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Geographical patterns of end-stage renal disease incidence and risk factors in rural and urban areas of South Carolina

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Abstract

To assess the geographical patterns of end-stage renal disease (ESRD) incidence and to identify the risk factors on the regional differences, the authors conducted an ecological study on incidence of ESRD and related risk factors in the 46 counties of South Carolina (SC). Age and gender adjusted, race specific incidence rates for each county in SC were calculated for the 11,346 ESRD patients of all ages who registered in the United States Renal Data Systems Network 6 from 1990 to 1999. County level exposure measures on population physician density, hospitalization rates of diabetes and hypertension, per capita income, percent college degree, and percent below poverty were evaluated. There was a significant increase in mean incidence rates of ESRD from 1990 to 1999 in SC ($p<0.0001$). The incidence rates were consistently higher in rural than in urban counties. Population physician density (relative risk (RR) 0.49, 95% confidence interval (95%Cl, 0.41–0.58) and rural residence (adjusted RR 1.66, 95%Cl 1.59–1.74) were significantly associated with ESRD incidence. The strong relationship between ESRD and physician density suggests that access to adequate treatment of diabetes and hypertension is of paramount importance for ESRD prevention, and has important public policy implications.

Keywords: End-state renal disease; Geographic patterns; Incidence; Rural-urban areas

Introduction

Multiple inherited and environmental factors are associated with the rapidly increasing incidence rates of end-stage renal disease (ESRD) in the United States, particularly in the southeast (US Renal Data System, 2002). The geographic variation of ESRD has been observed at both the local and the global level (Cass et al., 2001; US Renal Data System, 2002; Usami et al., 2000; Valderrabano et al., 1998). Racial or ethnic differences in the incidence of ESRD have been noted in USA, the United Kingdom, and Australia. African Americans suffered from four times higher rates of ESRD compared with Caucasians in the USA (Klag et al.,

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1997; Martins et al., 2002). Similarly, in the UK, the incidence of ESRD in South Asian and African Caribbeans is three times higher than in White Caucasians (Lightstone et al., 1995; Roderick et al., 1996). The Indigenous Australians had about nine times higher ESRD incidence than the non-Indigenous Australians (Spencer et al., 1998).

The reasons for the increasing incidence rates, as well as the geographic variation and racial differences of ESRD were not clear. Among the factors that have been implicated, diabetes (Crook et al., 2001; Crook, 2002; Ness et al., 1999; Van Dijk et al., 2005), hypertension (Klag et al., 1997; Moore and Carpenter, 1999; Valderrabano et al., 1998), socioeconomic status (Young et al., 1994), and decreased assess to health care (Cass et al., 2001) have all received attention as contributing to the problem. Diabetes and hypertension are the leading causes of ESRD, constituting more than one-third (39.5%) and one-fourth (25.2%) of the overall causes of ESRD in the US (US Renal Data System, 2002). In addition, socioeconomic status (SES) and lack of access to care have been reported to be potential risk factors of ESRD (Perneger et al., 1995; Young et al., 1994; Moy et al., 1995).

While there has been amply documented evidence in the geographic variation of ESRD (US Renal Data System, 2002), studies of regional patterns of ESRD incidence at the county level are lacking. This is particularly relevant in regions, such as in southern US states, where the incidence and economic burden of ESRD are higher (US Renal Data System, 2002). South Carolina (SC) has the highest ESRD incidence rate and youngest age at onset of ESRD in the country (US Renal Data System, 2002). Forty percent of ESRD patients in SC are age 55 years or younger at the initiation of renal replacement therapy. This contrasts with an average of 34% nationally (US Renal Data System, 2002; The Southeastern Kidney Council, End-Stage Renal Disease Network 6, 2002. The excessive diseases risks are particularly evident with high incidence rates for younger black adults (Lackland et al., 1998). The objectives of this study are two fold: first, to determine the spatial distribution of ESRD incidence using geographical information systems (GIS); and second, to evaluate the ecologic association between the county level risk factors and incidence of ESRD. The use of GIS in evaluating the spatial distribution of disease risk (Moore et al., 1999; Glass, 2000) may provide etiologic insights into ESRD in this high-risk region. If the factors contributing to the regional differences in ESRD dynamics can be identified, new treatments for renal disease and preventable strategies might be implemented.

Methods

Geographic regions

The 46 counties of SC were grouped into urban and rural counties. The 15 urban counties, defined as the counties with largest town of 25,000 or greater, comprise 71% of population in SC (US Bureau of the Census, 2001). The 31 rural counties, with the largest town less than 25,000 population, comprise 29% of SC population. Among the urban population, 70% are Caucasians, 25% African Americans, and 2% other races. The correspondent proportions for the rural population are 55%, 45%, and 1%, respectively. Because Caucasians and African Americans comprised 99% of the population in rural counties and 98% in urban counties, we excluded other races in this study.

Adjusted incidence rates of ESRD

The number of new patients with ESRD beginning dialysis therapy annually from 1990 to 1999 at each county of SC was obtained through the Network 6 of United States Renal Data Systems, which maintains a data collection and management system for all ESRD patients residing in SC, North Carolina, and Georgia (ESRD Network 6, 2002). The database obtained for this study included patient's date of birth, date of diagnosis, race, sex, and county of residence at the time of diagnosis. Age at diagnosis was calculated for each patient. Race specific standardized incidence rates, adjusted for age and gender, was calculated for each county from 1990 to 1999.

Mapping the geographic distribution of ESRD incidence rates in SC

For each county, the 10-year mean standardized incidence rates of ESRD were aggregated. This data was linked to US county database in the ArcView GIS (3.2a). The mean incidence rates of ESRD were mapped for African Americans and Caucasians at the county level.

Factors related to regional differences in ESRD

Data on factors that might affect regional differences in ESRD dynamics were obtained at the county level. Except population physician density, all the factors listed below are race-specific for African Americans and Caucasians.

Inpatient discharges for diabetes (ICD 250) and hypertension (ICD 401), the two primary causes of ESRD, were used to calculate the hospitalization rates (per population of 1000) of diabetes and hypertension. Population physician density (per population of 10,000), a health availability indicator, was also available for each county from 1990 to 1999. SES was assessed by three distinct measures: per capita income, percent population with college education, and percent population below poverty for 1990.

Statistical analyses

Differences in the demographic information of ESRD patients among rural/urban counties of SC were assessed for African Americans and Caucasians using Chi-squared test and student's *t*-test. Using linear regression, we estimated the trend of the standardized ESRD incidence rates from 1990 to 1999 for rural African American, rural Caucasians, urban African Americans, and urban Caucasians.

A Poisson model was constructed for multivariate analysis. For count data, such as the number of ESRD incident cases, the Poisson distribution is well suited (Allison and Institute, 1999). Multivariate Poisson models are appropriate for estimation of rates based on count data. Using this model, the incidence rates were modeled adjusting for patients' age, gender, and race. For the Poisson model, data was generated as the number of the ESRD incident cases in the10-year period by age groups (0–19, 20–44, 45–64, and $\geq$65), gender, and race of African Americans and Caucasians for each county. Exposure variables include the rates of diabetes, hypertension, population physician density, and SES indicators at the county level were merged with the count of ESRD incident cases. The urban/rural indicator was included in the model to account for regional variations in the adjusted incidence of treated ESRD.

Results

Annual ESRD incidence and increasing rate of ESRD incidence

A total number of 11,646 ESRD patients were reported from Network 6 of ESRD registry from 1990 to 1999. The study population included 11,346 (97.4%) African American and Caucasian ESRD patients in the ESRD Network 6 registry during the 10 year period from 1990 to 1999. The distribution of incident cases of ESRD by county of residence was summarized in Table 1. Rural counties comprised 29% of population but 36% of ESRD patients. African Americans comprised 62% of the all ESRD population in SC (71% in rural counties vs. 57% in urban counties, $p<0.0001$, Table 1).

Table 1
Distribution of incidence cases and standardized incidence rates of end-stage renal disease in South Carolina from 1990 to 1999 ($n = 11346$)[a]

	Rural counties ($n = 31$)		Urban counties ($n = 15$)	
	African American	Caucasian	African American	Caucasian
Number of patients (% total)	2918 (70.8)	1205 (29.2)	4151 (57.5)	3072 (42.5)
Standardized incidence rates[b]	591.1 (26.2)	189.9 (11.1)	504.4 (22.1)	125.5 (8.6)
Gender, *n* (% male)	1227 (42.1)	661 (54.9)	1779 (42.9)	1661 (54.1)
Age group, *n* (% race specific total)				
0–19	31 (1.1)	13 (1.1)	43 (1.0)	34 (1.1)
20–44	552 (18.9)	146 (12.1)	866 (20.9)	428 (13.9)
45–64	1252 (42.9)	437 (36.3)	1814 (43.7)	1135 (37.0)
$\geq$65	1083 (37.1)	609 (50.5)	1428 (34.4)	1475 (48.0)

[a]Cumulated incidence cases from 1990 to 1999 by race, sex, and age group. Chi-squared test of proportion resulted $p<0.0001$ between African American and Caucasian in both rural counties and urban counties.

[b]Mean (standard deviation) of standardized incident rates in the 10 year period from 1990 to 1999, rate per 1 million population.

The adjusted incidence rates of ESRD for Caucasians ranged from 60 to 344 per 1 million population among the 46 counties of SC, with a mean rate of 169 and a standard error of 9.0 (Table 1). Incidence rates for African Americans ranged from 327 to 979 per 1 million population with a mean rate of 563 and a standard error of 19.6. Incidence rate ratio for African Americans versus Caucasians among the 46 counties ranged from 1.43 to 7.06 with a mean ratio of 3.6. For both African Americans and Caucasians, a significant difference in the mean adjusted incidence rates was observed between the rural counties and the urban counties, with higher rates observed in rural counties ($p < 0.0001$).

Using linear regression to estimate the trend for the incidence rates of ESRD from 1990 to 1999, a significant increase in ESRD incidence was observed among rural and urban African Americans ($p < 0.0001$) and urban Caucasians ($p < 0.0001$), but not rural Caucasians ($p = 0.07$) in SC (Fig. 1).

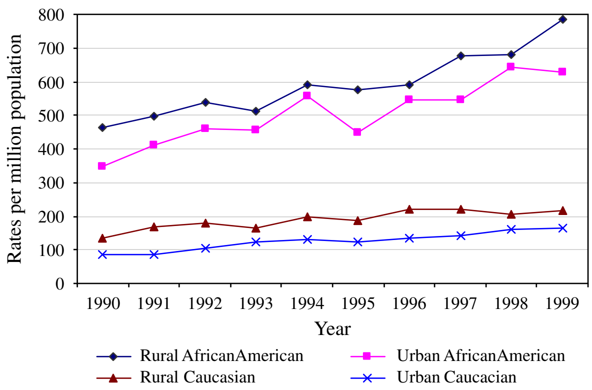

Fig. 1. The mean adjusted incidence rates of end-stage renal disease by race and by rural/urban counties in South Carolina. Linear regression slope for rural African American: 31.0; Urban African American: 28.9; Rural Caucasian: 8.4; and urban Caucasian: 8.6.

Maps of ESRD incidence in SC

The 10-year mean standardized incidence rates of ESRD for each county of SC were mapped for African Americans and Caucasians (Fig. 2). The 46 counties were grouped into four categories using the medians of the ESRD incidence rates for African Americans (median of 558 per million population) and Caucasians (median 155 per million population) as the cut points. The standardized incidence rates of 60–155 represented lower half for Caucasians of the 46 counties in SC, 156–344 represented upper half for Caucasians. For African Americans, the lower half of the incidence rates of ESRD ranges 327–558, leaving two counties overlapping with the upper half for Caucasians. Fig. 2 indicated that

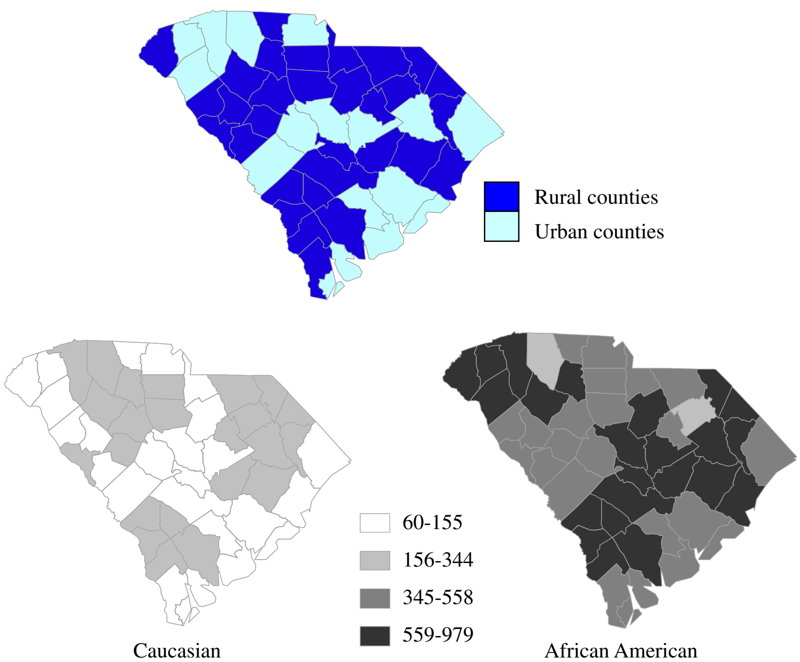

Fig. 2. The mean incidence rates (per million population) of end-stage renal disease by African Americans and Caucasians in rural/urban counties of South Carolina from 1990–1999. Using the median (155 for Caucasians and 558 for African Americans) as cut point.

ESRD incidence rates were higher among African Americans than those of Caucasians. Most of the county level ESRD incidence rates in the lower half for African Americans were above the upper half of ESRD incidence rates for Caucasians. There were 12 counties with ESRD incidence among the upper quartile (>627 and 196 per million population for African Americans and Caucasians, respectively), were all rural counties. None of the urban counties had ESRD incidence rates in the upper quartile.

Factors related to regional differences in ESRD

Risk factors for ESRD are shown in Table 2, stratified by rural and urban counties. Adjusted incidence rates, hospitalization rates of diabetes and hypertension, and percent population below poverty were significantly higher for African Americans than that of Caucasians. Within the same race, rural counties had higher rates compared to urban counties. College education was more prevalent among Caucasians than among African Americans and in urban residents than rural residents. Population physician density, the health care availability indicator, was higher in urban counties than in rural counties.

The association between the incidence of ESRD and related risk factors as the results of Poisson regression were shown in Table 3. Race and gender independently affect the ESRD incidence rates. African Americans had higher risk of ESRD incidence rates compared to Caucasians (adjusted relative risk (RR) 2.86, 95% confidence interval

Table 2
Characteristics of risk factors of end-stage renal disease in rural/urban counties of South Carolina[a]

Mean (SE)	Rural counties ($n = 31$)		Urban counties ($n = 15$)	
	African American	Caucasian	African American	Caucasian
Hospitalization rates of diabetes	19.2 (0.9)	13.9 (0.8)	19.1 (1.1)	11.9 (0.9)
Hospitalization rates of hypertension	21.8 (1.0)	18.5 (1.1)	23.0 (1.2)	17.2 (1.1)
Per capita income	6070 (132)	12461 (221)	7194 (204)	14472 (489)
Percent college graduate	8.2 (0.5)	19.5 (0.7)	13.0 (0.8)	28.4 (1.8)
Percent below poverty	33.9 (1.1)	10.5 (0.5)	29.0 (1.5)	8.1 (0.4)
Population physician density	45.6 (2.5)		54.5 (5.3)	

[a]Mean rates from 1990 to 1999 for standardized incidence rates, hospitalization rates (per 1000) of diabetes and hypertension, and population physician density (per 10,000 population), per capita income, percent college graduate, and percent below poverty in 1990. Student's *t*-test resulted $p<0.0001$ between African American and Caucasian in both rural counties and urban counties.

Table 3
Poisson regression model of end-stage renal disease incidence rates in rural/urban counties of South Carolina and related risk factors[a]

Variables	Adjusted relative risk (95% CI)[b]	
	African American	Caucasian
Male	3.85 (2.98, 4.98)	1.35 (1.27, 1.43)
Female	2.86 (2.35, 3.47)	1.0
Age group (years)		
0–19	0.83 (0.38, 1.97)	0.29 (0.21, 0.40)
20–44	0.61 (0.47, 1.84)	0.21 (0.19, 0.24)
45–64	2.86 (1.54, 3.92)	0.49 (0.46, 0.53)
⩾65	3.89 (3.05, 4.82)	1.0
Rural vs. urban counties	1.66 (1.59, 1.74)	
Population physician density	0.49 (0.41, 0.58)	
Hospitalization rates of diabetes	0.98 (0.97, 0.99)	
Hospitalization rates of hypertension	1.03 (1.02, 1.04)	
Percent college graduate	0.98 (0.97, 0.99)	

[a]Mean rates from 1990 to 1999 for hospitalization rates (per 1000) of diabetes and hypertension, and population physician density (per 10,000 population), per capita income, percent college graduate, and percent below poverty in 1990.
[b]Adjusted relative risks.

Table 4
Poisson regression model of end-stage renal disease incidence rates by race in rural/urban counties of South Carolina and related risk factors[a]

Variables	Adjusted relative risk (95% CI)	
	African American	Caucasian
Male vs. female	1.21 (1.16–1.27)	1.34 (1.26–1.43)
Age group (reference ⩾65)		
0–19	0.20 (0.16–0.26)	0.31 (0.22–0.43)
20–44	0.21 (0.20–0.23)	0.22 (0.20–0.26)
45–64	0.68 (0.64–0.71)	0.51 (0.48–0.54)
Rural vs. urban counties	1.39 (1.31, 1.47)	2.45 (2.24, 2.65)
Population physician density	0.50 (0.40, 0.61)	0.36 (0.29, 0.47)
Hospitalization rates of diabetes	0.97 (0.96, 0.98)	1.04 (1.01, 1.06)
Hospitalization rates of hypertension	1.02 (1.01, 1.04)	0.98 (0.96, 1.00)
Percent college graduate	0.97 (0.96, 0.98)	0.99 (0.98, 1.04)

[a]Mean rates from 1990 to 1999 for hospitalization rates (per 1000) of diabetes and hypertension, and population physician density (per 10,000 population), per capita income, percent college graduate, and percent below poverty in 1990.

(95% CI) 2.35–3.47) after adjusting age, gender and county of residence. Similarly, the adjusted RR for male versus female was 1.35 (95% CI of 1.27–1.43). There were significant interactions between race and gender with African American males having about four times higher risk of ESRD compared with Caucasian women. The significant interactions between race and age groups were also apparent with African Americans aged 65 years, the highest risk group. Rural county residents are about two times more likely to have ESRD compared to urban residents (adjusted RR 1.66, 95% CI 1.59–1.74). Higher population physician density (per 10,000 population) had a protective effect on the incidence of ESRD (adjusted RR 0.49, 95% CI 0.41–0.58).

Table 4 shows the same Poisson regression model stratified by race of African American and Caucasian. While the magnitude of the adjusted relative risks varied in models for all patients (Table 3) and by race (Table 4), the significant effect of population physician density and rural county residents on the ESRD incidence remained the same. The race-stratified model also indicated that the hospitalization rate of diabetes for Caucasians and the hospitalization rate of hypertension for African Americans were directly associated with ESRD incidence (adjusted RR 1.04, 95% CI 1.01–1.06, and RR 1.02, 95% CI 1.01–1.04, respectively). This regression model also indicated that college education had a protective effect for African Americans (adjusted RR 0.98, 95% CI 0.97–0.99) but not to Caucasians (adjusted RR 0.99, 95% CI 0.98–1.04).

Discussion

While the geographic variability of ESRD has been described previously at the state level in USA (US Renal Data System, 2002), Australia (Cass et al., 2001), and Japan (Usami et al., 2000), the basis for the variability has not been fully elucidated. Lack of access to care (Cass et al., 2001), lower SES (Spencer et al., 1998), variation in reporting, and incidence of underlying kidney diseases were among the possible explanations (US Renal Data System, 2002). This study examined the pattern of regional variation in ESRD incidence and identified the risk factors that may contribute to the different incidence rates in the state of SC. Our data support two main conclusions. First, the ESRD incidence was significantly higher in rural counties compared to urban counties in SC. The increasing trend in the adjusted incidence rates was consistent for both rural and urban counties. Second, higher physician density, an indicator of access to care, was associated with lower ESRD incidence. The combination of rural residency with lower physician density may contribute to the higher incidence of ESRD in rural areas in SC.

Definite and significant regional and racial differences in the ESRD incidence among the 46 counties of SC were identified in this study. The GIS mapping revealed the geographic pattern of the ESRD incidence rates in SC: African Americans had higher incidence rates than that of Caucasians; within the race subgroups, rural counties higher than that of urban counties (Fig. 2). This study illustrated the potential use of GIS technology as a new information vehicle for epidemiological study (Glass, 2000).

Higher morbidity and mortality rates identified in some populations suggested that individuals without a usual source of care received less screening, follow-up care, and timely treatment (Moy et al., 1995). Lower population physician density may reflect the lack of access to preventive care by delaying the detection and treatment of hypertension and diabetes, and thus causing delay in prevention of renal failure. Lack of access to medical care was found to be a cause of uncontrolled high blood pressure in US (Ballard et al., 1988), higher incidence of ESRD in Indigenous Australia (Cass et al., 2001; Moy and Hogan, 1993), and stroke in rural areas of SC (Lackland et al., 1995). Access to quality health care, however, is often impaired in SES deprived populations, including a large proportion of the African Americans. The relative risk of 0.49 is equivalent to a more than 50% reduction in risk of ESRD for each extra physician per population of 10,000. While the population physician was measured at whole county population rather than at the race subgroup, the effect of population physician appeared slightly different from African Americans to Caucasians. Our study indicated that rural county residents with lower physician density in the area experienced an increased incidence of ESRD regardless of race.

The findings of this study complemented and confirmed previous analyses on racial and gender differences of ESRD in the US and SC (Lackland et al., 2000; US Renal Data System, 2002). African Americans and males had relatively higher proportion of ESRD incidence and earlier age at onset of ESRD. Nationally, African Americans comprise 12% of the population and 30% of the ESRD patients (US Renal Data System, 2002). In SC, African Americans comprise 30% of the population and 61% of ESRD patients as indicated in this study. The Poisson regression indicated that the incidence of ESRD remained about threefold higher for African Americans than Caucasians after adjustments for age, sex, and geographic region. The adjusted risk ratio of ESRD for African Americans aged 45–64 was more than two times higher compared with Caucasians aged >65 (Table 3), indicating that younger African Americans have the same risk of ESRD as older Caucasians. Thus, the higher incidence of ESRD that has been consistently found in African Americans seems to be multi-factorial. Each factor may act alone or in concert with the others to affect renal outcome of the patients.

These data indicate that the effects of diabetes, hypertension, and SES on differences in ESRD incidence were relatively small compared to the effect of race, rural/urban residency, and population physician density. In the Poisson regression model, if only hospitalization rates of hypertension and diabetes were included as the predictive variables, adjusting for patients' demographics (age, race, and gender), both diabetes and hypertension were significantly associated with the incidence rates of ESRD. The significant detrimental effects of hypertension and diabetes attenuated, however, when rural/urban residency and physician density were added to the model. Previous studies documented that diabetes and hypertension are the two important causes of ESRD and are disproportionately higher in African Americans compared to Caucasians (Crook et al., 2001; Crook, 2002; Klag et al., 1997; Moore and Carpenter, 1999; Ness et al., 1999). Socioeconomic status was identified as an independent risk factor for the occurrence of renal failure in some epidemiological studies (Young et al., 1994). The three SES variables of per capita income, percent college graduate, and percent below poverty were highly correlated ($p<0.0001$). In the Poisson model, using one of the three SES variables to predict the ESRD incidence rates, the effect of per capita income (crude RR 0.94, 95% CI 0.92–0.96) and percent below poverty (crude RR 1.05, 95% CI 1.04–1.06) were smaller than that of percent college graduate (crude RR 0.91, 95% CI 0.90–0.94). Since the protective effect of income and risk of poverty on the ESRD incidence rates in this study are similar in magnitude and smaller than the effect of college education, the final Poisson model used percent college graduate as an indicator of SES.

One of the limitations of this study would be the failure to identify all ESRD patients, which would result in an underestimate of the true ESRD incidence, especially in the rural areas. Yet, the observed rural/urban variation in the 10-year period could not be entirely explained by problems with patient identification. In fact, the patient information obtained through USRDS, which maintains a database of all treated ESRD patients, may provide the most accurate count of treated ESRD patients at the county level. The major limitations of county-level data and the potential ecologic bias (Connor and Gillings, 1984; Glass, 2000) associated with population measures should always be considered in the reporting and interpretation of results. For example, the finding of a relationship between population physician density and incidence of ESRD does not necessarily imply that an individual's exposure to or experience with health care will alter the likelihood of renal failure.

This study identified the clear and significant regional differences among rural and urban counties in SC, reflected in both the mean incidence rates and the increasing rate of ESRD during 10-year period from 1990 to1999. We concluded that lack of access to medical care as indicated by lower physician density may contribute to the significantly higher incidence of ESRD in rural counties. These results have implications for the delivery of services to rural residents. Improving prevention and treatment services in high incidence areas should be a priority.

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