A population health assessment of screening mammography on breast cancer mortality in North Carolina

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Abstract
Purpose To identify predictors of screening mammography use and the effect of screening mammography on breast cancer mortality in North Carolina.
Methods This cross-sectional study integrated publicly available data from government and private data repositories to model predictors of screening mammography and breast cancer mortality in North Carolina.
Results In North Carolina during 2008—2010, on average, 68.1% of women aged 40–74 years underwent a screening mammogram in the previous two years (range: 38.7%–82.1). The ordinary least squares (OLS) regression demonstrated counties experiencing persistent poverty have mammography screening rates that are 4.3% less, on average, than counties without persistent poverty (estimate (SE) = −4.283 (2.105), \(p = 0.045\)). As the percentage of women with a college education increases, the mammography screening rates increase by approximately 0.3% (estimate (SE) = 0.319 (0.078), \(P < .001\)) and as the health literacy score increases, the mammography screening rate decreases by 0.3% (estimate (SE) = −0.318 (0.104), \(p = 0.003\)). These variables explain 7.0% of the variability in mammographic screening rates. The OLS regression analysis demonstrated that age-adjusted breast cancer incidence (Estimate (SE) = 0.074 (0.024), \(p = 0.003\)) and health literacy score (estimate (SE) = −0.175 (0.083), \(p = 0.039\)) are significantly related to breast cancer mortality.
Conclusions Demographic, socioeconomic, and environmental variables explain only a small percentage of the variability in the rates of screening mammography and breast cancer mortality in North Carolina. Advances in the available treatments are likely the major contributor to improving breast cancer mortality.

Keywords Screening mammography · Breast cancer mortality · Breast cancer incidence · Health literacy

Introduction

For women who are at average risk of developing breast cancer, screening mammography is widely considered to be a significant contributor to decreasing breast cancer mortality [1, 2]. This conclusion is based upon the results of several randomized clinical trials that were initiated first in the 1960s in the northeast United States [3] and subsequently in Sweden [4, 5], the United Kingdom [6], and Canada [7]. Mammographic screening is routinely administered as part of a women’s health maintenance as recommended by multiple professional organizations [8] and the National Comprehensive Cancer Network [9]. The United States Department of Health And Human Services initiative, Healthy People 2030, has set a goal that 77.1% of women age 40 to 74 years undergo screening mammography within the preceding two years [10]. There is not a consensus at what age to begin and the interval of screening, however, there is general agreement that the reduction in breast cancer mortality attributed to screening mammography outweighs the potential harm from radiation exposure, false positives, over diagnosis and resultant over treatment.

There are significant differences in the utilization of screening mammography among various racial groups [11].
These differences are believed to contribute to the disparities in outcomes among members of racial minority groups who experience worse breast cancer mortality. African American and Hispanic women have a significantly lower odds of undergoing screening mammography than their White counterparts and have a worse 5-year relative survival when compared to Whites [2]. Furthermore, African Americans and Hispanics women present with more advanced stage disease at diagnosis which has been attributed in part to disparities in the utilization of screening mammography [12].

North Carolina has a racially diverse population with African Americans representing over 20% of the population [13]. Age-adjusted breast cancer mortality varies substantially among the 100 counties of the state [14]. Considering these disparate breast cancer outcomes between counties, we investigated community-level predictors of mammography use and the degree to which screening mammography effects breast cancer mortality in North Carolina.

**Methods**

**Data sources**

The female population size was determined from the annual 2010 US Census estimates of the resident North Carolina population for selected age groups by sex [15]. Characteristics of the North Carolina counties within the domains of health behaviors, clinical care, social and economic environment as well as demographics were obtained from the Robert Woods Johnson Foundation (RWJF) county health rankings of North Carolina [16]. Characteristics and numbers of different health care providers (e.g., Ob/GYN) were obtained from the Area Health Resource File (AHRF) [17]. The location of certified mammography facilities was obtained from the U.S. Food & Drug Administration [18]. North Carolina health literacy scores were obtained from the Sheps Center for Health Services Research [19]. Health literacy scores were originally provided at the census block level. Weights were calculated based on block-level population size relative to its corresponding county. These weights are then used to estimate health literacy scores at the county level. The mammography screening rates were obtained from the National Cancer Institute (NCI)/Centers for Disease Control and Prevention (CDC) State Cancer Profiles Screening and Risk Profile Tables [20]. These estimates were created through a predictive model that uses data from the 2010 U.S. Census and 2011 5-year American Community Surveys (ACS) summary files. Prevalence estimates were based on women aged 40 years of age and older Cancer surveillance data (age-adjusted) were obtained from the North Carolina Cancer Prevention and Control Branch: N.C. Comprehensive Cancer Control Program [14]. Breast cancer mortality rates were from the years 2011–2015. All these data are publicly available and based on guidance from the Office of Human Research Protection, this study was determined not to require institutional review board review under 45 CFR 46.

**Determination of screening mammography rates**

Model-based estimates of the prevalence of mammographic screening at the county-level for North Carolina were obtained from the CDC [20] using combined data from the Behavioral Risk Factor Surveillance Systems (BRFSS) [21] and the National Health Interview Survey (NHIS) [22]. The BRFSS is a cross-sectional telephone survey that state health departments conduct monthly over landline telephones and cellular telephones using a standardized questionnaire with technical and methodologic assistance from the CDC. The NHIS is a nationally representative, stratified, multistage, area probability sample of approximately 40,000 households in the US. Survey information is collected annually based on face-to-face interviews. Both surveys include a question on whether a woman 40 years of age or older has had a mammogram in the past two years [23]. Because mammography screening rates were based upon population estimates from 2010, we utilized data sources that collected data in proximity to 2010 in this analysis.

**Statistical considerations and data analysis**

Analysis was performed at the county level with the county of residence as the primary exposure for women aged 40 to 74 years of age. Although recommendations for when to perform screening mammography vary somewhat [8], we elected to confine our analysis to this subset of women since most current screening mammogram recommendations target the 40- to 74-year-old age group. The primary outcomes were screening mammography rates and age-adjusted breast cancer mortality per 100,000 female residents aged 40 to 74. Continuous variables were summarized by presenting the mean and standard deviation (SD), while categorical variables are expressed as percentages. For comparison of county-level characteristics, mammography screening rates were categorized into quartiles. Characteristics were compared between quartiles using one-way analysis of variance (ANOVA) or chi-square test, as appropriate. Post hoc pairwise comparisons were performed using Tukey’s Honest Significance Difference test.

The relationship between county-level covariates and screening mammography rates was evaluated using Spearman’s correlation coefficient (r_s). Covariates in the domains of demographics, socioeconomic, and access to care, as defined in Appendix 1, were evaluated. Within each domain, ordinary least squares (OLS) regression was performed to
quantify how much variability in mammography screening rates is explained by the domain factors (R-squared value). OLS regression with backward elimination was used to obtain the best explanatory model with all domain factors listed in Appendix 1 initially included in the model. The criterion for staying in the model was set at 0.05. Based on the outcomes from the screening mammography model, OLS regression was performed to evaluate predictors of breast cancer mortality. Significant covariates from the screening model as well as percent of the population screened, incidence of breast cancer, and percentage of distant disease at diagnosis were included in the model.

Analyses were performed using SPSS Statistics (version 28.0, Armonk, NY) and SAS Statistical Software (v. 9.5, SAS Institute, Cary, NC). All tests are 2-tailed. P values less than 0.05 were considered statistically significant.

Results

Study population

In 2010, there were 9,535,483 residents of North Carolina, of which 2,511,135 (26.3%) were female who were 40 years of age or older. Of these, approximately 1,678,416 women are between the age of 40 and 74 years, inclusive. Table 1 summarizes, at the county level, the characteristics of the study population. Over three-quarters of the women (76.2%), on average, were non-Hispanic white alone while 20.5% were non-Hispanic black alone as defined by the US Census Bureau. On average, 19.4% have household income below the 100% Federal Poverty Level and 18.3% are uninsured.

Screening mammography rates

On average, 68.1% of women aged 40 and older underwent a screening mammogram in the previous two years (range: 38.7%–82.1). Table 2 provides a summary of county-level characteristics by mammography screening rate quartiles. Counties in the lowest quartile had a lower percentage of individuals completing college than those in the highest screening mammography quartile. Similarly, women residing in the lowest two quartiles were significant less likely to have access to Obstetrics and Gynecology MDs than women residing in counties in the highest quartile (Table 2).

Results of the Spearman’s rank correlation analysis are presented in Appendix 2. Of the demographic factors, percent non-Hispanic Whites ($r_s = -0.202, p = 0.044$), percent non-Hispanic Blacks ($r_s = 0.233, p = 0.020$), and the RWJF health outcomes rank ($r_s = -0.226, p = 0.024$) were significantly correlated with screening mammography rates. Of the socioeconomic factors, only percent unemployed was significantly correlated ($r_s = -0.501, p < 0.001$) with mammography screening rates. It is notable that there were no significant correlations between mammography screening rates and access to care variables (mammographic facilities or health care providers (Primary Care MDs, Obstetrics and Gynecology MDs, Physician Assistants, or Nurse Practitioners)) or breast cancer mortality ($r_s = -0.090, p = 0.371$) (Fig. 1).

Results of the OLS regression analysis are provided in Table 3. Within the demographic domain, none of the factors are significantly related to mammography screening rates, explaining only 0.9% of the variability (adjusted R-square = 0.009) (Table 3A). Within the socioeconomic domain, the only factors significantly related to mammography screening rates were persistent poverty (Yes versus No: estimate (SE) = −4.966 (2.228), $p = 0.028$) and health literacy score (estimate (SE) = −0.378 (0.133), $p = 0.005$), explaining 13.0% of the variability (adjusted R-square = 0.130) (Table 3A). Within the access to care domain, the only factor significantly related to mammography screening rates was the number of OB/GYN physicians per 10,000 women aged 40–74 years (estimate = 0.448 (0.223), $p = 0.048$), although the effect of percent completing college was marginal ($p = 0.051$). Collectively, these variables explain 7.0% of the variability in mammogram screening rates (adjusted R-square = 0.070). When all factors were evaluated simultaneously, the backward elimination method identified 3 significant variables: persistent poverty (Yes versus No), percent completing college, and health literacy score with an adjusted R-square of 16.7% (Table 3B).

Breast Cancer Mortality

The breast cancer mortality rate for North Carolina was 21.3 per 100,000 age 40 to 74 years, inclusive. At the county level, breast cancer mortality ranged from 8.20 to 34.0 per 100,000 women (mean 21.3 per 100,000). Using OLS regression, we evaluated the relationship between breast cancer mortality and distant disease at diagnosis, age-adjusted breast cancer incidence, and mammography screening rates. In addition, we included the 3 variables found to be significantly related to mammography screening rates: persistent poverty, percent college educated, and health literacy score. Results of the OLS regression analysis are presented in Table 4. Of the variables evaluated, only age-adjusted breast cancer incidence (Estimate (SE) = 0.074 (0.024), $p = 0.003$) and health literacy score (estimate (SE) = −0.175 (0.083), $p = 0.039$) are significantly related to breast cancer mortality.

Discussion

Screening mammography is considered an important contributor to improved breast cancer mortality [1]. In the current study, we hypothesized the substantial variability
of female breast cancer mortality rates in North Carolina counties and late stage at diagnosis might be explained, at least in part, by lack of access to screening mammography. Our results were unanticipated. We observed only a weak correlation of screening mammography rates at the county level in North Carolina with breast cancer mortality and in a multivariable analysis, screening mammography did not contribute to the predictive model of breast cancer mortality at the county level.

Screening mammography has been demonstrated to increase the proportion of early-stage breast cancer [24], of which some indeterminate percentage will not become clinically apparent in the woman’s lifetime [25]. However, the impact of screening mammography on decreasing late-stage breast cancer at diagnosis has been minimal since the advent of screening mammography [26]. Harding and colleagues [27] analyzed over 10 years of Surveillance, Epidemiology, and End Results (SEER) county-level data and could not
Table 2  Summary of characteristics of the study population by quartiles of the percent of women who had a mammogram within the last 2 years

| Variable [mean (SD)]                              | Quartile 1 (n = 26) | Quartile 2 (n = 21) | Quartile 3 (n = 24) | Quartile 4 (n = 23) | p value |
|---------------------------------------------------|---------------------|---------------------|---------------------|---------------------|---------|
| Percent screening mammograms [Min–Max]            | 61.3 (5.6) [38.7–65.6] | 66.7 (0.8) [65.7–68.0] | 69.5 (0.9) [68.2–71.0] | 74.8 (2.8) [71.1–82.1] | NA      |
| Demographics                                      |                     |                     |                     |                     |         |
| Number females aged 40 plus years                 | 10,339 (8701)       | 14,606 (1095)       | 21,343 (27,979)     | 21,020 (30,816)     | 0.220   |
| Race/Ethnicity                                    |                     |                     |                     |                     |         |
| Percent non-hispanic white alone                  | 79.0 (21.5)         | 77.9 (17.6)         | 76.0 (14.5)         | 70.0 (21.6)         | 0.345   |
| Percent non-hispanic black alone                  | 15.7 (18.6)         | 22.6 (18.5)         | 21.6 (13.8)         | 24.4 (17.1)         | 0.295   |
| Percent of population under age 65 without health insurance | 148.0 (19.5)     | 146.7 (18.5)       | 153.2 (15.4)       | 151.5 (22.9)       | 0.615   |
| Breast cancer incidence                           | 4.9 (1.7)           | 5.1 (2.1)           | 4.5 (1.5)           | 4.4 (1.6)           | 0.448   |
| Breast cancer mortality                           | 21.6 (4.8)          | 22.5 (3.9)          | 21.1 (4.3)          | 20.6 (5.1)          | 0.529   |
| Percent rurality                                   | 65.2 (24.8)         | 63.1 (25.4)         | 58.9 (29.5)         | 57.6 (33.3)         | 0.755   |
| Socioeconomic                                     |                     |                     |                     |                     |         |
| Income                                            |                     |                     |                     |                     |         |
| Persistent poverty (%) Yes                         | 4 (15.4%)           | 3 (12.5%)           | 1 (4.0%)            | 2 (8.0%)            | 0.549   |
| Percent < 100% federal poverty level               | 20.8 (5.2)          | 18.3 (4.3)          | 18.9 (3.9)          | 19.5 (5.7)          | 0.308   |
| Percent uninsured                                  | 18.0 (3.7)          | 19.0 (4.2)          | 18.7 (3.3)          | 17.5 (4.0)          | 0.510   |
| Percent unemployed                                 | 11.1(3.4)           | 10.4 (2.1)          | 10.2 (1.9)          | 10.5 (2.5)          | 0.647   |
| Education                                          |                     |                     |                     |                     |         |
| Percent completing college                         | 20.0 (7.8)*         | 20.1 (5.5)          | 22.2 (9.4)          | 26.9 (13.5)*        | 0.038   |
| Percent completing high school                     | 31.8 (4.5)*         | 31.7 (3.7)          | 30.8 (5.5)          | 27.9 (6.7)*         | 0.035   |
| Weighted health literacy                           | 240.4 (9.4)         | 241.0 (7.1)         | 240.2 (6.7)         | 241.2 (9.0)         | 0.973   |
| Social associations                                | 13.1 (3.3)          | 12.5 (4.2)          | 11.5 (2.1)          | 12.0 (3.6)          | 0.389   |
| Language                                           |                     |                     |                     |                     |         |
| Percent non-english-speaking households            | 1.4 (0.7)           | 1.9 (0.9)           | 2.2 (1.4)           | 2.3 (2.0)           | 0.106   |
| Percent spanish-speaking households                | 29.6 (11.8)         | 31.0 (11.0)         | 32.6 (8.7)          | 30.0 (11.6)         | 0.765   |
| Percent no internet subscription                   | 12.3 (3.3)          | 10.8 (3.1)          | 11.7 (3.1)          | 10.6 (3.2)          | 0.188   |
| Access to care                                     |                     |                     |                     |                     |         |
| Mammography                                        |                     |                     |                     |                     |         |
| Number of mammographic facilities                  | 1.6 (1.1)           | 1.9 (1.6)           | 3.2 (5.1)           | 4.1 (7.6)           | 0.200   |
| Number of mammographic facilities per 10,000 population | 2.0 (1.7)        | 1.3 (0.9)           | 1.4 (1.1)           | 1.5 (1.0)           | 0.200   |
| Health care providers per 10,000 population        |                     |                     |                     |                     |         |
| Number of primary care MDs                         | 25.4 (14.4)         | 21.8 (10.8)         | 25.3 (12.8)         | 33.6 (25.9)         | 0.104   |
| Number of obstetrics and gynecology MDs            | 2.7 (2.6)*          | 2.6 (2.4)*          | 3.7 (3.6)           | 6.5 (7.5)*          | 0.012   |
| Number of PAs                                      | 11.9 (9.5)          | 13.0 (12.6)         | 13.5 (9.4)          | 18.1 (15.1)         | 0.271   |
| Number of NPs                                      | 14.4 (8.2)          | 11.4 (7.3)          | 15.2 (7.8)          | 18.8 (19.7)         | 0.195   |

*a*Age adjusted  
*b*Per 100,000  
*c*Percentage of population under age 65 without health insurance  
*d*The health literacy estimates from 177 to 280, with higher numbers indicating higher health literacy and have been weighted by the county population  
*e*Number of memberships per 10,000 population  
*f*Women aged 40–74 years  
*g*Post hoc statistical significance by Tukey’s HSD test  
*h*Chi-square test
detect a mortality benefit of mammography screening at the county population level among women age ≥ 40 years with at least one mammogram in the past 2 years. Our findings are consistent with these observations. Although the incidence of breast cancer was predictive of increased breast cancer mortality, we did not observe any association in the percent-age of distant disease at diagnosis and the rate of screening mammography at the county level in North Carolina.

With the possible exception of the Canadian National Breast Screening Study [28], randomized clinical trials on the efficacy of screening mammography with up to 25 years of follow-up have demonstrated a reduction in breast cancer-specific mortality [3, 4, 6, 7]. In contrast to these trials, we utilized model-based percentages of all races who had a mammogram in the past 2 years to ascertain the effect of screening mammography on breast cancer mortality. This

![Image]

**Fig. 1** Percent of women aged 40 plus who had a mammogram within the last two years (2008 – 2010) and age-adjusted breast cancer mortality per 100,000 women by county (2011 – 2015)

| Variable | Comparison | Estimate | Standard error | p value |
|----------|------------|----------|----------------|---------|
| **A. Domains** | | | | |
| Demographics | | | | |
| Percent non-hispanic white alone | Per unit increase | − 4.887 | 5.502 | 0.377 |
| Percent non-hispanic black alone | Per unit increase | − 0.048 | 6.095 | 0.994 |
| Percent rurality | Per unit increase | − 0.022 | 0.021 | 0.303 |
| Adjusted R-square = 0.009 | | | | |
| Socioeconomic | | | | |
| Persistent poverty | Yes versus no | − 4.966 | 2.228 | 0.028 |
| Percent <100% federal poverty level | Per unit increase | 0.171 | 0.167 | 0.309 |
| Percent uninsured | Per unit increase | − 0.134 | 0.156 | 0.392 |
| Percent unemployed | Per unit increase | − 0.999 | 0.599 | 0.099 |
| Percent completing college | Per unit increase | 0.308 | 0.155 | 0.051 |
| Percent completing high school | Per unit increase | 0.163 | 0.305 | 0.594 |
| Weighted health literacy | Per unit increase | − 0.378 | 0.133 | 0.005 |
| Social associations | | | | |
| Percent non-english-speaking households | Per unit increase | 0.323 | 0.641 | 0.615 |
| Percent Spanish-speaking households | Per unit increase | − 0.070 | 0.071 | 0.323 |
| Percent no internet subscription | Per unit increase | − 0.397 | 0.222 | 0.078 |
| Adjusted R-square = 0.130 | | | | |
| Access to Care | | | | |
| Mammographic facilities per 10,000 population | Per unit increase | − 0.330 | 0.507 | 0.517 |
| Number of primary care MDs | Per unit increase | 0.048 | 0.065 | 0.465 |
| Number of obstetrics and gynecology MDs | Per unit increase | 0.448 | 0.223 | 0.048 |
| Number of physicians assistances | Per unit increase | 0.028 | 0.068 | 0.682 |
| Number of nurse practitioners | Per unit increase | − 0.123 | 0.086 | 0.159 |
| Adjusted R-square = 0.070 | | | | |
| **B. backward elimination method** | | | | |
| Final model | | | | |
| Intercept | | 137.823 | 24.122 | <.001 |
| Percent persistent poverty | Yes versus no | − 4.283 | 2.105 | 0.045 |
| Percent completing college | Per unit increase | 0.319 | 0.078 | <.001 |
| Weighted health literacy | Per unit increase | − 0.318 | 0.104 | 0.003 |
| Adjusted R-square = 0.1672 | | | | |
model-based approach was developed to address non-cover- age bias, non-response bias, and reduce the variability in the estimate due to small sample size and are considered reliable estimates of screening [29, 30].

Our findings suggest that the results of the previous clinical trials may not be directly applicable to populations at the county level in North Carolina. It is likely that the study cohorts in the randomized clinical trials are not comparable to the population of North Carolina. Given the demographics of the countries in which most of these randomized clinical trials were conducted, it is likely that only a small percentage of patients who were part of these studies were of African descent. This population characteristics is not the case in North Carolina where non-Hispanic African Americans may comprise as much as 62 percent of the population of women aged 40–74 years in some counties. Furthermore, these trials were initiated 4 to 6 decades ago and cannot account for the significant technological improvements that have occurred since those trials were conducted.

Screening mammography identifies breast cancer based upon anatomic findings and does not assess the biologic characteristics of the tumor which is most relevant to breast cancer prognosis [31]. Breast cancer is a heterogenous disease with different prevalences of breast cancer subtypes among races. Basal-like breast cancer is far more common in African Americans than non-African Americans and has a worse outcome compared to other breast cancer subtypes [32]. Although there is some suggestion that screening reduces breast cancer mortality of both African American and White women with triple-negative breast cancer [33], the likely substantial differences in the patient population of North Carolina from the study populations of the randomized clinical trials might have resulted in bias toward less benefit from screening mammography.

Improving the population health of women with respect to breast cancer outcomes has been the goal of screening mammography. Because the rate of screening mammography was not a predictor of breast cancer mortality in this study population, we investigated baseline characteristics of the population and covariates that, based upon existing literature, could confound the relationship between screening mammography and breast cancer mortality (Appendix 1). The incidence of breast cancer and health literacy at the county level were the only variables that predicted breast cancer mortality. The negative association of health literacy with screening mammography rates was unanticipated but may reflect individual risk assessment and increasing shared decision-making in population health [34] and warrants further investigation. Although the analysis meets the assumptions of linearity, clearly this is a complex health care system that requires a different framework to account for more complex interconnected relationships between components of the health care system, providers, patients, and the lived environment.

Because the preponderance of evidence supports the benefit of screening mammography, we explored the relationship between baseline characteristics of our study population and screening mammography rates. Access to care, as evidenced by the number of OB-GYN physicians per 10,000 women aged 40–74 years, but not the number of mammographic facilities, predicted an increase in the percentage rate of screening mammography. The county with the highest rate of screening mammography had no mammography facilities in the county although it was outlying to a central core-based statistical area and had one of the worst age-adjusted breast cancer mortality rates (Fig. 1). Multiple factors have been associated with different rates of utilization of screening mammography including contact with a physician, financial considerations, breast health beliefs and knowledge, and lifestyle and health characteristics [35]. Our analysis with the measured covariates supports the importance of other unaccounted for factors in the rate of screening mammography as this model accounted for only 7.0% of the variability in the rate of mammographic screening between counties.

Despite the general acceptance of the benefits of screening mammography, some have questioned the magnitude of benefit attributable to screening mammography and suggests that the lack of reduction in late stage at diagnosis breast cancer is evidence of overdiagnosis of cancers that were destined never to become clinically relevant [24, 36]. Statistical modeling suggests mammographic screening accounts for between 28 and 65% (median 46%) of the total reduction in

| Table 4 | Results of the ordinary least squares regression analysis of breast cancer mortality |
|-----------------|-----------------|-----------------|-----------------|
|                | Estimate | SE | p value |
| Intercept       | 57.653   | 22.922 | 0.014 |
| Percent mammography screening | −0.101 | 0.082 | 0.220 |
| Age-adjusted breast cancer incidence 2010–2014 (per 10,000) | 0.074 | 0.024 | 0.003 |
| Percent distant disease at diagnosis 2010–2014 | 0.368 | 0.242 | 0.131 |
| Persistent poverty | 1.485   | 1.604 | 0.357 |
| Weight health literacy score | −0.175 | 0.083 | 0.039 |
| Percent completing college | −0.016 | 0.070 | 0.823 |
breast cancer mortality [37]. We found that the breast cancer incidence rate in combination with health literacy accounts for only 16.7% of the variability in breast cancer mortality. This lends support to the view that the improvements in breast cancer mortality are due, in great part, to improved treatment [24, 26]. Our results also highlight the connections that exist among socioeconomic systems, health care access, and delivery, and the place where one resides. This complex series of interactions may not explain breast cancer outcomes in a linear fashion.

Our report is not without limitations. Because the screening rates were based upon population data from 2010, these findings may not represent the current screening mammography technology and advances in treatment and their potential effect on breast cancer outcomes. The screening rates utilized in this report were in women aged 40 and older as reported by the CDC [38]. Because mammographic screening is not routinely recommended beyond age 74, this may limit the strength of the Spearman’s rank correlations we performed. The absence of individual level data does not allow us to address patient level relationships. Furthermore, we did not examine the incidence of breast cancer or mortality over time which might provide further insight to the benefit of screening mammography. In contrast to randomized clinical trials, our observational analysis can only include variables that are contained within publicly available data repositories and for that reason we could not account for unrecognized confounding variables (i.e., treatment) that likely contribute to breast cancer outcomes as is evidenced by the low percentage of variability that is accounted for in the two outcome variables that were analyzed in the current study. However, this report does reflect actual clinical practice and suggests a difference between the efficacy (more good than harm under ideal circumstances) and the effectiveness (more good than harm under usual circumstances of clinical care) [39] of screening mammography in North Carolina. Finally, this analysis is specific to North Carolina and our findings may not be directly applicable to other states which have different population characteristics and demographics. However, the statistical modeling utilized in this study could be applied to other populations to understand the effect of screening mammography on breast cancer mortality.

Conclusions

Screening mammography remains an important part of the health maintenance of women at average risk for developing breast cancer. However, the usual demographic, socioeconomic, and environmental variables contained in population-based data repositories explain only a small percentage of the variability in the rates of screening mammography and breast cancer mortality in North Carolina. This suggests that improvements in breast cancer mortality are largely the result of improving treatments and not screening mammography.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Ashley E. Burch, William D. Irish, and Jan H. Wong. The first draft of the manuscript was written by [full name] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets generated during and/or analyzed during the current study are publicly available as follows. Bureau UC. United States Decennial Census. Accessed May 12, 2022. https://data.census.gov/cedsci/table?q=United%20States&tid=DECENNIALPL2020.P1

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Declarations

Ethics approval All these data utilized in this report are publicly available and based on guidance from the Office of Human Research Protection, this study was determined not to require institutional review board review under 45 CFR 46.

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