The Atlanta Urban Networks Study: a blueprint for endemic transmission

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Objective: To study prospectively social networks and behavior in a group of persons at risk for HIV because of their drug-using and sexual practices, with particular emphasis on the interaction of risks and concomitant network structure.

Methods: A longitudinal study was conducted of 228 respondents in Atlanta, Georgia in six inner-city community chains of connected persons, interviewing primary respondents and a sample of their contacts every 6 months for 2 years. Ascertained were: HIV and immunologic status; demographic, medical, and behavioral factors; and the composition of the social, sexual, and drug-using networks.

Results: The prevalence of HIV in this group was 13.3% and the incidence density was 1.8% per year. Substantial simultaneity of risk-taking was observed, with a high level of both non-injecting (crack, 82%) and injecting (heroin, cocaine or both, 16–30%) drug use, the exchange of sex or money for drugs by men (approximately 35%) and women (57–71%), and high frequency of same-sex sexual activity by men (9.4%) and women (33%). The intensity of interaction, as measured by network features such as microstructures and concurrency, was significantly greater than that observed in a low prevalence area with little endemic transmission.

Conclusion: The traditional hierarchical classification of risk for HIV may impede our understanding of transmission dynamics, which, in the setting of an inner-city population, is characterized by simultaneity of risk-taking, and moderately intense network interactions. The study provides further evidence for the relationship of network structure to transmission dynamics, but highlights the difficulties of using network information for prediction of individual seroconversion.

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Introduction

In the late 1980s, the World Health Organization promulgated a classification for the status of HIV transmission within countries: pattern I countries, characterized by spread among men who have sex with men, bisexual men, and injecting drug users; pattern II countries, whose spread was driven by heterosexual contact; and pattern III countries, whose low level endemic activity was related to their contact with countries of the first two patterns [1]. Heterogeneity within countries, rapidly changing global forces, and undesirable national labeling, influenced World Health Organization to abandon this schema in the early 1990s

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in favor of a more complex classification called Global Areas of Affinity that encompassed epidemiologic, programmatic, and societal influences [2].

Both of these systems considered the relative impact of the major modes of HIV transmission (blood products, homosexual/bisexual, heterosexual, injecting drug use, maternal–infant transfer) but did not consider the potential impact of joint risk, that is, the simultaneity of multiple risk factors in an individual or in groups. Most classification schemes for HIV/AIDS risk, beginning with the Centers for Disease Control and Prevention's hierarchical classification, drew clear boundaries between risk groups. Among the first 1000 cases in the USA, for example, 727 were classified as 'homosexual or bisexual men', although 81 of them were also 'intravenous drug abusers' [3]. Overlap was recognized, but downplayed, perhaps because of the considerable force of transmission generated independently by anal intercourse and needle-sharing.

The HIV/AIDS epidemic in the USA has evolved dramatically in recent years, with marked decreases in both incidence and mortality [4,5]. Attention has turned from rapid epidemic spread to persistent endemic transmission, primarily in urban centers. In this study, urban networks of persons are described whose risk-taking behavior and social network structure provide the substrate for ongoing endemic transmission of HIV, and whose entrenched transmission dynamics may characterize a significant portion of the epidemic in the USA for the foreseeable future. This analysis stems from the evolving hypothesis that individual behaviors do not sufficiently explain the propagation of infection, and network structure and dynamics play a critical, explanatory role by placing those individual behaviors in a context [6,7]. What is described here is a transmission system – the configuration of risks and interactions within a social network – that can be compared to other systems for their relationship to the transmission of infection.

Methods

Genesis

The Urban Network Project developed from earlier work in Colorado Springs, Colorado, USA [7–12], an area of low HIV prevalence and low endemic transmission. A major concern of that study was reconciling the presence of groups at substantial risk for HIV (commercial sex workers, injecting drug users, and the sexual partners of people in these groups) with the infrequency of transmission. The Urban Network Project sought to examine similar issues in an area of higher prevalence and, presumably, of higher incidence for HIV. For this purpose, a similar conceptual approach was used for data collection and analysis, though the studies differed in the details of design and information ascertainment. A companion study, the Rural Network Project, has also been completed and will the subject of a separate report [13].

Study design

This longitudinal study enrolled respondents from 1995 through 1998, with follow-up through August 1999. The initial interview was followed by up to three subsequent interviews at 6 monthly intervals. The study design was motivated by a desire to capture the network configuration in which risky behavior took place, and to examine the dynamic changes that occur in such structure. After a period of ethnographic investigation, three geographically separated community sites were selected (designated sites A, B, and C) and two persons at each site were identified as 'seeds' or initial respondents to start a connected chain of persons and their contacts (Fig. 1). This type of sampling is necessitated by the hidden or elusive nature of the population at risk, a characteristic that precludes 'top down' or 'descending' sampling [14]. Though a variety of names is given to the type of ethnographic sampling used [15] they all have a common theme: enumeration of a representative group based on a general knowledge of the community [16].

After interviewing an initial respondent, the second individual in the chain was selected from the first's contacts, the third from the second's, with continuation of this process until 10 persons and their contacts had been enrolled in the community chain. For one of the chains at each community site, the next respondent was chosen randomly from the contacts of the previous respondent ('random walk') [17]. For the other, the contact was nominated by the respondent ('chain link') [14]. For every chain constructed, all the contacts to the first, fourth, seventh, and tenth respondent were also interviewed. The net result, at the end of the first round of interviews, was the establishment of five community chains of 10 persons each that included their contacts, approximately 40% of whom were also interviewed. The sixth chain (site A, chain link) consisted of only seven persons, owing to a high level of recursion (persons naming those already named) in this group. Because of variability in the number of contacts, the number of respondents in the six groups varied from 10 at site A (chain link) to 36 at site B (chain link). By design, each of these community chains initially consisted of a single component of connected persons. It was anticipated that the single component would fragment with each reinterview, and so an attempt was made to interview not only the original respondents (not all of whom would be available) but also persons previously named and newly named by respondents nos. 1, 4, 7, and 10.

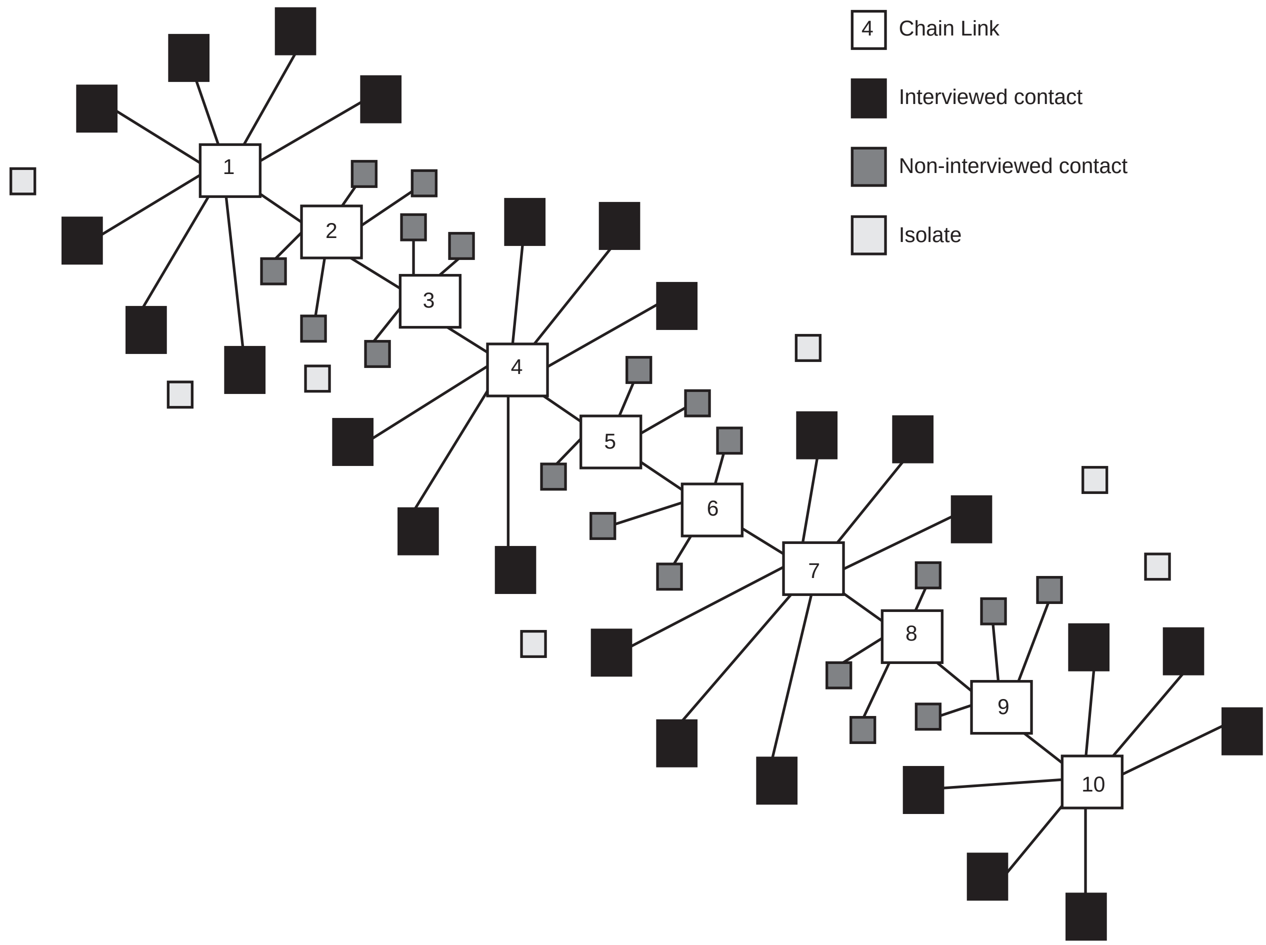

Fig. 1. Chain-link study design for Atlanta Urban Networks Project, 1995–1999. The study recruited six 'chains' of persons, using either random selection of the next interviewee, or a nomination by the previous interviewee. These six chains provided information on personal behavior and network association.

Study logistics

Virtually all interviewing took place in the target communities, at sites of the respondents' choosing, or of convenience (a quiet part of the park; the interviewer's car) or, on occasion, at the county jail or other institutional site. Security issues were minimized by the frequent presence of project staff in the community, and the occasional service (referral, transport) that staff could provide for participants and others in the community. Ongoing ethnographic activity (not reported here in detail) also improved the community rapport needed to maintain contact with participants. Despite the urban facade, many community members narrowly defined their relevant social space. Although Atlanta is a large city with almost four million residents, most respondents in this study did not often leave their immediate neighborhoods. In one extreme example, a respondent had not left a half-mile radius from his home in more than 2 years. Despite these favorable conditions, follow-up was often made difficult by the purposeful or enforced 'disappearance' of participants in response to their life events.

Data collection

The same instrument was used for the baseline and follow-up interviews, with a core set of questions divided into four main sections (survey instrument available on request). The questionnaire was designed to collect typical epidemiologic information as well as to maximize information on personal network structure. The questionnaire design was an integral part of the sampling strategy, by identifying persons to be interviewed at the next stage. The first section contained psychosocial and demographic variables such as place of residence, perceptions of the community, daily routine, and a brief medical history. Section two covered drug-related HIV risk, including an in-depth drug use history that collected information on the types of drugs used throughout the respondent's lifetime, as well as frequency of recent use. Section three addressed self-reported sexual behaviors, such as number of partners and frequency of oral, vaginal, and anal sex. The fourth section included a social network ascertainment, in which respondents provide the names, general locations, and descriptive background information of people with whom they associated. Contacts were defined as social (persons with whom the respondent shared resources such as food and shelter), sexual, drug-using, and needle-sharing. Friends and family members who did not fit any of these categories were occasionally mentioned, but were not systematically sought. A 'matrix' section, adopted from that used in the Colorado Springs study [12], requested information from respondents about all the relationships between all possible pairs of their contacts. A similar approach has been used in the General Social Survey, a large collection of egocentric information [18]. A test for HIV was administered, after consent and appropriate pre-test counseling (followed by post-test counseling when the results were communicated to the respondent). ELISA and Western blot testing on blood was used initially, but the oral HIV test (Orasure, Epitope, Inc., Beaverton, Oregon, USA) was adopted when the technology became available, since phlebotomy was often difficult to perform. If the respondent was found to be HIV-positive, blood was collected to measure CD4 cell counts.

Data analysis

SAS [19] was used to perform standard epidemiologic analyses and extract data in a format usable by UCI-NET-V [20] and KRACKPLOT [21] for social network analysis. Incidence was calculated from the number of observed seroconversions divided by the total person-years of observation. For each of the first three semi-annual interviews in the six community chains, network properties were calculated for the total group (all multiplex connections) as well as the subgroups formed by sexual, social, drug-using, needle-sharing, and sexual plus needle-sharing connections (a total of 108 subgroups). Four main types of network properties were measured: (i) density, the number of actual connections divided by the total number of possible connections, provides an estimate of the interconnectedness of the network; (ii) centrality (both individual and network centralization), is measured using several different approaches and provides information on persons who may be critical in transmission and the extent to which a network is centered on such persons; (iii) weak components (number and the largest size component as a proportion of the total group), which convey information about the potential for spread though interconnectedness within a group; and (iv) measures of network microstructure (including cliques, k-cores, k-plexes) that provide a measure of the potential intensity of transmission through opportunities for an infectious agent to 'cycle' within small subgroups [22].

To assess the amount of interaction within a group, a variant of density that we called 'recursion' was calculated. Standard density is the number of actual connections ('e') divided by the number possible $[N(N-1)/2]$, where N is the total number of persons (respondents and contacts) in the subgroup. Recursion is defined as the number of actual connections divided by the minimum possible for respondents only ('n'), given a particular study design. For this design, the minimum number of possible connections is n-1 (in a chain link of 10 persons, the minimum number of connections is nine; see Fig. 1). Thus, the minimum density is $(n-1)/[n(n-1)/2]$, or $2/n$, and recursion is actual density for respondents: $e/[n(n-1)/2]$ divided by minimum density, or $e/(n-1)$. By comparing the actual density within a group to the minimum density possible given the study design, a simple measure of the degree of connectivity within the group is obtained. It is expected, for example, that a group at risk will have a high degree of interactivity, and will thus have recursion that is substantially greater than one.

In addition, concurrence (kappa) was calculated for each group, defined as the mean number of concurrent partnerships per partnership, according to the method of Kretzchmar and Morris, in which kappa is calculated as: $\kappa = \sigma^2/\mu - 1$ where σ^2 and μ are the variance and mean of the degree distribution in the subgraph [23–25].

Using a previously described method [7], the risk configuration faced by a person within a community chain was calculated as the number of known risky contacts (sexual and drug-using) divided by the number of multiplex relationships available (for each contact, this denominator is four: sexual, social, drug-using, or needle-sharing). Risk configuration represents the general level of risk in the network environment of an individual. To calculate risk behavior, the number of potential risky contacts (sexual + needle-sharing + (0.5) × drug-using + (0.1) × social) divided by the number of actual contacts that a respondent named was calculated. The constants (0.5 and 0.1) are empirical estimates that are used to correct for possible information loss. Risk behavior is a measure of the actual risks being taken by an individual.

To compare the frequency of network structures with those obtained in other studies, data were standardized by dividing the number of structures identified in a subgroup by the number of persons in the subgroup. Data from this study were compared to those reported previously (with some additional reanalysis) from Colorado Springs [7] by examining the ratio of the two frequencies, which we called the Adjusted Frequency Ratio. The differences in distribution of the actual adjusted frequencies for each of the structures measured were then tested using the Mann–Whitney test. For each microstructure measured in the subgraphs the 15 observations from Colorado Springs and the 15 observations from Atlanta were rank ordered and the smaller sum of ranks was compared to the Mann–Whitney T statistic [26].

Results

Overview

A total of 292 persons were interviewed as part of the study. Of these, 228 were members of the six community chains, and the remainder were 'isolates', persons who were thought to be ethnographically important, or who were believed to be connected to one of the chains, but had not been specifically named. Of the 228, 157 were part of the original recruitment into the six chains. Additional persons were added during subsequent interviews as new contacts were named by respondents. After the original 157 interviews, there were 133 interviews in the second wave (85%), 122 in the third (77%), and 110 in the fourth (70%). These percentages are inflated, however, by the new persons who were added at each wave. Among the 157 persons who were first interviewed, 119 (76%) were interviewed at least twice and 90 (57%) were interviewed a third time. Among the entire group of 228 participants, 72% were interviewed at least twice.

Within the six community chains, 62% of respondents were men, and on average persons of both sexes were about 40 years old (Table 1). Ninety-one percent were over the age of 30 years and 89% were African American (data not shown). Fifty-two percent of persons stated that they had not completed high school (48% of men and 54% of women), 54% were unemployed (49% of men and 61% of women), and 35% of men and 24% of women described themselves as homeless (Table 1). Perhaps more important, 80% of the entire group had one or more of these characteristics: 18.9% were both homeless and unemployed, and 17.5% were unemployed and had dropped out of high school. The prevalence of all of these characteristics varied markedly within the community chains; homelessness, for example, varied from 8% to 64%, and unemployment, from 33% to 88% (100% of the group with one person), in part perhaps because of the relatively small numbers of respondents in each group. Few persons self-identified as prostitutes or drug dealers. As noted in the next sections, considerable exchange of money for sex and drugs did take place, but is not captured by stereotypic classifications of roles.

Table 1. Demographic and socioeconomic characteristics of respondents, all sites and network types, first interview, Atlanta Urban Networks Project, 1995–1999.

Characteristic	Men (%)	Women (%)
Age in years (mean)	40.3	39.4
Gender composition	62	38
High school dropout	48	54
Homeless	35	24
Unemployed	49	61
Prostitute	2	15
Drug dealer	1	2

Incidence and prevalence

In the entire group of 292 different persons, 234 (81%) were tested for HIV, and 31 (13.3%) were positive. Three seroconversions were observed during 164.8 person-years of observation, for an annualized incidence density of 1.8%. Based on the relationship that prevalence equals incidence times duration, the calculated mean duration of infection was 7.4 years, a result in keeping with the observed distribution of CD4 counts among infected persons. Overall, fewer than 5% of HIV-positive persons in this study had a CD4 cell count $< 200 \times 10^6$/l. This proportion increased, however, from 1.7% at the first and second interviews to 9.0% at the third interview. This study was initiated at about the time that highly active antiretroviral therapy first became available, and only a few respondents in the study had access to it during the study period.

Patterns of drug use

The overall level of drug use in this population was high (Table 2). Alcohol and marijuana had been used by most persons, with introduction in the teen years. Crack cocaine was the predominant 'hard' drug, but the age at onset was considerably higher (28.7 years). Nearly one-fifth of the population had injected heroin within the last 6 months and 23% had injected cocaine. On average, persons injected themselves with drugs on nearly half the days of the preceding month. Opiates and amphetamines had been tried by a substantial portion of the population, but were not a major feature of drug activity.

Sexual and drug risks

Though men and women reported different levels of drug and sexual risk-taking, levels for both sexes were high (Table 3). Men reported over 25 sex contacts in the past 6 months, and nearly seven, on average, during the past 30 days. Comparable figures for women were substantially higher (81.3 and 14.6); women reported that most of these encounters were of a commercial nature, though, as noted, few classified themselves as prostitutes. In addition to the usual risk factors, such as women exchanging sex for drugs (71.2%), or the sharing of needles with multiple persons by both men and women, several unanticipated factors were observed. Though only 6.9% of men stated that they had a male sexual orientation, 9.4% reported that they had sex with men, and 28.3% reported practicing insertive anal intercourse. In addition, 38.6% of men reported that they had received money for sex, and 35.4% reported that they had received drugs for sex – two practices reported more frequently among women. Nearly 19% of women stated that they had a female sexual orientation, and one-third reported that they had had sex with women.

Multiplex risk

Respondents identified both single and multiple relationships with their partners (Table 4). Uniquely sexual

Table 2. Patterns of drug use, first interview (all participants), Atlanta Urban Networks Project, 1995–1999.

Substance	Ever used (%)[a]	Age at first use (years)	last 6 months Used (%)	last 6 months Injected (%)	Last 30 days Days used (mean)[a]	Last 30 days Days injected (mean)[a]
Alcohol	95	15.2	84	–	18.4	–
Marijuana	88	16.6	56	–	6.8	–
Crack	90	28.7	82	–	18.0	–
Cocaine	68	22.5	30	23	12.8	11.5
Heroin	41	21.5	21	18	15.7	13.9
Heroin/cocaine	36	23.5	16	15	15.9	16.5
Methadone	15	30.0	6	1	< 1	< 1
Opiates	26	24.0	8	1	3.4	< 1
Amphetamines	35	20.8	4	1	1.9	< 1

[a]Data for age at first use, days used in the last 30 days, and days injected in the last 30 days include only those persons who reported the specific use categories.

Table 3. Differences in risk-taking between men and women, first interview, Urban Networks Project, Atlanta, Georgia 1995–1999.

Risk factor	Men (n = 160)	Women (n = 132)	Total group (n = 292[a])
Sexual activity			
Sex with men	9.4	97.7	49.5
Sex with women	97.5	33.3	68.5
Declared orientation for same-sex partners	6.9	18.9	12.3
Sex with an injecting drug user	50.3	47.7	49.1
Given money for sex	60.1	16.7	40.3
Given drugs for sex	74.2	19.7	49.5
Received money for sex	38.6	71.2	53.5
Received drugs for sex	35.4	56.8	45.2
Insertive anal intercourse	28.3	–	28.3
Receptive anal intercourse	4.4	15.9	9.7
Used condoms for anal sex (rarely or never)*	29.6	60.0	39.1
Used condoms for vaginal sex (rarely or never)	19.6	16.7	18.3
Sex contacts in last 6 months (mean)	26.4	81.3	51.3
Sex contacts in last 30 days(mean)	6.9	14.6	10.4
Drug activity[b]			
Shared needles or works in last 3 months	12.7	35.0	25.5
Shared works the last time used	11.5	15.8	13.3
Number shared with in last 30 days (range)	1–5	1–5	1–5
Number shared with in last 6 months (range)	1–12	1–5	1–12
Times shared in last 30 days (mean)	3.4	26.9	12.8
Did not clean works in last 30 days (%)	23.8	20.0	22.6
Did not clean works in last 6 months (%)	8.7	12.5	10.0
Did not use bleach to clean works	26.0	26.7	26.2

[a]A total of 292 persons were included in the study, but the denominator changes slightly in these categories because of missing information on some persons, or because the category does not apply. [b]Applies only to those persons who engage in the activity.

or needle-sharing relationships were uncommon in all the community chains (< 10%), but non-needle-sharing drug use relationships alone occurred commonly (20–40%). Simultaneous sexual and needle-sharing relationships between the respondent and a contact were not common (also < 10%), but combined sexual and non-needle-sharing drug use relationships occurred more frequently. The patterns of multiplex relationship vary considerably among the six community chains. For example, 32.8% of relationships at site A (chain link) involved both needle-sharing and drug use, compared to only 3.4% of relationships at site C (random walk). The relative absence of combined sexual and social relationships in any of the groups suggests that pairing in domestic relationships is infrequent, a finding confirmed by ethnographic observations.

Adjusted frequency ratio

Though not true in every case, the frequency of network structures (e.g. cliques, k-plexes, etc.) was in general substantially higher in Atlanta than in the Colorado Springs study [7]. When comparing the subgroups with any relationships, or each of the four possible relationships individually (Table 5), five of the ratios were undefined because the value in both Atlanta or Colorado Springs was zero; in two the ratio was 1.0; in eight of the categories the ratio was less than one (Colorado Springs > Atlanta) and for the remaining 45

Table 4. Distribution of multiplex risk (all possible combinations of sexual, needle-sharing, drug-using and social contacts), First Interview, Atlanta Urban Networks Study, 1995–1999.

Type of connection																			□	□	
Sexual				■				■	■	■				■	■	■		■	■	■	
Needle-sharing					■			■			■	■		■	■	■					
Drug-using						■			■		■		■	■		■	■	■		■	
Social							■			■		■	■		■	■	■	■		■	
Site	Type	N[c]																			
Site A	Chain link	45	3.3	4.9	1.6	29.5	1.6	0	0	1.6	32.8	1.6	0	0	6.6	1.6	13.1	1.6		8.2	3.2
	Random walk	225	11.6	4.4	0.9	38.2	1.3	0.4	7.6	0.9	8.9	0	9.8	0	0	4.4	9.8	1.8		2.2	13.8
Site B	Chain link	271	8.9	4.4	0	25.1	4.8	0	7.8	2.6	3.7	1.9	15.5	3.7	0.7	8.5	7.0	5.5		9.9	25.5
	Random walk	256	5.7	2.0	0.8	21.5	9.4	0	3.5	1.6	3.9	1.6	28.1	0.8	0	12.5	5.9	2.7		3.5	19.5
Site C	Chain link	157	19.1	0.6	5.1	22.3	6.4	1.3	6.4	1.9	10.2	0	9.6	0.6	1.9	5.7	6.7	2.6		6.4	15.3
	Random walk	206	9.2	9.7	0	38.4	4.9	0	9.7	2.9	3.4	0	11.2	3.4	0	4.4	2.4	0.5		3.9	18.0

*Includes all combinations in which sexual and needle-sharing relationships appear. [b]Includes all combinations in which sexual and drug-using relationships appear. [c]The total number of persons (both respondents and contacts) that were identified in the community chain during the first interview.

Table 5. Adjusted frequency ratio[a] of microstructures in Atlanta compared to Colorado Springs.

Type of relationship	Any relationship			Sexual			Needle-sharing			Drug-using			Social		
Interview number	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Microstructure[b]															
Clique (n = 3)	5.7	5.4	20.9	0/.001	0/0	0/0	0/0	12.4	0/0	7.6	9.2	59.8	4.9	10.7	.051/0
2-Clique (n = 3)	1.6	2.0	1.9	2.8	3.6	4.1	9.4	11.7	14.4	3.6	4.7	4.4	2.9	2.7	2.9
2-Plex (n = 3)[c]	0.9	1.4	0.6	0.5	0.6	0.5	12.3	12.5	14.5	2.4	5.0	2.2	1.0	2.1	1.0
2-Plex (n = 4)	6.0	5.6	30.9	.002/0	0/0	0/.001	.068/0	0/.001	.028/0	9.1	10.2	25.0	15.9	.030/0	.061/0

[a]In instances where either the numerator (Atlanta) or the denominator (Colorado Springs) or both are zero, the actual ratio is provided. The adjusted ratio is calculated by dividing the number of microstructures observed by the number of persons in the specific subgraph (see text). [b]The Mann–Whitney U-test results, performed by comparing the relative ranks of adjusted frequencies from Atlanta and Colorado Springs for each of the four microstructures were: 2-clique (n = 3), $P < 0.01$; 2-plex (n = 3), $P < 0.01$; 2-plex (n = 4), $P < 0.01$; clique (n = 3), $P < 0.05$ (T = 188 compared to upper limit of 185 for significance at 0.05 level). [c]The '2-plex (n = 3)' consists of three nodes in a line (a non-transitive triad) and may be thought of as equivalent to a concurrent partnership.

categories, the ratio was greater than one (Atlanta > Colorado Springs). A Mann–Whitney test [26] on the rank order of the actual frequencies for the two sites for each of the four microstructures using all five possible relationships demonstrated that three of the four were significant at the $P < 0.01$ level and the fourth narrowly missed significance at the $P < 0.05$ level.

General network properties

Six measures were used to summarize the interactions of network structure and risk-taking (Table 6). The largest component within the subgroups of sexual and needle-sharing connections included between 17% and 94% of group members. The distribution was bimodal: half of the groups were over 50% and the other half were under 35%. Risk configuration (the amount of potential risk faced by a member of the network) was uniformly < 20%, with an average over the 18 observations of 11%. Risk configuration uniformly declined over the period of observations, though most of these declines were small. Risk behavior (a measure of the actual risks incurred by participants based on the nature of their relationships) was higher than risk configuration in all groups, indicating a substantial level of risk taking as a result of the multiplex relationships within networks. Risk behavior also declined in all groups over the period of observation but with only one exception (site C, chain link), these declines were small. Despite the substantial level of same-sex sexual activity by men within this overall population, same-sex partners (as a percentage of all sex partners) did not figure prominently in any of the chains.

Kappa, a measure of the number of concurrent partnerships per partnership, is substantial in the first interview in each community chain (varying from 3.27 to 9.62), but declines thereafter at all sites. This finding suggests that the simultaneity of sexual or needle-sharing contact diminished over the period of observation. Recursion, which compares actual density among those interviewed to minimal density based on the study design, was measured only for the first interview, during which a single connected component was constructed. Recursion was substantial in all but one group, indicating a density up to 2.5 times higher than the minimum expected. An overall look of all the measures included in Table 6 provide little that is unique about the two community chains [site A (chain link) and site B (chain link)] in which seroconversions occurred. An overview of the data also suggests that there is little to distinguish between the random walk and chain link approaches.

Table 6. Network properties of the six community chains over the first three interviews[a]. Urban networks study, Atlanta, Georgia, 1995–1999

	Site A Random walk			Site A[b] Chain link			Site B Random walk			Site B[b] Chain link			Site C Random walk			Site C Chain link		
Interview	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Number in group	33	29	33	87	48	45	116	72	51	94	48	31	68	25	32	89	92	63
Largest component (%)	94	86	58	62	13	73	62	54	20	64	10	26	69	28	28	34	17	24
Risk configuration (%)	19	17	18	11	10	7	13	11	8	9	5	7	12	12	9	11	9	9
Risk behavior (%)	61	59	59	55	52	50	55	50	41	47	42	41	54	50	44	54	50	42
Same-sex partners (%)	0	3	0	0	0	0	1	0	0	0	2	0	0	0	0	4	3	6
Kappa[c]	9.6	6.9	3.8	4.5	1.7	3.0	6.2	3.8	1.6	6.2	1.3	1.2	5.1	2.7	0.5	3.3	3.9	4.4
Recursion	2.2			1.7			2.2			2.5			1.4			1.1		

[a]Data on the number in the group, the largest component, and kappa are for the subset that includes both sexual and needle-sharing contacts. Risk configuration, risk behavior, the proportion of same-sex partners, and recursion apply to the entire group. [b]These are the two community chains in which seroconversions occurred over the period of observation (see text). [c]Kappa is the number of concurrent partners per partner in the group ($\kappa = (\sigma^2/\mu) + \mu - 1$). For a group of only monogamous pairs, $\kappa = 0$; for a person with n partners, $\kappa = n - 1$, that is, there are $n - 1$ concurrent partnerships for each partner. The formula for kappa calculates the mean concurrence for a group. Kappa is calculated using only those persons within the group from whom information was obtained directly. Largest component (%), Number of persons in the largest component as a percent of the total number in the group; risk configuration (%), the proportion of sex and needle-sharing contacts out of all possible relationships (see text); risk behavior (%), the proportion of risky contacts out of all actual contacts (see text); same-sex partners (%), the proportion of all sexual contacts to men that are same-sex contacts.

Discussion

Though hierarchical classification schemes and risk-specific intervention programs have been in place for some time, there is considerable current interest in the more complex nature of risk [27–33] but little systematic documentation of such complexity. The picture derived from this quantitative overview of the urban networks of persons at risk for HIV is striking for both multiplicity within groups and heterogeneity between groups. Multiplicity is evident in the frequency with which persons engage in a variety of risk behaviors (drug-using; sex risk, including frequent contact with persons of the same and opposite sex; and surrogates, such as exchanging drugs for money, that have been shown to be associated with transmission); in the frequency of multiple relationships between partners (multiplexity, in network parlance); and in the frequency with which multiple risks exist within the same network. The striking level of same-sex partnerships, in the absence of self-identification as gay or lesbian, is general evidence for the polymorphous nature of these interactions. In this setting of inner city, minority persons at risk for HIV, the application of hierarchical or univariate classification of risk would impede an understanding of transmission dynamics.

Though the subjective judgment is debatable, we have described the level of prevalence (13.3%) and incidence (1.8% per year) as moderate. In these communities, we have also described the observed joint risk as moderate and stable (or declining) in most groups examined, and marked by considerable heterogeneity. The terminology stems from a comparison with Colorado Springs, previously classified as a low risk area [9], based on a prevalence in the groups at risk of approximately 3%, and the virtual absence of transmission over the course of the study. Only one seroconversion in a contact (none in respondents) was observed during the study interval [34] In this comparison, the usual questionnaire-based methods for assessing risk produced similar results (see Table 3 and [12]). Using a network-based assessment, risk configuration in the two Colorado Springs cohorts varied from 17 to 20% (higher than the risk configuration mean of 11% reported for this study), but risk behavior in Colorado Springs varied only from 10 to 20%, compared to an average of 50% in Atlanta. The ratio of risk behavior in Atlanta compared to Colorado Springs thus ranged from 2.5 to 5.0. Similarly, the frequency of microstructures in Atlanta was substantially greater than that in Colorado Springs, with an adjusted frequency ratio averaging 8.0 for non-zero values. Network-based quantitation of risk and structure cannot be related to disease occurrence directly in this study, but the prevalence ratio of 4.4 (13.3% / 3.0%) is consistent with the network findings. Though comparable data are not available for a high prevalence and incidence area, the fact that transmission probabilities are generally low [35] leads to the hypothesis that a considerable level of interactive joint activity is required to maintain higher levels of endemicity. One caveat in the interpretation of these findings is that somewhat different sampling schemes were used in Colorado Springs and Atlanta. Both, however, attempted to maximize the likelihood of finding interconnectivity, the latter through a purposeful design, the former through recruitment of persons ('cross-links') named by several others. Finally, we do not have longer term data that could describe the epidemiologic picture at the time (7–8 years ago) when many in this study might have contracted their infection. The underlying assumption, based on 4 years of follow up (data not shown) is that personnel change, but the underlying structure is not dramatically altered.

Two recent large-scale interventions obtained differing results when they tested the use of community-based sexually transmitted disease treatment as a mechanism for diminishing the transmission of HIV. The trial in Mwanza, Tanzania [36] observed baselines prevalences of 3.8% and 4.4% in intervention and comparison communities and a cumulative probabilities of HIV-seroconversion of 1.2% and 1.9%. In Rakai, Uganda, with a baseline HIV prevalence of 15.9%, a seroconversion rate of 1.5% per year was observed in both intervention and comparison groups [37]. The differences are the subject of intense, ongoing debate, but of interest here is that the incidence in both areas was similar to that observed in the Atlanta community groups, and the prevalence in this study approximated that in Rakai. Our study suggests the possibility that network factors may have played a role in the differential impact of sexually transmitted disease treatment on HIV transmission. In addition, it readjusts our perception of the intensity of HIV transmission in some communities in the USA.

This study highlights not only the multiplicity of risk interactions, but also the stereotypic classifications that are used to describe persons at risk. Traditional designations such as 'heterosexual', 'homosexual', 'prostitute', 'drug user', 'drug dealer', and similar appelations were of little use in these communities because of the frequency of multiple roles, and the changing patterns of risk taking. Though relatively few men self-identified as 'homosexual', a substantial number reported having sex with men, including insertive anal intercourse. Similarly, only a few women in the study defined themselves as working prostitutes, though the majority had exchanged sex for money or drugs. The heterogeneity of risk within groups, and the changing patterns of risk over the period of observations suggests that individuals' activity also varies in the short term.

One result of this complex pattern was that prediction of individual seroconversion from network structure and behavioral patterns is difficult. The three persons who were observed to seroconvert, and their networks, could not be readily distinguished from others. Thus, the pattern described by this study, together with earlier work, offers a general blueprint for the level and intensity of endemic transmission, but is difficult to use as a predictive model. It may be that some combination of mathematical modeling in conjunction with the continued collection of this type of data would be required to provide a firmer quantitative basis for linking incidence and prevalence with network structure and risk behavior. Such assessment might serve as the basis for targeting intervention services to areas and groups in greatest need.

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