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ORIGINAL RESEARCH

Identifying Geographic Disparities in the Early Detection of Breast Cancer Using a Geographic Information System

Jane A. McElroy, PhD, Patrick L. Remington, MD, Ronald E. Gangnon, PhD, Luxme Hariharan, LeAnn D. Andersen, MS

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Abstract

Introduction

Identifying communities with lower rates of mammography screening is a critical step to providing targeted screening programs; however, population-based data necessary for identifying these geographic areas are limited. This study presents methods to identify geographic disparities in the early detection of breast cancer.

Methods

Data for all women residing in Dane County, Wisconsin, at the time of their breast cancer diagnosis from 1981 through 2000 (N = 4769) were obtained from the Wisconsin Cancer Reporting System (Wisconsin's tumor registry) by ZIP code of residence. Hierarchical logistic regression models for disease mapping were used to identify geographic differences in the early detection of breast cancer.

Results

The percentage of breast cancer cases diagnosed in situ (excluding lobular carcinoma in situ) increased from 1.3% in 1981 to 11.9% in 2000. This increase, reflecting increasing mammography use, occurred sooner in Dane County than in Wisconsin as a whole. From 1981 through 1985, the proportion of breast cancer diagnosed in situ in Dane county was universally low (2%–3%). From 1986 through 1990, urban and suburban ZIP codes had significantly higher rates (10%) compared with rural ZIP codes (5%). From 1991 through 1995, mammography screening had increased in rural ZIP codes (7% of breast cancer diagnosed in situ). From 1996 through 2000, mammography use was fairly homogeneous across the entire county (13%–14% of breast cancer diagnosed in situ).

Conclusion

The percentage of breast cancer cases diagnosed in situ increased in the state and in all areas of Dane County from 1981 through 2000. Visual display of the geographic differences in the early detection of breast cancer demonstrates the diffusion of mammography use across the county over the 20-year period.

Introduction

Geographic differences in health status and use of health services have been reported in the United States and internationally (1), including stage of breast cancer incidence and mammography screening practices (2). Early diagnosis of breast cancer through mammography screening improves breast cancer treatment options and may reduce mortality (3,4), yet many women in the United States are not routinely screened according to recommended guidelines (5).

Needs assessment to account for noncompliance with breast cancer screening recommendations has focused on personal factors related to participation, including the barriers women perceive (6), the role of physicians (7), and the role of services such as mobile vans (8) and insurance coverage (9). Evaluations of the effectiveness of interventions directed at patients, communities, and special populations have also provided important information about mammography use (10). However, little attention has been paid to geographic location, except to focus on inner-city and rural disparities in mammography use (11,12).

The purpose of this study was to identify geographic disparities in the early detection of breast cancer using cancer registry data. This information can be used to identify areas where increased mammography screening is needed and to understand the diffusion of innovation in an urban or a rural setting.

Cancer registry data were used for these analyses. Validity of the use of these data rests on the correlation between the percentage of breast cancer diagnosed in situ and mammography screening rates; breast cancer in situ (BCIS) (excluding lobular carcinoma in situ [13-15]) is the earliest stage of localized breast cancer and is diagnosed almost exclusively by mammography (16). In the 1970s, before widespread use of mammography, BCIS represented less than 2% of breast cancer cases in the United States (15). A nationwide community-based breast cancer screening program showed that among populations of women screened regularly, the stage distribution of diagnosed cases was skewed to earlier stages, with BCIS accounting for more than 35% (17). Trends in the relative frequency of BCIS are closely correlated with trends in mammography use (reflected in data from surveys of mammography providers in Wisconsin) and with trends in self-reported mammography use (reflected in data from the Behavioral Risk Factor Surveillance System) (18-20).

In Wisconsin, either a physician can refer a patient for screening or a woman can self-refer. More than 60% of the mammography imaging facilities in the state accept self-referrals (21). Since 1989, Wisconsin state law has mandated health insurance coverage for women aged 45 to 65 years, and Medicare covers mammography screening for eligible women (22). In Wisconsin, the Department of Health and Family Services provides a toll-free number through which women can contact more than 400 service providers (22). Finally, several programs such as the Wisconsin Well Woman Program, which is funded by the Centers for Disease Control and Prevention, provide free or low-cost screening to underserved women.

Methods

Study population

All female breast cancer cases diagnosed from 1981 through 2000 were identified by the Wisconsin Cancer Reporting System (WCRS). The WCRS was established in 1976 as mandated by Wisconsin state statute to collect cancer incidence data on Wisconsin residents. In compliance with state law, hospitals and physicians are required to report cancer cases to the WCRS (within 6 months of initial diagnosis for hospitals and within 3 months for physicians, through their clinics). Variables obtained from the WCRS included histology (*International Classification of Diseases for Oncology, 2nd Edition* [ICD-02] codes), stage (0 = in situ, 1 = localized, 2–5 = regional, 7 = distant, and 9 = unstaged), year of diagnosis, county of residence at time of diagnosis, and number of incident cases in 5-year age groups by ZIP code for all breast cancer cases among women. ZIP codes and county of residences, self-reported by the women with diagnosed breast cancer, are provided to the WCRS. Only ZIP codes verified for Dane County by the U.S. Postal Service were included in the data set (n = 37). The ZIP code was the smallest area unit available for WCRS incidence data.

Study location and characteristics

Dane County is located in south central Wisconsin. The population of the county in 1990 was 367,085, with 20% of the population living in rural areas (23); approximately 190,000 people lived in Madison, the second largest city in Wisconsin and home to the University of Wisconsin. The 37 unique ZIP codes in Dane County incorporate 60 cities, villages, and towns (Figure 1).

Data analysis

We determined the percentage of breast cancer cases diagnosed as BCIS in Wisconsin and Dane County over time and by ZIP codes for Dane County. For ZIP codes that encompassed areas beyond the borders of Dane County, only women who reported their county of residence as Dane were included in the analysis. The percentage of BCIS by ZIP code was mapped using 1996 ZIP

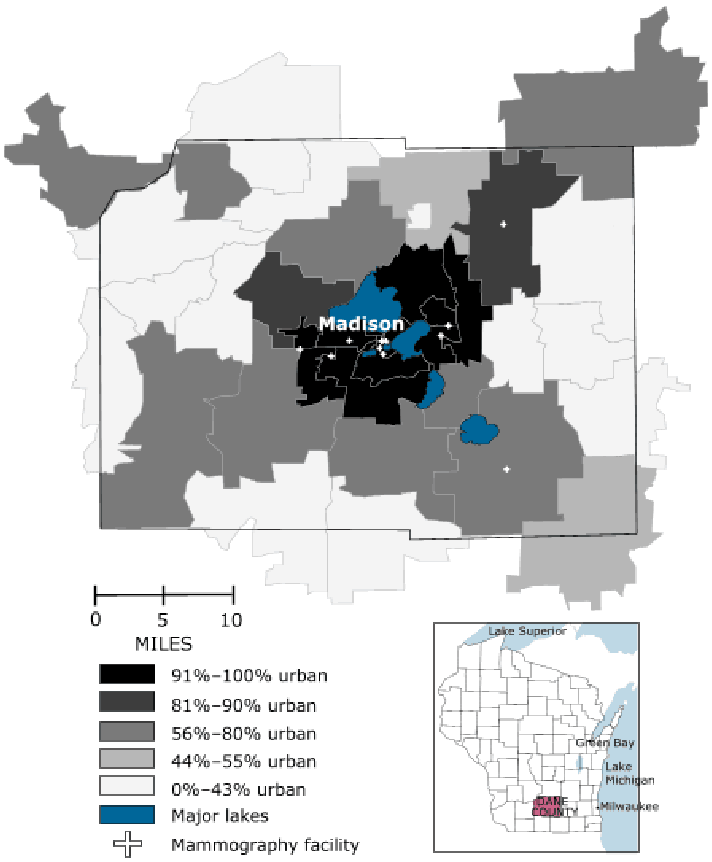

Figure 1. Map of Dane County, Wisconsin, showing capital city of Madison, major lakes, active mammogram facilities, and percentage of area classified as urban by ZIP code, using 1996 ZIP code boundaries and 1990 census data. Inset map shows location of Dane County within the state.

code boundary files. For 17 breast cancer cases in which the women's ZIP codes no longer existed, each ZIP code was reassigned to the ZIP code in the same location.

We used analytic methods to estimate rates of early breast cancer detection by ZIP code. Because of small numbers of BCIS cases in each ZIP code, a well-characterized statistical method was used to stabilize the prediction of rates by borrowing information from neighboring ZIP codes (24). This is done by using Bayesian hierarchical logistic regression models to estimate ZIP-code–specific effects on percentage of breast cancer cases diagnosed in situ (excluding lobular carcinoma in situ). ZIP-code–specific effects (log odds ratios) were modeled as a Gaussian conditional autoregression (CAR) (25). Using the CAR model, one assumes that the log odds ratio for one ZIP code is influenced by the average log odds ratio for its neighbors. The conditional standard deviation of the CAR model, the free parameter which controls the smoothness of the map, was given a uniform prior (24).

For each time period, two CAR models were fitted. The first model included age group as the only covariate. Age group effects were modeled using an exchangeable normal prior. The standard deviation of this distribution was given a uniform prior. The second model included additional ZIP-code–level covariates. Potential covariates were urban or rural status, education, median household income, marital status, employment status, and commuting time from the Summary Tape File 3 of the 1990 U.S. Census of Population and Housing (23). Census data from 1990 were used because 1990 is the midpoint of the years included in these analyses (1981–2000). Urban or rural status was defined as percentage of women living in each of the four census classifications: urban inside urbanized area, urban outside of urbanized area, rural farm, and rural nonfarm for each ZIP code. Education was defined as percentage of women in each ZIP code aged 25 years and older with less than a high school diploma. Median household income for each ZIP code was based on self-reported income. Marital status was defined as women aged 25 years and older in each ZIP code who had never been married. Employment status was defined as percentage of women aged 16 years and older in each ZIP code who worked in 1989. Full-time employment variable was defined as percentage of women 25 years and older in each ZIP code who worked at least 40 hours per week. Commuting time was divided into five categories of percentage of female workers in each ZIP code: worked at home, commuted 1 to 14 minutes, commuted 15 to 29 minutes, commuted 30 to 44 minutes, and commuted 45 minutes or more. Age was defined as age at diagnosis. These potential covariates were initially screened using forward stepwise logistic regression models, which included ZIP code as an exchangeable (nonspatially structured) random effect. Covariates included in the best model selected using Schwarz's Bayesian Information Criterion (BIC) (26) were used in the second covariate-adjusted model. The covariate effects and the intercept were given posterior priors.

Posterior estimates of the age-adjusted percentage of BCIS for each ZIP code in each time period were obtained from the CAR model. Posterior medians were used as point estimates of the parameters, and 95% posterior credible intervals were obtained. Analyses were performed using WinBUGS software (27). Covariate screening was performed using SAS software, version 8 (SAS Institute Inc, Cary, NC). ZIP-code–specific estimates were mapped using ESRI 3.2 ArcView software (Environmental Systems Research Institute, Redwood, Calif) and 1996 ZIP code boundary files to display the data.

As an empirical check on our mapping, we fitted a regression model to the BCIS rates by ZIP code. The dependent variable was BCIS rates (using the posterior estimates of age-adjusted percentage of BCIS), and the independent variable in the model was linear distance from the University of Wisconsin Comprehensive Cancer Center (UWCCC), located in Madison, to the centroid of each ZIP code.

Results

A total of 4769 breast cancer cases were reported in Dane County from 1981 through 2000: 825 from 1981 through 1985, 1119 from 1986 through 1990, 1239 from 1991 through 1995, and 1586 from 1996 through 2000. Percentage of cases in situ varied by age group from a high of 18% among women aged 45 to 49 years to a low of 0% among women aged 20 to 24 years. From the mid 1980s, the age group most frequently diagnosed with BCIS was women aged 45 to 49. In contrast, women aged 20 to 34 and older than 84 were the least often (≤2%) diagnosed with BCIS (data not shown). Based on the 1990 U.S. census, the total female population (aged 18 years and older) in Dane County was 145,974; 60% of the female population had more than a high school degree, and 15% of the female population aged 25 and older had never married.

In Dane County, the percentage of BCIS increased from 1.3% in 1981 to 11.9% in 2000. For the state, the percentage of BCIS increased from 1.5% in 1981 to 12.8% in 2000. From 1981 to 1993, Dane County had a higher percentage of BCIS diagnosis than the state as a whole. By the mid-1990s, the percentage of BCIS among breast cancer cases in Dane County was similar to the percentage in the state (Figure 2). Similar results are seen when mapping the observed data (maps not shown).

Figure 3 shows model-based estimates of the age-adjusted percentage of BCIS diagnosis by ZIP code in Dane County during four 5-year periods. These maps demonstrate the increase in the percentage of cases diagnosed as

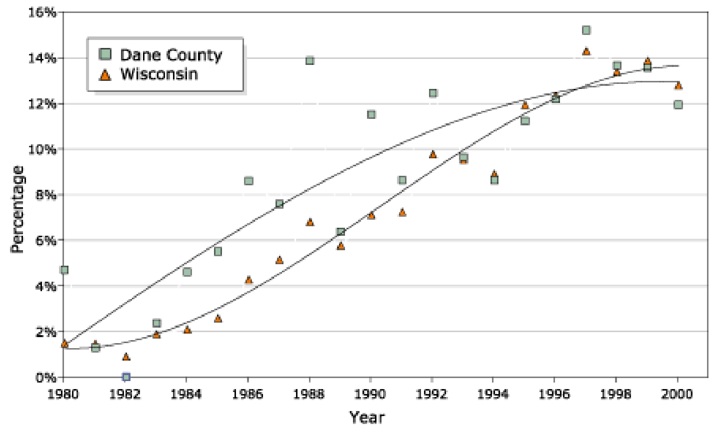

Figure 2. Smoothed trends in percentage of breast cancer cases diagnosed in situ (excluding lobular carcinoma in situ), Dane County, Wisconsin, and Wisconsin, 1981–2000. Data point for Dane County, 1980, was estimated from Andersen et al (28).

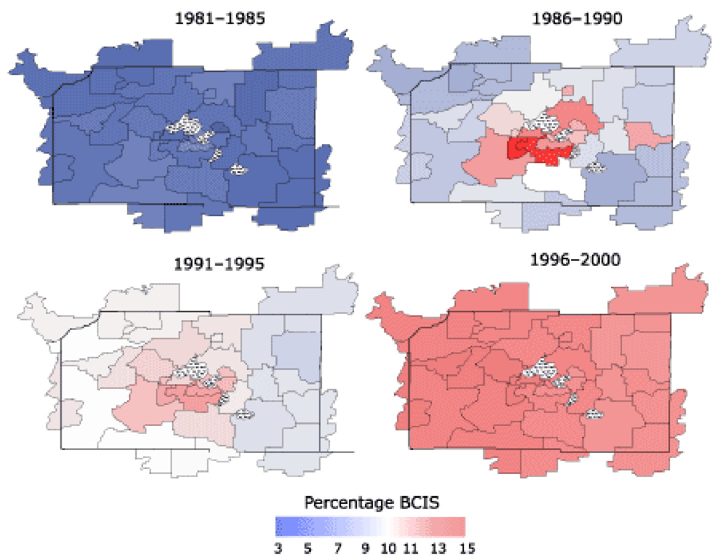

Figure 3. Model-based estimates of age-adjusted percentage of breast cancer cases diagnosed in situ during four 5-year periods, by ZIP code, Dane County, Wisconsin, 1981–2000. BCIS indicates breast cancer in situ.

BCIS noted in Figure 2. These maps also show that the increase in the percentage of BCIS was not uniform across Dane County. From 1981 through 1985, the entire county had uniformly low rates of BCIS (2%–3%). From 1986 through 1990, urban ZIP codes had markedly higher rates of BCIS (approximately 12%) compared with rural ZIP codes (approximately 5%). From 1991 through 1995, use of mammography screening had begun to increase in the rural ZIP codes (with a 7% rate of BCIS), although the rates of BCIS remained higher in urban ZIP codes (12%). From 1996 through 2000, mammography screening was fairly universal across the county, with BCIS rates of 13% to 14%. Similar patterns were observed from models that adjusted for additional covariates of marital status and education (data not shown).

From 1981 through 1985, there was no significant relationship between distance from UWCCC and the rate of BCIS (P = .27). From 1986 through 1990 and from 1991 through 1995, there was strong evidence of an inverse relationship between distance from UWCCC and the rate of BCIS (i.e., the closer to UWCCC, the higher the BCIS rate [P < .001] for both periods). From 1996 through 2000, there was a nonsignificant inverse relationship between distance from UWCCC and the rate of BCIS (P = .07).

Discussion

The frequency of BCIS diagnosis increased substantially in Wisconsin and in Dane County from 1981 through 2000. This increase in percentage of BCIS among diagnosed breast cancer cases is consistent with increases in self-reported mammography use, Wisconsin Medicare claims for mammography, and the number of medical imaging centers in Wisconsin (21). However, progress in mammography screening was not uniform across Dane County, and this lack of uniformity represents a classic case of diffusion of innovation. Early adopters of mammography use lived in and near the city of Madison. We can speculate that Madison embodies one characteristic that accelerates the diffusion process: namely, a more highly educated population living in a university community with a strong medical presence. One predictor of mammography use is education: women who are more educated are more likely to ask their physician for a referral or to self-refer (29), and the strongest predictor of mammography use is physician referral (30). Furthermore, physicians are more likely to have chosen to live in the Madison area instead of a more rural location because they value the opportunity for regular contact with the medical school and the medical community (31). Consequently, a greater number of interpersonal networks and more information exchange among physicians about adoption of this innovation might have occurred earlier in the Madison medical community than in the more rural areas of the county (32).

Although median household income by ZIP code was not a predictor of mammography use in our study, the amount of disposable income by individuals, which is not captured by this variable, might also have been an important factor for early adopters (33,34). In a national study of mammography use, income was a significant predictor of repeat screening in 1987 but not in 1990 (35). In the mid-1980s, few insurance plans covered mammography screening. Therefore, women of higher socioeconomic status (SES) would have been more likely to be able to pay the cost of the mammogram. Efforts to reduce costs, such as a 1987 statewide promotional campaign sponsored by the American Cancer Society, still required a $50 copay from women who were able to self-refer for a mammogram (36).

As the use of this technology diffused outward, increasing numbers of women living in suburban and rural areas surrounding Madison elected to get a mammogram. From 1996 through 2000, the geographic disparity in mammography use was muted, although the eastern corridor of Dane County still had slightly lower rates of BCIS than other parts of the county. The reasons for persistent disparity in this region of Dane County are unclear: it is unlikely to be because of proximity to mammography screening facilities, nor are the ZIP-code–level SES measures such as percentage unemployed, household income, percentage below poverty level, or education level statistically different from the western corridor of Dane County.

Differences in the trends of early detection of breast cancer within Dane County suggest that progress in mammography screening has not been uniform across the county. From 1996 through 2000, while more than 14% of age-adjusted breast cancer cases were diagnosed as BCIS in Madison, fewer than 6% of age-adjusted breast cancer cases were diagnosed as BCIS in a few outlying and more rural areas of Dane County, reflecting lower mammography use by residents in this area. The results of an earlier analysis of these data were shared with local health department staff in rural Dane County who were working to increase early detection efforts through outreach education and referrals to providers. As suggested by Andersen et al, strategies to improve mammography use include improving access to primary care physicians, increasing the number of mammography facilities located in rural areas, and increasing outreach efforts by a network of public health professionals promoting screening in their community (28). In addition, pointing out the variations in care may lead to improvements, since the first step toward change is identifying a problem. With identification of particular areas of need, resources can be garnered toward alleviating the disparity.

Persistent disparities in mammography use after adjusting for community level of educational attainment and marital status were found. Other studies have found that patients with cancer living in census tracts with lower median levels of education attainment are diagnosed in later disease stages than are patients in tracts with higher median levels of education (29). Studies have also shown that one predictor for getting a mammogram is being married (37).

This study demonstrates the use of percentage of BCIS as a tool for comparing population-based mammography screening rates in different geographic areas. Using cancer incidence data to monitor population-based rates of breast cancer screening is possible throughout the nation, because data from population-based cancer registries are now widely available, often by ZIP code or census tract. This method permits comparison of mammography screening rates among geographic areas smaller than areas used in many previous studies of geographic variation in the early detection of breast cancer (2).

The method described in this article can be used to complement other ways to assess the quality of health care in communities, such as the Health Plan Employer Data and Information Set (HEDIS), created by the National Committee for Quality Assurance. HEDIS addresses overall rates in managed care but does not include the underinsured or fee-for-service populations particularly at risk for inadequate screening (34). Cancer registry data are population based; therefore, using cancer registry data is not only effective but also economical and efficient for outreach specialists and health providers.

A potential weakness in this method is the representativeness of the statewide tumor registry. However, the WCRS has been evaluated by the North American Association of Central Cancer Registries and was given its gold standard for quality, completeness, and timeliness in 1995 and 1996, the first 2 years this standard was recognized (38). Completeness estimates are a general measure of accuracy. The WCRS participated in national audits that measured completeness in 1987, 1992, and 1996 as well as one formal study in 1982. Overall, the quality of the data improved slightly after 1994 when clinics and neighboring state data-sharing agreements were implemented (oral communication, Laura Stephenson, WCRS, July 2005). In addition, the tumor registry has used standard methods for classifying tumor stage (e.g., in situ) throughout the entire period of the study. Incidence data from data sources of lesser quality or completeness than the WCRS would need to be carefully evaluated for use in this type of analysis.

Another limitation of this type of analysis is our use of BCIS as a proxy for mammography screening practices. Undoubtedly, some diagnoses of BCIS result from diagnostic mammograms, but reported use of screening mammograms by individuals and medical facilities correlates strongly with percentage of BCIS over time, particularly ductal carcinoma in situ (18-20). Furthermore, we chose to exclude lobular carcinoma in situ from our BCIS category because this condition is often opportunistic (13-15).

A third limitation, which would be found in any type of geographic analysis, rests on the accuracy of the assignment of participants to the proper location. For area analysis (e.g., ZIP code, county), this legitimate concern is ameliorated by using tools to check ZIP codes and county assignments for correctness. For this study, women diagnosed with breast cancer provided their addresses, including county of residence, to their medical facilities. These addresses were forwarded to the WCRS, where quality-control checks were implemented to validate ZIP code and county assignments. For example, lists of ZIP codes and their county codes were cross-referenced to the ZIP codes and county codes of the addresses provided by the women diagnosed with breast cancer. Inaccuracies were corrected by the WCRS (oral communication, Laura Stephenson, WCRS, January 2005).

Although there has been significant improvement in breast cancer screening across the state and county, this study demonstrates that the improvement has not been uniform. The maps clearly indicate for program directors and policy makers the areas where further outreach and research should be conducted. More specifically, this type of analysis can be used to identify specific areas (such as ZIP codes) within a community (such as a county) with varying rates of early-stage breast cancer. Using this method, public health professionals can provide population-level data to all health care providers to target interventions to improve the early detection of breast cancer in other counties in Wisconsin and other states. Finally, this type of analysis is useful for comprehensive cancer control efforts and can be conducted for other cancers with effective screening methods, such as colorectal cancer.

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Author Information

Corresponding Author: Jane A. McElroy, PhD, Comprehensive Cancer Center, 610 Walnut St, 307 WARF, Madison, WI 53726. Telephone: 608-265-8780. E-mail: jamcelroy@wisc.edu.

Author Affiliations: Patrick L. Remington, MD, Comprehensive Cancer Center and Department of Population Health Sciences, University of Wisconsin, Madison, Wis; Ronald E. Gangnon, PhD, Department of Population Health Sciences and Biostatistics and Medical Informatics, University of Wisconsin, Madison, Wis; Luxme Hariharan, Department of Molecular Biology, University of Wisconsin, Madison, Wis; LeAnn D. Andersen, MS, Department of Population Health Sciences, University of Wisconsin, Madison, Wis.

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