Access to Cardiac Interventional Services in Alabama and Mississippi: A Geographical Information System Analysis

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by Barbara Ann Graves, PhD, RN

Abstract/Objective

The objective of this study was to determine the contribution of distance to hospitals with cardiac interventional services (CIS) to county age-adjusted myocardial infarction (MI) mortality rates (CAMR) in Alabama and Mississippi counties.

Methods

The study used three data sources: U.S. Census data, Centers for Disease Control and Prevention (CDC) mortality data, and American Hospital Association data. A geographical information system (GIS) was used to measure distance, providing an empirical measure of county access to CIS. Multiple regression analysis was conducted using measures of distance to CIS, county rural status, state, sex, poverty, education, race, and interaction as predictors of CAMR.

Results

Regression results indicate that the model significantly predicts CAMR, R^2 = .378, adjusted R^2 = .319, F = 6.321, p < .001. The model accounts for 31.9 percent of the variability.

Conclusions

The results of this study do not lead to the conclusion that cardiac outcomes as measured by CAMR were sensitive to the geographic location of CIS. However, statistically significant interactions supported the sensitivity of CAMR to complex patterns and issues of rural status, poverty, education, and race.

Key words: cardiovascular disease, myocardial infarction (MI) mortality, geographical information systems (GIS), healthcare access, healthcare disparities

Background

Coronary heart disease (CHD) is the leading cause of death in the United States today. In particular, regions in the rural South experience excessively high rates of morbidity and mortality. The Framingham study in the 1950s opened the gate to understanding CHD and myocardial infarction (MI), as well as the associated risk factors.[1] Prevalence of MI risk factors and mortality in both men and women has been reported in many large national and international studies.[2-9]

Differences in access to healthcare services and the resulting adverse health outcomes are major public health priorities. The Institute of Medicine and the U.S. Department of Health and Human Services have identified the need for strategies to improve access to healthcare services and to support the improvement of health outcomes.[10,11] Furthermore, *Healthy People 2010* designates two central goals for our nation's health: 1) to increase quality and years of healthy life, and 2) to eliminate health disparities.[12] Many studies have been conducted to identify the characteristics of disparities in healthcare access and health outcomes.[13–19] Findings of these studies indicate that while most Americans have high quality healthcare available, gaps or disparities in healthcare access and health outcomes continue to exist. The literature documents disparities associated with age, education, race and ethnicity, sex, income and socioeconomic status (SES), and place of residence or location of healthcare services.

The method used in this research was adapted from Andersen's behavioral model of health service use.[20,21] In his seminal works on healthcare access, Andersen posits that health service use is a function of people's predisposition to use services, factors that enable or impede use, and people's need for care. The model presents these factors as making individual contributions to the prediction of healthcare use. This author's model for the assessment of potential geographical access, adapted from Andersen's model, is discussed elsewhere.[22]

Predisposing characteristics that might explain the need for healthcare include demographic factors, measures of social structure, and health beliefs. Biological imperatives such as age and sex are included in demographic factors. Measures of social structure are education, occupation, and ethnicity as well as social networks, social interactions, and culture. While health beliefs also add to the model's ability to explain use of health services, measures of "enabling resources" and "need"[23] explain more of the variation in the use of health services.

In the assessment of "enabling resources," Andersen[23] further challenges researchers to go beyond measures of "regular source of care," "physician populations" and "hospital bed counts." Andersen believes that for utilization to happen, both "personal enabling resources" and "community resources" must be socially and geographically available. The kinds and types of health services available where people live as well as their organizational structure and process are important. Both community and personal enabling resources must be present. Most important, health personnel and facilities must be available where people live and work. Income, health insurance, a regular source of care, and travel and waiting times can also be important.[24]

One of the strongest determinants within this model of health service use is the "need" factor. The model defines "need" as perceived health status, evaluated health status, or consumer satisfaction. Evaluated need is most related to "kind and amount of medical care provided."[25] Mortality is an example of evaluated need.

While literature about CHD, MI, and associated risk factors abounds, a greater understanding of specific geographical enabling factors and predisposing characteristics is needed. More information about the relationships between and the effects of social and geographical factors that enable people to obtain treatment for MI is necessary. Specifically, are cardiac interventional services (CIS) located across Alabama and Mississippi in a manner that allows equal access? Research linking MI mortality in specific regions to access to CIS (as measured by distance) could provide information to assist in reducing the excess MI mortality in the region.

This study examines potential geographical access to CIS of Alabama and Mississippi populations and seeks to ascertain the relationship between potential access to CIS and mortality due to MI. Of primary interest was the relationship between distance to CIS and county-level age-adjusted MI mortality rates.

Methods

A descriptive, ecological, explorative study design was used with a retrospective cohort. The study used as variables certain predisposing characteristics and enabling resources of the Alabama and Mississippi populations that related to MI. The study was ecological, seeking to analyze the relationships of population characteristics and a particular healthcare service environment. For this study, CIS were defined as hospital facilities capable of providing percutaneous transluminal coronary angioplasty (PTCA) for the treatment of MI.[26]

A geographical information system (GIS) was used to provide distance data for multiple regression modeling of the potential access of Alabama and Mississippi populations to hospitals with CIS. The counties in Alabama and Mississippi (n = 149) were the unit of analysis. Existing MI mortality data from the Centers for Disease Control (CDC) was used as a measure of need.

Statistical inference was used to test the hypothesis that as distance to CIS increases, Alabama and Mississippi county-level MI mortality rates will increase while adjusting for education, race, rural status, sex, socioeconomic status (SES), and state. Multiple regression modeling was used to test for the existence of predictive relationships among the study variables.

Data Sources

Three principal sources provided the data for this study: U.S. Census 2000 data, CDC mortality data, and American Hospital Association data.[27-29]

U.S. Census 2000 data. U.S. Census TIGER (Topologically Integrated Geographical Encoding and Referencing system) Data County cartographic boundary files containing county location in terms of latitude and longitude and Census 2000 data were downloaded from the U.S. Census Bureau. County Profiles of General Demographic Characteristics: 2000 were also used to provide county level variables.[30]

Mortality data. County age-adjusted MI mortality rates per 100,000 were retrieved from the CDC Compressed Mortality Files (CMF) using the WONDER (Wide-range On-Line Data for Epidemiologic Research) data request Web site.[31]

American Hospital Association data. Addresses of hospitals capable of providing CIS to Alabama and Mississippi populations were obtained from the American Hospital Association guide.[32] Each hospital's street address was geocoded into a database for use in ArcView 3.2a GIS as a point location for the identified hospital.

Variables

Because geographical location of healthcare services is an important factor for enabling access to healthcare, the analysis used geoprocessing procedures to map hospitals with CIS in Alabama and Mississippi and to calculate the distance from each county centroid to the nearest hospital offering CIS.[33-39] The health and sociodemographic data was therefore analyzed in a geographical context using ArcView GIS 3.2a.

Using U.S. Census data and GIS, maps of Alabama and Mississippi counties were generated as the first thematic layer. The locations of hospitals with CIS across Alabama, Mississippi, and contiguous states were geocoded by latitude and longitude coordinates as point data on the maps. GIS was used to measure the straight-line distance from the population-weighted centroid of each county to the nearest hospital with CIS. These empirical data were used in a regression analysis to quantify the effect of distance on mortality while accounting for potential confounders.

Dependent variable. The dependent variable for modeling of adjusted effects was county-level, average age-adjusted MI mortality rates (CAMR) per 100,000 population for all 149 Alabama and Mississippi counties. The use of age-adjusted MI mortality rates removed the effect of age and allowed comparison of mortality data across counties with different age structures. The direct method for age adjustment weighted by a standard population was used and was standardized to the U.S. total population for the year 2000.

Independent variables. Because the death rate due to MI has been shown to vary by education, race, rural status, SES, sex, and distance, county-level measures of these variables were used as independent variables in the regression model. County Profiles of General Demographic Characteristics: 2000 from the U.S. Census 2000 Web site were used to compute a county-level measure of sex, education, SES, and race.[40]

- *Education*. A county-level measure of educational attainment was obtained from the U.S. Census Bureau and was recorded for each county as the percentage of the county population with less than a high school education.
- *Race*. A county-level measure of race was obtained from the U.S. Census Bureau. This variable was recorded for each county as the percentage of the county population that was nonwhite.
- *Sex*. A county-level measure of sex was obtained from the U.S. Census Bureau. This variable was recorded for each county as the percentage of the county population that was male.
- *Poverty*. A county-level measure of SES was obtained from the U.S. Census Bureau. This variable was recorded for each county as the percentage of individuals in the county population that was at or below the poverty level.
- *State*. State was defined as either Alabama or Mississippi.
- *Rural status*. Rural status was based on the Office of Management and Budget (OMB) classification of counties as metropolitan or nonmetropolitan.[41]
- *Distance*. Distance was defined as the straight-line (Euclidean) distance in miles from the population-weighted centroid of each county to the nearest hospital with CIS as measured using the GIS. Distance was used as an indicator of access to healthcare services.

Analytical Approach

Data were analyzed using Statistical Package for the Social Sciences SPSS 13.0 and ArcView version 3.2a, a commercially available GIS produced by Environmental Systems Research Institute, Inc. (ESRI). Descriptive statistics were used to characterize the study population. Regression modeling was conducted to investigate the relationship of CAMR to distance to hospitals with CIS. County-level demographic variables were investigated as covariates. From available population-weighted census tract centroids, the ArcView GIS was used to determine population-weighted county centroids for each county in Alabama and Mississippi (see Figure 1). Hospitals with CIS were identified and mapped using geocoding and "nearest feature" functions in ArcView (see Figure 2). Distance was measured from each county's centroid to the nearest hospital with CIS. This measurement provided straight-line Euclidean distance, an empirical measure of county-level access, and was recorded in miles to the nearest tenth of a mile (see Figure 3).

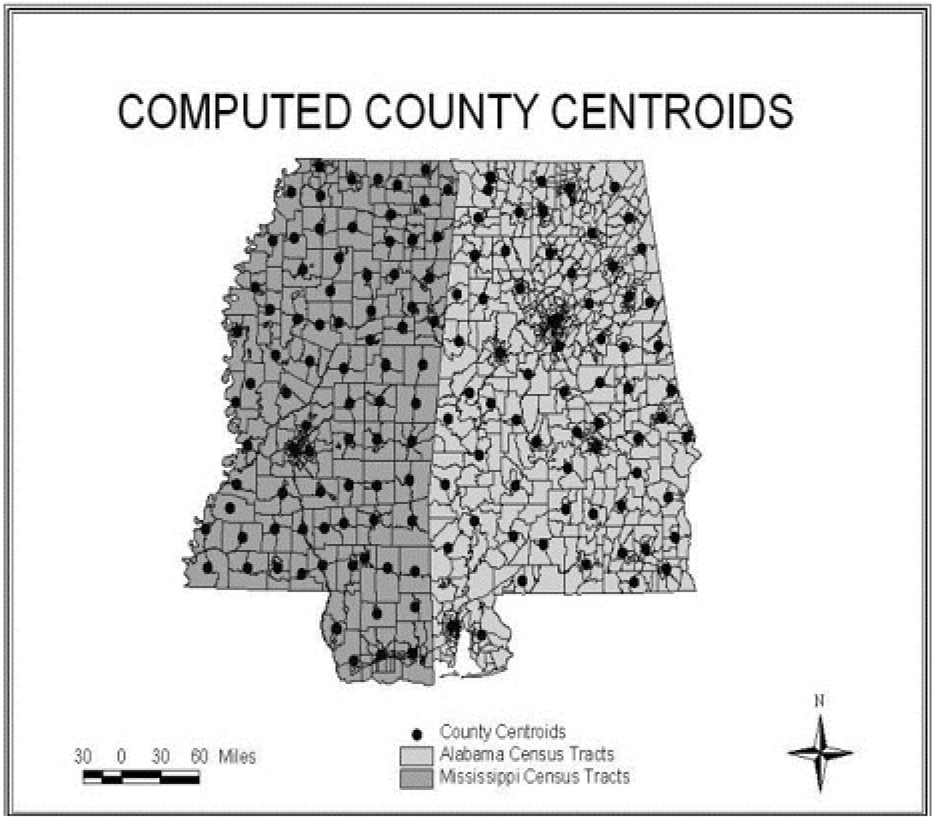

Figure 1: Alabama and Mississippi Computed County Centroids

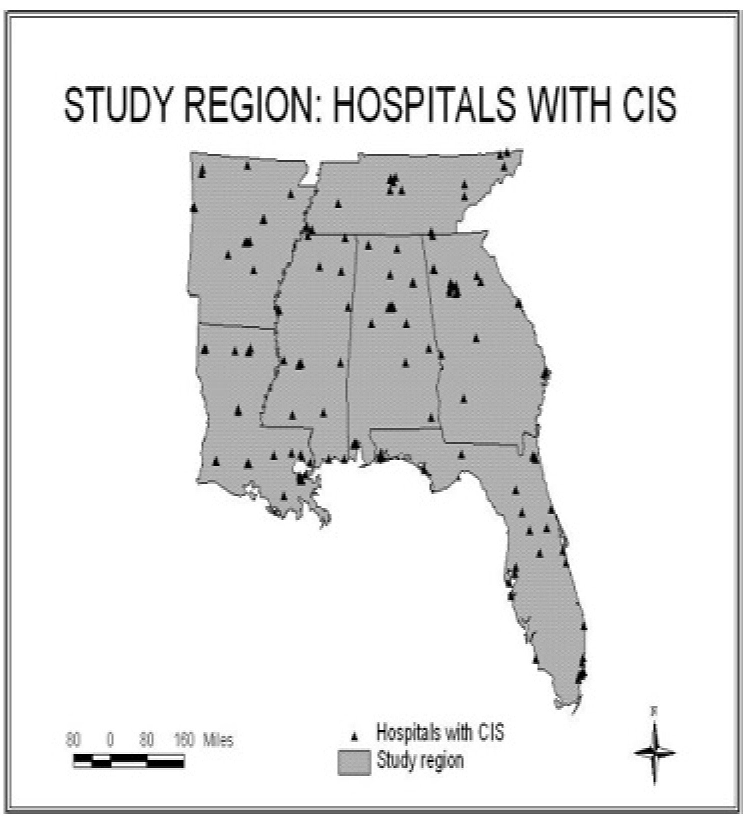

Figure 2: Hospitals Capable of Providing Percutaneous Transluminal Coronary Angioplasty (PTCA) as Cardiac Interventional Services (CIS) for Alabama and Mississippi Populations

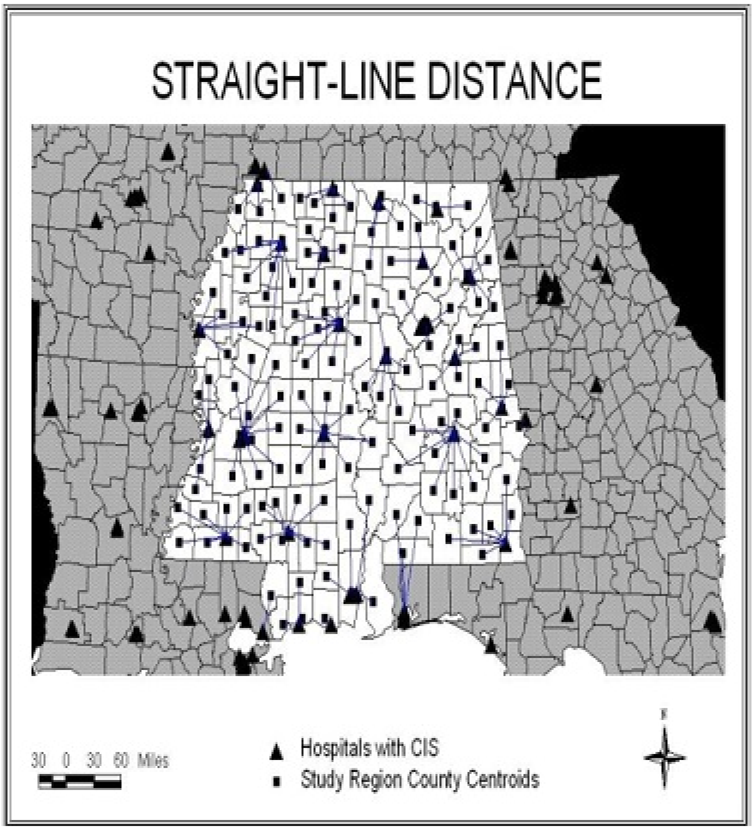

Figure 3: Straight-Line Distance as County-Level Measures of Access to Alabama and Mississippi Hospitals with Cardiac Interventional Services (CIS)

The beginning model contained seven independent variables as well as all possible two-way interaction variables. These independent variables were entered as percentages of the county population that were male (sex), were below poverty level (poverty), had less than high school education (education), and were nonwhite (race). Because two states were included in the study, the state was also included as a variable. The two-way interaction variables were created as the product of each possible two-way combination of the independent variables and were included in the model as product terms (e.g., poverty*distance). The interaction variables were used to check for possible interactions due to the possibility that independent variables could combine and have more than an additive effect on the CAMR.

A preliminary regression analysis of all independent variables and all possible two-way interactions was conducted. Regression coefficients were assessed, and all interactions with $p > .25$ were removed from the model. The arbitrary use of $p > .25$ allowed interaction terms with little statistical support to be dropped from the model, producing a reduced regression model for further analysis.[42] This exploration method allowed potentially important interactions to be assessed. Six significant interactions from the preliminary model were retained along with the original seven independent variables, which produced a regression model with 13 independent variables.

The five continuous independent variables were centered to overcome problems with multicollinearity. Taking the difference between each of the 149 observations and the mean of all observations for that variable can reduce multicollinearity among first-order and higher-order terms for independent variables. Interaction terms were also generated as product terms using the centered variables.

Because regression diagnostics indicated problems with influential observations, iteratively reweighed least square (IRLS) regression and the Huber weight function were used as an alternative to transformations. Five iterations were performed. The weights and residuals were reassessed, and convergence occurred with the first weighted iteration. The reduced regression model produced by the first IRLS iteration was used as the final regression model. See Table 1 for the independent variables or predictors of CAMR used in the final analysis model.

Table 1: Distribution of Variables by Percentage of County Population (N = 149)

	Range	Mean	SD
Percentage at poverty level or below	6.3–41.1	21.26	7.46

Percentage nonwhite	0.6–86.9	36.28	21.37
Percentage male	42.9–56.5	48.35	1.65
Percentage with less than high school education	13.2–46.3	31.21	6.78

Results

Descriptive Statistics

Mortality due to MI was studied in the 149 counties that constitute Alabama and Mississippi. CAMR ranged from 55.9 to 412.5 deaths per 100,000 population. The mean was 156.4 with a standard deviation of 59.2. The median CAMR was 147.9.

Forty-four (29.5 percent) of the counties were classified as metropolitan, and 105 (70.5 percent) were classified as nonmetropolitan. Distance to CIS ranged from 1.0 mile to 68.9 miles with a mean of 28.1 miles and a standard deviation of 16.6 miles. Table 1 summarizes the independent variables by percentage of county population.

Figure 2 shows the distribution of hospitals with CIS in the seven-state study region. Hospitals with CIS in the states adjoining Alabama and Mississippi were included in the study to allow for the most accurate calculation of potential access to CIS. A total of 165 hospital facilities with CIS were identified. Alabama had 20 hospital facilities with CIS, and Mississippi had 19 hospital facilities with CIS. Concentrations of CIS in the urban areas of Alabama and Mississippi were evident, as would be expected for any tertiary healthcare service.

Regression Analysis

The findings from the regression model supported the combination of variables as predictors of CAMR. Regression results indicate that the overall reduced model significantly predicts CAMR, R^2 = .378, adjusted R^2 = .319, F = 6.321, p < .001. The coefficient of multiple determination indicated that the model accounts for 31.9 percent of the variability in CAMR. A summary of regression coefficients is presented in Table 2. The analysis indicates that five of the six interactions tested significantly contribute to the model.

Table 2: Coefficients for Final (Reduced) Regression Model Variables

	Unstandardized Coefficients			Standardized Coefficients	
Predictor	***B***	**SE**	**Beta**	***t***	***p***
Constant	155.683	6.674		23.328	.000
Rural	6.501	5.557	.114	1.170	.244
State	−7.368	4.096	−.139	−1.799	.074
Distance	.884	.476	.280	1.858	.065
Poverty	−.165	1.451	−.023	−.114	.910
Education	−1.687	1.025	−.219	−1.645	.102
Race	.128	.395	.051	.324	.746
Sex	−1.463	2.340	−.046	−.625	.533
Rural*distance	.756	.495	.217	1.527	.129
Rural*poverty	5.893	1.468	.782	4.014	.000
Rural*education	−3.163	1.073	−.368	−2.948	.004
Rural*race	−2.268	.394	−.881	−5.760	.000
Poverty*education	−.520	.103	−.585	−5.039	.000
Poverty*race	.115	.033	.391	3.515	.001

Note: R^2 = .378; adjusted R^2 = .319 (p < .001).

The interaction between rural status and distance was not statistically significant, $t = 1.527$, $p = .129$. The interactions of rural status with poverty, education, and race were each statistically significant at p =.000, p = .004, and p = .000, respectively. The interactions of poverty with education and race were each statistically significant, p = .000 and p = .001, respectively. None of the original seven predictors was statistically significant.

Discussion

Access to healthcare services for disparate populations is an important policy issue. The literature recognizes the multidimensional nature of access to healthcare services. Access and health outcomes have been shown to vary by age, race, sex, education, and SES as well as geographical location.
In this study, the analysis did not completely support the research hypothesis. No significant relationships between potential geographical access to hospitals with CIS, MI mortality rates, and sociodemographic variables in Alabama and Mississippi counties were identified. No statistically significant association was noted between county-level age-adjusted MI mortality and the distance to hospitals with CIS. However, the statistical significance of four interactions including measures of county-level rural status, poverty, education, and race lends support to the complex nature of the web of causation and outcomes for acute MI. Based on the findings of this study, the following conclusions were made.

1. Cardiac outcomes as measured by county age-adjusted MI mortality rates did not show sensitivity to the geographical location of cardiac interventional services.
2. Excessive MI mortality found in some areas of these states cannot be attributed solely to the distance to hospitals with CIS.
3. While the results of this study do not lead to the conclusion that cardiac outcomes as measured by CAMR were sensitive to the geographic location of CIS, statistically significant interactions supported the sensitivity of CAMR to complex patterns and issues of rural status, poverty, education, and race.

Limitations

The use of GIS technology is a relatively new research methodology, and proper controls of procedures and data have not been completely standardized. GIS use can present common sources of error and threats to internal validity. Particular to this study were the following sources of errors: data input, data manipulation, data output, and incomplete understanding of the results. In GIS, geocoding procedures and inaccurate digitized data present instrumentation threats that can reduce the validity of study results. Particular to GIS use, inappropriate class intervals, boundary errors, slivers, and artifacts of overlay are problems that can occur with the manipulation of data. Data output inaccuracies in map scaling and resolution are other threats to internal validity.

In the interpretation of GIS research, it is important to consider issues of the spatial aggregation of data and the potential for confounding conditions. Geographical disease or health data are generally available aggregated by census tract, zip code, or county. While the analysis of small-area data can provide valuable insight into disparities in health outcomes, small-area rates can be statistically unstable. This instability can be especially true in rural populations but can be overcome by further aggregation of the data. This study used county-level data and a six-year study period to improve validity.

Modifiable areal unit problem (MAUP) is a common difficulty encountered in medical geography research. Because variance changes with scale, the zones of analysis can greatly affect the outcomes. Aggregating areas to different scales can cause measurable associations to vary significantly or cause an ecological fallacy. When individual-level data is aggregated, a leveling of central tendency can occur. There is more variance at the census tract level than at the county level, more variance at the county level than at the state level, and so forth. The results have less to do with cause and effect than with how the research findings are measured and generalized. Because aggregation of data by independent variables can inflate correlation coefficients, Meade and Earickson recommend the use of regression coefficients to reduce the problems of MAUP.[43] Care must also be exercised to prevent the reporting of patterns of association at one scale of analysis as being true at another scale.

Conclusions

Although little statistical significance was demonstrated among the variables chosen for this study, the implications for future research and practice are evident. The results of this study highlight the complex nature of MI rates as related to poverty and rural populations. Models such as the one used in this study can be invaluable in providing information about “what” health services are provided, “where” (geographic coverage) they are provided, to “whom” (population served or beneficiary) they are provided, and by “whom” (organization) they are provided, as well as where health services are lacking.

The findings of this study provide baseline descriptions of potential contributors to persistent patterns of excess MI mortality in Alabama and Mississippi. This study of excess MI mortality demonstrates the application of concepts of geographical access and the use of GIS analysis to examine patterns of ecological and social disparities. This analysis can serve to guide policy deliberations and health resource allocations and allow for targeting of priorities. Furthermore, it implicates the need for more interventions, particularly through education, to target modifiable risk factors in the battle against heart disease.

Because the burden of heart disease is great in terms of cost and disability, further research into the multivariate factors associated with heart disease is essential. It is important to learn as much as possible about the ecology of heart disease as well as the relationships between risk factors. Further research is also needed in the use of GIS to empirically measure spatial relationships of geographical, environmental, and social influences of heart disease and MI mortality. Furthermore, more research into the predisposing characteristics and enabling factors for other specific populations is needed. This knowledge can form a basis for further understanding of MI risk and contribute to the development of intervention programs to reduce MI mortality rates.

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Notes

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