	0.49	0.66
Below poverty	0.48	0.51	0.54	0.82	0.85	0.60
Female-headed households	0.39	0.39	0.33	0.34	0.39	0.33
Expensive homes	0.48	0.39	0.53	0.41	0.36	0.60
Median housing value	0.51	0.40	0.65	0.65	0.56	0.70
Low education	0.62	0.49	0.70	0.49	0.49	0.55
High education	0.70	0.54	0.84	0.53	0.46	0.73
High school or higher	0.62	0.49	0.70	0.49	0.49	0.55
Crowded households	0.41	0.35	0.45	0.25	0.25	0.30
Rented houses	0.10	0.18	0.10	0.37	0.42	0.12
Households with no car	0.40	0.33	0.49	0.46	0.41	0.51
SEP index	0.72	0.68	0.78	0.82	0.76	0.78
Area SES summary score	0.69	0.58	0.84	0.71	0.63	0.78
Index of Local Economic Resources	0.34	0.41	0.53	0.57	0.48	0.54
SEP1	0.78	0.58	0.72	0.49	0.46	0.64
SEP2	0.79	0.58	0.81	0.61	0.55	0.81

(To be continued)

SES: Socioeconomic status; SEP: Socioeconomic position

Appendix 7. Pearson Correlations between Area-level SES Measures *(Continued)*						
	Gini coefficient	**Per capita income**	**Non-salary income**	**Below poverty**	**Female-headed households**	**Expensive homes**
Working class						
Unemployment						
White collar						
Median household income						
Low income						
High income						
Gini coefficient	1.00					
Per capita income	-0.03	1.00				
Non-salary income	-0.14	0.76	1.00			
Below poverty	0.32	0.77	0.60	1.00		
Female-headed households	0.09	0.42	0.51	0.52	1.00	
Expensive homes	-0.26	0.62	0.63	0.43	0.37	1.00
Median housing value	-0.07	0.79	0.69	0.59	0.31	0.69
Low education	-0.06	0.67	0.67	0.57	0.43	0.49
High education	-0.24	0.76	0.73	0.51	0.28	0.59
High school or higher	-0.06	0.67	0.67	0.57	0.43	0.49
Crowded households	-0.09	0.43	0.46	0.42	0.36	0.31
Rented houses	0.40	0.22	0.25	0.46	0.52	0.10
Households with no car	-0.04	0.58	0.44	0.42	0.28	0.43
SEP index	0.09	0.89	0.74	0.81	0.49	0.60
Area SES summary score	-0.07	0.88	0.82	0.69	0.41	0.66
Index of Local Economic Resources	0.02	0.59	0.35	0.44	0.05	0.38
SEP1	-0.26	0.66	0.64	0.53	0.47	0.60
SEP2	-0.18	0.78	0.67	0.59	0.41	0.59

(To be continued)

SES: Socioeconomic status; SEP: Socioeconomic position

Appendix 7. Pearson Correlations between Area-level SES Measures *(Continued)*						
	Median housing value	**Low education**	**High education**	**High school or higher**	**Crowded households**	**Rented houses**
Working class						
Unemployment						
White collar						
Median household income						
Low income						
High income						
Gini coefficient						
Per capita income						
Non-salary income						
Below poverty						
Female-headed households						
Expensive homes						
Median housing value	1.00					
Low education	0.53	1.00				
High education	0.76	0.68	1.00			
High school or higher	0.53	1.00	0.68	1.00		
Crowded households	0.26	0.62	0.39	0.62	1.00	
Rented houses	0.06	0.21	-0.02	0.21	0.28	1.00
Households with no car	0.64	0.41	0.53	0.41	0.26	-0.01
SEP index	0.71	0.74	0.75	0.74	0.46	0.33
Area SES summary score	0.84	0.76	0.89	0.76	0.46	0.17
Index of Local Economic Resources	0.60	0.38	0.56	0.38	0.11	-0.09
SEP1	0.60	0.64	0.67	0.64	0.40	0.11
SEP2	0.67	0.63	0.74	0.63	0.39	0.17

(To be continued)

SES: Socioeconomic status; SEP: Socioeconomic position

Appendix 7. Pearson Correlations between Area-level SES Measures*(Continued)*

	Households with no car	SEP index	Area SES summary score	Index of Local Economic Resources	SEP1	SEP2
Working class						
Unemployment						
White collar						
Median household income						
Low income						
High income						
Gini coefficient						
Per capita income						
Non-salary income						
Below poverty						
Female-headed households						
Expensive homes						
Median housing value						
Low education						
High education						
High school or higher						
Crowded households						
Rented houses						
Households with no car	1.00					
SEP index	0.51	1.00				
Area SES summary score	0.59	0.88	1.00			
Index of Local Economic Resources	0.44	0.55	0.58	1.00		
SEP1	0.44	0.71	0.69	0.43	1.00	
SEP2	0.50	0.79	0.78	0.49	0.78	1.00

SES: Socioeconomic status; SEP: Socioeconomic position

Appendix 8: Multilevel models in Chapter 6

The multilevel logistic regressions used in this study were expressed as:

$$\text{Logit}(\Pr(y_{ij}=1)) = \alpha + \beta_{cmp}\chi_{cmpj} + \beta_c\chi_{cj} + \beta_q\chi_{qij} + u_j + \varepsilon_{ij}$$

Where $\Pr(y_{ij}=1)$ indicates the probability of self-reported being adherent to stool test, colonoscopy, or overall CRCS for respondent *i* in county *j*; β_{cmp} is the coefficient for physician composition; β_c represents coefficients for other county-level covariates, e.g., county-level SES; β_q represents coefficients for individual-level covariates; u_j are county-specific random intercepts; and ε_{ij} are residuals.

Vita

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EDUCATION

Doctor of Philosophy, Epidemiology, Virginia Commonwealth University 2011-present

- Study focus: cancer, cancer screening
- Dissertation title: Investigating the effects of racial residential segregation, area-level socioeconomic status, and physician composition on colorectal cancer screening
- Intend to graduate Spring 2016
- GPA: **4.00**/4.00

Post-baccalaureate Graduate Certificate in Geographic Information Systems, Virginia Commonwealth University 2014-2015

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Master of General Practice Medicine, Capital Medical University, China 2007-2010

- Thesis title: Analyses on the quantity and quality of health workforce in community health facilities in Beijing, China

Bachelor of Medicine, Preventive Medicine, Capital Medical University, China 2002-2007

PROFESSIONAL EXPERIENCE

RESEARCH

Research Assistant to Dr. Resa M. Jones, Department of Family Medicine and Population Health, Division of Epidemiology, Virginia Commonwealth University 2012-2015

- Involved in developing colorectal cancer screening shared decision-making intervention materials (e.g., pamphlet, website)

- Provided support in implementing the colorectal cancer screening shared decision-making intervention in the clinical and community settings
- Built comprehensive but user-friendly Microsoft Access databases for data collection in clinic and community settings
- Performed stratified random sampling for community surveys on cancer screening
- Involved in questionnaire development and data collection in the community survey on cancer screening
- Performed statistical analysis to evaluate the effect of shared decision-making intervention on the uptake of colorectal cancer screening
- Prepared abstracts and manuscripts to disseminate study findings

Research assistant to Dr. Yi Ning, Department of Family Medicine and Population Health, Division of Epidemiology, Virginia Commonwealth University — 2011

- Analyzed causes of death among cancer survivors using National Health and Nutrition Examination Survey (NHANES)
- Prepared abstracts and posters to disseminate study findings

Research assistant to Prof. Aimin Guo, Department of General Practice, Capital Medical University, China — 2007-2010

- Involved in designing and conducting a cross-sectional survey of human resources in the community health facilities in Beijing
- Using Delphi procedure to develop indicators to evaluate training capacities of community health facilities
- Performed data analysis
- Prepared abstracts, posters and manuscripts to disseminate findings

TEACHING

Teaching Assistant, Department of Family Medicine and Population Health, Division of Epidemiology, Virginia Commonwealth University — 2013-2014

- EPID 547 Applied Data Analysis LAB I
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Tutor, Department of Family Medicine and Population Health, Division of Epidemiology, Virginia Commonwealth University — 2013-2014

- BIOS 553 Linear Regression
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INTERNSHIPS

Intern, Beijing Municipal Center for Disease Prevention and Control, Beijing, China — 2005–2006

- Participated in food and nutrition survey, data entry and analyses, and surveillance and reporting of infectious diseases

Intern, Beijing Anzhen Hospital, Beijing, China — 2004–2005

- Provided basic medical care to patients under supervision

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"Investigating the effects of racial residential segregation, area-level socioeconomic status, and physician composition on colorectal cancer screening" — 2016

- Funded by Massey Center Cancer Prevention and Control (CPC) Doctoral Dissertation Research Support Program

PUBLICATIONS

1. **Shen Q**, Cohen SA, Jones RM, Wheeler DC, Matsuyama RK, Lu J. The association between physician composition and colorectal cancer screening adherence. Submitted to Cancer Causes & Control.
2. Jones RM, Mink PJ, **Shen Q**, Wiseman KP, Bishop DL. Preferences for colorectal cancer screening: People want to discuss their options. Submitted to Cancer.
3. Wiseman KP, Bishop DL, **Shen Q**, Jones RM. Survivorship care plans and time since diagnosis: Factors that contribute to who breast cancer survivors see for the majority of their care. Support Care Cancer.2015;23(9):2669-76.
4. Ning Y, **Shen Q**, Herrick K, Mikkelsen R, Anscher M, Houlihan R, Lapane KL. Cause of death in cancer survivors [abstract]. In: Proceedings of the 103rd Annual Meeting of the American Association for Cancer Research; 2012 Mar 31-Apr 4; Chicago, IL. Philadelphia (PA): AACR; Cancer Res 2012;72(8 Suppl):Abstract nr LB-339. doi:1538-7445.AM2012-LB-339
5. **Shen Q**, Yang J, Huang YF, Wei XM, Zhang XD, Feng ZL, et al. Quantities and qualities of health human resources in community health facilities in Beijing. Chinese General Practice, 2009, 12(23):2169-72.

In Preparation

6. **Shen Q**, Jones RM, Lu J, Wheeler DC, Matsuyama RK, Cohen SA. Evaluating effects of area-level socioeconomic status measures on colorectal cancer screening adherence and

choice of area-level socioeconomic status measures. Intended to Cancer Epidemiology, Biomarkers & Prevention

7. **Shen Q**, Wheeler DC, Cohen SA, Lu J, Matsuyama RK, Jones RM. Evaluating the association between facility proximity to racial residential segregation areas and facility-level colorectal cancer screening adherence. Intended to Health & Place.

PRESENTATIONS

1. **Shen Q**, Lu J, Jones RM, Wheeler D, Matsuyama RK, Cohen SA. Evaluating the association between area-level socioeconomic status measures and colorectal cancer screening adherence. Presented at the 40th Annual American Society of Preventive Oncology Conference, Columbus, OH, United States, March, 2016.
2. **Shen Q,** Cohen SA, Jones RM, Wheeler D, Matsuyama R, Lu J. Evaluating the association between physician composition and colorectal cancer screening adherence. Presented at the 9th Annual National Conferences on Health Disparities, Washington, DC, United States, March, 2016.
3. Jones RM, Mink PJ, Carlson PS, **Shen Q**, Orr J, Britt HR. Increasing colorectal cancer screening in a general population-based, community-wide shared decision making intervention. Presented at the 2015 Joint International Shared Decision-Making and International Society for Evidence Based Health Care Conference, Sydney, New South Wales, Australia, July, 2015.
4. Jones RM, Mink PJ, **Shen Q**, Hansberger R, Wiseman K, Orr J. Shared decision making with nurse clinicians in primary care practice increases colorectal cancer screening. Presented at the 2015 Joint International Shared Decision-Making and International Society for Evidence Based Health Care Conference, Sydney, New South Wales, Australia, July, 2015.
5. **Shen Q**, Jones RM. Spatial patterns of colorectal cancer screening facilities, screening adherence, and colorectal cancer mortality. Presented at the 142nd American Public Health Association Annual Meeting and Exposition. New Orleans, Louisiana, United States, November, 2014.
6. **Shen Q**, Jones RM. Spatial patterns of colorectal cancer screening facilities, screening adherence, and colorectal cancer mortality. Presented at the 31st Watts Day, Richmond, VA, United States, October,2014.
7. Jones RM, Kramer J, Bishop DL, Wiseman KP, **Shen Q**. Optimizing a shared decision making intervention for community-based primary care practice. Presented at the 34th Society of Behavioral Medicine Annual Meeting. San Francisco, CA, United States, March, 2013.
8. **Shen Q**, Herrick K, Mikkelsen R, Houlihan R, Lapane KL, Ning Y. Cause of Death in Female Cancer Survivors. Presented at 8th Annual Women’s Health Research Day, Richmond, VA, United States, April, 2012.

9. Zhao Y, **Shen Q**, Lu X, Du J, Cui S, Wang W, Guo A. Development of evaluation indicators for training capacities in community health facilities. Presented at World Organization of Family Doctors (WONCA) Asia-Pacific Regional Conference, Hong Kong, China, June, 2009.
10. **Shen Q**, Guo A. Development of evaluation indicators for training capacities in community health Facilities. Presented at the International Community Genetics Conference & Public Health and Community Health Service Annual Conference in Asia, Beijing, China, Oct. 2008.

HONORS

Travel Scholarship, 9th Annual National Conference on Health Disparities	2016
Member of Golden Key International Honor Society	2014
Nominated for the Honor Society of Phi Kappa Phi	2012
Registration Scholarship, Virginia Network Conference	2012
Third Prize Scholarship for Graduate Student, Capital Medical University	2009
Honor of Outstanding Graduate, Capital Medical University	2007
Honor of Outstanding Student Leader, Capital Medical University (Annually)	2003-2007
Social Work Prize, Capital Medical University (Annually)	2003-2007
Second Prize Scholarship for Undergraduate Student, Capital Medical University (Annually)	2003-2006
The Merit Student, Beijing Municipal Commission of Education	2005
"The Star of Volunteer" of Red Cross Organization, Capital Medical University	2004

SKILLED SOFTWARES

- **Proficient in:** SAS (5 years), Geographic Information Systems (2 years) ,Microsoft Access (3 years), Microsoft Excel (10 years)
- **Had experience in:** R, M-plus

REVIEWERS

Ad Hoc Reviewer

- Drug and Alcohol Dependence
- Prevention Science

Conference Abstract

- American Public Health Association

MEMBERSHIPS

- American Public Health Association
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