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Social and Geographic Distance in HIV Risk

RICHARD ROTHENBERG, MD,* STEPHEN Q. MUTH, BA,† SHAUNA MALONE, MPH,* JOHN J. POTTERAT, BA,† AND DONALD E. WOODHOUSE, JD†

Objective: The objective of this study was to examine the relationship between social distance (measured as the geodesic, or shortest distance, between 2 people in a connected network) and geographic distance (measured as the actual distance between them in kilometers [km]).

Study: We used data from a study of 595 persons at risk for HIV and their sexual and drug-using partners (total N = 8920 unique individuals) conducted in Colorado Springs, Colorado, from 1988 to 1992—a longitudinal cohort study that ascertained sociodemographic, clinical, behavioral, and network information about participants. We used place of residence as the geographic marker and calculated distance between people grouped by various characteristics of interest.

Results: Fifty-two percent of all dyads were separated by a distance of 4 km or less. The closest pairs were persons who both shared needles and had sexual contact (mean = 3.2 km), and HIV-positive persons and their contacts (mean = 2.9). The most distant pairs were prostitutes and their paying partners (mean = 6.1 km). In a connected subset of 348 respondents, almost half the persons were between 3 and 6 steps from each other in the social network and were separated by a distance of 2 to 8 km. Using block group centroids, the mean distance between all persons in Colorado Springs was 12.4 km compared with a mean distance of 5.4 km between all dyads in this study ($P < 0.0001$). The subgroup of HIV-positive people and their contacts was drawn in real space on a map of Colorado Springs and revealed tight clustering of this group in the downtown area.

Conclusion: The association of social and geographic distance in an urban group of people at risk for HIV provides demonstration of the importance of geographic clustering in the potential transmission of HIV. The proximity of persons connected within a network, but not necessarily known to each other, suggests that a high probability of partner selection from within the group may be an important factor in maintenance of HIV endemicity.

AN UNDERLYING NOTION IN geographic analysis is that contiguity is associated with homogeneity and that heterogeneity increases with distance.[1] An underlying notion of transmission dynamics for human immunodeficiency virus (HIV) and sexually transmitted diseases (STDs) is that small, cohesive groups of people may account for a disproportionate amount of transmission (the so-called core-group hypothesis).[2] Some empiric evidence has emerged in recent years demonstrating the local, geographically compact distribution of such groups.[3–7] Although diverse with regard to age, sex, ethnicity, and other sociodemographic variables, members of such groups share behavioral risks for transmission and often are interconnected by a social network that facilitates disease propagation.[5,8,9]

Several initial attempts to examine the spatial distribution of cases of STDs[10–14] have underlined the need for precise information about the location of persons with diagnosed illness, their direct contacts, and the social, sexual, or drug-using networks in which they are embedded. One hypothesis generated by current work as well as by theoretical considerations is that geographic contiguity may be linked to social contiguity and may be an important element in the dynamics of transmission among some groups. Using data from a study conducted in Colorado Springs, Colorado, we report on the relationship between social distance and geographic distance in persons at risk for HIV.

Methods

The data for this report were collected between 1988 and 1992 as part of a study of a community in Colorado Springs, Colorado, at presumed high risk for HIV.[15] The methods have been described in detail previously.[16–21] Briefly, persons in this study were recruited from street sites known to be frequented by prostitutes, from a county STD clinic, and from a county methadone maintenance clinic. Six categories of persons at risk were sought: women who worked as prostitutes, their paying and nonpaying partners, injecting drug users and their sexual partners, and a small group of persons identified by network methods as belonging to 1 of the those groups but who did not themselves claim such membership. Those enrolled underwent testing for HIV and an interview that sought information about demographics, medical history, knowledge of AIDS, and risk behavior. A special section—the network interview—elicited names and identifying information on their sexual, social, drug-using, and needle-sharing contacts. Those contacts named by 2 or more respondents were sought and, if found, were interviewed and tested. A subset of the initial group of 595 was reinterviewed. In all, 8920 different people were identified in connection with the study (approximately 3% of the population of Colorado Springs). The first interview with 595 respondents identified 6433 dyads. Seventeen of the 595 (3%) in the respondent group were HIV-positive. Of the 595, 418 named other respondents, and this latter group contained a connected component of 348 persons. Thus, for this latter group, there was a path of some length from every person to every other person as well as complete interview information on all group members.

From *Emory University School of Medicine and the Rollins School of Public Health at Emory University, Atlanta, Georgia; †Independent consultant.

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Correspondence: Richard Rothenberg, MD, Professor, Department of Medicine, Division of Infectious Disease, Emory University School of Medicine, Editor, Annals of Epidemiology, 64 Jesse Hill Jr. Drive, Atlanta, GA 30303. E-mail: rrothen@emory.edu

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The first interviews on the 595 respondents and the subcomponent of 348 connected respondents furnish the data for the current study. Exact place of residence (address) was obtained from approximately 85% of participants. A surrogate (nearest cross streets, centroid of block face) was used for others. These markers were transformed into a set of coordinates that permitted calculation of the distance between any 2 people. For the first interviews, we calculated the geographic distance between pairs as a function of age, sex, ethnicity, behavioral category, HIV status, and type of relationship (sexual, social, drug-using, needle-sharing). For the subcomponent of connected respondents, we calculated the Euclidean (as the crow flies) geographic distance (in kilometers) between all possible pairs. As an alternative to Euclidean distance, we calculated the shortest actual paths between all possible pairs. These distances were, as expected, uniformly longer, but their substitution in the analysis produced no change in the observations and these data are not reported. We used 2 measures of social distance: 1) the geodesic, or shortest number of steps between any pair of persons; and 2) the strength of the relationship between the subset of persons who were directly connected (a geodesic of 1). The strength of relationship was assessed by asking all respondents to provide an estimate, from 1 to 10, of how close they were to each person they named in their network. Seventy-five percent of persons who named each other had a difference of 3 or less in their estimate of the strength of the relationship. In the situations in which respondents named each other, the average of both respondents' assessment of relationship strength was computed for the tie connecting the 2 respondents.

Analytic and Network Methods

We used UCInet, version 6,[22] for network analysis, Pajek[23] for network visualization and ArcView (http://www.esri.com/software/arcview/) for placement of coordinates on the map of Colorado Springs. We examined the frequency distribution of distances to determine the percentile cutoffs in kilometers for the distance between persons with specified characteristics. We graphed the frequency of dyads with each combination of observed social distance (geodesic) and geographic distance (to the nearest whole kilometer) and examined the correlation coefficient between the 2 measures. We then compared the distribution of geographic distance for each geodesic distance. Within the group of 348, we selected respondents who were HIV-positive and examined the subgraph of the positives plus persons within a geodesic of 3 from any HIV-positive respondent. On a map of Colorado Springs, we superimposed this subgraph and mapped the actual distance between these persons. Finally, we mapped the geographic distance between all those with a geodesic of 1 in this subcomponent, coloring the edge between them according to the strength of the social relationship.

Population Comparisons

We compared the distances observed in our study population to an estimate of the distances between all persons in Colorado Springs using 2 methods. First, we used block group data, the smallest areal designation for which population numbers are available to calculate the mean distance between persons. The centroid of the block group was used as the "address" and the distance between all possible pairs of block groups, weighted for the proportion of dyads in the pair, was calculated. The mean distance is the sum of the weighted distances. We compared the unweighted mean distance, for which a variance estimate is available, to the mean distance in our population using a *t* test for the difference of means. This statistical testing approach was used for all distance

TABLE 1. Distance Between 595 Respondents and Their Contacts by Category of Respondent, Type of Relationship, and HIV Serostatus

Characteristic	Number of Dyads	Distance in Kilometers	
		Mean	Median
Type of relationship			
Sexual	1116	6.0	4.3
Drug	376	5.5	4.3
Sex and drug	93	5.1	3.7
Needle	130	4.0	3.0
Social	2636	4.9	3.0
Sex and needle	23	3.2	2.7
Category of respondent			
Paying partners	602	6.1	4.8
Prostitutes	1032	5.2	3.9
Injecting drug users	1418	5.6	3.8
Nonpaying partners	377	4.8	3.4
Other	282	4.3	2.3
Sex partner of an injecting drug user	271	4.9	1.9
HIV-positive	87	2.9	1.3
All dyads	3982	5.4	3.7

comparisons. Second, we plotted the number of persons in Colorado Springs by census tract and compared the resulting choropleth map with a plot of the persons in our study. This procedure is equivalent to comparing density because the denominator (census tract areas) is the same.

Results

Dyad Distances by Characteristic

Considering all the dyads identified from interviews with the 595 respondents, 52% were geographically separated by a distance of 4 km or less. The mean distance between dyads was 5.3 km. The mean and median distance between partners differed by category of respondent, by the type of relationships, and by the HIV

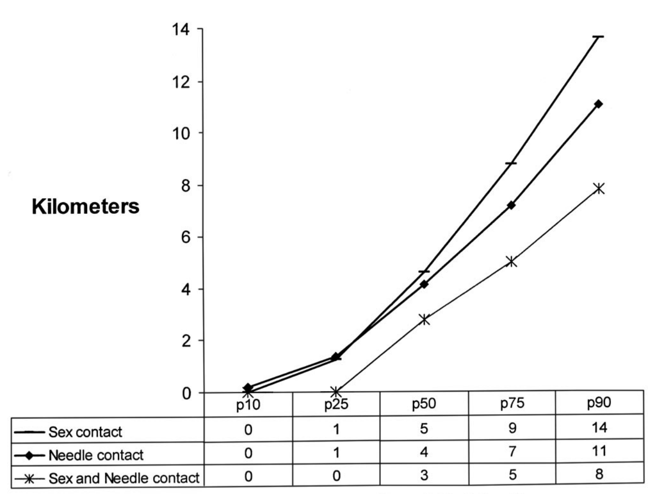

Fig. 1. Distribution of distances among sexual, needle, and sexual plus needle contacts to the 595 respondents.

serostatus of the respondent (Table 1). Dyads that involved both sexual relationships and needle-sharing lived closer together (mean, 3.2 km; median, 2.7 km) than dyads that involved sex alone (mean, 6.0 km; median 4.3 km) ($P < 0.001$) or needle-sharing alone (mean, 4.0 km; median, 3.0 km) ($P < 0.05$). Dyads involving a prostitute and a paying partner were more widely separated (mean, 6.1 km; median, 4.8 km) than those involving a prostitute and a nonpaying partner (mean, 4.8 km; median 3.4 km) ($P < 0.01$). The shortest distances were associated with the sex partners of injecting drug users (mean, 4.9 km; median, 1.9 km) and with the partners of HIV-positive persons (mean, 2.9 km; median, 1.3). The latter estimate, however, was based on only 87 dyads. The consistent difference between the mean and median for all characteristics reflects the long tail to the right in the distribution of dyad distances. This distribution is demonstrated by comparing the percentile cutoffs (in kilometers) for sexual contacts, needle contacts, and those dyads with both types of contact (Fig. 1). Twenty-five percent of sex plus needle contacts were at a distance of 0 km (lived together) and 75% were at a distance of 5 km or less. The maximum distance for 90% of sex contacts was 14 km, compared with 11 km for needle contacts and 8 km for sex plus needle contacts.

TABLE 2. Codistribution of Social (Geodesic) Distance and Geographic Distance (to the Nearest Whole Kilometer) in the Dyads Generated by 348 Respondents Who Were Part of a Connected Component

Geographic Distance (km)	Social Distance (Geodesics)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	84	167	321	409	366	263	142	88	36	35	6	4	1	
2	69	317	650	827	756	562	306	135	65	25	25	10	2	
3	62	291	813	1094	997	728	407	198	116	49	20	3	2	
4	65	369	860	1266	1061	772	484	267	123	46	25	9		
5	66	372	964	1369	1292	966	558	320	132	53	30	20	3	
6	85	448	1078	1565	1505	1122	713	312	174	59	27	2	1	
7	60	342	941	1280	1236	921	581	296	124	61	14	11	6	
8	49	265	736	1034	1016	749	459	260	100	56	19	7	2	1
9	28	137	449	693	694	556	313	172	90	46	18	7	1	2
10	17	115	343	531	588	478	336	169	83	35	7	6	2	
11	13	78	266	398	542	376	274	143	67	23	15	1	2	
12	14	44	171	370	397	298	212	132	54	25	7	2		
13	8	35	130	197	242	244	183	96	57	15	8	1		
14	8	18	70	134	168	166	114	74	22	9	5			
15	4	16	45	106	145	162	107	67	38	14	5	1		
16	1	17	46	67	106	95	78	40	17	9	2	3		
17		10	25	64	76	70	54	22	9	9	3	1	1	
18	4	6	28	41	44	58	49	27	13	3				
19	3	5	18	36	32	49	25	16	7	3	3			
20		5	16	19	31	29	22	8	2	4	8	1		
21	1	2	6	15	20	13	16	9	8	3	1			
22			4	8	9	8	11	5	3	2	1	3		
23		6	5	14	16	12	9	15	2					
24		4	5	12	6	5	6	4	2	1				
25		2	5	5	11	14	8	1	3					
26	1	5	4	12	9	10	16	10	2	1				
27		7	10	14	15	29	17	5	3	5	1			
28		9	20	12	15	15	25	22	11	1				
29	3	12	24	25	33	42	45	42	17	7	3			
30	1	11	14	8	13	23	31	17	3					
40	10	27	72	123	170	224	207	106	32	8	12	9	2	
50	1	7	14	52	47	41	20	8	4	1				
60							2	2						

Box	Criterion	Percent of observations
	700 or greater obs	47%
	100–699 obs	35%
	10–99 obs	9%
	Fewer than 10 obs	1%

Eight percent of the dyads—the connections of 13 persons—did not have associated distances because these people were transients and had no fixed locale at the time of interview.

TABLE 3. The Percentile Distribution for Distances Between 2 Persons by Geodesic for the Connected Component of 348 Respondents Who Named Other Respondents as Contacts

	Distance (kilometers)								
Geodesic	No.	Mean	p5	p10	p25	Median	p75	p90	p95
1	695	5.3	0.0	0.3	1.8	4.4	6.8	10.2	13.6
2	3171	6.0	0.9	1.5	3.0	5.1	7.2	10.1	13.5
3	8164	6.2	1.2	1.8	3.3	5.4	7.6	10.7	13.3
4	11,810	6.6	1.2	1.9	3.5	5.6	8.0	11.4	14.3
5	11,664	7.1	1.4	2.0	3.8	5.9	8.7	12.1	15.6
6	9103	7.8	1.4	2.1	3.9	6.1	9.4	14.0	19.5
7	5831	8.5	1.5	2.3	4.2	6.5	10.2	15.7	28.5
8	3086	8.8	1.5	2.5	4.4	6.7	10.6	16.3	28.5
9	1419	8.3	1.5	2.4	4.1	6.5	10.3	14.9	25.8
10	608	7.9	0.9	2.0	3.9	6.6	9.7	14.8	19.7
11	265	8.5	1.4	1.8	3.6	6.0	10.7	19.0	28.1
12	101	9.2	1.1	1.7	4.0	6.2	9.3	21.6	35.7
13	25	8.7	1.1	1.8	4.1	6.6	9.2	16.4	36.6
14	3	8.2	7.4	7.4	7.4	8.5	8.7	8.7	8.7

p5–p95 are the percentile cutoffs in kilometers for the distribution of distances at each geodesic. No. is the number of dyads at each geodesic. Thus, for persons in this connected component, those who are 6 steps apart are at median distance of 6.1 km from each other.

The Connected Component of 348 Respondents

The 348 respondents who form a connected component, with a path of some length from every person to every other person, permit direct examination of the relationship between social distance, as measured by the shortest number of steps between 2 persons, and geographic distance, measured in kilometers as the distance between their locations. The codistribution of social (geodesic) and geographic distance further reveals the compact nature of associations (Table 2). Within this group of 348, persons were separated by geodesic distances of 1 to 14 steps. Those with a geodesic of 1 were direct contacts. Those of distance of 0 km and a geodesic of 1 lived together. Almost half the persons in this group of 348 were between 3 and 6 steps from each other and were separated by a distance of 2 to 8 km. Fifty-seven percent are included in the box bounded by geodesics 1 to 6 and distances 0 to 8. The darkly shaded area in Table 2 defines the "neighborhood" of primary interaction among persons involved in this network. For comparison, the 237 of 595 respondents were slightly more separated from each other (mean, 9.4 km;

Fig. 2. Nongeographic network visualization of the subcomponent of 9 HIV-positive persons (larger nodes) and their contacts (N = 221), including only those persons within a geodesic distance of 3 or less from any HIV-positive person. (Uses Fruchterman-Reingold algorithm as implemented in Pajek.)

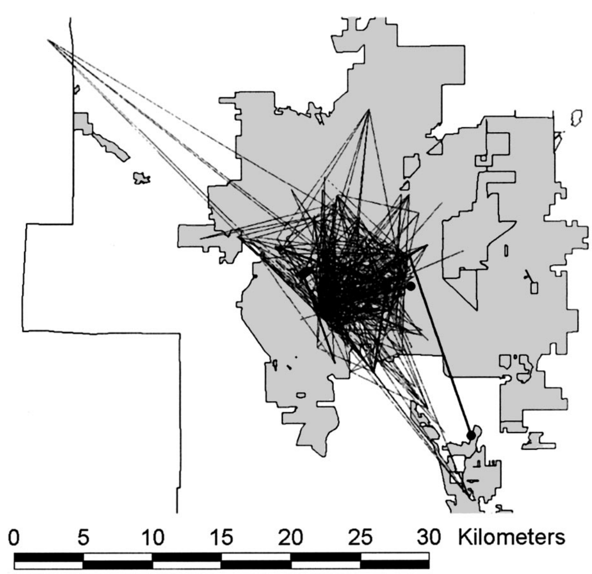

Fig. 3. Geographic display of the network depicted in Figure 2. The map contains 208 persons (of 221) with geographic coordinates.* (Thirteen persons in this network either resided outside the study area or had an unknown address.) *The large nodes and attached dark lines represent, respectively, HIV-positive persons and those who are directly connected to them (geodesic of 1). The remaining connections include all persons who are 3 steps or less from HIV-positives, as in Figure 2. With 1 exception, all HIV-positive persons and the majority of their connections occupy a small, well-defined area of downtown Colorado Springs.

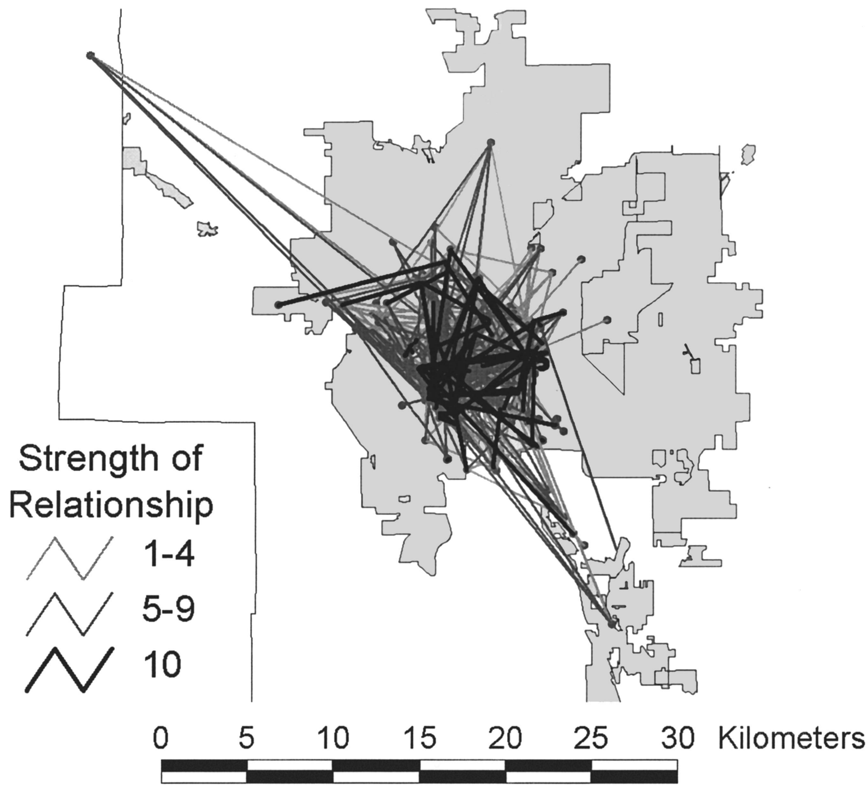

Fig. 4. Geographic display of the network depicted in Figures 2 and 3 by strength of relationship.

median, 7.7 km) than were the persons in the connected component. The unconnected group had a higher proportion of paying partners and a lower proportion of prostitutes, and were thus less central geographically.

Despite the obvious clustering of values in a small region, the overall Pearson correlation coefficient between geodesic and geographic distance was 0.14 ($P < 0.0001$). The correlation coefficient is small, although strongly significant, by virtue of the large sample size. This lack of correlation is reflected in the narrow range of distances between people at any geodesic within the subgroup (Table 3). The median distance for a geodesic of 1 is 4.4 km. The median distance for geodesics from 2 to 13 varies from 5.1 to 6.7 km and at a geodesic of 14, with only 3 observations, with a median of 8.5. The distances demarcating the lower percentiles are in general quite small and vary little by geodesic. As expected, those at the upper percentiles are large with greater variation with geodesics.

The Connected Component of HIV-Positive Persons and Their Contacts

The subcomponent of persons who are HIV-positive and their contacts provide a basis for more manageable visualization of the network. A nongeographic network picture, including only those with relationships at a geodesic of 3 or less from HIV (Fig. 2), demonstrates the complexity of interrelationships among the groups. This traditional approach provides no sense of the geographic proximity. When superimposed on a map of Colorado Springs, the intense geographic clustering (the "neighborhood") is made evident (Fig. 3). Although there are several longer distances displayed, the majority of the connections are compressed into the downtown area of Colorado Springs, especially those that are directly connected to HIV (i.e., a geodesic of 1). Using the strength of relationship, rather than geodesic, as a marker of social distance (Fig. 4), a similar picture emerges. The strongest relationships are those most aligned geographically, clustered in the central downtown area. Restricting the view to only the network of HIV-positive persons and their direct contacts and visualizing the strength of relationship, the strongest relationships are entirely in the downtown region and the remaining relationships, with few exceptions, peripheral to them (Fig. 5).

Comparison With the General Population

We estimated that the weighted mean distance between persons in Colorado Springs was 14.3 km (unweighted, 12.4 km). The difference between this mean and the mean distance between dyads in our study (5.4 km) was highly significant ($P < 0.0001$). A comparison of maps of the general population and our study population revealed markedly different patterns, with our population found primarily in the central city and the general population largely located in the periphery (maps provided on request).

Discussion

Much of the prior work on the geography of STDs and HIV has used choropleths (maps that use graded shading or coloring to designate difference in characteristics among predefined areas) to display the occurrence of disease. High concentrations of gonorrhea, for example, in small predefined areas lend validity to the core group hypothesis.[6,10,11,14] Zenilman and colleagues[13] went beyond choropleths to map and measure the actual distance between persons with gonorrhea and their partners. They demonstrated significantly smaller distances between dyads within core areas of Baltimore compared with noncore areas, reinforcing the importance of local neighborhood and geographic compactness in

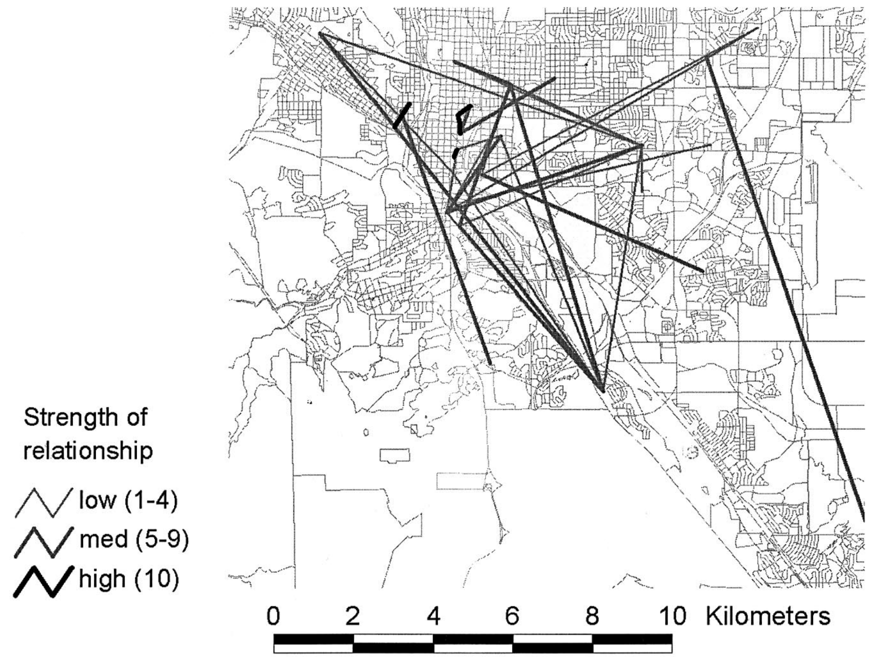

Fig. 5. Geographic display of the network* depicted in Figure 4, restricting the view to direct contacts to HIV, colored by the strength of relationship. *Although this map has insufficient detail to read the exact placement of nodes, we have randomly altered the position of each node by approximately 1600 m to protect confidentiality, better observe network configuration, and still preserve the geographic relationships.

*Though this map has insufficient detail to read the exact placement of nodes, we have randomly altered the position of each node by approximately 1600 m in order to protect confidentiality, better observe network configuration, and still preserve the geographic relationships.

the dynamics of gonorrhea transmission. In the current study, we have used the same approach to examine distances based on the characteristics of respondents and partnerships (Table 1, Fig. 1) and, because of the available connected components, have been able to plot an actual network in real geographic space.

Our comparison of social and geographic distance reveals the spatial compactness of a highly interactive group whose behaviors presumably placed them at risk for HIV. The focal nature of our sampling scheme (the "stroll"; county STD and maintenance clinics) does not predict a priori that the living quarters of our clients and their contacts would necessarily be in proximity. In addition, such a distribution differs significantly from the average distance between persons in Colorado Springs and from the distribution of the general population in the city. We demonstrate that there are gradients of geographic closeness depending on the type of relationship and the category of respondent. Paying partners of prostitutes are further away than their nonpaying partners. Persons who share sex and needle risk are substantially closer geographically than are couples with a single risk. Women who are the sexual partners of injecting drug users tend to be in close proximity to them. From the analysis of a large connected component derived from our primary respondents, it is clear that people who are at a considerable social distance are nonetheless in the same general geographic space, a circumstance that can promote mixing among persons at risk who are not directly connected. The configuration suggests that those within this group have a high probability of selecting new partners from within the group, an essential feature for maintaining disease endemicity.

Such observations are not generalizable, but they do provide a coherent picture of the relative relationship of risk, social connection, and geographic proximity in this group and suggest that geographic distance may be an integral part of some network configurations that can foster transmission of disease. Ethnographic and network descriptions of other inner-city populations, whereas not containing specific geographic information suggest that neighborhoods are bounded, personal mobility is considerable but only within a small geographic space and that risk groups tend to be geographically compact.[24–31] The demonstration in this group that the social connections reflect geographic proximity is, at least, a partial proof of principle that deserves further confirmation. Should it prove generalizable, it will be further confirmation of the need for focused, targeted approaches in STD and HIV prevention.

Like many other network features, however, geographic proximity is not fully explanatory. Although substantial compared to a general population, the prevalence of HIV in this group was low (3% of respondents) compared with many other populations that have been studied. We have previously reported that the network position of HIV-positive persons may have mitigated against active transmission within the group,[15,20] but a comprehensive understanding of network features and their interaction awaits further elucidation. Continuing advances in geographic information systems and in visualization of networks in real-time and space offer exciting possibilities for understanding disease dynamics.

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