ORIGINAL ARTICLE

Geographic epidemiology of gonorrhoea and chlamydia on a large military installation: application of a GIS system

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Objectives: The geographic epidemiology of infectious diseases can help in identifying point source outbreaks, elucidating dispersion patterns, and giving direction to control strategies. We sought to establish a geographic information system (GIS) infectious disease surveillance system at a large US military post (Fort Bragg, North Carolina) using STDs as the initial outcome for the model.
Methods: Addresses of incident cases were plotted onto digitised base maps of Fort Bragg (for on-post addresses) and surrounding Cumberland County, NC (for off-post addresses) using MAPINFO Version 5. We defined 26 geographic sectors on the installation. Active duty soldiers attending the post preventive medicine clinic were enrolled between July 1998 and June 1999.
Results: Gonorrhoea (GC) was diagnosed in 210/2854 (7.4%) and chlamydia (CT) in 445/2860 (15.6%). African-American male soldiers were at higher risk for GC (OR = 4.6 (95% CL 3.0 to 7.2)) and chlamydia (OR = 2.0 (1.4 to 2.7)). For women, there were no ethnic differences in gonorrhoea prevalence, but chlamydia was higher in African-Americans (OR = 2.0 (1.4–2.7)). Rank and housing type were associated with gonorrhoea and chlamydia in men, but were not significant factors in women. For gonorrhoea, two geographic sectors had prevalences between 14.0%–16.5%, three between 10.3%–13.9%, three between 7.1%–10.2%, and five between 3.0%–7.1%.. The geographic distribution demonstrated a core-like pattern where the highest sectors were contiguous and were sectors containing barracks housing lower enlisted grade personnel. In contrast, chlamydia prevalence was narrowly distributed.
Conclusion: GIS based disease surveillance was easily and rapidly implemented in this setting and should be useful in developing preventive interventions.

Infectious disease surveillance is a core public health function.[1] Interest in surveillance has increased markedly over the past decade owing in large part to the evolution of two parallel trends. Firstly, the rapid development of inexpensive computers and software has made tedious paper based surveillance systems obsolete and has made real time surveillance possible on a broad scale. Secondly, the emergence of new infectious agents, the development of antimicrobial resistance, and the potential threat of biological terrorism have emphasised the need for effective surveillance systems.

Case report data on time, place, and person form the traditional framework of infectious disease surveillance. The collection of such data, usually through passive reporting systems, is subject to substantial time lags in reporting and in the detection of epidemic patterns (that is, variations from expected rates). Computerisation of surveillance data collection and computer assisted analyses can significantly accelerate these processes.

Geographic information systems (GIS) have added an exciting new dimension to the epidemiology of infectious diseases.[2] GIS technology provides for the rapid integration of data from a wide variety of sources, with the added benefit of computer graphics assisted display. Such systems have been widely proposed as public health tools for the investigation of chronic diseases,[3] zoonoses,[4] injury and accident patterns, allocation of health resources,[5] occupational morbidity and environmental exposures.[6 7] Within defined areas, development of GIS for disease morbidity is particularly attractive for surveillance of acute infectious diseases that are related to point source outbreak events. Because of this characteristic, GIS has been applied to, and has greatly enhanced understanding of, the epidemiology of sexually transmitted diseases (STD) such as gonorrhoea and chlamydia[8–14] and syphilis.[15 16]

Military installations offer potentially attractive settings for evaluating new surveillance systems and monitoring infectious disease morbidity. Installations have defined geographic boundaries and the population typically seeks most of its health care within a single healthcare system. However, there tend to be large and unpredictable variations in populations, information pertaining to locations of individuals and risk factors for exposure may be unavailable for security reasons, and commercial digitised mapping sources may lack current information for installations since streets and building addresses are often not consistent with the surrounding civilian communities. Nevertheless, we believed that development of prototype GIS based surveillance technology at a large military installation was feasible and would enhance existing disease surveillance methodologies.

Our goals in developing a pilot system included application of technology which was commercially available, inexpensive, and considered relatively easy to use; building data collection methods and expertise on-site; developing on-site analytical capability; and developing a system that was flexible, expandable to include the monitoring of multiple disease entities, and transportable to other fixed military facilities. We chose surveillance of STD morbidity as our first objective.

METHODS

Study venue

The project site was Fort Bragg, a large US army installation located near Fayetteville (Cumberland County) in rural southeastern North Carolina. During the study period, there

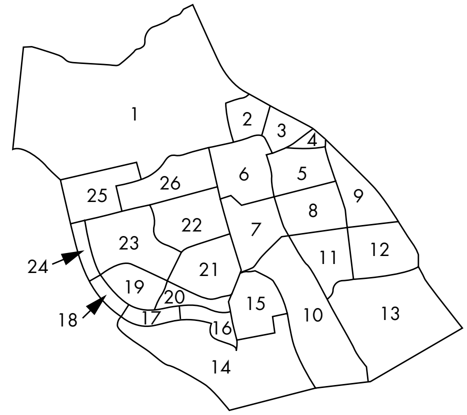

Figure 1 Sectors defined for Fort Bragg, North Carolina.

were about 40 000 active duty service members and approximately 117 000 dependants and retirees receiving care through the Womack Army Medical Center (WAMC) military healthcare system at Fort Bragg. The active duty army population at this facility was largely male (89%), white (62% white, 24% African-American), and young (64% <30 years of age).

STD screening and referral services for active duty service members, their dependants, and retirees were provided by WAMC through the epidemiology and disease control (EDC) clinic. Case management was coordinated with the local Cumberland County Health Department. The EDC clinic functioned as the centralised source for STD preventive services at Fort Bragg, typically providing over 4500 evaluations annually. Approximately 70% of visits were by active duty personnel; the remainder were by spouses, other dependants, and retirees. Tests for chlamydia and gonorrhoea, as well as serology for syphilis and HIV, were performed routinely on over 95% of clinic attendees. During the first 5 months of the study, chlamydia was diagnosed by enzyme immunoassay (Syva Company, San Jose, CA, USA) and gonorrhoea by Gram stain and culture (modified Thayer-Martin). Thereafter, *Chlamydia trachomatis* and *Neisseria gonorrhoeae* were identified by direct DNA detection (GenProbe, San Diego, CA, USA). Treatment and partner notification services were provided on site.

The study population consisted of active duty personnel who received care at the Fort Bragg EDC clinic during July 1998–June 1999. During the study period, all people presenting for care, and those investigated by the contact tracing service were evaluated. Data were extracted from routinely collected information provided by patients at the time they were seen for health care by EDC clinic providers, and stripped of all identifiers. Demographic information included age, ethnicity, military unit, pay grade, and type of housing. In the US military, eight pay grades constitute the vast majority of enlisted personnel (E1–E8 with E1 being the lowest); for our analysis, we divided these into two strata—E1–E4 and E5–E8. Commissioned and warrant officers were considered as a single group. Many individuals, especially officers, those with families, and higher grade enlisted personnel, have the option of living off base in private housing. The off-base group was considered as a separate housing stratum. The institutional review boards of the Johns Hopkins University, Baltimore, MD, and WAMC approved this study.

Development of the geographic information system

The GIS for Fort Bragg was based on procedures we had developed for similar systems in Baltimore City, using a 260 MHZ desktop Pentium computer equipped with an inkjet plotter and MAPINFO Version 5 software[8] (MapInfo Corporation, Troy, NY, USA). MAPINFO is a vector based software mapping system with address matching capability.

For the mapping function, we initially used commercially available digitised base maps of Cumberland County, NC, which includes Fort Bragg. The base maps included information on street, highway, railroad and walkway locations, water bodies, and major institutional boundaries. Geographic boundaries included 1990 census tracts, 1990 census block groups, 1990, towns and villages within the county five digit zip code regions, transportation zones, and regional planning districts. Many buildings on the military post were not included on the commercially available maps. Moreover, many addresses on Fort Bragg were only provided as a building number rather than a street number and name. We therefore modified the commercial maps using data supplied by the Fort Bragg Department of Public Works and Engineering to incorporate these locations. Addresses within the study area were mapped using the street address (or building number) and zip

Table 1 Demographic features of soldiers with gonorrhoea or chlamydia diagnosed on a US army base

Active duty	Gonorrhoea	Risk ratio (95% CL)	Chlamydia	Risk ratio (95% CL)
Males	180/2039 (8.8%)		288/2038 (14.1%)	
Whites	29/850 (3.4%)	Referent	82/872 (9.4%)	Referent
Others	16/329 (4.9%)	1.4 (0.7 to 2.7)	57/301 (18.9)	2.1 (1.4 to 3.1)
Blacks	135/ 860 (15.6%)	4.6 (3.0 to 7.2)	149/865 (17.2%)	2.0 (1.4 to 2.7)
Residence				
Off post	53/815 (6.5%)	Referent	91/813 (11.2%)	Referent
Barracks	123/1114 (11.0%)	1.8 (1.3 to 2.5)	182/1114 (16.3%)	1.6 (1.2 to 2.1)
On post other	4/110 (3.6%)	0.5 (0.2 to 1.6)	15/111 (13.5%)	1.2 (0.7 to 2.3)
Rank				
Officers	2/82 (2.5%)	Referent	4/75 (5.3%)	Referent
E1–E4	138/1421 (9.7%)	4.3 (1.6 to 25)	225/1446 (15.6%)*	3.3 (1.1 to 11.6)
E5–E8	41/532 (7.7%)	3.3 (0.8 to 20.3)	59/517 (11.4%)*	2.3 (0.7 to 7.7)
Females	30/815 (3.3%)		157/822 (19.1%)	
Whites	21/440 (4.8%)	Referent	66/458 (14.4%)	Referent
Others	4/97 (4.1%)	0.9 (0.2 to 2.7)	29/77 (37.7%)	3.6 (1.8 to 3.7)
Blacks	6/278 (2.2%)	0.4 (0.2 to 1.1)	64/287 (22.2%)	1.7 (1.1 to 2.1)
Residence				
Off post	9/368 (2.5%)	Referent	70/364 (19.2%)	Referent
On post other	21/447 (4.8%)	1.99 (0.9 to 4.7)	87/458 (19.0%)	1.0 (0.7 to 1.4)
Rank				
Officers	0/22 (0%)	Referent	2/23 (8.7%)	Referent
E1–E4	26/607 (4.3%)	0.9 (0.1 to 19)	139/616 (22.5%)	3.1 (0.7 to 19)*
E5–E8	4/186 (2.2%)	0.5 (0.1 to 11)	16/183 (8.7%)	1.0 (0.2 to 6.8)*

*Statistically significant difference between these two groups (p<0.001).

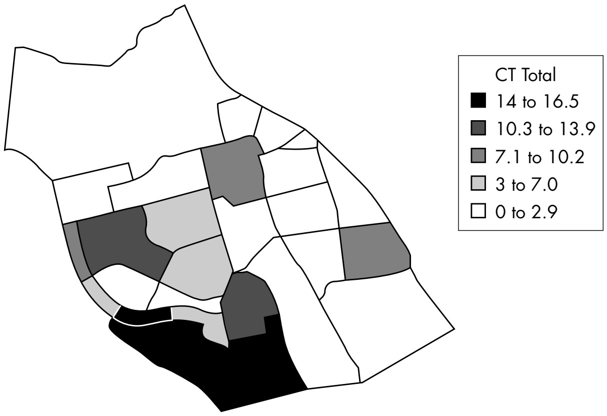

Figure 2 Fort Bragg July 1998–June 1999. Gonorrhoea positivity rates.

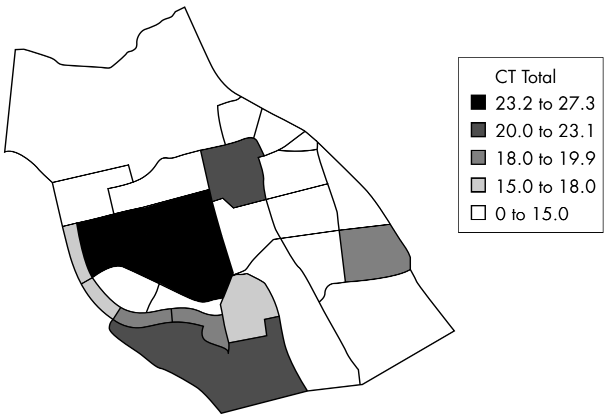

Figure 3 Fort Bragg July 1998–June 1999. Chlamydia positivity rates.

code fields extracted from patient records and encoded within a relational database.

Establishing a set of geographic boundaries

On Fort Bragg, there are no formally defined subdivisions or census tract-like boundaries that can be used for regionalisation of the address data. We therefore divided the installation into 26 geographic sectors or boundaries (fig 1). Although these are arbitrary designations, boundary lines were drawn with consideration to residential patterns, major streets, and activity areas, and care was taken to represent neighbourhood or barracks clusters to the highest degree possible. Sectors were designated at the outset of the study in order to minimise bias.

Analysis

Disease prevalence was defined as the positivity rate among those tested. Since accurate denominators were not available, true prevalence could not be measured. Dependent variables for the analysis were presentation for STD care and specific diagnoses. Independent variables were demographics, rank, geographic region, and sexual behaviour variables. Data on all variables were not available for all study participants. Data were analysed using PC-SAS (ver 6.04) or Excel (Office 97). Odds ratios and confidence limits were calculated using either PC-SAS (ver 6.04) or EPI-INFO STATCALC ver 6 (Centers for Disease Control, Atlanta, GA, USA) For the geographic analyses, case rates were defined as the proportion of positive tests/total tests performed by geographic sector. Because of the transitory nature of the population, sector specific denominators could not be calculated.

RESULTS

Study population

During the study period, nearly 3000 active duty personnel were evaluated for STD (table 1) and over 95% consented to the study. Of the 2854 tested for gonorrhoea, 210 (7.4%) were positive, while 445 of 2860 (15.6%) had chlamydia. Gonorrhoea rates for active duty males attending the EDC clinic were 8.8%, for females 3.3%; for chlamydia 14.1% of tests were positive in males and 19.1% were positive in females.

The epidemiological data are presented in table 1. In males, gonorrhoea and chlamydia were associated with African-American ethnicity (for gonorrhoea OR = 4.3 (3.0–7.2) for chlamydia OR = 2.0 (1.4–2.7)), living in barracks (OR = 1.8 (1.3–2.5) and OR = 1.6 (1.2–2.1) respectively), and lower enlisted ranks (OR = 4.3 (1.6–25) and OR = 3.3 (1.1–11.6) respectively). For women, there were no ethnic differences in gonorrhoea prevalence, but chlamydia was higher in African-Americans (OR = 1.70 (1.4–2.7)), and the "other" ethnic groups, which was composed predominantly of Hispanic-Americans (OR = 3.6 (1.8–3.7)). Within the enlisted groups, women in the lower pay grades (E1–E4) had twofold increased odds of having gonorrhoea or chlamydia compared to the higher enlisted grades (E5–E8), but there was no significant association between infection status and race or housing type.

People living in on-post non-barracks housing had the lowest prevalence of disease. This probably reflects the high proportion of family units living in on-post apartments or homes.

Table 2 Gonorrhoea and chlamydia prevalences, by sex and geographic sector

	Gonorrhoea			Chlamydia		
Sector	Males	Females	Total	Males	Females	Total
0	72/971 (7.4%)	11/430 (2.6%)	83/401 (5.9%)	109/969 (11.3%)	81/435 (18.6%)	190/1404 (13.5%)
6	6/57 (10.5%)	2/37 (5.4%)	8/94 (8.5%)	13/58 (22.4%)	9/37 (24.3%)	22/95 (23.1%)
12	12/119 (10%)	5/122 (4%)	17/241 (7.1%)	25/119 (21.0%)	22/122 (18.0%)	47/241 (19.5%)
14	6/39 (15.4%)	1/11 (9.1%)	7/50 (14.0%)	7/39 (17.9%)	3/11 (27.3%)	10/50 (20.0%)
15	18/161 (11.2%)	5/79 (6.3%)	33/240 (13.8%)	25/162 (15.4%)	12/79 (15.2%)	37/241 (15.3%)
16	2/51 (3.9%)	2/21 (9.5%)	4/72 (5.6%)	7/51 (13.7%)	6/21 (28.6%)	13/72 (18.1%)
17	31/183 (16.9%)	0/6 (0.0%)	31/189 (16.4%)	36/183 (19.7%)	0/6 (0.0%)	36/189 (19.0%)
18	11/181 (6.1%)	0/4 (0.0%)	11/185 (5.9%)	18/180 (10.0%)	0/4 (0.0%)	18/184 (9.8%)
21	2/33 (6.1%)	0/10 (0.0%)	2/43 (4.7%)	11/33 (33.3%)	1/11 (9.1%)	12/44 (27.3%)
22	1/37 (2.7%)	2/63 (3.2%)	3/100 (3.0%)	9/38 (23.7%)	19/67 (28.4%)	18/105 (26.7%)
23	7/62 (11.3%)	3/35 (8.6%)	10/97 (10.3%)	7/62 (11.3%)	16/35 (45.7%)	23/99 (23.2%)
24	10/113 (8.8%)	1/5 (20%)	11/118 (9.3%)	18/112 (16.1%)	1/5 (20%)	19/117 (16.2%)

Maps

Patients tested for gonorrhoea or chlamydia were plotted on the digitised maps, and based on address, were assigned to a sector. If an individual lived off the post, they were assigned sector 0. In each of 12 sectors, >40 people were tested for gonorrhoea and chlamydia. These sectors were included in the geographic analysis and were: 0,6,12,14–18,21–24 (figs 2 and 3). Tabular results are presented in table 2 for the sectors with greater than 40 tests reported.

For gonorrhoea, the highest prevalence was in sector 17 (16.4%), which was a sector primarily housing men in barracks. Two sectors had rates between 14.0–16.4%; two had rates between 10.3–13.9%, three between 7.1–10.2%, and four between 3.0–7.0%. This geographic distribution demonstrated a core-like pattern where the two sectors with highest prevalence were contiguous. Analysis of the most severely impacted sectors such as sectors 17 and 15 (each with more than 30 cases) demonstrated that there was no predilection for members of specific military units, but that specific barracks or housing areas had microclusters of cases. In the highest three morbidity areas (sectors 14, 15, 17), which accounted for 53% of all gonorrhoea diagnosed on the post, 88.0–93.1% of personnel were lower enlisted (grades E1–E4). By comparison, 69.2% of the total sample population was grades E1–E4.

The geographic distribution of chlamydia was different. Firstly, chlamydia prevalence was higher overall in both men and women. Secondly, chlamydia had the characteristics of a widely prevalent disease. All of the on-post sectors where >40 tests were performed had prevalence between 15.3–27.3%. A cluster of three sectors (sectors 21, 22, 23) had the highest chlamydia rates, between 23.2–27.3%. These sectors were geographically distinct from the high rate gonorrhoea cluster.

DISCUSSION

We found that gonorrhoea had a focal distribution on Fort Bragg similar to the focality observed in civilian communities. Clustering was related to geographic residence on Fort Bragg but not to military unit. In contrast, the distribution of chlamydia was much more widespread.

Gonorrhoea prevalence was higher in African-Americans and in individuals at the lowest end of the pay scale. These patterns are similar to those in US urban areas, and to studies of syphilis at Fort Bragg, which demonstrated higher prevalence in African-American military personnel.[17] Chlamydia was higher in African-American males, but was there was no racial disparity in the rates of chlamydia infection seen in females evaluated. Chlamydia prevalence across all racial and ethnic groups was consistently above 15.3% in the on-post EDC clinic population. Since we tested clinic attendees, we expect higher rates than a population based screening programme.

Since population denominators were not available for the designated sectors, our data may be biased. We used the test positivity rate as a surrogate for prevalence. Nevertheless, proportional data can be expected to correlate to the actual population based incidence. For example, studies of penicillinase producing *Neisseria gonorrhoeae* (PPNG) in civilian communities found that the area with highest incidence of gonorrhoea also had the highest proportion of PPNG, which suggests that a proportional analysis has validity in assessing trends.[11] Although women comprised only 11% of active duty personnel, nearly one third of clinic attendees were female. Anecdotal reports also suggest that individuals in the higher enlisted pay grades and officer corps may choose to seek confidential care from the private sector. Despite this, those who lived off post (sector 0) still had appreciable disease prevalence—5.9% for gonorrhoea and 13.5% for chlamydia.

Although we observed intriguing patterns of gonorrhoea and chlamydia prevalence, the sector geographic boundaries may not reflect the social networks that promote STD transmission such as venues for recruiting sex partners, termed by Potterat *et al* as "places of social significance."[18] Unfortunately, in the absence of personal identifiers and social history/risk factor data, the degree of interaction and networking among these individuals is unknown.

We were intrigued that the highest test prevalence, and the highest number of cases was reported from sector 17, an area dominated by male only barracks. These data suggest that there are conditions promoting high risk behaviour in this social situation. This hypothesis is supported by studies of the Royal Thai Army, in which the group dynamic was critical in supporting high risk sexual behaviours.[19] Implementation of structural interventions led to profound decreases in HIV/STD risk and disease incidence.

Our data are consistent with other studies at Fort Bragg. Analysis of gonorrhoea and chlamydia trends during 1985–96 found that adjusted incidences of these infections in active duty service members were higher than comparable state and national rates.[20] Gaydos *et al* found that chlamydia prevalence in active duty army women being evaluated at annual Pap examination was 7.3%.[21] Similarly, among EDC clinic patient volunteers who were evaluated by more sensitive nucleic acid amplification tests, chlamydia prevalence was 12.3% (compared to 10.1% by EIA), and gonorrhoea prevalence was 4.9%, compared to 2.9% by culture.[22]

This GIS system provided insight into the epidemiological patterns of STDs on Fort Bragg and also helped form the basis for potential future interventions. A commercially available system was successfully implemented within budget and local personnel were easily trained to operate the programme. Purchased maps were incomplete, but this shortcoming was corrected locally. The Fort Bragg GIS operators showed that the system could produce information important to the development of effective interventions. Lastly, the prototype GIS was flexible, and was successfully adapted to the investigation of an on-post *Shigella* outbreak.[23] Transportability of the Fort Bragg system to another military installation is currently being tested.

For high morbidity events, such as STDs, the system allows the localisation of high risk areas, and the application of population specific interventions. GIS may have particular utility in establishing epidemiological relations between acute disease incidence events where geography is the only common factor.

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CONTRIBUTORS

JMZ, conceptualisation of project, study design, analysis, and principal author of manuscript; GG, conceptualisation, develop project design, secured project funding, data analysis; TS, principally responsible for data analysis; development and implementation of software; PRJ on-site project coordination and implementation, enrolment of subjects, collection of data; JCG, project design, conceptualisation, arranged funding, writing the manuscript; KTMcK, project design, on-site commander during project implementation, collaborate in data analysis, writing the manuscript.

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