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Geographic Identification of High Gonorrhea Transmission Areas in Baltimore, Maryland

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Geographic approaches to sexually transmitted infection (STI) research frequently seek to identify areas where outreach STI testing may most effectively interrupt continued transmission of STIs. Many of the studies are limited, however, in that they fail to control for racial/ethnic composition of the high prevalence areas. These studies thus may be merely identifying the broader sexual networks of the high morbidity population and not the high transmission networks within them. Cluster detection analysis may be an appropriate approach to identify critical STI disease transmission locations. This study determined whether statistically significant geographic clusters of high prevalence gonorrhea cases can be located after controlling for race/ethnicity. Using a spatial scan statistic, the authors analyzed reported cases of gonorrhea (n = 32,454) in Baltimore City, Maryland, from 1994 to 1999 geocoded to the primary address and aggregated to census block groups (n = 709). They adjusted for the underlying distribution of the population aged 15–39 years and percent African American per census block group. The results identified eight significant clusters of high STI prevalence areas, reinforcing the inference that risks for gonorrhea are associated with definable sociogeographic spaces. The areas identified may be critical to control STIs and may provide important direction for further study and targeted interventions.

disease transmission; geographic information systems; gonorrhea; risk factors; sexually transmitted diseases

Abbreviation: STI, sexually transmitted infection.

Geographic approaches to sexually transmitted infection (STI) research and prevention have received increasing attention in recent years (1–7). The research has demonstrated that STIs are not equally distributed across geographic areas or in population subgroups. Researchers have hypothesized that locations characterized by high STI prevalence may represent key targets for STI prevention and control (8–12). Thus, one focus of STI geographic analysis is to identify high transmission risk areas where outreach STI testing may most effectively interrupt continued transmission of STIs. Specifically, STI surveillance may search for areas with high prevalence sexual networks containing "core transmitters," that is, individuals who play a prominent role in maintaining and propagating STIs (13–15). Not all high prevalence sexual networks, however, represent core transmission networks (16). The simple identification of high prevalence locations in many geographic STI studies fails to distinguish areas representing broad sexual networks of the high morbidity population and areas representing sexual networks with core transmitters. Thus, much geographic STI research to date has not been sufficiently specific to guide a targeted approach to high-risk case finding.

Within high-risk STI locations (usually neighborhoods or other socially defined geographic areas), risk may differ significantly by race/ethnicity. This does not reflect any underlying biologic difference but may represent differences in partner selection by race/ethnicity (17). The greatest morbidity from STIs lies within the African-American population (18, 19). In part, this is because sexual networks are generally segregated according to race/ethnicity (17). The racial/ethnic segregation of sexual networks is in part determined by a strong tendency for individuals to preferentially select a sexual partner of the same race/ethnicity (17, 20–22). The segregation of sexual networks is also a function of

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the availability of sexual partners (3, 8, 17, 20, 23–29). The availability of sexual partners has a significant geographic component that reflects patterns of residential and social interaction (20).

In many US cities, African Americans tend to live in highly segregated communities, and STIs remain confined to African-American neighborhoods because their sexual networks are also racially and geographically segregated (30, 31). As such, locations identified as high prevalence neighborhoods might simply be a marker for the presence of these segregated networks. While this information may be useful for general community-based screening programs, it does not point to specific areas within segregated networks to target testing and treatment. Geographic studies focused on identifying areas where these prominent subgroups may be found must adjust for the location of broader segregated networks.

Recent advancements in geographic analysis provide the capacity to control for racial/ethnic population composition while examining the geographic dispersion of infections. Studies of STI clustering frequently rely on exploratory or graphics-based analyses using, for example, arbitrary cutoff points for determining "high" STI prevalence areas (1, 4). In addition, as noted previously, many studies have failed to adequately adjust for race/ethnicity. In this analysis, we utilize an advanced cluster detection approach using the SaTScan program (Statistical Research and Applications Branch, Surveillance Research Program, Division of Cancer Control and Population Sciences, National Cancer Institute, Bethesda, Maryland) (32). The SaTScan approach eliminates the subjectivity in defining high and low prevalence cutoff points while providing a statistically objective approach for identifying both the existence and location of significant geographic clusters. SaTScan also allows for the adjustment of population-based identifiers such as race/ethnicity composition. SaTScan is a publicly available software program that has been applied in many cancer studies but has yet to be utilized in STI research (33–35).

The objective of this study was to identify statistically significant clusters of neighborhoods (represented by census block groups) with a high prevalence of gonorrhea that persists after adjustment for the racial/ethnic composition of the census block groups. We hypothesized that sexual networks found through cluster detection analysis after adjustment for African-American race/ethnicity would identify important STI transmission networks.

MATERIALS AND METHODS

Data

Data on all reported gonorrhea cases from 1994 to 1999 (n = 41,465) in Baltimore City were extracted from Baltimore City Health Department STI program databases. State law in Maryland requires mandatory provider and laboratory reporting of gonorrhea cases. A reported case of gonorrhea was defined as a laboratory-confirmed case of *Neisseria gonorrhoeae* by urethral, cervical, pharyngeal, or rectal culture or by urine-based polymerase chain reaction (Amplicor; Roche Diagnostic Systems, Branchburg, New Jersey). Under quality-controlled conditions, the sensitivity of culture is high for both males and females; for example, in women, a single endocervical culture is estimated to have a sensitivity of 80–95 percent. Polymerase chain reaction has been shown to have 80–94 percent sensitivity and 99.6 percent specificity (36). The study was approved by the Johns Hopkins University Joint Committee on Clinical Investigation and the institutional review board of the Baltimore City Health Department.

Cases of gonorrhea were used as the indicator STI because in Baltimore there is high morbidity (approximately 6,000 reported cases per year). In addition, gonorrhea is relatively acute and does not suffer from the same ascertainment bias as, for example, chlamydia, because of its generally symptomatic nature. We used reported gonorrhea cases over 6 years to provide a stable measure of disease over time and geography (per census block group) and because measures of networks accumulated over time are more informative than static measurements (26).

Demographic characteristics including date of birth, gender, race/ethnicity, and primary residential address were available from morbidity reporting data. Data from the 2000 US Census included census block group boundaries, total population, population aged 15–39 years, and the percentage African American.

To eliminate duplicate cases, we excluded gonorrhea cases that were reported more than one time for the same individual within a 2-week period. This is based on the fact that a gonorrhea infection tends to be symptomatic, and the standard of care for a gonorrhea infection is a single-dose regimen that has greater than 98 percent efficacy (37).

Cases were geocoded to the reported residential address of the case using MapInfo (MapInfo, version 6.0; MapInfo Corporation, Troy, New York) and Baltimore City Urban Planning Commission 2000 base maps. The cases were then aggregated to the 710 Baltimore City block groups of the 2000 US Census. Gonorrhea rates per 100,000, using the population aged 15–39 years in each census block group, were computed and averaged over the 6 years.

Statistical analysis

Summary statistics were computed for the reported STI morbidity and corresponding population demographics using Stata software (Intercooled Stata, version 7.0; Stata Corporation, College Station, Texas). Maps of census block group gonorrhea case counts and rates per 100,000 for Baltimore City were generated using MapInfo. The SaTScan spatial cluster detection program described previously was used to identify possible core areas of gonorrheal disease. We defined a core area as an isolated bounded geographic region with a higher than expected prevalence of gonorrhea.

Using SaTScan, we first determined groups of contiguous census block groups, representing potential clusters or high counts of gonorrhea cases, by considering each block group the center of a potential cluster and then expanding out in a radial fashion to include neighboring block groups. The procedure resulted in contiguous block groups, including each block group individually, and various forms of neighboring block groups. We limited any possible cluster so it would not exceed 50 percent of the total Baltimore City population at risk (aged 15–39 years).

For each potential cluster, a likelihood ratio test was used to determine if the expected number of gonorrhea cases within the potential cluster, based on the total number of observed cases from the inclusive census block groups, was significantly higher than the overall expected number of gonorrhea cases for the city. Expected numbers of cases were calculated on the basis of the null hypothesis of complete spatial randomness, which is synonymous with assuming that the number of gonorrhea cases in each block group or any collection of block groups were independent Poisson random variables with a constant mean rate (38).

The sets of potential clusters were then rank ordered according to the magnitude of their likelihood ratio test statistic. Corresponding p values were calculated using Monte Carlo simulation. Under the null hypothesis of complete spatial randomness, simulated maps of block group gonorrhea cases conditioned on the total number of observed cases (n = 32,454) were repeatedly generated (9,999 times), and likelihood ratio test statistics were calculated for each potential cluster. Potential clusters whose corresponding observed likelihood ratio test statistic was within the upper 5 percent tail of the corresponding simulated (expected) distribution were deemed significant at the 0.05 level. Details describing the method and applications of the SaTScan program have been previously reviewed (32, 39).

The SaTScan cluster detection analysis was conducted in two stages: first, analyzing gonorrhea cases, adjusting for the underlying population at risk (persons aged 15–39 years); and second, analyzing gonorrhea cases, adjusting for the underlying population at risk (persons aged 15–39 years) and controlling for the race/ethnicity distributions (percent African American) per census block group. SaTScan uses indirect adjustment to control for population-based characteristics. Results from the SaTScan analysis were imported back into MapInfo to generate maps identifying significant clusters (core areas) of elevated gonorrheal density. Summary statistics including sums, means, and mean rates were computed for each core and noncore area.

A sensitivity analysis was also conducted to address potential issues of racial/ethnic reporting bias created by differential reporting by private versus public providers (40, 41). Subsequent to the primary analysis, the sensitivity analysis was conducted by increasing the number of reported cases of gonorrhea found in White individuals (a proxy measure for private reporting) by 20 percent, 30 percent, and 40 percent and rerunning the SaTScan analysis; these methods have been previously documented (41). The sensitivity analysis, performed to explore the potential effects of underreporting by race/ethnicity, found no qualitative differences in the results of our analyses.

RESULTS

Of the 41,465 gonorrhea cases reported over the 6 years, approximately 9 percent (3,768 cases) represented nonresidential addresses. Among the 37,697 gonorrhea cases with a residential address, approximately 96 percent (36,250 cases) geocoded successfully. The cases that could not be geocoded included post office box addresses and addresses that were missing, incomplete, or otherwise unlocatable on the basis of the information provided. Proportions of nongeocoded cases versus those with a geocodable address were not significantly different across race/ethnicity and age groups, but nongeocoded cases were more likely to be male ($p < 0.05$). Additional exclusion criteria for this analysis were cases with a reported residential address outside the geographic boundary of Baltimore City, representing 8 percent (2,985 cases) of cases, and cases with missing demographic information, representing 2 percent (602 cases) of cases.

Upon calculation and inspection of gonorrheal rates per census block group, we excluded from the analysis one census block group that experienced a large population drop between 1990 and 2000 as a result of the destruction of a large housing tenement; the population loss created an unstable measure of disease. Cases from this census block group represented less than 1 percent (103 cases) of the total analyzed. A total of 32,454 gonorrhea cases were used in this analysis.

The 32,454 gonorrhea cases over the 6 years represented approximately 26,712 individuals. Gonorrhea cases in Baltimore City from 1994 to 1999 were 54 percent male and 97 percent African American, and the mean age was 27 (standard deviation: 9.6) years (table 1). The average yearly rate of gonorrhea for Baltimore City was 2,250 cases per 100,000 for the population aged 15–39 years. A map of the corresponding 1994–1999 gonorrhea case rate stratified by census block group is shown in figure 1, which clearly indicates a nonhomogenous distribution of gonorrhea over the geographic region of Baltimore City.

In the first analysis, using the SaTScan program adjusting only for the underlying population at risk, four statistically significant ($p < 0.05$) high gonorrhea prevalence clusters (core areas) were identified. These core areas are shown in figure 2 and comprise approximately one third (233 census block groups) of the total 709 block groups analyzed. The core census block groups combined over the 6-year period

TABLE 1. Demographic characteristics of reported cases of gonorrhea in Baltimore City, Maryland, 1994–1999

Years 1994–1999	No.	% or SD*
Total	32,454	100.0
Gender	32,377	
Male	17,400	53.74
Female	14,977	46.26
Unknown	77	
Race/ethnicity	26,987	
White	726	2.69
African American	26,261	97.31
Missing	5,482	
Age (years)		
Mean (SD)	27	9.6
Median	23	

* SD, standard deviation.

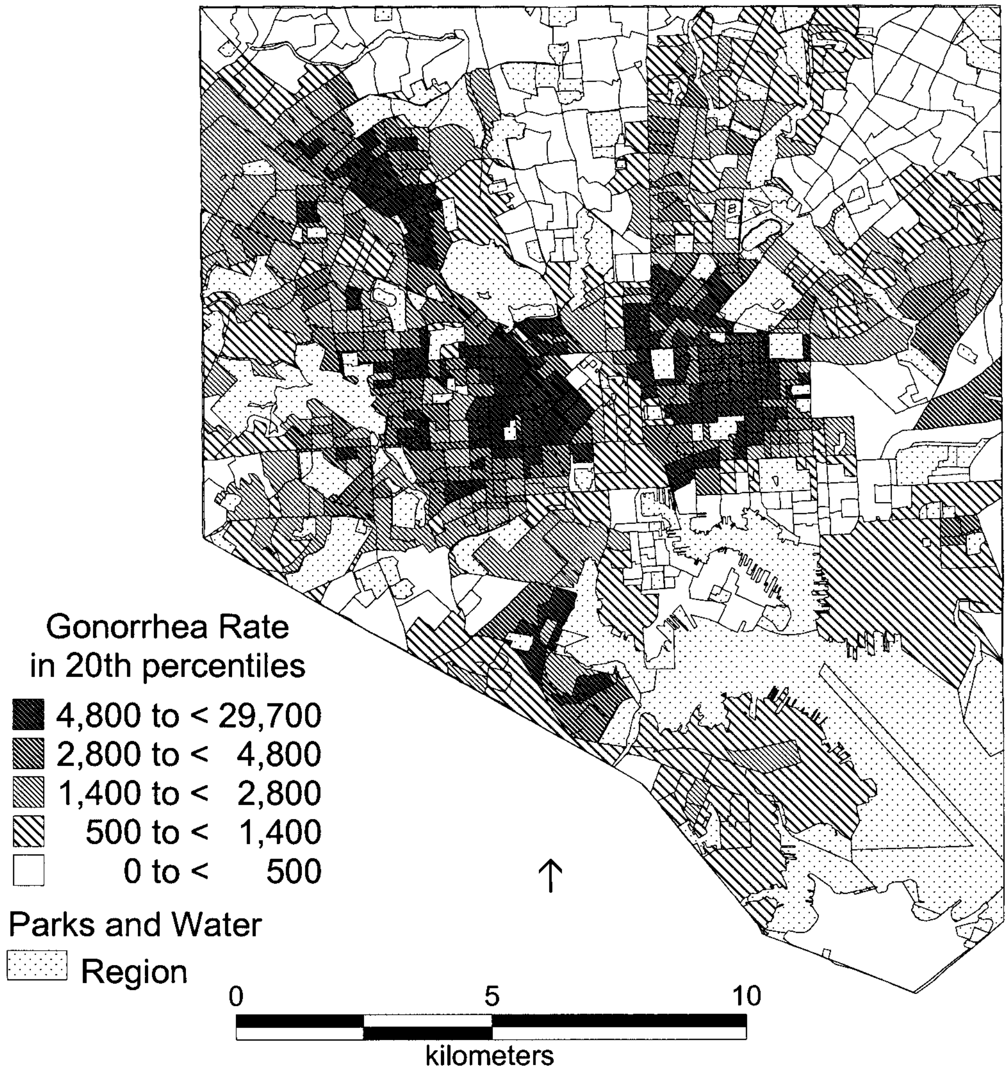

FIGURE 1. Reported gonorrhea case rates per 100,000 per census block group reported in 20th percentiles, Baltimore City, Maryland, 1994–1999.

were responsible for 55 percent (n = 17,832) of the gonorrhea cases, with an average rate of 5,547 cases per 100,000 persons per year, and were on average 95.8 percent African American.

The largest cluster was located on the east side of Baltimore City, comprised 134 census block groups, encompassed 7.9 square miles (20.5 km^2), and had an overall prevalence rate ratio of 2.18. The second largest cluster was located on the west side of Baltimore City and comprised 95 census block groups with an overall prevalence rate ratio of 2.46. The third and fourth clusters were located in the northwest part of Baltimore City and comprised three and one census block groups, encompassing 0.15 and 0.13 square miles (0.39 and 0.33 km^2) with prevalence rate ratios of 1.76 and 1.87, respectively.

In the first analysis, the 476 noncore census block groups combined over the 6-year period were responsible for 45 percent or 14,622 cases of gonorrhea, had an average rate of 1,601.4 cases per 100,000 persons per year, and were on average 52.9 percent African American.

In the second analysis, further controlling for the population race/ethnicity distribution, we identified eight statistically significant ($p < 0.05$) high gonorrhea prevalence clusters. These core areas are shown in figure 3 and comprise approximately 5 percent (36 block groups) of the total 709 block groups analyzed. The core areas were responsible for 10 percent or 3,184 cases over the 6 years, had an average rate of 7,408.1 cases per 100,000 persons per year, and were on average 98.7 percent African American.

The largest cluster was located on the east side of Baltimore City, comprised 17 census block groups, and spanned

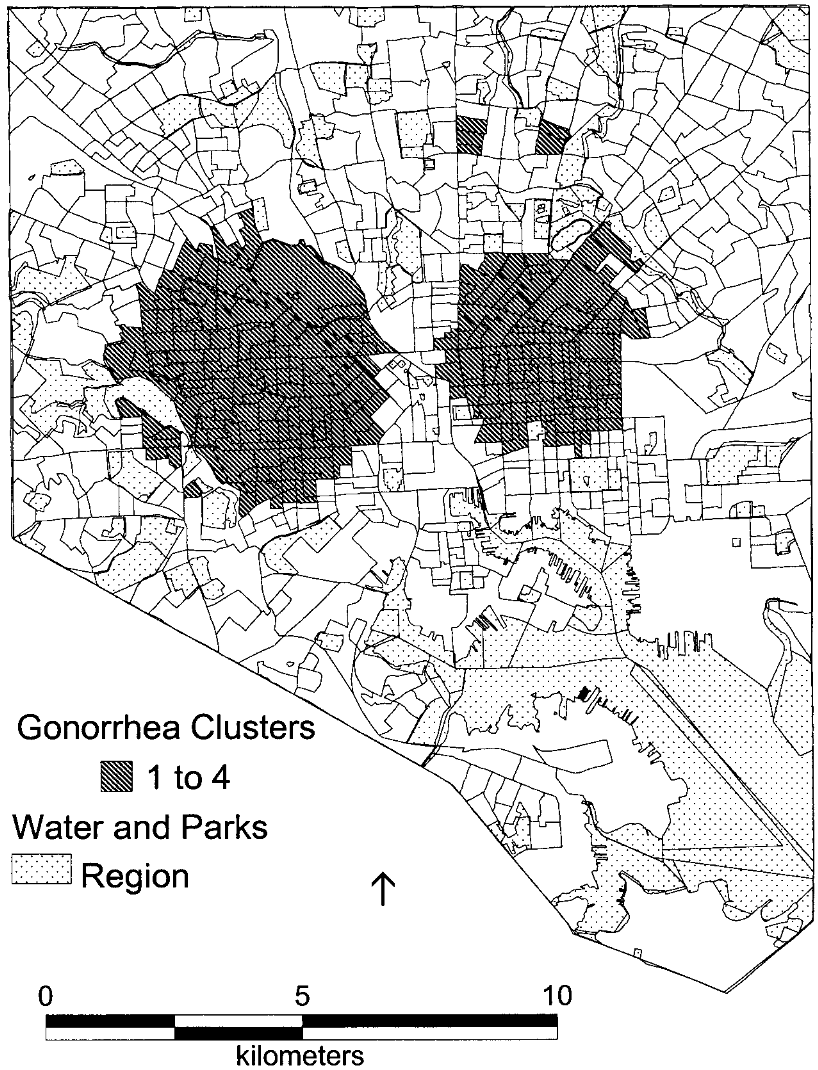

FIGURE 2. Cluster detection results for reported gonorrhea cases per census block group, Baltimore City, Maryland, 1994–1999. Four clusters identified by SaTScan, version 2.1, software (Statistical Research and Applications Branch, Surveillance Research Program, Division of Cancer Control and Population Sciences, National Cancer Institute, Bethesda, Maryland) were significant ($p < 0.05$).

0.58 square miles (1.50 km^2), with a prevalence rate ratio of 1.15. The second largest cluster was located on the west side of Baltimore City, comprised 11 census block groups, and encompassed 0.48 square miles (1.24 km^2), with a prevalence rate ratio of 1.22. The two identified clusters correspond to the two largest clusters identified in the previous unadjusted analysis (figure 2), although notably decreased in size. The third largest cluster included three census block groups and spanned 0.08 square miles (0.21 km^2), with a prevalence rate ratio of 1.37. The remaining five clusters comprised one census block group each, with areas ranging from 0.03 to 0.07 square miles (0.08–0.18 km^2) and prevalence rate ratios ranging from 1.15 to 7.92.

In the second analysis, the 673 noncore census block groups over the 6-year period were responsible for 90 percent or 29,270 cases of gonorrhea, had an average rate of 2,644 cases per 100,000 persons per year, and were on average 65.3 percent African American.

DISCUSSION

Our data demonstrated statistically significant geographic clustering of reported gonorrhea cases in Baltimore after adjustment for African-American race/ethnicity. The results support the conclusion that risks for gonorrhea are associated with definable sociogeographic spaces, which may be fundamental ecologic units of STI transmission (24). These clustered geographic areas of high disease burden may represent high prevalence transmission sexual networks that are critical for targeted disease transmission control (20, 23, 26, 42–45).

A number of factors coalesce in this urban environment to create a context in which the impact of geographic avail-

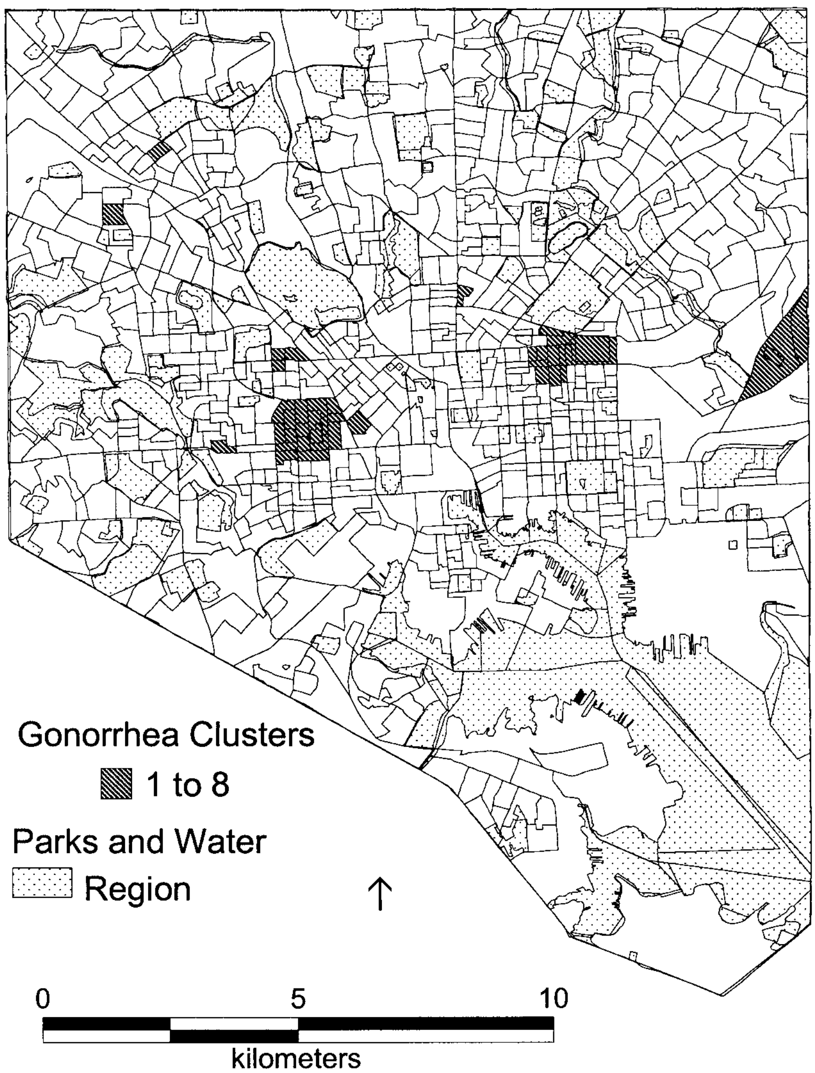

FIGURE 3. Cluster detection results controlling for race/ethnicity for reported gonorrhea cases per census block group, Baltimore City, Maryland, 1994–1999. Eight clusters identified by SaTScan, version 2.1, software (Statistical Research and Applications Branch, Surveillance Research Program, Division of Cancer Control and Population Sciences, National Cancer Institute, Bethesda, Maryland) were significant ($p < 0.05$).

ability and sex partner preferences on STI prevalence may be particularly relevant. The first factor is that there is a high degree of residential segregation in Baltimore City: 76 percent of Baltimore City census block groups can be defined as either equal to or greater than 75 percent African American or equal to or greater than 75 percent White. This fact, coupled with sex partner selection patterns that tend to be highly assortative by race/ethnicity, particularly within the African-American population, suggests that both ethnic residential patterns and sex partner preferences may act as macroboundaries to sexual network formation (17, 20, 46). The exploratory analysis (figure 1) and cluster analysis without controlling for race/ethnicity (figure 2) may identify African-American sexual networks that may be important for community-based screening. Cluster analysis adjusting for race/ethnicity (figure 3), however, may identify areas within the segregated networks where targeted STI testing and treatment could be focused.

An important tension in the application of scarce public health dollars for STI prevention and control is whether to focus on screening and treatment among a large high prevalence population or whether to focus on targeted outreach and screening among a smaller high risk group, that is, an STI core transmitter group. Each approach has its merits, and the approaches are not mutually exclusive. While we recognize and appreciate the value of broader screening and treatment programs, our intent is to identify high transmission risk areas where outreach STI testing may most effectively interrupt the continued transmission of STIs. This is a critical distinguishing feature of our approach that has not been clearly addressed in many geographic STI studies.

We did not include socioeconomic status in our analysis for two reasons. First, socioeconomic status has been shown to have different effects within strata of race/ethnicity (17, 47). Evidence suggests that socioeconomic status may be associated with STIs among White populations but less so among African Americans. Second, socioeconomic status is a complex construct that has been measured by numerous combinations of indicators such as occupation, education, and income. The SaTScan method of cluster detection does not permit a full investigation into the effects of socioeconomic status by race/ethnicity, and a more investigative approach such as that allowed by modeling approaches would be more appropriate.

Compared with public providers, private providers have been found to underreport confirmed cases of sexually transmitted disease (17, 40, 48, 49). To explore the potential effects on our results of underreporting by race/ethnicity, we conducted a sensitivity analysis as described in the Materials and Methods section. The sensitivity analysis found no qualitative differences in the results. This does not suggest that there is no ethnically biased reporting. Rather, the sensitivity analysis confirms our contention that our cluster detection analysis is robust to this type of reporting bias.

A limitation to this analysis is that sexual networks may be subject to temporal trends, have inconstant rates of formation and dissolution, and may be highly dependent on identified linkages. We attempted to stabilize the patterns by aggregating reported gonorrhea cases over a 6-year period. By not relying upon traditional network analysis methods, this analysis is not dependent on the specific links reported between individuals (50).

Further, we acknowledge that we used only one method of spatial cluster analysis to identify clusters, as there are a host of other statistical tests, such as focused tests and global clustering tests, which could be used (51, 52). Briefly, focused tests require a prespecified point source and test for increased disease around the source; this was not applicable for the current objectives. Global tests for clustering are able to detect clustering throughout the study area but do not geographically locate the clusters (52). The spatial scan statistic is preferable for this analysis because it determines the existence of significant clusters and their geographic locations.

Despite these limitations, we are confident that our approach provides an objective and practical method to identify sociogeographic areas of risk for continued STI transmission. This research extends our understanding of the geographic distribution of gonorrhea in an urban environment and may aid our understanding of STI transmission in a high prevalence inner city population.

Recent evidence suggests that geographic approaches to control and prevention, such as venue-based testing, may enhance disease control efforts (53). Traditional methods of STI control by public health departments include partner elicitation and partner notification/contact tracing. The traditional methods may not be adequate for locating core transmitters because of poor locating information obtained from their sexual and social contacts (54–56). The current study provides additional evidence to support other public health approaches to appropriate STI control policies, suggesting the use of community-based, focused intervention strategies (e.g., sexual network interventions) appropriate to the identified epidemiology.

The results suggest the existence of high prevalence STI transmission areas that may imply the existence of dense sexual networks of high-risk individuals. A next step would be to conduct a sexual network study within the identified high and low prevalence STI transmission areas. Other objectives would be to conduct a household study to confirm results and identify structural features of neighborhoods that may distinguish between the high and low prevalence areas (57–59).

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