System failure: the spatial distribution of septic mortality and its association with area-based racial composition, socioeconomic, and health-resource measures

Introduction

Severe sepsis, a condition of system-wide physiologic dysfunction typically caused by bacterial infection acquired in hospital settings, is the most common cause of mortality in the intensive care unit (ICU) and the 10th leading cause of death in the US overall (Angus, Linde-Zwirble et al. 2001). Its incidence has increased since 1993 (Dombrovskiy 2007) and while the prognosis for severely septic patients has improved it remains poor with a mortality rate of about 18% (Martin, Mannino et al. 2003).

In response to the climbing incidence of septic mortality, medical researchers have identified new prevention and treatment protocols for containing sepsis in hospitals. The proliferation of such studies, however, has not been matched with research identifying the spatial distribution of septic mortality and its association with population characteristics and local health-service availability (Linde-Zwirble and Angus 2004). Mapping methods using Geographic Information Systems (GIS) technology and spatial statistics provide a set of tools to identify clusters of septic mortality "hotspots", analyze local associantions between septic mortality rates and area-based measures, and optimize the distribution of health services.

The current study asks three questions: (1) how do septic mortality rates vary across health-service areas (HSAs) in the US; (2) how are HSA racial composition and median household income associated with septic mortality rates; and (3) are the observed relationships from the second question explained by differences across HSAs in healthcare resources, including hospital beds and licensed physicians for every 1,000 persons, and percent of hospitals with airborne infectious-disease isolation rooms and geriatric services. Using GIS-based mapping and Exploratory Spatial Data Analysis (ESDA), I examine variation in septic mortality across health service areas (HSAs) in the US. With these patterns determined, I then use geographically weighted regression (GWR) to analyze local associations between HSA demographic, socioeconomic, and health-service attributes and septic mortality rates.

Background

Septic mortality: etiology and epidemiology

Mortality as a result of severe sepsis is really the product of a complex and generally nonspecific process involving any number of insults to the human body. Systemic inflammatory response syndrome (SIRS) marks the first stage of this process. Rapid heart rate, irregular body temperature, impaired respiration, and abnormal white blood cell count are all signs of SIRS. Risk factors for SIRS include both acute infectious and noninfectious insults such as trauma (including trauma caused by invasive surgical procedures), burns, ischemia, and pancreatitis (Bone, Balk et al. 1992). If left untreated SIRS may lead to severe sepsis, a condition that typically impairs the healthy functioning of the lung, kidney, and cardiovascular system (Angus, Linde-Zwirble et al. 2001; Guidet, Aegerter et al. 2005). Severely septic patients may also develop septic shock, a state of acute cardiovascular dysfunction and life-threatening hypotension.

Mortality rates among severely septic individuals have declined in recent years from an average of 28% among all septic hospital patients between 1979-1984 to 18% between 1995-2000 (Martin, Mannino et al. 2003). New medical interventions to treat severe sepsis (e.g., fluid resuscitation; activated protein C) have no doubt contributed to this decline. Such advancements, however, may be overshadowed due to the increase in the incidence of severe sepsis that unfolded over the same time period, a trend that has doubled the septic mortality rate among the US population from 21.9 per 100,000 in 1979 to 43.9 in 2000 (Angus, Linde-Zwirble et al. 2001).

Several studies have identified groups at heightened risk for severe sepsis and septic mortality, including men (Martin, Mannino et al. 2003; Esper, Moss et al. 2006), older individuals (Martin, Mannino et al. 2006), African Americans (Barnato, Alexander et al. 2008), and uninsured individuals (Danis, Linde-Zwirble et al. 2006). At least one study has suggested that area poverty is also linked to septic mortality, with non-poor areas at lower risk than poor areas (Barnato, Alexander et al. 2008). Limitations of this study include a study sample drawn from only six US states and an untraditional measure of area poverty (i.e., percent of non-Hispanic white individuals under the federal poverty line in sampled ZIP codes).

With few exceptions, scholarly work devoted to septic mortality has focused on intra-hospital procedures for managing severe sepsis. It would be useful to know the spatial patterns of septic mortality, as the identification of highly impacted clusters would better direct resources to underserved and overburdened areas. It would also be useful to understand how differences in health-service areas contribute to this spatial variation. Demographers have shown that the quantity and quality of health services are not distributed randomly or evenly across administrative units (Gobalet and Thomas 1996; Pol and Thomas 2001), yet the contextual correlates of septic mortality have gone largely ignored. An ecological approach can account for disparities in the distribution of health resources across areas and inequalities in septic mortality.

Spatial inequalities and variation in septic mortality

Demographers have long been recognized for their contributions to health policy (Keyfitz 1993; Preston 1993). Spatial methods refined by demographers are well-suited for analyzing a wide range of contextual attributes that help explain variations in mortality across places (de Castro 2007). Demographic traits and socioeconomic characteristics of the spatial units frequently studied by demographers (e.g., counties; health-service areas; states) have been linked to mortality in many past studies. Three national studies found a positive association between the percent African American and all-cause mortality among either US counties, census tracts, or spatial units approximating census block groups (LeClere, Rogers et al. 1997; McLaughlin, Stokes et al. 2001; Huie, Hummer et al. 2002). Similar to each of these, other studies have also found community socioeconomic traits to be significantly associated with mortality. Using regression methods that account for spatial autocorrelation, Lorant and colleagues (2001) found that high mortality rates tended to be clustered in areas with higher poverty rates. In their study of mortality following the 1995 Chicago heat wave, Browning and Wallace (2006) found higher mortality rates in communities marked by commercial disinvestment.

Studies of population health emphasizing the role of context have proved very useful in identifying the patterns and spatial correlates of mortality; however, some have argued that the literature has bordered on an *over*emphasis of only a few contextual factors. A recent survey of the literature on context and health published in the journal *Demography* showed that over 70% of studies use area-based measures of poverty as the key explanatory variable (Entwisle 2007). By comparison, less than nine percent of such studies examined area-level health-service measures as the principal contextual predictor. As such, there remain a host of unexplored health-service characteristics that may help explain the link between well-researched contextual traits (e.g., racial composition and poverty) and mortality.

The compositional and economic traits of places may impact mortality rates by weakening the local health-service infrastructure. Some have observed that areas densely populated by racial minorities—especially African Americans—and heavily impacted by poverty are less likely to attract and maintain quality medical services (Robert 1999). In support, multiple studies show that area poverty and minority concentration are inversely associated with the quantity and quality of health services (Williams and Collins 1995; Baicker, Chandra et al. 2005).

Current study

I examine the spatial variation in septic mortality and area-based traits that may explain this variation. Using mapping and exploratory spatial data analysis (ESDA), I first analyze variation in the septic mortality rate across HSAs in the continental US. I then use geographically-weighted regression (GWR) to assess associations between HSA racial composition and median household income and septic mortality rates. Finally, I add measures of the local health-service environment to determine whether differences in health resources explain the link between area-based demographic and economic measures and septic mortality.

Data

Mortality data are accessed through the National Cancer Institute's surveillance epidemiology and end result (SEER) program (National Cancer Institute 2010), an online tool to extract mortality data collected and maintained by the National Center for Health Statistics (NCHS). Racial composition and household income data are drawn from the American Community Survey 5-year file, 2005-2009. Finally, the Area Resource File is used to construct measures of the health service environment in 2005. In their original form all data are at the county-level, which I then aggregate to the health-service area level to create a dataset representative of all HSAs in the contiguous US. Health-service areas are clusters of counties and independent cities where Medicare patients obtained routine care in 1988 (Pickle, Mungiole et al. 1996). HSAs were originally designed to approximate health-service markets, identify underserved areas, and be used for health-service planning. Because individuals often receive medical services beyond the boundaries of their county of residence, HSAs better approximate the environments from which individuals receive care.

Measures

Septic mortality is measured using age-adjusted 5-year rates (2003-2007) of mortality due to septic infection (ICD-10 cause of death codes A40-A41). SEER does not report data for counties with fewer than four deaths in the years considered here; thus, these counties are recoded to zero (0). HSA-level rates are calculated by weighting the county-specific rates by the proportion of the HSA population comprised of that specific county and aggregating the product.

Racial composition is based on two measures from the ACS: (1) the percent of each HSA comprised of non-Hispanic blacks and (2) the percent of Hispanics/Latinos.

Median household income is an aggregate measure of county-level median household income adjusted for the proportion of each HSA comprised of a specific county's population. After this adjustment, the county measure is aggregated to achieve the HSA-level measure.

Health resource availability is measured with four variables: hospital beds per 1,000 persons in each HSA; licensed physicians per 1,000 persons; percent of hospitals with airborne infectious isolation rooms; and percent of hospitals offering geriatric care services.

Analysis

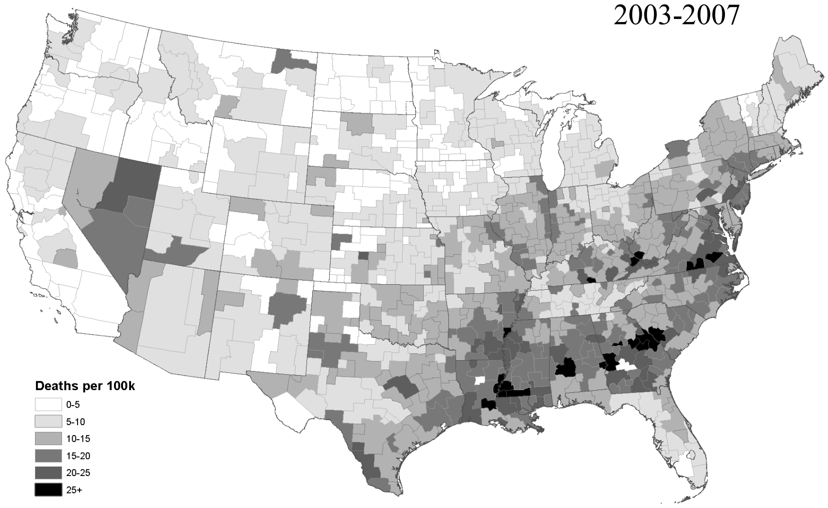
Descriptive statistics include means and standard deviations for all analytic variables in their untransformed state. Moran's *I,* a measure of spatial autocorrelation, is used to determine whether there is a spatial structure to the distribution of septic mortality rates. Geographically weighted regression (GWR) is used to model associations between the independent variables and septic mortality. Preliminary results using a Rook's first-order spatial weight yielded the highest Moran's *I* correlation coefficient. Accordingly, this weight is used in all GWR models. All independent variables are *Z*-transformed to ease comparisons of effects across measures. To account for sex differences and the contribution of comorbidity to the septic mortality rate, all models control for percent male and number of hospital admissions per 1,000 persons.

Table 1. Sample description (n = 798)

Variable	Mean	σ
Septic mortality rate	10.96	6.06
% Black	9.00	.13
% Hispanic/Latino	8.80	.13
Median household income	42,725.16	9,627.69
Doctors per 1,000	1.68	.99
Hospital beds per 1,000	4.08	3.28
% Hospitals w/ isolation rooms	56.80	.32
% Hospitals w/ geriatric services	32.87	.28
% Male	49.50	.01
Hospital admissions per 1,000	117.54	39.35
Moran's *I* coefficient	.65	($p < .001$)

Results

Figure 1. Choropleth map of age-adjusted septic mortality rates 2003-2007



The map shown to the right provides evidence of a spatial pattern to the incidence of septic mortality. This is consistent with the Moran's *I* statistic reported in Table 1, which suggests moderate to high spatial dependence in septic mortality across the US. Clusters of high septic mortality rates, shaded with darker colors, can be seen in areas of the Southeast and in the Mississippi Delta region.

Table 2 provides results from two sets of GWR models. Because GWR models are designed to explore *local* associations, there are three versions of each coefficient and fit statistic: the minimum coefficient found, the maximum, and the average effect of each variable across all HSAs. Results from Model 1 show that the percent black is a strong predictor of higher septic mortality rates, while percent Hispanic and median household income are non-significant. The percent of variation in septic mortality explained by Model 1 ranges from 4% in some areas to a high of 69% in some other areas, which suggests that the variables in Model 1 are more relevant to septic mortality rates in some areas and less so in others (in spatial parlance, the effects are said to be non-stationary). Model 2 adds measures of health service availability and finds that none are significantly associated with septic mortality. Further, while the addition of these variables does appear to explain a portion of the effect of the percent black, the mediation effect is small.

Table 2. Results from GWR models predicting HSA septic mortality rates (n = 798)

	Model 1			Model 1		
	Local effect of predictors (□)			Local effect of predictors (□)		
	Average	Min	Max	Average	Min	Max
% Black	3.571***	-.974	10.013	3.386***	-1.576	9.093
% Hispanic	.655	-2.189	4.559	.712	-1.569	4.471
Median household income	-.759	-3.055	1.051	-.659	-1.973	1.652
Hospital beds per 1,000 persons	--			.356	-.946	1.695
Doctors per 1,000 persons	--			.838	-.494	4.249
% hospitals w/ isolation rooms	--			.352	-.994	.924
% hospitals w/ geriatric services				-.089	-.804	.499
Local R^2	.324	.044	.687	.368	.084	.685

All models control for % male and hospital admissions per 1,000 persons

Discussion

This study aims to identify spatial variation in septic mortality, investigate its association with area-based demographic and income measures, and test whether health-resource availability explains the aforementioned associations. Preliminary results suggest spatial patterning of septic mortality, but mixed explanations for this variation. Prior to presenting my work at PAA 2012, I plan to investigate other socioeconomic measures (e.g., % under the poverty line; % uninsured) as alternatives to the median household income measure. I also plan to widen the current vector of health-service measures to include more refined indicators of health-service availability, such as the ratio of physician residents to licensed physicians.

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