Using Geographic Information Systems to Understand Health Care Access

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Background: Determining a community’s health care access needs and testing interventions to improve access are difficult. This challenge is compounded by the task of translating the relevant data into a format that is clear and persuasive to policymakers and funding agencies. Geographic information systems can analyze and transform complex data from various sources into maps that illustrate problems effortlessly for experts and nonexperts.

Objective: To combine the patient data of a community health center (CHC) with health care survey data to display the CHC service area, the community’s health care access needs, and relationships among access, poverty, and political boundaries.

Design: Georeferencing, analyzing, and mapping information from 2 databases.

Setting: Boone County, Missouri.

Participants: Community health center patients and survey respondents.

Main Outcome Measures: Maps that define the CHC service area and patient demographics and show poor health care access in relation to the CHC service area, CHC utilization in relation to poverty, and rates of health care access by geopolitical region.

Results: The CHC serves a distinctly different area than originally targeted. Subpopulations with unmet health care access needs and poverty were identified by census tract. These underserved populations fell within geopolitical boundaries that were easily linked to their elected officials.

Conclusions: Geographic information systems are powerful tools for combining disparate data in a visual format to illustrate complex relationships that affect health care access. These systems can help evaluate interventions, inform health services research, and guide health care policy.

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To improve access to health care, it is crucial to monitor how access varies across geography and subpopulations. Assessing access across communities or even states, however, can be difficult. Geographic information systems (GIS) can help by combining and analyzing complex information from multiple sources and then displaying it as maps. Geographic information systems can generate and store multiple map layers, each containing a unique variable, from different sources, and display them in various combinations. In this way, phenomena of interest come into sharp relief. Geographic information systems have been helpful for understanding a variety of health care issues such as defining hospital service areas, examining the affect of distance on access, and disease patterns. Despite some early innovations in using GIS to understand health care access within communities, it has remained largely underutilized. We used GIS to combine data from assessment of one county’s health care needs with the patient database of a community health center (CHC). In doing so, we hoped to answer specific questions about the health care access needs of underserved subpopulations within an otherwise well-served community. We also wanted to demonstrate the usefulness of GIS for analyzing...
Boone County is a metropolitan statistical area in central Missouri with a population of 130,000 (Figure 1A). The county’s 7 hospitals include an academic medical center. Its physician-to-population ratio (6:1000) is the highest in Missouri.12 Surveys of Boone County citizens regarding health care and human services issues in 1992, 1995, and 1998 led to several interventions. One major intervention was the development of a federally qualified CHC that now has 2 practice sites in the county’s largest city (Figure 2). The target population of the CHC is Boone County residents with incomes of 200% or less of the federal poverty level who lack a regular health care provider or health insurance. Its initial target service area was a collection of census tracts with federal designation as medically underserved populations (Figure 1B).

The 1998 Boone County Health and Human Services Needs Assessment survey reassessed community health and documented ongoing needs.13 These data alone could not show whether the CHC was meeting the access needs of its target population or whether other populations remained underserved, since only 5% of survey respondents claimed the CHC as their usual source of care. Although we could have weighted these responses to estimate the total population, these data likely would have been biased because 21% of the CHC’s population had no telephone and could not have participated in the survey. The clinic database captures only individuals currently served by the CHC, and so offers no information about underserved populations. We believed that by using GIS to combine the CHC data with the county assessment data, we could determine the CHC service area; then we could assess how populations inside and outside of the service area differ regarding demographics and health care access. Outside of the service area, we were particularly interested in locating any subpopulations with poor access to health care so that they could be targeted for future outreach. Finally, we used GIS to display access data by geopolitical regions to test how complex data might be displayed to persuade political leaders of the compelling health care access problems in their districts.

### MATERIALS AND METHODS

#### STUDY DESIGN

**Types of Information and Units of Analysis**

Three data sets were required for this research. The first set consists of the 3314 patient records of the CHC for 1998. Each record contains the home address, number of visits, age, sex, payment method, and household income. The second set consists of the results from the 1998 Boone County Health and Human Services Needs Assessment survey reassessed community health and documented ongoing needs. These data were collected from a probability sample of 2100 adults aged 18 years or older who responded to a telephone survey of self-reported health behaviors. Questions were modeled after the Behavioral Risk Factors Surveillance System, Centers for Disease Control and Prevention, Atlanta, Ga.
Details on sample and instrument design for the county assessment have been reported elsewhere. The third consists of geographic information, including coverages for incorporated areas, roads, census enumeration areas, ZIP codes, and district boundaries for Missouri’s House of Representatives. These were obtained from the Missouri Spatial Data Information Service.

Before maps and spatial analyses could occur, the residence of each patient and survey respondent had to be located on a map coverage. This process, known as “geocoding,” located approximately 94% of patients and respondents, high by GIS standards (typically 70%-80%). Boundaries for incorporated areas and census tracts were coded as well, which allowed analysis by various geographic areas.

Geocoded clinic and survey data, with the various spatial coverages, allowed us to analyze results for various geographic areas. Boone County’s 29 census tracts were the statistical unit of analysis for county assessment data, a resolution adequate to display spatial variation within the county. Due to small populations, 5 census tracts had less than the required number of respondents to calculate stable percentages and were combined with sociodemographically similar tracts for analysis. Census block groups are smaller subunits of census tracts and provide a finer spatial resolution. We were able to use census block groups as our unit of analysis for CHC data. Finally, House of Representative districts were the unit of analysis in our example for relating information from our data sets to elected policymakers.

Software and Maps

Commercially available GIS software (ArcView 3.1; Environmental Systems Research Institute, Inc, Redlands, Calif; available at: http://www.esri.com/software/arcview/) was used to produce the maps that illustrate phenomena by geographic location. The dot map uses points to communicate spatial density of discrete geographic phenomena. This map illustrates well the residence location of CHC patients. Choropleth mapping, derived from the Greek words choros (place) and pleth (value), is used in all of the maps, with distinctive shading to illustrate variation from place to place in accordance with values represented. This technique was chosen because it best displays differences of variables between geographic units of analysis.

TYPES OF ANALYSIS

Defining Medical Service Area

In 1994, when the clinic was approved as a federally qualified health care center, 16 of Boone County’s 29 census tracts were designated as having medically underserved populations (Figure 1B). These were predominantly located within the city of Columbia. However, the designation does not guarantee that people from these tracts will optimally utilize the clinic. In general, utilization can vary considerably within geographically defined medical service areas. To define the actual service area of the CHC, we used the clinic database to map patients by census block group, then weighted each by the number of visits made. As mentioned previously, census block groups were used instead of census tracts to improve spatial resolution and to better identify areas within census tracts that used the CHC the most. A measure of utilization known as the Griffith commitment index was then calculated as the total number of visits for a block group divided by the total number of visits for Boone County. The commitment index
measures the extent to which patients from defined geographic areas utilize a health care facility. Block groups were ranked by their commitment indices in descending order and placed in the medical service area in rank order until it contained 60% of all clinic visits.17

Access

To operationalize health care service access, we drew on research by Andersen and Aday,20 studies that have enhanced their conceptual work, and other investigations that have supported the creation of separate variables for poor access and for potentially poor access.1,21-27 We chose to assess only individuals with realized poor access because they represent an existing need for intervention. Information on health care access was available from the county assessment survey. We classified individuals as having poor access to health care if (1) they had no health insurance or regular source of health care, used the emergency department as their usual source of care, or had Medicaid/Medicare insurance coverage; and (2) they reported a time during the past 12 months when they needed to see a physician or dentist but for some reason could not (reasons included cost, transportation, physician/dentist would not accept Medicaid/Medicare) or indicated that cost had kept them from filling at least 1 prescription in the past 12 months.

Location Quotient

To determine the proportion of the target population (households with incomes below 200% of the federal poverty level) that used the CHC, location quotients were calculated and mapped by census tract. This quotient is a relevant index used when the spatial pattern of variables, not statistical correlation, is of interest.28 The location quotient we used (Figure 2) is the proportion of the total clinic patient visits from target household areas in a census tract divided by the proportion of the total Boone County population in the same household income range residing in that census tract. Data used to calculate the numerator came from 1998 clinic records; results from the 1998 county assessment survey provided the basis for the denominator. Because this index focuses on households with low incomes, it can reveal impoverished areas with relatively higher and lower use of the CHC.

The confidentiality of patients and survey respondents was protected in the following 3 ways: first, rather than mapping addresses so that individual homes could be located, address dots were mapped on street segments within a range of addresses; second, no patient names were attached to addresses; and third, we deliberately and randomly offset dots a distance of 0.1 mile from the actual location. With dot maps there is potential for discovery in areas of extremely low population density; however, Boone County does not have any areas of such low density that this would be a risk for our study. The University of Missouri–Columbia Institutional Review Board approved this study.

RESULTS

In 1994, the initial CHC target service area consisted of census tracts located in Columbia (Figure 1B). Socioeconomic data from the 1990 census qualified these predominantly urban tracts as medically underserved population areas. Clinic patient households from 1998 are shown as dots in relation to the 1994 target service area (Figure 1C). There is a clustering in the initial target service area. However, when patient households are weighted by number of visits, it becomes clear that the actual service area is quite different from the 1994 target (Figure 1D). Several rural census block groups emerge as areas of high use, whereas certain federally designated underserved population areas in east Columbia do not. Geographic information systems also allowed us to analyze the target and actual service areas and the rest of Boone County to compare demographics and other issues pertinent to federal and state funding (Table). Thus, GIS can generate an easily grasped visual statement as well as more traditional statistical information to make a case for more resources in these areas.

We also were interested in how much the target population used the

CHC Target Service Area Demographics*
CHC. This relationship is displayed as a location quotient map in which darker areas represent higher utilization by poor households and lighter areas represent underutilization (Figure 2). West Columbia and north central Columbia emerge as the areas with the greatest relative use of the CHC, whereas portions of central Columbia, southwest Columbia, and northeast and east Boone County are utilizing the CHC less than expected. Six census tracts in the initial target service area have location quotients of less than 0.88, indicating these tracts have fewer clinic visits by target households compared with Boone County as a whole. Comparing this map with the 1998 actual service area (Figure 1D), none of these 6 census tracts is within the actual service area.

Overall, 13.1% of Boone County adults reported health care service access problems in 1998 (Figure 3). This aggregate percentage, however, hides considerable variation. Tracts in east Columbia and southwest Boone County have the highest concentrations (19.9%-26.6%) of adults with poor access, whereas tracts in west and northeast Columbia have low concentrations (1.4%-7.7%). Geographic information systems also allowed us to estimate the number of adults with poor access by House Districts. Approximately 60% of estimated adults with health care access barriers in Boone County reside in the predominantly urban 23rd and 25th House Districts.

With the exception of 2 tracts, the areas with the highest proportion of adults with poor health care access are generally outside the actual CHC service area (Figure 4).

**COMMENT**

This study showed that the CHC actual service area in 1998 is considerably different from the 1994 target service area. We now have information about how these service areas differ demographically and how they are different from the rest of the county. It is an easily grasped visual statement that has immediate value for addressing questions from local, state, and federal fund-
The map depicting poor health care access locates distinct subpopulations in the county that have unmet health care needs (Figure 4). The census tracts that capture the CHC service area have better-than-average health care access. In contrast, subpopulations with the poorest access lie outside the CHC service area. This information will help target these areas for research on access barriers and interventions. This information may also justify applications for funding to expand the CHC service area. The analysis and easily grasped visual nature of maps also can help community and political leaders develop pertinent health care policy.

These findings are consistent with those of previous studies that demonstrated great potential for health geographic information to increase our understanding of the complex relationship between socioeconomic factors and health status. Although poverty correlates strongly with health care access variables, it has not strengthened the assessment of health care access when included. However, we believe that impoverished households that face barriers to health care are at greater risk of poor health outcomes. As mentioned previously, 6 census tracts outside the CHC 1998 service area were identified as having low use of the CHC by households with incomes below 200% of the federal poverty level (Figure 2). With such information, health care planners and policymakers can target scarce resources to areas in greatest need of help.

Superimposing areas of poor access on political boundaries (Figure 4) visually links politicians to their underserved constituents. For example, the representative of the 23rd District can see in compelling fashion that 31.6% of the county’s citizens with poor health care access live in that district and, based on the actual service area, generally do not seek care at the CHC. (Figures 3 and 4). Using GIS, various geopolitical boundaries could be applied to these data to inform communities and their political leaders.

Previous studies suggest that use of GIS technology has increased significantly in local governments in the past decade. However, the public health care field has been slow to adapt. The Dartmouth Atlas is perhaps the most notable application of GIS to health care services research, and its 1998 edition states that “...in health care, geography is destiny.” Since 1993, the Dartmouth Atlas has investigated how health care is used by defined populations consisting of hospital service areas. These populations were defined by linking patients’ ZIP codes of residence to hospitals where they receive care. This effort has been remarkably helpful for identifying regional differences in Medicare expenditures for physicians’ services, utilization patterns of patients with chronic diseases, and health maintenance organization penetration, among other things. This methodological and geographic scope is an important application of GIS technology, but it is not refined enough in resolution to help understand health care issues within communities.

We believe that using national, state, or regional assessments to improve access to health care can go only so far. Small-area analysis needs further refinement if the goal is to improve access for underserved populations. These groups can be imbedded in communities that appear to be relatively well served by summary statistics. Large-area analyses cannot answer fundamental questions about services to at-risk populations. Farley and colleagues were early innovators who used GIS to assess the socioeconomic status and create a visual picture of their primary care practice population. They recognized that it enhanced the capacity for health care services research and planning for satellite offices and outreach development. More recently, GIS have been used to measure distances between patients and their primary health care centers to evaluate geographic barriers to health care access. They have been used to combine clinic data with population data to assess spatial patterns of drug use and lead poisoning within communities. Geographic information systems have also been helpful in a spatial analysis of hospital location/allocation in which patient hospital-discharge data were combined with transportation system data and hospital location data. These studies have used GIS to study disease patterns and specific health care access issues. We believe our GIS study is the first to spatially identify health care access needs in a medically well-served community in relation to an ongoing clinical intervention (CHC) and to investigate relevant issues that might increase fiscal and political support to enhance that intervention’s success.

Geographic information systems increasingly may allow communities, health care services researchers, and health care policy developers to link data sources, thus highlighting areas where public health interventions can be applied. To this end, the Middle Eastern nation of Qatar has created a national GIS system that will capture and georeference health care transactions to assist in planning and policy making. Health care services researchers in the United States have been frustrated when using existing national databases to study health care access, most recently with the nationwide effort to improve access for children through the State Children’s Insurance Program (CHIP). The federal legislation that authorized CHIP requires enrollment reports from states; however, most national surveys cannot generate statistically reliable state-level estimates. Geographic information systems may provide a mechanism for linking national da-
tabases or even national with state or local databases to address health care access better in general, and particularly for CHIP. It also might be helpful in the future if national surveys included common georeferencing elements.

General limitations of GIS include the potential for ecological fallacy, insufficient sample size for small-area analysis, and biased interpretations of access issues if potential confounders or modifiers are not considered. Ecological fallacy generally occurs with efforts to make individual-level inferences from group-level data. We have not made such inferences. Sample size was not a problem for us because we were able to geocode more than 94% of county assessment responses, and because we analyzed all of these responses at the census tract level without stratification. We attempted to avoid confounding by basing our health care access variable on the best current models for measuring access and by using direct responses to the county assessment survey.

Although this study shows how GIS can be used at the local level, it also speaks for what GIS offer to health care services research and health care policy on the national level. Just as we used GIS to combine and visualize data regarding poverty and health care access, many other data sets of interest to public health care professionals and policymakers also could be adapted. Nationally and within states, GIS could pull together disparate research efforts to understand the successes and failings of federal and state programs like CHIP. Besides CHIP, existing databases could be linked to identify visually the areas most at risk for shortage of health care professionals, to create simple maps that illustrate the geographic inequities of graduate medical education funding, and to investigate regional variations in quality of care. Locally, GIS can assist public health clinics or health care systems to design community-oriented interventions, strengthen applications for funding, and prioritize outreach services. Locally or nationally, GIS can offer a picture of problems occurring within specific political boundaries—a picture that may move politicians to recognize needs in their areas and to allocate resources accordingly.

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