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Social Networks of Substance-Using Populations: Key Issues and Promising New Approaches for HIV

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Abstract

Purpose of Review This paper presents recent literature on substance using networks and HIV, highlighting renewed and emerging themes in the field. The goal is to draw attention to research that holds considerable promise for advancing our understanding of the role of networks in shaping behaviors, while also providing critical information for the development of interventions, programs, and policies to reduce HIV and other drug-related harms.

Recent Findings Recent research advances our understanding of networks and HIV, including among understudied populations, and provides new insight into how risk environments shape the networks and health of substance-using populations. In particular, the integration of network approaches with molecular epidemiology, research on space and place, and intervention methods provides exciting new avenues of investigation.

Summary Continued advances in network research are critical to supporting the health and rights of substance-using populations and ensuring the development of high-impact HIV programs and policies.

Keywords Substance use · Social networks · HIV · Molecular epidemiology · Place · Intervention

Introduction

Global estimates indicate that there are 15.6 million people who inject drugs (PWID) across 179 countries, almost 21% are women, 28% are younger than 25, and approximately 18% are living with HIV [1]. Numbers of people who use drugs (PWUD), more broadly, are harder to find, but it is estimated that a quarter of a billion people, roughly 5% of the global adult population, used drugs at least once in 2015 and that 29.5 million of those people have a drug use disorder, most of whom never received treatment [2]. Opioids, including heroin and synthetic opioids (e.g., fentanyl), remain the most harmful drug type in terms not only of overdose, but also for the acquisition of HIV and hepatitis C; however, trends toward increased amphetamine and cocaine use, often in combination with opioids, are of growing concern as well [2]. In recent years, there has been heightened public interest in substance use, stemming primarily from the opioid and overdose epidemic in the USA, but also with regard to high-profile HIV outbreaks. In 2014–2016, Scott County, Indiana saw one of the worst HIV outbreaks since the introduction of combination antiretroviral therapy, an outbreak directly related to injection drug use [3]. Globally, alarming rates of HIV incidence related to injection drug use in Eastern Europe and Central Asia also highlight the need for continued research and public health efforts addressing the social and structural factors driving substance use and HIV [4].

Effective harm reduction and HIV prevention and treatment require knowledge of the structure and dynamics of the social networks through which pathogens are transmitted. Networks shape health-related social and interpersonal behavior through the provision of social support, influence, engagement, access to resources, and material goods, as well as through direct exposure to infectious diseases, such as HIV [5]. Importantly, social networks can constrain or enable

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actors by blocking or encouraging possibilities for action or knowledge acquisition, by constructing identities and goals, and by providing the normative evaluations that guide action [6]. Among people who use or inject drugs, network data can provide essential information for assessing the context in which risk occurs, examining transmission patterns and dynamics, and for developing interventions and policies.

The examination of how social networks shape health is a growing field, but research on injection drug use was an early adopter of this approach and, thus, has a rich history. A large body of research demonstrates that injection network characteristics play an important role in the spread of HIV and shape risk/protective behaviors among PWUD and PWID [7–12]. For instance, seminal work has shown that network size [9, 10], centrality or network position [8, 13, 14], density or clustering [9], network turnover [15], and the strength or weakness of social ties [16–18] are associated with injection practices and HIV acquisition or transmission. Early work also indicates that factors like social support, influence, trust, and isolation play a role in both drug use practices and HIV among substance users [7, 11, 12, 18–20]. Characterizing the structure and composition of networks is thus crucial to understanding HIV transmission dynamics among drug-using populations.

Recent research has built upon this fundamental work to broaden the scope of what we know about the role of substance-using networks in shaping HIV and other health outcomes. This paper presents recent literature on substance-using networks and HIV, highlighting renewed and emerging themes in the field, including exciting new avenues in the integration of network approaches with molecular epidemiology, space and place, and intervention approaches. The goal is to draw attention to research that holds considerable promise for advancing our understanding of how networks shape behaviors, while also providing critical information for the development of interventions, programs, and policies to reduce HIV and other drug-related harms.

Overview of Key Issues in Network Research with Substance-Using Populations: Understanding the Social Pathways to HIV

Despite extensive research on the networks of substance-using populations, our understanding of how risk epidemiology, viral characteristics, and social determinants intersect with networks to shape HIV transmission continues to develop. New research supports the importance of network size [21], structure [22], bridging (i.e., ties connecting different groups) [23], clustering (i.e., nodes grouping together) [24], multiplexity (i.e., ties with multiple social connections, such as a sexual and drug use connection) [25–27], and social support and capital [28–30] for HIV risk behavior, transmission, viral suppression, HIV disclosure, and ART initiation. This work entails an expanded focus on populations that have historically received less attention, including research on the networks of non-injecting drug users [31, 32], substance users in suburban and rural areas [22, 31, 33–36], and the role of networks in newly emerging HIV outbreaks, both domestically [37–39] and globally [3, 40–43]. Of particular note, recent research has evolved to utilize new network concepts and to more fully account for risk environment factors that shape health.

Recent studies have advanced our understanding of how HIV spreads through vulnerable communities, like PWID and PWUD, with concepts like network "firewall" and "network viral load" that elucidate micro and macro aspects of networks. Specifically, new simulation work on the early epidemic shows how self-organizing processes within micronetwork structures may have created a firewall effect that reduced the spread of HIV [44]. In other words, key breakpoints in risk networks might emerge from naturally occurring patterns in PWID network formation that disrupt the spread of HIV from high-risk pockets to uninfected segments [45]. It is important to note, however, that external disruptions to PWID network connections through processes of marginalization or forced migration, for instance, can have the opposite effect, increasing HIV transmission and driving outbreaks by reshaping existing networks [44]. Coming from a macro perspective, Skaathun developed a new metric of the composite viral load within an uninfected individual's risk network, called network viral load, that moves beyond individual behavior to account for community-level factors driving HIV infection [46]. The advantage of moving from a metric of population or community viral load, which tends to be based on geography, to one based on an individual's network, which accounts for mobility of both individuals and their partners, is greater precision in the measurement of risk for HIV acquisition and transmission potential [45]. Both concepts provide useful tools for thinking about the complexity of networks, how network factors exogenous to the individual drive risk for HIV, and the active role network members can play in building community resilience.

Aspects of the risk environment also increase harm among substance users, and networks are key part of this [47, 48]. In particular, recent work examines how inequities related to race/ethnicity and economic position underlie who interacts with whom, what those interactions look like, and how these dynamics increase vulnerability to HIV. For instance, evidence suggests that despite having lower drug risk behaviors, individuals with racially homophilous networks that are all black are more likely to have HIV-positive network members [49]. This may be explained, in part, by racial discrimination that isolates substance users in disadvantaged neighborhoods and into higher risk relationships that are more likely to lead to HIV [50–52]. Economic conditions matter for networks as well, especially homelessness, which shapes peer and

positional attributes, network size, social influence, and norms in ways that impact drug use patterns, HIV risk behaviors, and transmission, especially for young people [36, 53, 54].

As the research introduced here demonstrates, networks are formed, changed, and dissolved in response not only to interpersonal dynamics but also to larger social systems, and this has real repercussions for health. When people are marginalized within society, networks are affected, and for people who use substances that can translate into HIV infection, overdose, or other harms. Our understanding of networks and HIV must therefore include an expanded focus on the social, economic, physical, and political context in which substance use occurs, while also taking into account viral dynamics, which will be discussed more in the next section.

Promising Approaches in Network Research with Substance-Using Populations

Although network research with PWID has a long history, there are a number of exciting areas where the field is advancing, particularly as it relates to the integration of social network analysis with other methodological approaches. Three areas in particular stand out: molecular epidemiology, research on space and place, and intervention research. Recent work in these areas shows how genetic sequencing data or information on place can illuminate HIV transmission networks (i.e., the injection and sexual pathways through which HIV spreads) and provide greater detail on the contexts in which drug use and the spread of HIV occur. Harnessing the power of networks, especially in combination with these other forms of data, represents an important tool for developing and targeting public health responses to substance use and HIV, and represent exciting areas of research to cultivate.

Molecular Epidemiology and Networks

As discussed, the structure and dynamics of substance-using networks underlie the epidemiology of HIV, but social network approaches that elicit information on network members, either through network surveys or contact tracing, face limitations due to incomplete and inaccurate data that affect inferences about transmission pathways [55]. Further, information about possible transmission routes from social network data provide information on shared risks (e.g., sharing syringes or unprotected sex), but do not necessarily provide evidence of the transmission of HIV [56]. Given that these approaches are dependent on self-report and thus subject to recall and social desirability biases [55], increasingly, molecular sequencing data has been used to infer disease transmission pathways. Molecular epidemiology merges molecular biology with epidemiological study to identify the causes, pathogenesis, and transmission of disease. Such methods can be used to estimate infectious disease spread parameters, to study spatial viral disease distribution, and to reconstruct transmission pathways on a community level [56, 57]. Although challenges with these approaches do exist [56, 57], molecular epidemiology has been an important addition to HIV research, providing more reliable evidence on transmission networks [58].

For HIV, these methods have been used to study epidemic patterns, transmission network structure and dynamics, and to develop targeted intervention efforts [59]. One of the prime examples of how molecular epidemiologic and network methods were combined occurred in response to the outbreak of HIV in Scott County, Indiana, during 2014–2016. The outbreak was concentrated among PWID and tied to economic and policy factors, including high levels of unemployment and a lack of syringe exchange programs [38]. In a phylodynamic analysis [37], transmission networks were generated using data on self-reported high-risk contacts (i.e., contact tracing) and behaviors as well as viral genetics, the integration of which showed the utility of these methods for developing a deeper understanding of HIV transmission dynamics during outbreaks. In this case, the analysis demonstrated that the majority of HIV infections (80%) occurred prior to the declaration of a public health emergency and thus could have been prevented with earlier awareness and intervention [37, 38]. In other words, had syringe exchange and other harm reduction programs been in place, the outbreak would likely have been less severe.

In other contexts, like Athens and Bucharest, public health responses to outbreaks among PWID were strengthened by enhanced molecular surveillance, which provided information on the origin, causal pathways, dispersal patterns, and transmission dynamics of HIV [42]. Similarly, in Ukraine, phylogeographic research with PWID traced the movement of HIV-1 pol sequences to identify patterns of the spread of HIV [60]. Interestingly, the authors were able to demonstrate that there was movement of the virus from war-affected regions to other parts of the country, resulting from the displacement of populations, including those with HIV [60]. In Scotland, after seeing a spike in HIV infections among PWID, researchers examined pol sequences to estimate epidemic parameters from the outbreak cluster, finding evidence of ongoing transmission, particularly among individuals with a history of homelessness [61]. At the USA-Mexico border, phylogenetic and network analysis showed cross-border clusters of HIV in San Diego and Tijuana [62]. The information garnered from these studies provided critical data that can be used to target harm reduction and HIV services to the specific people and places where need is greatest.

These examples illustrate the need for more timely information on transmission dynamics, including the integration of molecular surveillance with biobehavioral network data, which can be used to respond to HIV outbreaks and develop prevention programs. In particular, the combination of

network methodologies with techniques of molecular epidemiology reduces biases associated with only one approach and provides a powerful tool for the development of targeted interventions. For instance, phylodynamic models that account for network structure may produce more accurate estimates of transmission chains as social network data can provide information on other members of the network (e.g., both infected and non-infected individuals) and more recent risk connections [56, 59, 63]. At the same time, social network analysis that integrates molecular epidemiology can infer past events that are difficult to gather due to recall bias; network models can also be strengthened by the ability to identify factors associated with transmission clustering, such as age, gender, race/ethnicity, stage of HIV infection, and HIV-related risk behaviors [64–66]. From a public health standpoint, the use of both network and molecular epidemiologic approaches is an exciting tool for expanding our understanding of and responses to the spread of HIV, particularly among marginalized populations, like PWUD and PWID.

Space, Place, and Networks

Network research with substance-using populations has also been enhanced by the integration of geospatial and place-based research methods with social network approaches. At its core, the transmission of HIV is both a biological and a social enterprise, situated in time and space. For instance, the spaces where people live, work, and use drugs shape substance use experiences and are an integral part of the HIV-risk environment [48]. Importantly, neighborhoods and venues are essential to understanding HIV transmission dynamics because they serve as locations where networks converge. At the same time, we know that networks often transcend geographic space, which has implications for HIV transmission and public health efforts: studies show cross-border PWID networks between San Diego and Tijuana [62, 67] and suburban and urban networks near Chicago [35, 36].

Broadly, research on space, place, and injection drug use has shown that local characteristics, like geographic residence, social disorder, police tactics, and policies toward drug users create risk environments associated with HIV infection and injection risk behavior. For example, injection in street settings, in shooting galleries, or in other unsafe public places is associated with increased needle sharing, overdose, riskier sex, and exposure to violence [68–71]. Previous studies also show that neighborhood social disorder predicts overdose [72] and that local policing practices lead to rushed injections, affect where drugs are bought and used, and increase overdose and HIV infection [71, 73]. Neighborhood of residence can also affect risk of initiation into injection [74]. Assessing the local environment is thus an essential aspect of understanding risk behaviors, exposures, and the development of community resilience [50, 75], but also has relevance for network dynamics of HIV transmission.

Increasingly, researchers have combined place-based methods with network research in ways that have illustrated the geographic and sociospatial dynamics underlying drug use-related harms and HIV. For example, recent work has shown the impact of neighborhood context and movement across neighborhoods on network composition, stability, and bridging and how these shifts may increase vulnerability to HIV [35, 36, 76, 77]. Among substance-using individuals relocating from public housing complexes in Atlanta, both old and new neighborhood characteristics shaped networks: on the one hand, prior residence in violent neighborhoods predicted future illicit drug-using networks [77]. However, relocating to neighborhoods with better social and economic conditions was associated with smaller networks of substance users and more turnover out of substance-using networks. Work in Chicago with young PWID found that crossover transience between urban and suburban places was a significant risk factor for syringe sharing and multiple sex partners, but that transience was often tied to homelessness [35, 36]. Importantly, this study suggests that this movement served as a spatial bridge for HIV between higher prevalence and lower prevalence areas [35, 36]. Collectively, this research highlights the need to better understand how movement across geographic space shapes networks in ways that may increase or reduce vulnerability to substance use and HIV.

The integration of geographic information systems (GIS) with network studies of PWUD also holds promise for advancing our understanding of health. For instance, work in Winnipeg, Canada, combined these analytic methods, including data on social network contacts, residence location, and risk activity places, to explore the "sociospatial network" of high risk individuals, including PWID and individuals who trade sex [78]. The authors found substantial overlap in risk networks in space, above and beyond what was found in person-to-person contacts, indicating more cohesive networks and thus possible HIV transmission routes [78]. The important thing to note is that as people interacted with others directly and indirectly (e.g., by accessing drugs, drug equipment, disease prevention information, clean or used needles, or condoms), they did so in specific places, many of which were "hotspots" of infectious disease, that intersected with networks [78]. The combination of this information is useful for thinking about how and where to target prevention and intervention strategies.

Another approach that warrants greater attention is the examination of venue affiliation networks. Given the challenges of collecting reliable data on risk contacts and the potential for serious sampling biases [79, 80], networks can instead be identified by looking at how actors are tied to each other indirectly through their affiliation to specific places, such as venues where drugs are used [81, 82]. Most of this work has

focused on sexual networks [27, 83, 84], but among PWID, this approach was used to show clustering of HIV in Canadian hotels and informed public health responses [85]. More recently, ongoing work with female PWID in Tijuana integrates venue affiliation network data with detailed information on the social and built environment to examine how connections to multiple risk venues increase exposure to injection-related harms, HIV, and violence [86]. Preliminary findings show evidence of venue-based clustering of HIV-risk behaviors and spatial bridging [86]. These data allow us to assess social influence within venues and how places are linked through people's connections to these spaces, providing key information on where and how to target interventions [87]. Unlike traditional methods of mapping hotspots, such analyses could imply that public health efforts be concentrated in places with more linkages to other venues or those linking the core and periphery. Information on how people and places are connected can then support the diffusion of interventions through networks of venues and individuals [82].

Simultaneous spatial and social network analysis, and data on people's network connections to risk venues, can provide invaluable information on patterns of HIV transmission and risk behavior; however, research with substance users is limited, as is research in low- and middle-income contexts where targeted interventions are greatly needed. Incorporating place information into network analysis involving PWUD will enhance research on local pathogen transmission patterns and inform public health efforts to develop targeted interventions focused on the creation of safer environments. Given that research on place suggests that interventions that re-shape the spaces in which people inject (either by changing which spaces risk occurs in or by altering aspects of the spaces themselves) hold considerable promise for reducing HIV risk and other drug-related harms, this is an area that warrants further attention [47, 88, 89].

Network Interventions

As alluded to in earlier sections, network data can be incredibly important for the development and implementation of health promotion and harm reduction interventions for PWUD, though this research is limited [90]. In addition to underlying the partnerships that support implementation and the selection of who will deliver an intervention, networks also mediate intervention effects as they define the social context of how people receive a program [91]. For example, in the needs assessment phase, work should be done to determine if there is a network, to identify subgroups, and to see whether individual or group attributes underlie network ties or structure; in the design phase, networks can be used to identify change agents, recruit participants, and in the consideration of the social context; at the implementation stage, identifying centrality related to behavior change, marginal individuals, and the way that the intervention may change networks is also key [91]. Despite evidence that network-informed interventions and programs are more effective [91], a systematic review through 2015 of HIV and networks among substance-using populations found that of 58 studies, only 22% involved network interventions, highlighting a need for more work in this area [90].

Network interventions describe a range of approaches that use social network data to accelerate behavior change [90, 92]. The primary ways in which networks are used for intervention are for participant recruitment and for the selection of influential nodes as change agents in peer-driven interventions (PDI), both of which have proven effective [90, 93, 94]. In terms of recruitment, the use of PWUD peers, rather than traditional outreach methods, has been shown to be 6.3 times more powerful as a recruitment mechanism, reaching more marginalized PWID, like women, younger individuals, and people who inject a wider variety of substances [95]. Interventions have also utilized respondent-driven sampling to find, test, and/or treat PWID at risk for HIV [34, 41].

Alternatively, the networks of HIV-infected PWID have been directly targeted to prevent transmission [96, 97]. For example, Project Protect in Ukraine identified recently infected individuals and distributed community alerts within risk networks [97], and the Transmission Reduction Intervention Project (TRIP) with PWID in Greece utilized strategic network tracing to access and treat networks of newly infected PWID [96]. Work in both Ukraine and Baltimore also found that integrating a peer-led intervention into HIV prevention programs for PWID was associated with reduced HIV incidence and risk behaviors [93, 98]. Collectively, these examples highlight the efficacy and promise of network interventions for supporting harm reduction and HIV prevention among substance-using population.

To move this avenue of research forward and more fully harness the power of networks, however, we need to move beyond using influential network members to think about the many ways that network data can be leveraged to improve the health of PWUD and PWID. As Valente notes when discussing network interventions, more broadly, other approaches warrant additional attention, including segmenting networks to reduce disease transmission probabilities [99], network outreach, and network manipulation [100]. I would add to that the need to move beyond person-to-person (or group-to-group) contacts to expand our understanding of the social context in which networks exist and how network connections to places also provide information that is critical to the development and implementation of interventions. Further, there is a need for a deeper understanding of how network interventions can capitalize on the mechanisms that promote and sustain behavior change, like social norms, support, cohesion, modeling, rewards, influence, and identity [100, 101]. Finally, the bulk of current studies focus on HIV

prevention to the neglect of other outcomes on the HIV care continuum (e.g., diagnosis, care linkage, retention, ART prescribed and adherence, and viral suppression), suggesting a missed opportunity for the application of network intervention approaches more widely [90]. This suggests that future work encompassing individuals, their networks, and the broader context of substance use and HIV could open new opportunities for the development and implementation of high-impact interventions.

Conclusion

Although there is a large literature on how aspects of social networks contribute to HIV infection and risk behaviors among substance-using populations, recent research demonstrates that there is still much to be learned about how we can utilize network information to improve harm reduction and public health responses to HIV. Research that illuminates networks and HIV among understudied substance-using populations, as well as work that focuses on how risk environments shape networks and the health of PWUD, is instrumental in making sure we reach key subpopulations at increased risk for HIV infection while also addressing the structural factors that underlie inequities. A sustained focus on these issues is necessary, but future research should also pay greater attention to the networks of substance-using women, overdose networks, and PWID and PWUD networks in low- and middle-income contexts. As new drugs enter communities, like emerging synthetic opioids, stimulants, or other substances, there may also be a need for research into how networks shape and are shaped by changing drug markets and how this may impact the health of PWID and PWUD. Finally, as research on substance-using networks and HIV continues to grow, the addition of molecular epidemiologic, place-based, and intervention methods shows great promise for building better HIV surveillance and programs, but there is much work to be done.

With the introduction of new approaches, as well the use of old ones, there is also a need for a close eye to ethical issues related to research with marginalized and often criminalized communities, such as PWUD. For instance, a recent study among HIV-infected individuals, individuals at high risk of HIV infection, and HIV care and prevention workers found support for the benefits of molecular epidemiologic research, but the authors cited a need for greater attention to concerns around privacy protection and for ensuring that participants truly understand what molecular epidemiology is and the potential risks [102]. In terms of geospatial and place-based research on the networks of PWUD, ethical concerns are also incredibly important as the mapping of drug use locations could draw attention to hotspots of illegal activity, which could put individuals at greater risk of being targeted by law enforcement [103]. Network interventions also face a range of potential ethical challenges that must be considered, including the ways in which social influence is used, whether peer educators actually follow scripts, and potential unintentional consequences of interfering with existing networks [104]. To address these concerns and strengthen emerging methodological approaches, more research is needed that focuses specifically on the ethics of social network research with substance-using populations.

The research reviewed here highlights the many ways in which network research can inform our understanding of the connections between substance use and HIV. Advances in network research are critical to supporting the health and rights of substance-using populations, but as this review suggests, there are many fruitful avenues of research yet to explore. The development of new methodologies, as well as the repurposing of old approaches to contemporary issues, is necessary to push research on substance use and HIV forward by harnessing the power of networks.

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Compliance with Ethical Standards

Conflict of Interest The author declares that he has no conflict of interest.

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