Published in final edited form as:

Curr Opin HIV AIDS. 2009 July ; 4(4): 260–265. doi:10.1097/COH.0b013e32832c7cfc.

HIV Transmission Networks

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Abstract

Purpose of Review—Over the past several years, one segment of the complex field of HIV transmission dynamics —heterosexual networks—has dominated theoretical and empirical investigation. This review provides an overview of recent work on HIV risks and networks, with a focus on recent findings in heterosexual network dynamics.

Recent findings—Qualitative (ethnographic) assessments have demonstrated the heterogeneity and complexity of heterosexual connections, particular in Africa where tradition, official polygamy, and unofficial multi-person arrangements lead to concurrency of sexual partnerships. A large, quantitative study on Likoma Island, Malawi, demonstrated the considerable, interlocking sexual connections that arise from a high-concurrency sexual setting, even with a low average number of partnerships (low-degree) of long duration. Such settings, as suggested by ethnographic studies, may be common in Africa and, coupled with newer information about transmissibility during acute and early infection, may provide a plausible explanation for endemic transmission and possibly for rapid HIV propagation.

Summary—Recognition of high- concurrency, low-degree networks is an important development for understanding HIV transmission dynamics. Their relevance to heterosexual transmission, and possible extension to other epidemiologic settings, reinforces the heterogeneity and complexity of HIV transmission dynamics.

Keywords

HIV; AIDS; heterosexual transmission; transmission dynamics; epidemiology

Now nearing the end of its third decade, the HIV/AIDS pandemic resists easy characterization. The major risk factors have been known for some time, but our understanding of how these risk factors mesh with human and viral dynamics continues to evolve. Though still referred to as epidemic, HIV/AIDS is now perceived as an endemic, chronic disease¹ whose critical features are markedly heterogeneous.² In any given setting, the complex mix of risk epidemiology, viral characteristics, host immunology, social networks, demographic phenomena, and social determinants influences transmission, incidence, prevalence, mortality, and the efficacy of interventions. HIV transmission networks provide an organizing principle for viewing these multifaceted issues, and networks have received substantial attention in this mix. One of the important concepts in the field has been that active transmission takes place in groups that have a disproportionate number of persons with many contacts (often referred to as “scale-free” networks, though this is probably a statistical misnomer³ in most instances). Recent work, predominantly focused on heterosexual networks that are dominated by persons

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with relatively few contacts (“low degree”) but a high level of simultaneity (“high concurrency”), suggests that some alternative network substrates may also underlie transmission.

Recent trends

Men continue to predominate in the notification of HIV/AIDS cases in the United States. From 2004–2007, the number of reported cases of HIV/AIDS in men who have sex with men increased from 17,898 to 22,472, and the number in male IDU was relatively constant at about 3,000.⁴ Nonetheless, the overall HIV/AIDS “endemic” is frequently described as having a disproportionate effect on women—in particular, those who are members of minority groups.^{4–5} For both men and women, the number of reported cases of HIV/AIDS attributable to high risk heterosexual contact (defined as sexual contact with an infected person of the opposite sex, or sex with an injecting drug user [IDU] of the opposite sex, or, for a woman, with a man who has sex with men [MSM]) has remained constant or declined during the current decade. The proportion of such cases has risen, however, more dramatically for women than for men (Figure 1). These trends suggest that women now have an increasing share of a declining disease occurrence. A recent upward adjustment of the estimate of overall HIV/AIDS incidence,⁶ based on the emerging technology to detect recent infection, may change the perception of this disproportion.

MSM and IDU transmission networks

Investigations of male-to-male and IDU transmission during the past several years have focused on social network characteristics as risk factors.^{7–13} For example, in a study of men in Baltimore, MSM were more likely to be HIV positive than were heterosexual men, the networks of MSM were less dense, and those MSM who reported injection drug use also reported greater needle sharing than their heterosexual counterparts.¹³ Similarly, among IDU in Winnipeg, relationship to a risk network member, difficulty of access to syringes, and dyads who pooled resources were all at greater risk for syringe sharing.¹² Though these investigations are important contributions to the epidemiology of risk, their primary concern was not with transmission dynamics.

Heterosexual transmission networks

In contrast, studies of heterosexual transmission have investigated both risk factors and dynamics. As noted, heterosexual transmission has increasing prominence in the epidemiology of HIV/AIDS in the United States, and has been of special importance in many other areas of the world for some time. Though their settings differ from that of the United States, several other countries—notably Russia,¹⁴ Brazil,¹⁵ and France¹⁶—have furnished data supporting the increasing prominence of heterosexual transmission. Current epidemiologic investigation continues to focus on risk factors for transmission in the heterosexual setting, including unsafe sex and history of STIs (Thailand),¹⁷ illicit drug use and migration (Caribbean),¹⁸ childhood sexual and physical abuse (Southeastern United States),⁵ and inadequate condom use (Southwestern United States).¹⁹ A meta-analytic review of 68 epidemiologic studies²⁰ confirmed that the number of sex partners, history of paid sex, and infection with Herpes Simplex Virus type 2 or other STIs were significantly associated with HIV infection. The authors also found that these associations were present after stratification for high and low prevalence areas, suggesting that risk factors persist even as epidemics mature. This association of sexual risk factors with HIV is at odds with the findings of several large studies^{21–24} conducted in Africa during the 1990s and the findings from a subsequent review.²⁵ Some of the discrepancy may lie in the study approach. The earlier reports and review examined ecologic correlations between the level of sexual risk factors in multiple sites and the prevalence of HIV (though note was made as well of inconsistencies in the association of personal risk

factors and HIV). The current meta-analytic review²⁰ is a comprehensive assessment of the association between an individual's risk factors and HIV. The underlying assumption of both the ecologic and cross-sectional approach is that current sexual activity reflects risk at the time that HIV was acquired, and is supported to some extent by the review's finding that the associations were similar in high and low prevalence areas. None of the studies under consideration, however, was in a position to know the relationship of current HIV infection to sexual activity at the time of acquisition. The studies are markedly heterogeneous with regard to the level of risk variables,²² and two critical factors—frequency of sexual contact and time since acquisition (a surrogate for the transmission probability)—are missing, rendering interpretation of both ecologic and risk factor associations difficult. The emerging technology for identifying acute infection may clarify future inquiry, but is unlikely to resolve past inconsistencies.

Network assessment

Some important recent work has gone beyond risk factor assessment, and explored the role of network phenomenon in heterosexual propagation of HIV. At least two major factors—concurrency and bridging—have been studied extensively without the use of formal network designs.

Concurrency, originally proposed as an important factor in transmission in the early 1990s,²⁶ is a prominent feature of heterosexual groups at risk. In Houston, TX, among a group of 553 women from high risk, high poverty, high HIV prevalence areas, 49% reported concurrent partnerships (and only 26% reported condom use at their last sexual contact).¹⁹ In the rural southern United States, 25% of women and 42% of men had multiple partnerships in the preceding year; 26% of such partnerships were concurrent, and 38% of partnerships in the preceding 5 years were concurrent.²⁷ This sexual substrate, coupled with under-education and food insecurity, makes poverty a major factor in person's taking on sexual risk,²⁸ and economics in general a driving force in sexual reciprocity.²⁹

The latter studies are representative of the growing importance of qualitative contributions to the understanding of disease transmission. An ethnographic exploration of cohabitation suggests that marriage, or at least exclusivity, may be protective against transmission of HIV. 30 Hattori and colleagues addressed this issue in detail³¹ using a sample of women drawn from the slums of Nairobi, Kenya. They stress the complexity of relationships, noting the different forms of formal (officially recognized) and informal pairing, and their varying social implications. They note that the 2003 Demographic Health Survey in Kenya reported a low prevalence of women with multiple partnerships in the preceding year (1.7%), but that the frequency of such reports varied with cohabiting status. In their sample from the Nairobi slums, more than twice the proportion of women reported two or more partners in the past year (4.6%), and there was important variation in this group as well. One percent of married, co-residing women (71% of the sample; representativeness is not discussed specifically, and the authors note that their study group is a selected subset) reported two or more partners, but 11.5% of co-residing women, 11.1% of widowed women, and 20.5% of divorced women reported two or more partners. Non-exclusivity was also a feature of older age, less education, and Catholic religion. Of special interest was the observation that women living with co-wives were more likely to have other male partners. Thus, the data suggest that in this impoverished group the overall population prevalence of 1-year non-monogamy was not high, but was strongly influenced by social, cultural, and demographic factors. These findings confirm those of a subsequent review and commentary³² that found wide-spread reporting of concurrent relationships embedded in complex social and sexual arrangements, and suggested that attention to such factors may be critical in the elucidation of transmission dynamics in Africa. Such thinking was underscored in a commentary by Dworkin and Ehrhardt,³³ who pointed

out the simple ABC approach (Abstinence, Be faithful, use Condoms) needs to be amplified by a focus on GEM (Gender relations, Economics, Migration).

A formal network approach

Using a network design that incorporated both qualitative and quantitative elements, HELLERINGER and KOHLER reported on 923 persons from Likoma Island, Malawi.³⁴ They identified a network configuration characterized by long term relationships of low degree (3-year mean number of partners was 2.6 for men and 2.2 for women [IQR 1–3 for both]) and high concurrency. The concurrent relationships generated a giant connected component containing about half of the participants, with a large bicomponent (in which every member is connected to at least two others), containing approximately 25% of survey respondents. That such a component structure can emerge from a low-degree, high-concurrency sexual configuration was predicted theoretically and by simulation.³⁵ This structure may be capable of supporting rapid transmission of HIV, particularly with new introduction of the virus, and a preponderance of acute infections.^{36–37} In the Likoma group, HIV prevalence was 10.6% among women and 4.7% among men, with a greater concentration of HIV-positive persons in the periphery of the network (as opposed to the highly interactive bicomponent). In a letter, BREWER et al.³⁸ assert that this finding undermines the likelihood that the described network configuration underlies HIV transmission, because prior network descriptions had placed a preponderance of HIV-positive persons centrally in a network of high prevalence, and peripherally in a network of low prevalence. Likoma, a setting substantially different from either of the two networks cited, lies between them on the prevalence spectrum, and appears to be past any period of rapid transmission that may have taken place, so that prior observations cited by BREWER et al. may not be predictive of Likoma's HIV configuration.

Bridging

In the United States, most of the recent work on bridging has focused on African American men who identify as heterosexual but also have sex with men without making their female partners aware of this activity (the so-called “down low”) as well as on the general population of men who have sex with both men and women (MSMW). For the former, several have written that the term is socially constructed and in many ways inappropriate,^{39–41} since it “exoticizes” the activity and makes it qualitatively distinct from identical behavior in men who are not of African American ethnicity. In addition, SATCHER et al.⁴² refer to U.S. national data to point out that the proportion of women who report having possibly contracted HIV because of sex with a bisexual man has remained constant in recent years, and was highest for African American women. MALEBRANCHE et al. review the issue in detail, and support the view that African American MSMW may be a “bisexual bridge” to African American women, and may account in part for their higher prevalence.⁴³ Other recently described bridging populations include bisexual men in China,⁴⁴ and transmission from IDU groups to non-IDUs through heterosexual contact.^{14, 45} Several authors have stressed the nuances of sexual activity in assessing bridging. Though official reporting systems are silent on the matter, heterosexual anal sex is common,⁴⁶ and may be increasing.⁴⁷ Bisexual men in China are reported to have anal intercourse with their female partners more often if they also have anal sex with their male partners.⁴⁴ The variability of sexual behaviors among those with a high risk of transmitting HIV,⁴⁸ however, reinforces the idea that the simple presence of possible sexual connections, in the absence of behavioral, biological, and network information, makes assessment of bridging difficult. Finally, investigations of bisexual bridging have focused on the origination, rather than the destination, of the bridge. Requisite studies, comparing women of differing ethnicities with regard to the sexual activity of their partners, appear to be lacking.

Modeling heterosexual transmission

Mathematical consideration of the trajectory of HIV has for many years been dominated by sexual transmission between men, or by injecting drug use. Recently, considerable attention has been devoted, directly or indirectly, to models of heterosexual transmission.^{49–63} Though the models are sophisticated, complex, and detailed, the major results for most of them are simply stated, and in some instances contradictory. Abbas and colleagues assert that antiretrovirals would not have a major impact on transmission, with only an 11.2% greater decline with their widespread use in 10 years compared to the decline in their absence.⁴⁹ In contrast, Granich et al. present a model that finds that universal testing coupled with widespread use of antiretrovirals would successfully eliminate HIV.⁵⁴

Several models have explored the complexity of simultaneous effects. A decline in prevalence attributed to a behavioral intervention may actually result from changes in immigration patterns and declines in mortality through treatment rather than from the intervention itself.⁶³ In a similar vein, a decrease in cross-generational sex and limiting partner change may decrease individual risk but would have little effects on the overall epidemic trajectory.⁵⁵ Hertog stressed that models must take into simultaneous consideration mixing patterns, pattern change, and infectiousness, since these factors interact and do not occur in isolation.⁵⁶ Finally, Gouws et al. have stressed the importance of geographic area in assessing the proportion of HIV attributable to different routes of transmission.⁵³

Models have been used recently to explore several contested areas of HIV/AIDS epidemiology. Dunkle et al. presented a construct to show that between 60% and 94% of heterosexual transmission occurs between (cohabiting) serodiscordant couples.⁵¹ (In an exhaustive review of the available empirical data, Guthrie et al. reach a similar, though non-quantified, conclusion about the importance of discordance.⁶⁴ The default assumption in this work is that serodiscordant couples are monogamous, and missing from this discussion is a consideration of the potential interaction of serodiscordance and concurrency.) Deuchert and Brody report a model-based statistical analysis that questions whether parameters used in many models are in keeping with the extant empirical estimates for transmission probabilities or partner change.⁶⁵ This conclusion might be reconsidered in light of changing concepts about the probability of transmission. Similar points were raised in an exchange in which Rapatski and colleagues assert that the bulk of transmission occurs during late-stage HIV disease, rather than during acute or early infection.^{61, 66}

Modeling continues to be a fundamental tool for evaluating disease transmission. Recent theoretical advances in network modeling, based on a the family of exponential random graph models, have led to operational approaches and the development of practical tools for performing such analyses.^{67, 68} Such approaches offer considerable promise for amalgamating theoretical considerations and simulations with empirical observations, such as those made on Likoma Island.

Conclusion

Several themes motivate current investigation in HIV transmission networks. The simplistic sense of an epidemic as the sum of homogeneous events is giving way to the view of transmission as a complex and heterogeneous phenomenon, embedded in networks that may facilitate rapid propagation. Investigators are paying increasing attention to contextual issues, and qualitative tools are now being brought to bear more seriously on this complex system. These studies create some discordance between the frequent qualitative description of concurrent sexual arrangements and the survey reporting of infrequent multiple partnerships. An expanding view of HIV transmission heterogeneity will hopefully resolve some of the

inconsistencies, create a more coherent picture of the interrelationship of elements, and ultimately lead to a setting-specific mix of appropriate interventions.

Acknowledgments

This review was supported in part by R01 DA019393 from the National Institute on Drug Abuse, National Institutes of Health.

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Figure 1.

Number of reported cases of HIV/AIDS attributed to heterosexual transmission and the proportion of heterosexual transmission cases out of the total cases reported, for men and women, United States, 1984–2006

Source: <http://www.cdc.gov/hiv/topics/surveillance/resources/reports/past.htm#surveillance>