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Racial disparities in travel time to radiotherapy facilities in the Atlanta metropolitan area

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Abstract

Low-income women with breast cancer who rely on public transportation may have difficulty in completing recommended radiation therapy due to inadequate access to radiation facilities. Using a geographic information system (GIS) and network analysis we quantified spatial accessibility to radiation treatment facilities in the Atlanta, Georgia metropolitan area. We built a transportation network model that included all bus and rail routes and stops, system transfers and walk and wait times experienced by public transportation system travelers. We also built a private transportation network to model travel times by automobile. We calculated travel times to radiation therapy facilities via public and private transportation from a population-weighted center of each census tract located within the study area. We broadly grouped the tracts by low, medium and high household access to a private vehicle and by race. Facility service areas were created using the network model to map the extent of areal coverage at specified travel times (30, 45 and 60 min) for both public and private modes of transportation. The median public transportation travel time to the nearest radiotherapy facility was 56 min vs. approximately 8 min by private vehicle. We found that majority black census tracts had longer public transportation travel times than white tracts across all categories of vehicle access and that 39% of women in the study area had longer than 1 h of public transportation travel time to the nearest facility. In addition, service area analyses identified locations where the travel time barriers are the greatest. Spatial inaccessibility, especially for women who must use public transportation, is one of the barriers they face in receiving optimal treatment.

Keywords

Breast cancer treatment; Geographic disparities; Radiation therapy; Geographic information systems; Healthcare access

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Introduction

Radiation therapy following breast conserving surgery is a currently recommended treatment for local-regional breast cancer and completion of the required course of radiation therapy has been shown to substantially reduce the risk of recurrence as well as to reduce risk of breast cancer mortality (EBCTCG, 2011; Fisher et al., 2002; Julien et al., 2000; National Institutes of Health, 1991; Veronesi et al., 2002; Wapnir et al., 2011). Studies have shown African American and Hispanic women are less likely to receive radiation therapy compared to white women. Women with lower SES and education compared to women with higher SES and education, uninsured women compare to insured women, and women having Medicaid as their health insurance compared to women with other sources of insurance are also less likely to receive radiation therapy (Foley et al., 2007; Parise, Bauer, & Caggiano, 2012; Royak-Schaler et al., 2012; Smith et al., 2010; Tuttle et al., 2012; Voti et al., 2006).

Because radiation therapy requires daily sessions over the course of five to six weeks, initiation and completion of therapy may be especially vulnerable to transportation availability and travel time and distance barriers. These barriers may potentially affect the choice between a mastectomy and breast-conserving surgery. Several studies described a greater likelihood of women undergoing mastectomy rather than breast conserving surgery if they were at a greater distance from a radiation facility or if they were in a rural vs. urban geographic location (Boscoe et al., 2011; Jacobs, Delley, Rosson, Detrain, & Chang, 2008). A study using SEER registry data found that women living 15 miles or further from a radiation facility were less likely to undergo breast-conserving surgery (Nattinger, Kneusel, Hoffmann, & Gilligan, 2001). A study of travel time in northern England found that women who lived further from a radiotherapy center were less likely to undergo radiation therapy (Jones et al., 2008). Similarly in New Zealand, poorer breast cancer survival time was associated with longer travel time to a cancer center (Haynes, Pearce, & Barnett, 2008). Once treatment is initiated, time and distance barriers to facilities may also play a role in the completion of radiation therapy. Ramsey et al. (2009) examined completion of therapy among Washington State Medicaid enrollees and found that 22% of women beginning radiation therapy did not complete the recommended course of treatment and that 24% had at least one interruption. This measure of suboptimal treatment may contribute to the poorer survival rates. In particular, African American women have higher mortality rates compared with white women despite their lower incidence rates (30.5 vs. 21.6 per 100,000 respectively) (U.S. Cancer Statistics Work Group, 2013).

Whereas most of these studies describe time and distance as barriers to healthcare in rural settings or for larger geographic areas comparing both urban and rural settings, simple distance and time measures of access have received less attention and may be less meaningful for urban areas (Guagliardo, 2004). Of the five dimensions of access described by Penchansky and Thomas (1981), the measurements of availability (supply of services) and accessibility (mobility to services) may require a different approach in urban areas. In contrast with rural areas, urban areas have more healthcare facilities, shorter distances to facilities, and multiple modes of travel and routes to these facilities. Nevertheless transportation barriers may exist for lower income, minority, or disadvantaged populations who may depend on public transportation. Access to a private vehicle differs by race in urban areas such as Atlanta where more than 15% of black households have no private vehicle access while only 4% of white households have no private vehicle access (US Census, 2000).

Focusing on public transportation, the aim of our study was to quantify travel time transportation barriers to radiation facilities in the two-county Atlanta metropolitan area. Approaches to quantifying transportation barriers typically have included methods such as Euclidean distance measures from point to point, using the number of facilities within buffers around a point as a measure of accessibility, and the use of trip planners to better quantify travel time barriers. Our approach involved the construction of a multimodal transportation network that allowed us to create services areas for each radiation facility, enabling us to quantify the proportion of women within specified travel times to the nearest facility as well as to highlight geographic areas where travel time to treatment was especially difficult for women using public transportation.

Methods

Overview

Two methods were used to examine access to radiotherapy facilities. The first allowed us to calculate time and distance to facilities and the second provided a way of mapping accessibility to facilities within specified travel times. Both relied on the construction of a multi-modal transportation network model that included all bus and rail routes and stops, and system transfers that provided for the capture of travel, walk, and wait times experienced by public transportation system travelers in the Atlanta metropolitan area. We also built a private transportation network to model travel times by automobile. Using these networks, we calculated travel times to radiation facilities via public and private vehicle transportation from a population-weighted center of each of the 282 census tracts located within the 2-county area served by the Metropolitan Atlanta Rapid Transit Authority (MARTA). A full description of the construction of the multimodal public transportation models has been published previously (Peipins et al., 2011).

Service areas for each facility were created using the network model to map the areal coverage for specified travel times (30, 45 and 60 min) for both public and private vehicle modes of transportation. Using these service areas, we calculated the number of women over 40 years of age within a given travel time to the radiation facilities.

Data sources

We used 2000 U.S. Census data to determine the number of women 40 years of age and older, race, and household access to a private vehicle in each census tract of our study area. The 2000 Census definition of vehicle access describes the number of private vehicles (none, 1, 2, 3, 4, and 5 or more automobiles, vans, or small trucks) available for use by members of a household. We defined access to a private vehicle as none vs. 1 or more vehicles available to a household and categorized access to a private vehicle into tertiles defined as: low vehicle access = more than 20% of the population had no access to a private vehicle, medium vehicle access = 5%– 20% of the population had no access to a private vehicle, and high vehicle access = less than 5% of the population had no access to a private vehicle. Race categories included non-Hispanic black, non-Hispanic white, and all other races (Asian, American Indian and Alaska Native, Native Hawaiian and Pacific Islander and those noting 2 or more races) classified by majority (> = 50%).

No comprehensive database of all radiation therapy facilities in the United States exists (Ballas, Elkin, Schrag, Minsky, & Bach, 2006), so lists must be compiled from a variety of sources. We identified 18 facilities in the two-county study area from facilities listed with the Georgia Department of Community Health, Division of Public Health and the Radiologic Physics Center (Georgia Department of Community Health, 2010). The locations of radiation oncology facilities were geocoded to the street address level of precision using Centrus geocoding software.

The Metropolitan Atlanta Rapid Transit Authority (MARTA) provided an extensive route network containing streets, all bus and rail routes, bus and train and stops, and station entrances as of October 2008. MARTA runs several hundred buses over 138 routes covering over 1000 route-miles. The train system includes 59 miles of rail lines and 38 stations, largely limited to the city of Atlanta and a portion of the surrounding area (MARTA, 2009).

Mapping and analysis

Dasymetric mapping was used to locate a population-weighted centroid for each census tract so as to provide a more realistic representation of the actual distribution of the population within a census tract (Wright, 1936). TeleAtlas boundary file data were used to identify uninhabited areas such as parks, shopping centers, and bodies of water. Population counts of women 40 years and older were used at the census block level. Using the mean center algorithm provided with ArcGIS 9.3 software (ESRI, Redlands, California), the centroid was calculated as an average of the x and y geometric center values of the zero-population areas and the census blocks within each tract using population counts as weights. Because zero population areas have no weight, the census tract centroid is ‘pulled’ toward those blocks with the highest population counts.

ArcGIS Network Analyst® was used to estimate the minimal travel time from the population-weighted centroids of each tract to the closest radiation facility (by time) for both public and private transportation. We did not attempt to model the variability seen in day-to-day commutes that is due to inclement weather, traffic congestion, time of day, road conditions, road repair work, crashes, and individual variability in walking or driving. Our travel time was a constant that varied only by mode of transportation. Each travel time constant was an approximation of travel speeds during average conditions based on published estimates. We used a walking time of 2.7 miles/hour (U.S. Department of Transportation, 2009); a bus rate of 15 miles/hour (St. Jacques & Levinson, 1997) that averaged speeds for central city and suburbs; an average train speed of 48.3 from MARTA’s published train schedules; and automobile rates for each segment from the TIGER/Line File Census Feature Class codes for specific road types (Wang, 2006). The bus wait time of 16 min and train wait time of 6 min were based on MARTA’s published bus and train schedules and were calculated as the midpoint between a full wait time (having just missed a bus or train) and no wait time (having arrived with bus or train). The private transportation model was based on street-level layers provided by MARTA.

Travel time was calculated as the sum of time traversed for each bus, rail and walking segment plus wait times for bus and rail stops. The formula $T + L/R$ was used to calculate travel time where T is the travel time through each segment, L is the length of the line segment, and R is the rate of travel. Each line segment (bus, rail, walking) had a corresponding travel time which was stored as an attribute of that segment. Each census tract was associated with a travel time by both private and public modes of transportation. We calculated travel time (means, medians, and interquartile ranges) by levels of household access to a private vehicle stratified by majority (> = 50%) non-Hispanic white women, majority non-Hispanic black women, and neither majority. All summary travel time measures were calculated by weighting the travel time for each tract by the number of women 40 years of age and older in that tract. We multiplied travel times by the number of women 40 years and older in each census tract, added these across each vehicle access-race category, and divided by the total population of women 40 years and older in that category.

Service areas

We used ESRI's Network Analyst to create radiation facility service areas calculated as the area accessible to each facility within specified impedance, in this instance, time. For example, a 30-min private transportation service area includes all public roads that can be traversed by car within 30 min of a radiation facility. Similarly, a 30-min public transportation service area encompasses the area accessible from a facility within that time limitation by bus, rail, or on foot. We created 30-, 45-, and 60-min service areas for both public and private vehicle transportation from all eighteen radiation facilities in Fulton and DeKalb counties using our multimodal network and our road network.

A GIS overlay of year 2000 Census tracts onto each service area boundary was performed to calculate an area proportion of the number of women 40 years of age and older within a service area. If an entire tract fell within the service area, all of the tract's study population was included in that service area. At times a given service area may only partially extend into some census tracts; in such instance the percentage of the tract area contained in the service area was used to calculate the percentage of women 40 years and older to be included in that service area. For example, if 70% of a tract fell into the service area, the total number of women 40 years and older in the entire tract was multiplied by 0.7 and allotted to that service area. The remaining 30% of the tract would fall outside the boundary and these women would not be within the service area of this clinic.

Results

Table 1 presents a description of the 282 census tracts in Fulton and DeKalb counties. Across all census tracts, the median public transportation travel time to the nearest radiation facility was 56 min, compared to approximately 8 min by private transportation. The median travel time by public transportation was more than 7 times that of private transportation and the maximum travel time by public transportation was nearly 4 h. The distances to the nearest radiation facility were similar regardless of whether women traveled by car or by public transportation. Overall, in our two-county study area,12% of households had no access to a private vehicle, and more than 27% of households were below the 200% poverty level. There was a strong correlation (*r* = 0.91) between lack of access to a private vehicle and poverty.

Table 2 shows vehicle access by race/ethnicity. One hundred and fifteen tracts were classified as majority white (> = 50% non-Hispanic white); 154 tracts were majority black (> = 50% non-Hispanic black). Only 13 of the 282 census tracts (5%) in Fulton and DeKalb counties could not be classified as majority white or majority black and of those, only 3 tracts were majority Hispanic. Because of the small number of tracts with no majority or Hispanic majority, we present only travel times for census tracts with majority black and majority white women 40 years of age and older. We observed a positive association between increasing public transport travel time with increasing vehicle access for both whites and blacks. However, for each of the three levels of vehicle access, residents of majority black census tracts had the longer median public travel time to the nearest radiation facility when compared with whites.

For residents of low vehicle access tracts, the median public transportation travel times from majority black tracts were three times the travel times of white majority tracts although estimates for majority white women at low vehicle access were based on only two census tracts. Residents of majority black census tracts with medium vehicle access had twice the public transportation travel times of white majority tracts. The difference in public transportation travel time for residents of majority black vs. majority white high vehicle access tracts was not as striking. Private transportation time to the nearest facility ranged from less than 1 min to just over 38 min (in 1 of these tracts, the centroid of the tract was immediately adjacent to the facility). Similar to the pattern seen for public transportation, blacks experienced longer private transportation time across all vehicle access categories.

Fig. 1 shows the distribution of women 40 years of age or older by census tract for the 2-county study area, as well as the 30-, 45-and 60-min service areas for both public and private modes of transportation. Service areas clearly follow the major arteries of the transportation network and extend beyond any potential circular distance buffer around the facility as well as exclude areas within a potential buffer. Relatively large sections of the two-county area were outside the 60-min travel time to the nearest facility. The inset table in Fig. 1 shows the estimated number of women 40 years of age and older for each of the 30-, 45-, and 60-min service areas. Just over 61% (*n* = 180,856) of women 40 years of age and older are within a 1-h travel time of a radiation facility by public transportation. By private transportation the percentage increases to 99.98% (*n* = 296,102).

Fig. 2 presents a comparison of the areal coverage of one radiation facility by 1-, 3- and 5 mile buffers with the service area created by the network analysis. Access to the radiation facility via the transportation network is clearly not distributed evenly across buffers. A proportion of the 60 min service area falls outside the largest, 5-mile buffer and a proportion of the area within the 3-mile buffer is outside the service area. Because these buffers are not aligned with the actual transportation network, time estimates based on circular buffers are more likely to be misclassified than are estimates based on a network analysis.

Discussion and conclusions

The median public transportation travel time to the nearest radiation facility in the 2-county study area was more than 56 min compared with 8 min median travel time by private transportation. We found a positive association between availability of private transportation and increase in travel time with residents in the tracts with lowest access to a private vehicle having the shortest travel times. We also noted a positive association between availability of a private vehicle and travel distance. These observations demonstrated a suburban pattern where those outside of a central city are more likely to have a private vehicle and have longer travel distances. In terms of median travel times, it appears that radiation therapy facilities are advantageously located for women in tracts with low private vehicle availability, typically tracts in the central part of the city. Despite this advantage, we found that the census tracts with a majority black population had longer travel times at every level of vehicle availability. With respect to private transportation, time to the nearest radiation facility did not appear to pose a barrier to women who had access to a private vehicle. Almost all women over 40 years of age in the study area are within a 60-min travel time to a facility by car (99.98%), and 99.1% are within a 30-min drive time. However, even for private transportation, longer travel times were seen for residents of majority black census tracts compared with residents of majority white tracts. Contrary to results seen for private transportation, only 61.1% of the study population was within the 60-min travel time by public transportation. This percentage decreased substantially to 12.4% for a 30-min public transportation commute. Thus more than 87% of women are more than 30 min away from a radiation facility by public transportation. In our analysis, distance to the nearest facility by private and public transportation was similar while travel times differed greatly. An exploration of time and distance travel to health care services in Great Britain found that for those without a car, travel times were longer although travel distances shorter than for those with a car. This discrepancy resulted in lower utilization of medical care for those without a car (Hine & Kamruzzaman, 2012).

Studies of transportation barriers to cancer services such as radiation treatment facilities have used a variety of methods to illustrate and measure barriers such as the use of Euclidean distance from point to point (Nattinger et al., 2001; Punglia, Weeks, Neville, & Earle, 2006; Voti et al., 2006), density of facilities within a buffer drawn around a point, or calculation of a more robust direct transportation measure of time and distance based on actual road networks, trip planners or travel diaries (Boscoe et al., 2011; Schroen, Brenin, Kelly, Knaus, & Slingluff, 2005). Although easier to implement, a method such as straight-line distance between points is subject to an underestimation of travel time as it does not adequately simulate real world travel routes nor does it measure travel times by public transit. A measure of facility density within a distance-defined buffer may either over- or underestimate actual travel time. Our approach used a network analysis to create time-delineated services areas for each radiation facility that geographically displays travel time and distance as well as to identify underserved areas. These service areas in Fig.1 clearly align with the major arteries of the transportation network and extend well beyond an arbitrary, but commonly used, 1-, 3- or 5-mile circular transportation buffer. Areas excluded from a potential buffer due to lack of roads can also be seen. Thus, our approach presents a more realistic picture of travel time barriers in transportation (Fig. 2).

Among the limitations to be noted are assumptions we made in the construction of our multi-modal transportation network. As with any model, a certain amount of data aggregation is necessary. We did not account for rush hours or other delays in calculating average and median travel times nor include an estimation of travel time over the weekend inasmuch as very few facilities are open on Saturdays or Sundays. Also, we based our estimates on scheduled times recognizing that on-time performance of rail and bus services may vary by census tract. We estimated average walking times and wait times at stops.

We also assumed that the traveler without vehicle access had no choice but take public transportation and would be going to the closest available facility. Thus we established minimal travel burden for each traveler—a best case scenario in terms of public transportation. Other factors such as the characteristics of the clinic or referral patterns could influence the choice of a facility. However, if other facilities were chosen based on size of clinic, convenience of appointment time, or cost, travel times would be longer which would increase the burden for a woman who must take public transportation—especially if she had, for example, a 1 h travel time to treatment and back and had to do this daily for 6 weeks.

Because of our sample size of 282 census tracts and our analysis that stratified by race, we could not examine in detail more than 3 categories of vehicle access. Furthermore, we conservatively based our classification of census tracts on access to at least 1 vehicle per household vs. no access. It is possible that having only 1 vehicle in a large household may not fulfill the needs of all household members. In our data, poverty and household vehicle access were strongly correlated. Although general measures of economic deprivation such as levels of poverty or education are used to classify or group geographic units, our analysis of transportation barriers used household access to a private vehicle as a more direct way to classify our study population.

The concept of access includes availability, accessibility, accommodation, affordability and acceptability (Penchansky & Thomas, 1981). We have focused on the spatial dimensions of availability and accessibility but also recognize the importance of the non-spatial dimensions. Affordability or financial accessibility has probably been the most studied dimension (Guagliardo, 2004). Yet financial accessibility itself is multidimensional and includes such factors as lost wages, transportation costs or parking fees, co-payments, and deductible insurance costs. Low-income, uninsured or underinsured women face added barriers of locating subsidized programs or programs offering care on a sliding scale through community health centers or public hospitals. Upon addressing financial barriers, women must still overcome other challenges such as means of transportation, a feared or actual lack of cultural awareness on the part of medical staff, problems in navigating the medical care system, and low health literacy. Thus the reasons for disparities in access are multifactorial and can operate at the individual level, the community level, or at the systems level. Furthermore, to address these disparities will require action at multiple levels using multiple approaches. The data sources we used do not measure many of these important factors. Ours is an ecologic case study that quantifies travel barriers from census tracts to nearest facility

—one barrier in a larger picture of access to care for disadvantaged and minority women and one that may be significant given the course of treatment that is required.

Results of this study are not generalizable beyond the Atlanta metropolitan area inasmuch as urban areas differ in their spatial structures, demographics, and transportation systems. However, the methodology is replicable by researchers elsewhere and once a network is constructed, it is a potentially useful method for answering a number of transportation-related questions in urban areas. Another approach to investigate public transportation travel patterns is through the use of trip planners, either for specific urban metropolitan transportation networks or through Google Trip Planner. These provide estimated travel times from one location by direct route of public transportation to the nearest location of interest and offer various options of start time for trips and day of the week.

Despite these limitations, this study adds to the literature demonstrating differences in spatial accessibility to radiation treatment facilities by race and related socioeconomic characteristics. Our analysis also reveals that transportation in urban areas, usually thought of as being better served and having a greater variety of options than rural areas, likely do not provide uniform access across neighborhoods and populations.

We found that irrespective of the level of vehicle availability for a household, black women have longer travel times to radiation facilities than do white women. Furthermore, we found great disparity in the length of travel time for women using public transportation compared with those who travel by car. Our analysis pinpoints those areas where travel times are the longest and for which additional transportation services or radiation therapy services would assure better accessibility. Transportation barriers are but one of a myriad of factors that influence receipt of optimal breast cancer care which include preferences by patient and physician, social support, demographic characteristics, appropriateness of radiation therapy for the stage and type of tumor, and other individual and health care system characteristics. However given the lengthy course of radiation therapy, the proven benefit of this therapy, and evidence suggesting travel time and distance may play a role in type of treatment received, methods to alleviate the travel burden should be considered. While effective shorter courses of radiation therapy are being tested (McCormick, 2012; Vaidya et al., 2010), other approaches may include expansion or modification of current public transportation services, a focus on transportation concerns by patient navigation service providers, locating new facilities in underserved areas, and the provision of housing accommodation near facilities for women undergoing therapy.

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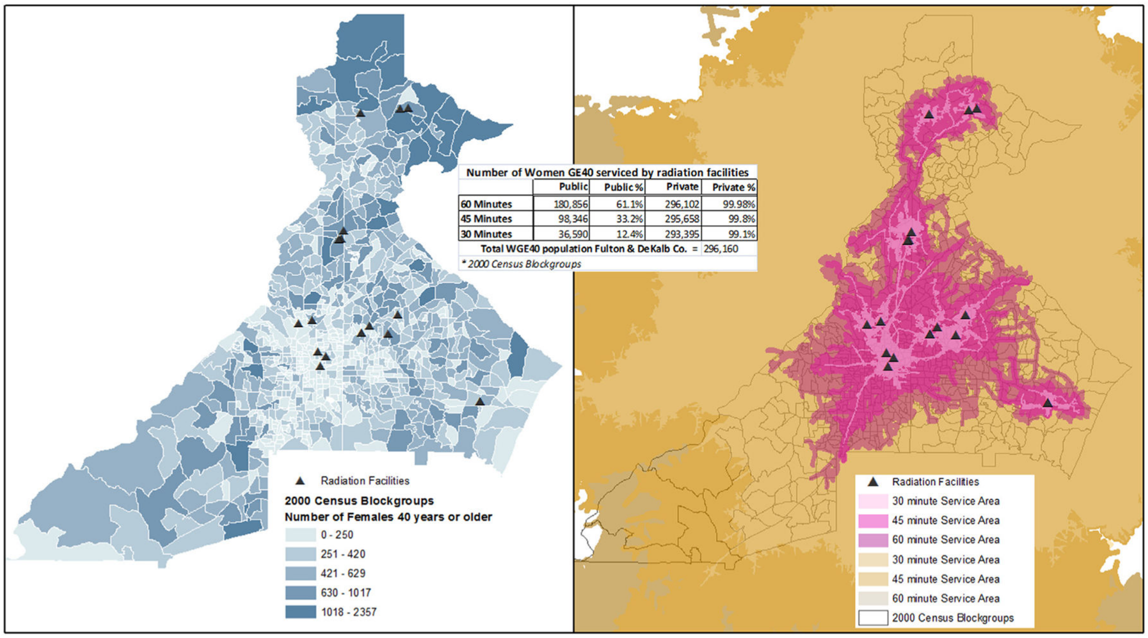

Fig. 1.

Public and private transportation service areas, Fulton and DeKalb counties.

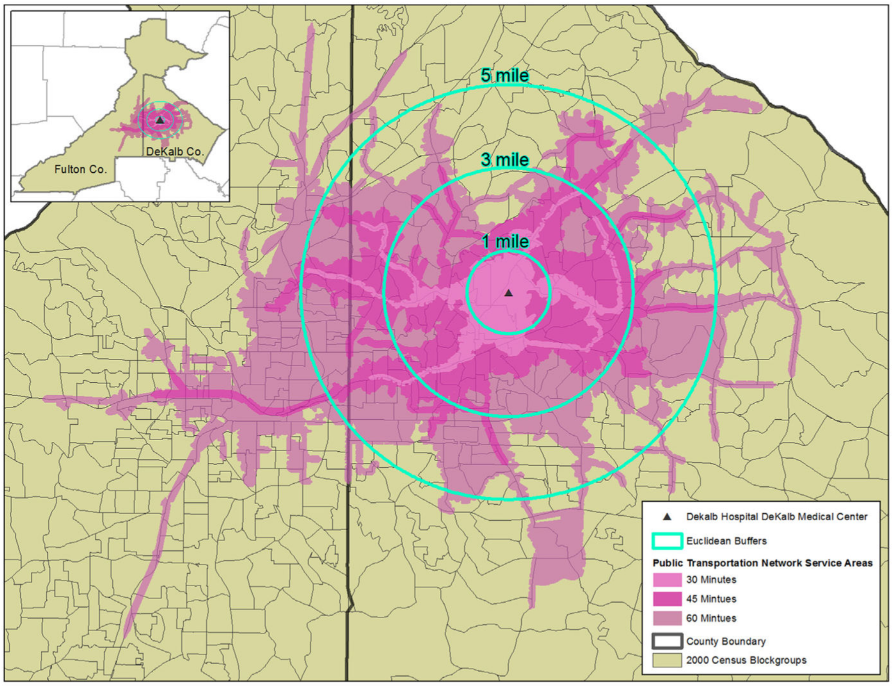

Fig. 2.
Comparison of service area and 1- and 3- and 5-mile circular buffers, Fulton and DeKalb counties.

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Table 1

Descriptive statistics of Atlanta (Fulton and DeKalb counties) census tracts (n = 282).

	Mean	Median	Minimum	Maximum
Public transportation time to nearest facility (minutes)	60.6	56.3	0.3	223.0
Private transportation time to nearest facility (minutes)	8.7	7.9	0.1	38.1
Public transportation distance to nearest facility (miles)	6.6	5.5	0.1	29.7
Private transportation distance to nearest facility (miles)	5.6	4.9	0.1	29.7
Percentage of residents below 100% poverty level	17.5%	12.3%	0.0%	75.7%
Percentage of residents below 200% poverty level	27.4%	21.9%	0.0%	92.9%
Percentage of residents with no vehicle access	12.2%	7.5%	0.0%	80.2%
Percentage of non-Hispanic black residents	53.5%	66.1%	0.1%	100.0%
Percentage of non-Hispanic white residents	35.8%	19.8%	0.0%	95.7%
Percentage of Hispanic residents	5.9%	2.7%	0.0%	71.2%
Percentage of non-Hispanic other race residents	4.8%	3.1%	0.0%	25.6%

Table 2

Public and private transportation time to radiological facilities by household availability of a private vehicle and by race, Fulton and DeKalb counties.

	Majority black women (40 + years)					Majority white women (40 + years)				
	# Tracts (*n* = 154)	**Mean**	**Median**	**25%**	**75%**	**# Tracts (*n* = 115)**	**Mean**	**Median**	**25%**	**75%**
Public transportation time (minutes)										
Low vehicle access (NVA > 20%)	80	46.0	45.6	38.9	55.2	2	13.1[a]	13.4[a]	13.4[a]	13.4[a]
Medium vehicle access (NVA 5–20%)	56	68.4	66.6	58.7	79.3	62	36.6	33.7	24.7	43.0
High vehicle access (NVA < 5%)	18	91.6	85.1	69.6	112.3	51	73.4	69.8	48.2	90.6
Private transportation time (minutes)										
Low vehicle access (NVA > 20%)	80	7.5	7.6	5.2	9.8	2	1.4[a]	1.5[a]	1.5[a]	1.5[a]
Medium vehicle access (NVA 5–20%)	56	12.0	10.4	8.2	15.1	62	5.4	4.3	2.9	6.3
High vehicle access (NVA < 5%)	18	11.8	11.6	10.0	13.5	51	8.0	7.6	5.8	10.3

NVA No vehicle access.

[a]Estimates based on 2 data points, interpret with caution.