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Geographic access to mammography and its relationship to breast cancer screening and stage at diagnosis: a systematic review

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Abstract

Introduction—A review was conducted to summarize the current evidence and gaps in the literature on geographic access to mammography and its relationship to breast cancer-related outcomes.

Methods—Ovid Medline and PubMed were searched for articles published between January 1, 2000 and April 1, 2013 using Medical Subject Headings and key terms representing geographic accessibility and breast cancer-related outcomes. Due to a paucity of breast cancer treatment and mortality outcomes meeting the criteria (N=6), outcomes were restricted to breast cancer screening and stage at diagnosis. Studies included one or more of the following types of geographic accessibility measures: capacity, density, distance and travel time. Study findings were grouped by outcome and type of geographic measure.

Results—Twenty-one articles met inclusion criteria. Fourteen articles included stage at diagnosis as an outcome, five included mammography utilization, and two included both. Geographic measures of mammography accessibility varied widely across studies. Findings also varied, but most articles found either increased geographic access to mammography associated with increased utilization and decreased late-stage at diagnosis or no statistically significant association.

Conclusion—The gaps and methodologic heterogeneity in the literature to date limit definitive conclusions about an underlying association between geographic mammography access and breast cancer-related outcomes. Future studies should focus on the development and application of more precise and consistent measures of geographic access to mammography.

INTRODUCTION

Breast cancer is the most frequently diagnosed cancer among women and the second leading cause of cancer death among women in the U.S. (Siegel et al., 2014). Early breast cancer detection through regular mammography screening is an important factor in breast cancer survival, as screen-detected cancers are more likely to be diagnosed with more favorable prognostic factors than symptom-detected cancers (Burke et al., 2008; Chiarelli et al., 2012; Dillon et al., 2004). Numerous studies have documented persistent disparities in mammography utilization and in late-stage diagnosis across age, race/ethnicity, and socioeconomic status.

Disparities in utilization may be due to a number of potential barriers in accessing mammography services, including poor geographic access to services. If only a few mammography facilities are located in a large geographic area or in an area serving a large population this may result in limited availability of mammography appointments and longer wait lists to be seen. This can present as a barrier to women seeking regular screening mammography or timely diagnosis of abnormal mammograms. Long travel distance/times to a mammography facility may also be a barrier that hinders women from seeking screening mammography on a recommended schedule. Longer times between screenings due to this barrier may result in a later stage at diagnosis.

There are numerous ways to define access to healthcare services. Aday and Anderson define access, specifically geographic accessibility, as a “function of time and physical space that must be traversed to receive care” which is aside from the mere existence of care (Aday & Andersen, 1974). Penchansky and Thomas define five specific dimensions of access: availability, accessibility, accommodation, affordability, and acceptability. Within this concept, availability refers to the adequacy of supply of physicians or facilities, whereas accessibility refers to the supply location in relation to demand (Penchansky & Thomas, 1981). With respect to healthcare facility accessibility, capacity (number of facilities that exist per number of individuals served in a pre-defined area) and density (number of facilities in a pre-defined area) and are two measures that have been previously reported. Other geographic measures, such as distance, travel time or some combination of both measures have also been utilized. Yang, Goerge, and Mullner found that the combination of measures, such as distance to nearest facility, and demand for services comprise the best geographic accessibility measures. Examples of such measures include the two-step catchment area (2SFCA) method and the kernel density (KD) method (Yang, Goerge, & Mullner, 2006). Geographic information systems (GIS), computer systems used to manage and display spatially referenced data on maps, can be used to describe the distribution of health services or disease patterns over space and time (Higgs, 2004) and can be used to calculate spatial accessibility measures such as the 2SFCA and KD method (Yang et al., 2006).

Studies have evaluated the relationship between geographic access and mammography utilization and/or stage at diagnosis, and have shown mixed results with regards to direction of the association and statistical significance. The purpose of this review is to synthesize the existing literature examining the relationship between geographic access measures (capacity, density, travel distance and travel time) and both mammography utilization and breast cancer stage at diagnosis. The goal is to better understand the scope of the literature on this topic, assess the direction of these relationships across studies, and identify future research needs.

METHODS

Literature Search

Searches were conducted in Ovid Medline and PubMed using the following Medical Subject Headings and key terms in the title/abstract: (“Geographic Information Systems”[MeSH] OR “Geographic information systems” OR “geographic distance” OR “Spatial Analysis” [MeSH] OR “spatial analysis” OR “Geographic Mapping”[MeSH] OR “geographic mapping” OR “geographic locations” OR GIS OR “kernel density” OR “service density” OR “geographic density” OR “Health services accessibility” OR “accessibility” OR “travel time”)) AND (“Breast Neoplasms”[MeSH] OR “Mammography/utilization”[MeSH] OR “mammography utilization” OR “breast neoplasms” OR (“breast cancer” AND (incidence OR screening OR survival OR “drug therapy” OR therapy OR “follow-up time” OR “time-to-treatment”))). The search was limited to English language articles that were published between January 1, 2000 and April 1, 2013. Articles were limited to those published since 2000 due to technologic advancements in GIS and the development of the 2SFCA in 2000 (Radke & Mu, 2000).

Inclusion Criteria and Data Extraction

After excluding duplicates (N=553), the initial query returned 798 articles of which the title and abstract were screened by two reviewers (JLE and JAK; Figure 1). Studies were excluded if conducted outside the U.S. due to differences in healthcare systems that may affect accessibility to mammography. Articles were restricted to those including a specific set of geographic measures of mammography access (i.e., capacity, density, travel distance, and travel time; Table 1) and breast cancer related outcomes (i.e., mammography screening or diagnostic utilization, stage at diagnosis, timeliness or type of treatment received and breast cancer mortality). Capacity measures are calculated as the number of facilities per number of individuals served in a pre-defined geographic area, whereas density measures include those calculated as the number of facilities in a pre-defined geographic area. Travel distance and travel time measures include road network-based or Euclidean (“as the crow flies”) measures.

Four articles included treatment outcomes (Lipscomb et al., 2012; Punglia et al., 2006; Schroen et al., 2005; Voti et al., 2006), only two of which used comparable treatment outcome measures. Two articles included breast cancer mortality outcomes (Russell et al. 2011; Tian et al., 2012), but used different geographic measures (capacity vs. travel time/distance). Due to a paucity of articles found on treatment received or breast cancer mortality and limited ability to group these articles by geographic measures or outcomes for

comparison, the authors decided to focus the review only on access to screening mammography facilities and its relationship with mammography utilization and stage at breast cancer diagnosis. Ultimately, seventeen articles met our inclusion criteria. The bibliographic references listed in relevant papers were manually searched, through which 4 additional references were identified, resulting in a total of twenty-one articles for review. Data were extracted from these articles by JLE and JAK into an excel spreadsheet which included columns for data source for both study population and mammography facilities, population, location, descriptions and categorization of the geographic measure(s) of access, descriptions and categorizations of outcomes, additional covariates included in the analysis, and primary results. Any articles for which inclusion was questionable were discussed by all authors until consensus was reached. Specifically, the authors decided to keep one article in which the outcome was tumor size (Schroen & Lohr, 2009) since it is one of the main components of breast cancer TNM staging (*AJCC Cancer Staging Manual*, 2010). Descriptions of included articles are presented in two tables separated by outcome (mammography utilization and stage of diagnosis). Tables are organized by type of access measure: capacity, density, distance, and travel time.

RESULTS

Table 2 describes the articles (n=7) examining the relationship between geographic access and mammography utilization, while Table 3 includes articles (n=16) examining the association with stage at diagnosis. Many articles reported results on more than one access measure and are therefore listed multiple times.

Mammography Utilization

Seven articles analyzed geographic access to mammography in relation to screening (Table 2)(Coughlin et al., 2008; Elkin et al., 2010; Elting et al., 2009; Engelman et al., 2002; Marchick & Henson, 2005; Meersman et al., 2009; Rahman et al., 2009). Most authors used FDA-certified mammography facility locations and defined mammography utilization as having had a mammogram within the previous two years. Five included measures of capacity (Coughlin et al., 2008; Elkin et al., 2010; Elting et al., 2009; Marchick & Henson, 2005; Rahman et al., 2009), two included a density measure (Marchick & Henson, 2005; Meersman et al., 2009), two included distance measures (Engelman et al., 2002; Meersman et al., 2009), and none included travel time. While the outcome definition was fairly consistent across articles, there was variability in the methods and categorizations of geographic measures.

Sample sizes varied from 2,042 (Rahman et al., 2009) to 891,929 (Elkin et al., 2010), and geographic areas ranged from smaller areas, such as cities and counties, to nationwide coverage. Rahman et al. was the only article that reported mammography utilization among a population of women who had been diagnosed with breast cancer, whereas the other articles included a screening population (Rahman et al., 2009). Studies by Rahman et al. and Meersman et al. were conducted in metropolitan areas (Denver metropolitan area and Los Angeles County, respectively), whereas the other five studies were conducted with state or national level data (Meersman et al., 2009; Rahman et al., 2009). Data sources included state

cancer registries (Elting et al., 2009; Rahman et al., 2009), California Health Interview Survey (CHIS) (Meersman et al., 2009), Behavioral Risk Factor Surveillance System (BRFSS) (Coughlin et al., 2008; Elkin et al., 2010; Elting et al., 2009), Medicare (Elkin et al., 2010; Engelman et al., 2002), and Surveillance Epidemiology and End Results (SEER) (Marchick & Henson, 2005). Marchick et al. was the only ecologic study among the group with states used for the unit of analysis (Marchick & Henson, 2005).

Geographic measures of capacity varied in complexity from the presence of at least one mammography facility in a county (Elting et al., 2009), to the number of mammography screening centers or machines per X number of women in a county (Coughlin et al., 2008; Elkin et al., 2010; Marchick & Henson, 2005), to the more complex 2SFCA at the zip code level (Rahman et al., 2009). Density was described as both the number of mammography facilities within a 2 mile buffer of residence (Meersman et al., 2009) and the number of mammography facilities per 1,000 square miles (Marchick & Henson, 2005). Distance based on the road network was used for one study (Engelman et al., 2002), while Euclidean distance was measured in another (Meersman et al., 2009).

Both Elting et al. and Elkin et al. found that increased mammography capacity was positively associated with having had a mammogram within the last 2 years, whereas Marchick et al. found no association between mammography use within the last year and capacity (Elkin et al., 2010; Elting et al., 2009; Marchick & Henson, 2005). Coughlin et al. found slight, but statistically significant, differences in the percentage of women who had a mammogram within the last 2 years by the number of mammography facilities per 100,000 women in bivariate analysis (Coughlin et al., 2008). Mammography use was lowest for 3 or more facilities (73.7%) and increased from <1 (76.1%), 1–2 (77.3%), to 2–3 (77.9%) facilities; however, no association was found in multivariate analysis (Coughlin et al., 2008). Diverging from the other studies, Rahman et al. found an inverse association such that women with greater accessibility scores were less likely to report having had a previous mammogram (Rahman et al., 2009). Both Meersman et al. and Marchick et al. found increased mammography use associated with increased density of mammography facilities (Marchick & Henson, 2005; Meersman et al., 2009). While Engelman et al. found an inverse association between distance and having had a mammogram (Engelman et al., 2002), Meersman et al. did not find an association between mammography use and distance from residence to nearest mammography facility (Meersman et al., 2009).

There appeared to be trends in results by size of the geographic area. Conclusions varied within the state and smaller area studies (Elting et al., 2009; Meersman et al., 2009; Rahman et al., 2009), whereas more consistent positive associations between access and mammography use were found in larger national studies (Elkin et al., 2010; Engelman et al., 2002; Marchick & Henson, 2005).

Stage at Diagnosis

Sixteen articles analyzed geographic access to mammography in relation to stage at breast cancer diagnosis (Table 3)(Celaya et al., 2010; Dai, 2010; Elting et al., 2009; Goovaerts, 2010; Gumpertz, Pickle, Miller, & Bell, 2006; Henry et al., 2011; Henry et al., 2013; Huang, Dignan, Han, & Johnson, 2009; Lian, Struthers, & Schootman, 2012; L. Luo, McLafferty, &

Wang, 2010; Marchick & Henson, 2005; McLafferty & Wang, 2009; Onega et al., 2011; Schroen & Lohr, 2009; Tarlov et al., 2009; Wang et al., 2008). Authors either used FDA-certified mammography facilities, did not report the source of mammography facility locations, or used study-specific Group Health radiology facilities (Onega et al., 2011). Four articles included measures of capacity (Dai, 2010; Elting et al., 2009; Lian et al., 2012; Marchick & Henson, 2005), three included a density measure (Henry et al., 2013; Lian et al., 2012; Marchick & Henson, 2005), seven measured distance (Celaya et al., 2010; Goovaerts, 2010; Gumpertz et al., 2006; Huang et al., 2009; L. Luo et al., 2010; Schroen & Lohr, 2009; Tarlov et al., 2009), and seven measured travel time (Celaya et al., 2010; Henry et al., 2011; Henry et al., 2013; Lian et al., 2012; McLafferty & Wang, 2009; Onega et al., 2011; Wang et al., 2008). The majority of articles used AJCC or SEER staging systems and categorized the outcome into advanced or late stage disease at diagnosis versus early stage. One article used AJCC tumor size categories as their outcome (Anneke T. Schroen & Lohr, 2009) and was included in this section since staging is dependent on tumor size.

Sample sizes varied from 1,306 (Onega et al., 2011) to 161,619 women (Henry et al., 2013) and geographic areas ranged from smaller metropolitan areas to larger nationwide coverage. The majority of the studies included women 40 and older diagnosed with breast cancer. Marchick et al. was an ecologic study using the percent of advanced stage diagnoses at the county level as an outcome (Marchick & Henson, 2005). Data sources included state cancer registries (Celaya et al., 2010; Dai, 2010; Elting et al., 2009; Goovaerts, 2010; Henry et al., 2011; Henry et al., 2013; Huang et al., 2009; Lian et al., 2012; L. Luo et al., 2010; McLafferty & Wang, 2009; Schroen & Lohr, 2009; Tarlov et al., 2009; Wang et al., 2008), SEER (Gumpertz et al., 2006; Marchick & Henson, 2005) and enrollees in the Group Health integrated health care delivery system (Onega et al., 2011).

Capacity measures included the presence of mammography facilities in a county (Elting et al., 2009), number of mammography facilities per 10,000 women (Marchick & Henson, 2005) and 2SFCA scores (Dai, 2010; Lian et al., 2012). Lian et al. applied six different levels of weighting to the 2SFCA and analyzed each type of weighted accessibility score (Lian et al., 2012). Density was measured as the number of mammography machines at facilities reached within a 30 minute drive time (Lian et al., 2012), number of mammography facilities within 1,000 square miles (Marchick & Henson, 2005), and an accessibility score that considered both the number of mammography facilities and drive times (Henry et al., 2013). Distances were measured from the patient's address (Celaya et al., 2010; Goovaerts, 2010; Huang et al., 2009; Schroen & Lohr, 2009; Tarlov et al., 2009), or zip code (L. Luo et al., 2010) or census tract centroid (Gumpertz et al., 2006; L. Luo et al., 2010) to the nearest mammography facility using road network (Celaya et al., 2010; Huang et al., 2009; L. Luo et al., 2010; Schroen & Lohr, 2009; Tarlov et al., 2009) and Euclidean measurements (Goovaerts, 2010). Travel time was calculated from the patient's address (Celaya et al., 2010; Henry et al., 2011), zip code (McLafferty & Wang, 2009; Wang et al., 2008), census tract or block centroid (Henry et al., 2013; Lian et al., 2012; Onega et al., 2011) to the nearest mammography facility (Celaya et al., 2010; Henry et al., 2013; Lian et al., 2012; McLafferty & Wang, 2009; Wang et al., 2008) or the patient's diagnostic facility (Henry et al., 2011) based on the road network (Celaya et al., 2010; Henry et al., 2013; Lian

et al., 2012; McLafferty & Wang, 2009; Onega et al., 2011; Wang et al., 2008) or Euclidean distance (Henry et al., 2011).

Overall, findings were mixed and largely not statistically significant. There did not appear to be any trends in results by size of the geographic area. Conclusions varied within the national level studies, as well as within state and smaller area studies. Three articles found increased odds of late stage diagnosis with decreased mammography facility capacity (Dai, 2010; Elting et al., 2009; Lian et al., 2012), while one study found no association (Marchick & Henson, 2005). Of the three articles with density measures, one found less accessibility associated with late stage at diagnosis (Henry et al., 2013) another found no association (Lian et al., 2012), and the third found a positive correlation between access and late stage diagnosis among white women and a negative association among black women (Marchick & Henson, 2005). Four of the seven distance measure articles found no association between distance and late stage diagnosis (Celaya et al., 2010; Goovaerts, 2010; Schroen & Lohr, 2009; Tarlov et al., 2009). Gumpertz et al. and Huang et al. found increased odds of late stage diagnosis with increased distance from mammography (Gumpertz et al., 2006; Huang et al., 2009). Luo et al. also found a negative association, but only at by zip code level and only in one of the two counties included in the study (L. Luo et al., 2010). Henry et al. found an unexpected result that women living greater than a 40 minute travel time to their diagnosing facility were less likely to be diagnosed at a later stage compared to women living less than 40 minutes from their diagnosing facility (Henry et al., 2011). None of the other articles examining travel time found significant associations.

DISCUSSION

Acknowledgement of system-level factors in the role of health has brought attention to issues such as access to mammography. Additionally, advancements in GIS methods and increasingly available large electronic datasets have made the evaluation of geographic access more feasible than it has been in the past. However, the most appropriate GIS methods and measures of mammography accessibility have not yet been established and this review demonstrates that there is great variation in current approaches. Improvements have been made by researchers such as W. Luo, F. Wang, M. McGrail, and P. Delamater, although their methods have not been adopted widely in the public health literature (Delamater, 2013; W. Luo & Qi, 2009; W. Luo & Wang, 2003; McGrail, 2012). The purpose of this review was to assemble and describe the literature examining geographic access and breast cancer-related outcomes as well as identify gaps in this area of the literature. The variation in measures used and results from these studies were described. While some studies examined access to treatment facilities and other outcomes, such as receipt of treatment and mortality, this area of the literature is sparse and does not allow for sufficient comparison. This is revealed as a gap in the literature requiring further attention. Although unable to provide firm conclusions, this review does serve to introduce future researchers to the state of the science and gaps in the literature.

Overall, there was great variability in measures of geographic access to mammography. Outcomes also varied, but the majority found either increased geographic access to mammography was associated with increased utilization and decreased late-stage at

diagnosis or no statistically significant association. Only three articles found an unexpected reverse association (Henry et al., 2011; Marchick & Henson, 2005; Rahman et al., 2009). Few articles distinguished between rural/urban populations inhibiting comparisons between the two. The majority of analyses using distance and travel time measures found no statistically significant results between geographic access and mammography use or late-stage at diagnosis, whereas the majority of results from capacity and density found statistically significant associations. This suggests that distance and travel time alone may not be sufficient measures of geographic access to care since neither method accounts for size of the geographic area being examined or the underlying population composition (i.e., service demand) (Eberth et al., 2014; Gumpertz et al., 2006), however it is difficult to draw conclusions based on inconsistencies across studies in methods of measurement within each type of geographic measure.

There are several limitations including the potential accuracy and wide variability in measures that creates difficulty in drawing conclusions on the effect of access to mammography facilities on patient outcomes. The majority of studies examined access to the nearest mammography facility rather than actual facilities used by women for screening. For example, it could be possible that the facility nearest to a woman's home may not accurately represent the facility she visits (Liu et al., 2008; Tai, Porell, & Adams, 2004). Some women may travel further for screening out of preference or due to insurance factors (Liu et al., 2008; Tai et al., 2004). The nearest facility approach is especially biased in urban areas, where women have more choices of mammography facilities to choose from (McGrail, 2012). Women may also seek care closer to their workplace since appointments may occur during work hours. Actual travel patterns may be more strongly tied to patient outcomes than measures of potential accessibility (Massarweh et al., 2014; Schroen et al., 2005); however, clinical and public health datasets rarely collect data on women's place of employment or origin for care-seeking. Henry et al. examined both actual travel time to each woman's diagnosing facility as well as their nearest mammography facility among women from 10 U.S. states (Henry et al., 2011). On average, the travel time to a woman's actual diagnosing facility was longer than to the nearest mammography facility. Interestingly, the study found women with longer travel times to their diagnosing facility had lower odds of late stage diagnosis than those with shorter travel times. No association was found between travel time to the nearest mammography facility and stage at diagnosis. These unexpected and differing results between actual and potential access suggest a need to further explore the actual geographic patterns of seeking care rather than access to the nearest facilities.

The great variability in measures of geographic access to mammography hinders the ability to draw definitive conclusions from this literature. Even examined separately by type of access measure (capacity, density, travel distance, travel time), there was major heterogeneity in measurement. For example, some studies used a geographic centroid to represent patient residence, while others used actual patient address. Furthermore, most articles used one method of measuring access which did not allow for making comparisons across methods. Lian et al., however, sought to compare several measures of mammography accessibility including two measures of travel time to the nearest facility, a density measure, and six variations of the 2SFCA in metropolitan St. Louis, in which 337,966 women of screening age live (Lian et al., 2012). The study found low correlation and low agreement

between accessibility measures. Only one of the measures, the most precise 6-time zone weighted 2SFCA, showed increased accessibility associated with decreased odds of late stage diagnosis, whereas all other measures were not statistically significant (Lian et al., 2012). Given the low agreement across measures, as well as mixed findings between measures in Lian et al's study, it proves difficult to draw definitive conclusions across this literature. However, it is important to note that Lian et al's study was confined to a two adjacent counties and did not use actual facilities visited or specific patient addresses, rather they used the nearest facilities and census block centroids. Providing a sensitivity analysis across measures does represent a significant advancement in how studies have been conducted to date.

IMPLICATIONS FOR PRACTICE AND/OR POLICY

This review suggests that additional research, using sophisticated measures of geographic accessibility, is needed to provide more conclusive evidence of the effect of geographic access to mammography on breast cancer related outcomes. These studies can provide valuable information about regionally-specific relationships between access to care and patient outcomes, which can in turn help inform targeted interventions to increase geographic access to care in specific areas or among subgroups of the population.

CONCLUSIONS

To draw clearer conclusions about the role of geographic access to mammography and mammography use and cancer outcomes, more accurate representations of geographic access to care are needed. In addition to improved measures, future studies should explore actual travel patterns in patient care-seeking (e.g., utilized accessibility).

References

- Aday LA, Andersen R. A framework for the study of access to medical care. *Health Serv Res.* 1974; 9(3):208–220. [PubMed: 4436074]
- Edge, S.; Byrd, DR.; Compton, CC.; Fritz, AG.; Greene, FL.; Trotti, A., editors. *AJCC Cancer Staging Manual.* 7th. 2010.
- Burke JP, Power C, Gorey TF, Flanagan F, Kerin MJ, Kell MR. A comparative study of risk factors and prognostic features between symptomatic and screen detected breast cancer. *Eur J Surg Oncol.* 2008; 34(2):149–153. DOI: 10.1016/j.ejso.2007.03.025 [PubMed: 17498912]
- Celaya MO, Berke EM, Onega TL, Gui J, Riddle BL, Cherala SS, Rees JR. Breast cancer stage at diagnosis and geographic access to mammography screening (New Hampshire, 1998–2004). *Rural Remote Health.* 2010; 10(2):1361. [PubMed: 20438282]
- Chiarelli AM, Edwards SA, Sheppard AJ, Mirea L, Chong N, Paszat L, O'Malley FP. Favourable prognostic factors of subsequent screen-detected breast cancers among women aged 50–69. *Eur J Cancer Prev.* 2012; 21(6):499–506. DOI: 10.1097/CEJ.0b013e328350b0f4 [PubMed: 22273849]
- Coughlin SS, Leadbetter S, Richards T, Sabatino SA. Contextual analysis of breast and cervical cancer screening and factors associated with health care access among United States women, 2002. *Soc Sci Med.* 2008; 66(2):260–275. doi: S0277-9536(07)00509-6 [pii]10.1016/j.socscimed.2007.09.009. [PubMed: 18022299]
- Dai D. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. *Health Place.* 2010; 16(5):1038–1052. DOI: 10.1016/j.healthplace.2010.06.012 [PubMed: 20630792]

- Delamater PL. Spatial accessibility in suboptimally configured health care systems: a modified two-step floating catchment area (M2SFCA) metric. *Health Place*. 2013; 24:30–43. DOI: 10.1016/j.healthplace.2013.07.012 [PubMed: 24021921]
- Dillon MF, Hill AD, Quinn CM, O'Doherty A, Crown J, Fleming FJ, O'Higgins N. Surgical intervention in screen-detected patients versus symptomatic patients with breast cancer. *J Med Screen*. 2004; 11(3):130–134. DOI: 10.1258/0969141041732238 [PubMed: 15333271]
- Eberth JM, Eschbach K, Morris JS, Nguyen HT, Hossain MM, Elting LS. Geographic disparities in mammography capacity in the South: a longitudinal assessment of supply and demand. *Health Serv Res*. 2014; 49(1):171–185. DOI: 10.1111/1475-6773.12081 [PubMed: 23829179]
- Elkin EB, Ishill NM, Snow JG, Panageas KS, Bach PB, Liberman L, Schrag D. Geographic access and the use of screening mammography. *Med Care*. 2010; 48(4):349–356. DOI: 10.1097/MLR.0b013e3181ca3ecb [PubMed: 20195174]
- Elting LS, Cooksley CD, Bekele BN, Giordano SH, Shih YC, Lovell KK, Theriault R. Mammography capacity impact on screening rates and breast cancer stage at diagnosis. *Am J Prev Med*. 2009; 37(2):102–108. DOI: 10.1016/j.amepre.2009.03.017 [PubMed: 19524392]
- Engelman KK, Hawley DB, Gazaway R, Mosier MC, Ahluwalia JS, Ellerbeck EF. Impact of geographic barriers on the utilization of mammograms by older rural women. *J Am Geriatr Soc*. 2002; 50(1):62–68. [PubMed: 12028248]
- Goovaerts P. Visualizing and testing the impact of place on late-stage breast cancer incidence: a non-parametric geostatistical approach. *Health Place*. 2010; 16(2):321–330. DOI: 10.1016/j.healthplace.2009.10.017 [PubMed: 19959392]
- Gumpertz ML, Pickle LW, Miller BA, Bell BS. Geographic patterns of advanced breast cancer in Los Angeles: associations with biological and sociodemographic factors (United States). *Cancer Causes Control*. 2006; 17(3):325–339. DOI: 10.1007/s10552-005-0513-1 [PubMed: 16489540]
- Henry KA, Boscoe FP, Johnson CJ, Goldberg DW, Sherman R, Cockburn M. Breast cancer stage at diagnosis: is travel time important? *J Community Health*. 2011; 36(6):933–942. DOI: 10.1007/s10900-011-9392-4 [PubMed: 21461957]
- Henry KA, Sherman R, Farber S, Cockburn M, Goldberg DW, Stroup AM. The joint effects of census tract poverty and geographic access on late-stage breast cancer diagnosis in 10 US States. *Health Place*. 2013; 21:110–121. DOI: 10.1016/j.healthplace.2013.01.007 [PubMed: 23454732]
- Higgs G. A Literature Review of the Use of GIS-Based Measures of Access to Health Care Services. *Health Services and Outcomes Research Methodology*. 2004; 5(2):119–139. DOI: 10.1007/s10742-005-4304-7
- Huang B, Dignan M, Han D, Johnson O. Does distance matter? Distance to mammography facilities and stage at diagnosis of breast cancer in Kentucky. *J Rural Health*. 2009; 25(4):366–371. DOI: 10.1111/j.1748-0361.2009.00245.x [PubMed: 19780916]
- Lian M, Struthers J, Schootman M. Comparing GIS-based measures in access to mammography and their validity in predicting neighborhood risk of late-stage breast cancer. *PLoS One*. 2012; 7(8):e43000.doi: 10.1371/journal.pone.0043000 [PubMed: 22952626]
- Lipscomb J, Gillespie TW, Goodman M, Richardson LC, Pollack LA, Ryerson AB, Ward KC. Black-white differences in receipt and completion of adjuvant chemotherapy among breast cancer patients in a rural region of the US. *Breast Cancer Research & Treatment*. 2012; 133(1):285–296. doi: <http://dx.doi.org/10.1007/s10549-011-1916-1>. [PubMed: 22278190]
- Liu JJ, Bellamy G, Barnett B, Weng S. Bypass of local primary care in rural counties: effect of patient and community characteristics. *Ann Fam Med*. 2008; 6(2):124–130. DOI: 10.1370/afm.794 [PubMed: 18332404]
- Luo L, McLafferty S, Wang F. Analyzing spatial aggregation error in statistical models of late-stage cancer risk: a Monte Carlo simulation approach. *Int J Health Geogr*. 2010; 9:51.doi: 10.1186/1476-072X-9-51 [PubMed: 20959015]
- Luo W, Qi Y. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health Place*. 2009; 15(4):1100–1107. DOI: 10.1016/j.healthplace.2009.06.002 [PubMed: 19576837]

- Luo W, Wang F. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design*. 2003; 30(6): 865–884.
- Marchick J, Henson DE. Correlations between access to mammography and breast cancer stage at diagnosis. *Cancer*. 2005; 103(8):1571–1580. DOI: 10.1002/cncr.20915 [PubMed: 15772962]
- Massarweh NN, Chiang YJ, Xing Y, Chang GJ, Haynes AB, You YN, Cormier JN. Association between travel distance and metastatic disease at diagnosis among patients with colon cancer. *J Clin Oncol*. 2014; 32(9):942–948. DOI: 10.1200/jco.2013.52.3845 [PubMed: 24516014]
- McGrail MR. Spatial accessibility of primary health care utilising the two step floating catchment area method: an assessment of recent improvements. *Int J Health Geogr*. 2012; 11:50.doi: 10.1186/1476-072x-11-50 [PubMed: 23153335]
- McLafferty S, Wang F. Rural reversal? Rural-urban disparities in late-stage cancer risk in Illinois. *Cancer*. 2009; 115(12):2755–2764. DOI: 10.1002/cncr.24306 [PubMed: 19434667]
- Meersman SC, Breen N, Pickle LW, Meissner HI, Simon P. Access to mammography screening in a large urban population: a multi-level analysis. *Cancer Causes Control*. 2009; 20(8):1469–1482. DOI: 10.1007/s10552-009-9373-4 [PubMed: 19543987]
- Onega T, Cook A, Kirlin B, Shi X, Alford-Teaster J, Tuzzio L, Buist DS. The influence of travel time on breast cancer characteristics, receipt of primary therapy, and surveillance mammography. *Breast Cancer Res Treat*. 2011; 129(1):269–275. DOI: 10.1007/s10549-011-1549-4 [PubMed: 21553117]
- Penchansky R, Thomas JW. The concept of access: definition and relationship to consumer satisfaction. *Med Care*. 1981; 19(2):127–140. [PubMed: 7206846]
- Punglia RS, Weeks JC, Neville BA, Earle CC. Effect of distance to radiation treatment facility on use of radiation therapy after mastectomy in elderly women. *International Journal of Radiation Oncology, Biology, Physics*. 2006; 66(1):56–63.
- Radke J, Mu L. Spatial Decompositions, Modeling and Mapping Service Regions to Predict Access to Social Programs. *Geographic Information Sciences*. 2000; 6(2):105–112. DOI: 10.1080/10824000009480538
- Rahman S, Price JH, Dignan M, Rahman S, Lindquist PS, Jordan TR. Access to Mammography Facilities and Detection of Breast Cancer by Screening Mammography: A GIS Approach. *Int J Canc Prev*. 2009; 2(6):403–413. [PubMed: 20628557]
- Russell E, Kramer MR, Cooper HL, Thompson WW, Arriola KR. Residential racial composition, spatial access to care, and breast cancer mortality among women in Georgia. *J Urban Health*. 2011; 88(6):1117–1129. DOI: 10.1007/s11524-011-9612-3 [PubMed: 21847712]
- Schroen AT, Brenin DR, Kelly MD, Knaus WA, Slingluff CL Jr. Impact of patient distance to radiation therapy on mastectomy use in early-stage breast cancer patients. *Journal of Clinical Oncology*. 2005; 23(28):7074–7080. [PubMed: 16192590]
- Schroen AT, Lohr ME. Travel Distance to Mammography and the Early Detection of Breast Cancer. *The Breast Journal*. 2009; 15(2):216–217. DOI: 10.1111/j.1524-4741.2009.00706.x [PubMed: 19292817]
- Siegel R, Ma J, Zou Z, Jemal A. Cancer statistics, 2014. *CA Cancer J Clin*. 2014; 64(1):9–29. DOI: 10.3322/caac.21208 [PubMed: 24399786]
- Tai WT, Porell FW, Adams EK. Hospital choice of rural Medicare beneficiaries: patient, hospital attributes, and the patient-physician relationship. *Health Serv Res*. 2004; 39(6 Pt 1):1903–1922. DOI: 10.1111/j.1475-6773.2004.00324.x [PubMed: 15533193]
- Tarlov E, Zenk SN, Campbell RT, Warnecke RB, Block R. Characteristics of mammography facility locations and stage of breast cancer at diagnosis in Chicago. *J Urban Health*. 2009; 86(2):196–213. DOI: 10.1007/s11524-008-9320-9 [PubMed: 18972211]
- Tian N, Goovaerts P, Zhan FB, Chow TE, Wilson JG. Identifying risk factors for disparities in breast cancer mortality among African-American and Hispanic women. *Womens Health Issues*. 2012; 22(3):e267–276. doi: <http://dx.doi.org/10.1016/j.whi.2011.11.007>. [PubMed: 22265181]
- Voti L, Richardson LC, Reis IM, Fleming LE, Mackinnon J, Coebergh JW. Treatment of local breast carcinoma in Florida: the role of the distance to radiation therapy facilities. *Cancer*. 2006; 106(1): 201–207. [PubMed: 16311987]

- Wang F, McLafferty S, Escamilla V, Luo L. Late-stage breast cancer diagnosis and health care access in Illinois. *Prof Geogr.* 2008; 60(1):54–69. [PubMed: 18458760]
- Yang DH, Goerge R, Mullner R. Comparing GIS-based methods of measuring spatial accessibility to health services. *J Med Syst.* 2006; 30(1):23–32. [PubMed: 16548411]

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Figure 1.
Flowchart of selection of articles for review

Table 1

Descriptions of included geographic spatial accessibility measures

Distance	The network or Euclidean distance from a location X (e.g., patient home address, tract centroid) to the closest N mammography facilities
Travel Time	The time required to travel by a specified mode of transportation from a location X to the closest N mammography facilities
Capacity	The number of facilities (or mammography machines) per number of persons in the population (e.g., number of clinics per 1,000 women). The two-step floating catchment area (2SFCA) is a more recent measure of accessibility that takes into account both the supply and demand of services within specified geographic catchment area. Variations of this approach have been proposed including the enhanced 2SFCA (E2SFCA), variable 2SFCA (V2SFCA), the spatial accessibility score (SA), and the McGrail Index of Rural Access.
Density	The number of facilities (or mammographic machines) in a pre-defined area (e.g. number of facilities within a 1 mile radius of patient home)

Summaries of articles measuring geographic access to mammography and its relation to breast cancer screening

Table 2

Study Author, Publication Date	Data Source: Population; Mammography Facilities	Sample	Geographic Access Measure	Outcome Description	Model Variables	Overall Results
Outcome: Mammography Utilization						
Spatial Variable: Capacity						
Coughlin et al. 2008	2002 BRFSS ^a ; 2004 Area Resource File	Women over age 40 (n=91,492)	No. of mammography facilities per 100,000 women using the sum of facilities per county	Mammogram vs. no mammogram in the previous 2 years	Adjusted for age, race, Hispanic ethnicity, marital status, education, household income, number of persons in household, health insurance status, rural/non-rural residence, and four interactions between 1) race and number of health centers per 100,000 female population, 2) Hispanic ethnicity and number of health centers per 100,000 women, 3) percentage of county female population non-Hispanic Black and race, 4) percentage of county female population Hispanic and percentage of county female population non-Hispanic Black	In bivariate analysis, mammography use was lowest for 3 or more facilities (73.7%) and increased from <1 (76.1%), 1–2 (77.3%), to 2–3 (77.9%) facilities (p 0.001) No significant association in multivariate analyses (OR not reported).
Elkin et al. 2010	2006 BRFSS and 2004–2005 Medicare beneficiaries; 2004 FDA ^b	BRFSS – Women over age 40 (n=128,802); Medicare – Women over age 65 (n=891,929)	No. of machines per 100,000 women age 40+ by county	Mammogram vs. no mammogram in the previous 2 years	BRFSS analysis adjusted for age, race marital status, education, household income, insurance status, regular source of health care, and check up in the past 2 years. Medicare analysis adjusted for age, race visit with primary care physician during 2004–2005, and comorbidity.	Women in counties with inadequate capacity had reduced odds of having a mammogram (BRFSS-OR: 0.89, 95% CI: 0.80–0.98 ; Medicare-OR: 0.86, 95% CI: 0.85–0.87).
Elting et al. 2009	2004 BRFSS linked to Texas Cancer Registry; 2002–2004 FDA	Women over age 40 (n=2,418)	Presence of at least one mammography facility in county	Mammogram vs. no mammogram in the previous 2 years	Adjusted for age, race, ethnicity, education, income, insurance status, self-reported health, household, usual source of health care, and number of active physicians per capita.	Women in counties with facilities were more likely to have screening (OR: 3.27, 95% CI: 1.11–9.60).
Marchick et al. 2005	2000 SEER ^c ; 2003 FDA	African American and White women	No. of mammography facilities per 10,000 women by county	Percent of women who had a mammogram within the previous year by state	Unadjusted.	No significant correlation (r =0.185; p=0.19).

Study Author, Publication Date	Data Source: Population; Mammography Facilities	Sample	Geographic Access Measure	Outcome Description	Model Variables	Overall Results
Outcome: Mammography Utilization						
Rahman et al. 2009	1999–2001 Colorado Cancer Registry; 1999–2001 Colorado Department of Public Health and Environment	Metropolitan Denver women (n=2,042)	2SFCA ^d combined with travel distance to create an accessibility measure at various distances (10, 20, 30, 40, 50 miles)	Previous mammogram ^e	Adjusted for age, race/ethnicity, education, insurance status, family history, hormone replacement therapy, physician recommendation, and breast cancer stage at diagnosis.	In the 10 mile model, women with high access were less likely to have a previous mammogram (OR: 0.41, 95% CI: 0.22–0.76).
Spatial Variable: Density						
Marchick et al. 2005	2000 SEER; 2003 FDA	African American and White women	No. of mammography facilities per 1,000 sq. miles	Percent of women who had a mammogram within the previous year by state	Unadjusted.	Positive correlation between percent of women with mammogram and the number of mammography facilities ($r=0.556$, $p<0.0001$).
Meersman et al. 2009	2001 CHIS ^f ; 2001 FDA	Los Angeles County women ages 40–84 (n=4,294)	No. of mammography facilities within a 2 mile buffer of residence; categorized into quartiles 0–1, 2–4, 5–10, 11+	Mammogram vs. no mammogram in the previous 2 years	Adjusted for race/ethnicity, education, income, marital status, history of breast cancer, self-reported health, insurance status, and the interaction between English proficiency and usual source of care.	Women with few nearby facilities were less likely to have a mammogram (OR: 0.76, 95% CI: 0.60–0.97).
Spatial Variable: Distance						
Engleman et al. 2002	1997–1998 Medicare beneficiaries; 1997–1998 FDA	Women ages 65–79 (N=117,901)	Road network distance from case residence to permanent and mobile mammography facility; categorized as 0–4, 5–9, 10–19 and 20	Mammogram vs. no mammogram during the study period	Adjusting for age, race, and county education level.	Women living further from permanent mammogram facilities were less likely to have mammogram (OR: 0.97 for each 5-mile increase in distance, 95% CI: 0.95–0.99).
Meersman et al. 2009	2001 CHIS; 2001 FDA	Los Angeles County women ages 40–84 (n=4,294)	Euclidean distance from case residence to the nearest mammography facility; categorized as 0–0.53, 0.54–1.07, 1.08–1.82, 1.83–26.5	Mammogram vs. no mammogram in the previous 2 years	Euclidean distance did not meet criteria for multivariate modeling.	No significant association (OR not reported).

^aBehavioral Risk Factor Surveillance System^bUnited States Food and Drug Administration^cSurveillance Epidemiology and End Result^dTwo-Step Floating Catchment Area

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No timeframe indicated
California Health Interview Survey

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Table 3

Articles measuring geographic access to mammography and its relation to breast cancer stage at diagnosis

Study Author, Publication Date (Reference Number)	Data Source: Population, Mammography Facilities	Sample	Geographic Access Measure	Outcome Description	Model Variables	Overall Results
Outcome: Stage at Diagnosis						
Spatial Variable: Capacity						
Dai 2010	1998–2002 Michigan Cancer Surveillance Program; 2009 FDA ^d	Metropolitan Detroit women (n=12,413)	2SFCA ^b combined with travel time to create an accessibility measure assigned to the zip code	Late-stage (regional/distant) vs. early stage (in situ/localized) diagnosis ^c	Adjusting for percent Black, linguistically isolated households, 25 and older without a high school degree, 16 and older without employment, 17 and older below the poverty level, professional and managerial occupations, occupied home ownership, carless household, occupied home with > 1 occupant per room, female headed household, median income, median housing value, and median gross rent.	Access is negatively correlated with late-stage diagnosis (p<0.05).
Elting et al. 2009	Texas Cancer Registry; 2002–2004 FDA	Women over age 40 (n=2,418)	Presence of at least one mammography facility in county	Locally advanced or disseminated disease vs. very early stage (in situ) ^c	Adjusting for age, race and ethnicity.	Women in counties with facilities were less likely to be diagnosed at advanced stage (OR: 0.36, 95% CI: 0.26–0.51).
Marchick et al. 2005	2000 SEER ^d ; 2003 FDA	African American and White women	No. of mammography facilities per 10,000 women by county	Percent of women with advanced stage (III or IV) vs. early stage (0–II) ^c	Unadjusted.	No significant correlation ([r] not reported).
Lian et al. 2012	2002–2006 Missouri Cancer Registry; 1997–2001 FDA	Metropolitan St. Louis women over age 40 (n=4,205)	2SFCA with 6 different levels of weighting for each census block group	Late stage (II–IV) vs. early stage (0–I) ^e	Adjusted for socioeconomic deprivation, an index based on 6 domains of socioeconomic variables including education, occupation, housing, income and poverty, racial composition, and	Significant association between lower accessibility scores and increased odds of late stage diagnosis for both 6-time zone weighted 2SFCA scores, but not for other types of 2SFCA weighted scores. (No weight: OR: 1.12, 95% CI: 0.96–1.30; Continuous

Study Author, Publication Date (Reference Number)	Data Source: Population, Mammography Facilities	Sample	Geographic Access Measure	Outcome Description	Model Variables	Overall Results
Outcome: Stage at Diagnosis						
residential stability variables.						
weighting: OR: 1.11, 95%CI: 0.97–1.27; 3-time zone weighted: quick-distance-decay OR: 1.09, 95%CI: 0.95–1.25; slow-distance-decay OR: 1.08, 95%CI: 0.95–1.24; 6-time zone weighted: quick-distance-decay OR: 1.15, 95% CI: 1.01–1.32 ; slow-distance-decay OR: 1.19, 95% CI: 1.03–1.37)						
Spatial Variable: Density						
Henry et al. 2013	2004–2006 population-based cancer registries from 10 states; 2006 FDA	Women ages 40+ (n=161,619)	Geographic accessibility score considering number of mammography facilities and the distribution of drive times from census tract centroid to all facilities; 5, >5–10, <10–20, >20–30, >30	Late stage (regional or distant) vs. early stage (in situ or localized) ^c	Adjusted for age, race/ethnicity, census tract poverty, and census tract random effects.	Women living in less accessible areas had slightly higher odds of late stage diagnosis (OR: 1.06, 95%CI: 1.02–1.10).
Lian et al. 2012	2002–2006 Missouri Cancer Registry; 1997–2001 FDA	Metropolitan St. Louis women over age 40 (n=4,205)	No. of mammography machines at facilities that can be reached within 30 minutes/block group population	Late stage (II–IV) vs. early stage (0–I) ^e	Adjusted for socioeconomic deprivation, an index based on 6 domains of socioeconomic variables including education, occupation, housing, income and poverty, racial composition, and residential stability variables.	No significant association (OR: 0.90, 95%CI: 0.79–1.04).
Marchick et al. 2005	2000 SEER; 2003 FDA	African American and White women	No. of mammography facilities within 1,000 square miles	Percent of women with advanced stage (III or IV) vs. early stage (0–II) ^c	Unadjusted.	Among white women, there was a positive correlation between number of mammography facilities per 1,000 square miles ($ r =0.17$, p=0.02). Among African-American women, a negative correlation was observed ($ r =-0.21$, p=0.0040).
Spatial Variable: Distance						

Study Author, Publication Date (Reference Number)	Data Source: Population, Mammography Facilities	Sample	Geographic Access Measure	Outcome Description	Model Variables	Overall Results
Outcome: Stage at Diagnosis						
Celaya et al. 2010	1998–2004 New Hampshire Cancer Registry; 1998–2004 FDA	Women age 40+ (n=5,966)	Network distance to closest facility address from patient's home address; categorized as <5, 5–9, 10–14, and 15	Late stage (stage II–IV) vs. early stage (0–I) ^c	Adjusting for age, marital status, insurance and time of year of diagnosis.	No significant association (<5 ref: 5–9 OR: 0.967, 95%CI: 0.854–1.095; 10–14 OR: 1.112, 95%CI: 0.932–1.327; 15 OR: 0.993, 95%CI: 0.765–1.288).
Goovaerts et al. 2010	1985–2002 Michigan Cancer Surveillance Program; Facility source not reported	White women (n=2,118)	Euclidean distance from patient's residence to closest screening facility	Late stage (regional or distant) vs. early stage (in situ or localized) ^c	Adjusting for poverty and the interaction between poverty and distance to clinics.	No significant association (Poverty estimation constant across census tracts OR: 1.25, 95%CI: 0.63–2.47; Poverty estimation spatially varying OR: 1.38, 95%CI: 0.75–2.51).
Gumpertz et al. 2006	1992–1996 SEER; 2000 FDA	Los Angeles County women (n=24,933)	Distance to nearest screening facility to the census tract of the patient's residence	Advanced (regional with tumor diameter larger than 10cm or distant with any tumor size) vs. non-advanced disease ^g	Adjusting for age, marital status, birthplace, year, first primary, tumor characteristics, census tract socioeconomic variables and aggregated health district tumor characteristics.	Black, Hispanic and White women who lived further from mammography facilities were more likely to be diagnosed with advance disease (OR: 1.35, 95%CI: 0.50–3.68; OR: 2.99, 95%CI: 1.50–5.98 and OR: 1.47, 95% CI: 1.10–1.97, respectively).
Huang et al. 2009	1999–2003 Kentucky Cancer Registry; Facility source not reported	Women age 40+ (n=12,322)	Network distance to closest mammography facility address from patient's home address; categorized as <15 and 15+ miles	Advanced stage (III or IV) vs. early stage (0–II) ^c	Adjusted for age, race, health insurance, and education at census tract level.	Odds of advanced diagnosis were significantly greater for women living 15 miles or farther (OR: 1.5, 95%CI: 1.25–1.80).
Luo et al. 2010	1998–2002 Illinois State Cancer Registry; Facility source not reported	Kane and Peoria County women (n=1,906)	Shortest network travel distance (continuous) from population-weighted zip code centroid and census block geographic centroid to nearest mammography facility	Late stage (II–VII) vs. early stage (I–II) ^c	Adjusting for age and race.	In Kane county, no significant association. In Peoria county, a negative association between zip code level distance and late stage diagnosis was observed (Mean coeff: -3.51 E-4, p 0.1).
Schroen et al. 2009	2000–2001 Virginia State Cancer Registry; 2004 FDA	Women age 40+ (n=8,170)	Shortest network driving distance (continuous) between residence and nearest mammography facility	Tumor size (T1, T2, T3) ^f	Adjusting for age, race, and per capita income.	No significant association (OR not reported).

Study Author, Publication Date (Reference Number)	Data Source: Population, Mammography Facilities	Sample	Geographic Access Measure	Outcome Description	Model Variables	Overall Results
Outcome: Stage at Diagnosis						
Tarlov et al. 2009	1996–1998 Illinois State Cancer Registry; 1997 FDA	Chicago women ages 45+ (n=4,533)	Mean network distance to nearest 5 facilities	In situ, local, regional, distant ^c	Adjusting for age, race/ethnicity, socioeconomic position, and neighborhood racial/ethnic, economic and crime characteristics.	No significant association (OR not reported).
Spatial Variable: Travel Time						
Celaya et al. 2010	1998–2004 New Hampshire Registry; 1998–2004 FDA	Women age 40+ (n=5,966)	Network driving time from closest facility address to patients home address; categorized as <5, 5–9 and 10+ minutes	Late stage (stage II–IV) vs. early stage (0–I) ^c	Adjusting for age, marital status, insurance status and time of year of diagnosis.	No significant association (<5 min OR: 0.911, 95%CI: 0.795–1.043; 10 min OR: 1.002, 95%CI: 0.882–1.139).
Henry et al. 2011	2004–2006 Cancer registries from 10 states; 2005 FDA	Women ages 40+ (n=161,619)	Travel time from residence to mammography facility was assessed by shortest path calculator (a combination of Euclidean distance and speed limit); categorized as <40 and 40+	Late stage (regional or distant) vs. early stage (in situ or localized) ^c	Adjusting for age at diagnosis, race/ethnicity, rural/urban residence, and poverty.	Women who lived >40 minutes from their diagnosing facility had reduced odds of being diagnosed late stage (OR: 0.90, 95%CI: 0.85–0.94).
Henry et al. 2013	2004–2006 population-based cancer registries from 10 states; 2006 FDA	Women ages 40+ (n=161,619)	Shortest network drive time from population-weighted centroid of each census tract to closest mammography facility; categorized as 5, >5–10, <10–20, >20–30, >30	Late stage (regional or distant) vs. early stage (in situ or localized) ^c	Adjusted for age, race/ethnicity, census tract poverty, and census tract random effects.	No significant association (5 min OR: 1; >5–10 min, OR: 0.99, 95%CI: 0.97–1.03; <10–20 min, OR: 1.00, 95%CI: 0.97–1.03; >20–30 min, OR: 1.05, 95%CI: 0.99–1.11; >30 min, OR: 1.07, 95%CI: 1.00–1.14).
Lian et al. 2012	2002–2006 Missouri Cancer Registry; 1997–2001 FDA	Metropolitan St. Louis women over age 40 (n=4,205)	Shortest network travel time from population-weighted block group to mammography facilities	Late stage (II–IV) vs. early stage (0–I) ^e	Adjusted for socioeconomic deprivation, an index based on 6 domains of socioeconomic variables including education, occupation, housing, income and poverty, racial composition, and residential stability variables.	No significant association (OR: 0.99, 95%CI: 0.86–1.14)
Lian et al. 2012	2002–2006 Missouri Cancer Registry; 1997–2001 FDA	Metropolitan St. Louis women over age 40 (n=4,205)	Average travel time of the first 5 shortest network travel times	Late stage (II–IV) vs. early stage (0–I) ^e	Adjusted for socioeconomic deprivation, an index	No significant association (OR: 0.99, 95%CI: 0.86–1.14)

Study Author, Publication Date (Reference Number)	Data Source: Population, Mammography Facilities	Sample	Geographic Access Measure	Outcome Description	Model Variables	Overall Results
Outcome: Stage at Diagnosis						
McLafferty et al. 2009	1998–2002 Illinois Cancer Registry; Facility source not reported	Breast cancer cases (n=44,070)	Centroid of each zip code to nearest screening facility based on road network	Late stage (regional or distant) vs. early stage (in situ or localized) ^c	based on 6 domains of socioeconomic variables including education, occupation, housing, income and poverty, racial composition, and residential stability variables. Adjusting for socioeconomic disadvantage, sociocultural barriers, health care needs, and spatial access to primary care.	No significant association (Coeff.: 0.002, p 0.05 (exact p value not reported)).
Omega et al. 2013	1990–1994 and 1996–1999 Washington State Group Health enrollees linked to SEER; Group Health radiology facilities	Breast cancer diagnoses of first primary, invasive, stage I, IIA or IIB unilateral breast carcinoma among women 65 years old (1990–1994 cohort) and 18 years (1996–1999 cohort) (n=1,306)	Centroid of each census block to nearest Group Health radiology facility based on road network; categorized as 0–10min, >10–20min, >20–30min, >30min	Late stage (node positive involvement or invasive cancer >1 cm) vs. early stage (node negative and <1 cm); stage IIA vs stage I; stage IIB vs. stage I ^e	Adjusting for age and race No significant associations. Late vs early: >10–20min (RR: 1.02, 95%CI: 0.78–1.44) >20–30min (RR: 1.25, 95%CI: 0.93–1.68), >30min (RR: 1.17, 95%CI: 0.80–1.70) Stage IIA vs. stage I: >10–20min (RR: 0.97, 95%CI: 0.87–1.08), >20–30min (RR: 1.06, 95%CI: 0.75–1.49), >30min (RR: 1.07, 95%CI: 0.70–1.64) Stage IIB vs. stage I: >10–20min (RR: 0.80, 95%CI: 0.44–1.48), >20–30min (RR: 1.23, 95%CI: 0.65–2.35), >30min (RR: 0.75, 95%CI: 0.28–1.96)	No significant association (Coeff.: 0.002, Std. Error: 0.002, p=0.395)
Wang et al. 2008	1998–2000 Illinois Cancer Registry; 2000 FDA	Late-stage breast cancer cases (n=9,077)	Network travel time (continuous) to nearest mammography facility from zip code centroid	Late-stage (stages II–VII) vs. early stage ^f	Adjusting for socioeconomic disadvantage, sociocultural barriers, health care needs, and spatial access to primary care physicians.	No significant association (Coeff.: 0.002, Std. Error: 0.002, p=0.395)

^aUnited States Food and Drug Administration^bTwo-Step Floating Catchment Area

^f Authors developed their own staging classification or did not state classification system used

^e Based on the American Joint Committee on Cancer Staging Classification

^d Surveillance Epidemiology and End Result

^c Based on the Surveillance Epidemiology and End Result Staging Classification

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