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Implementing Geospatial Science and Technology to Get to Zero New HIV Infections

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Abstract

Purpose of Review Tremendous advancements have been made in HIV treatment and prevention during the last 40 years that zero new HIV cases has become an attainable goal declared by international agencies. However, new cases of HIV infection persist.

Recent Findings The emerging field of geospatial science is positioned to play key role in the reduction of continued HIV incidence through technology-driven interventions and innovative research that gives insights into at-risk populations. As these methods become more utilized, findings consistently show the important role of location and environment plays in HIV incidence and treatment adherence. This includes distance to HIV provider, locations of where HIV transmissions occurs compared to where people with HIV reside, and how geospatial technology has been leveraged to identify unique insights among varying groups of those at increased risk for HIV, among others.

Summary Given these insights, leveraging geospatial technology would play a prominent role in achieving zero new cases of HIV infections.

Keywords HIV/AIDS · Infectious diseases · Spatial analysis · Disease hotspot · Spatio-temporal analysis

Introduction

More than 40 years into the HIV infection epidemic, medical advancements in the treatment and prevention of this infection have now made it possible to significantly reduce new HIV cases through prevention as treatment and biomedical prevention efforts, (pre-exposure prophylaxis [PrEP] and Post-Exposure Prophylaxis [PEP]) [1]. Though these medical advancements have the potential to end the HIV epidemic, anticipated reductions have yet to be realized in many parts of the world, particularly in the USA [2]. Persistent new HIV infections resulting from deficits in HIV testing, linkage to medical care, continued engagement in medical care, and medication nonadherence have served to interrupt these advancements, preventing the anticipated reduction in HIV infections [3, 4]. Significant barriers to HIV treatment adherence exist at each stage of the HIV care continuum, most prominently associated with social determinants of health; mental health disorders, including substance use [5]; experienced and perceived intersectional racial, gender and sexual identity discrimination [6]; community-level stigma and social anxiety; and limited access to medical care [5, 7, 8]. Although evidence-based interventions designed to improve adherence and engagement to care and medication have been developed and implemented, many of these have had limited impact [9]. These challenges to adherence to HIV-related healthcare are difficult when managing living with inconsistent housing, experienced mental health needs, and inaccessible healthcare [10, 11]. The enactment of the Ryan White Care Act in 1990, and its current renewal, was established to address many of the challenges related to living with HIV infection by funding comprehensive services to address barriers to care exist. The program has been shown to be successful in managing HIV infection, specifically among medical case management-supported individuals, in reducing viral loads, improving CD4 counts faster and reducing missed clinic visits compared to those without

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such service [12••, 13]. Furthermore, individuals who do not know their HIV status continue to drive much of the new infection patterns in the USA [14]. Novel technologies and innovative ideas are still of necessity in order to further mitigate barriers across the HIV prevention and care continuum, with the continued goal of getting to zero cases.

Geospatial sciences are broadly considered the collection, analysis, and presentation of geographic information. These types of sciences have seen significant growth in the past decade in its utilization for public health research, particularly as advancements in technology continue to grow [15–17]. In particular, as spatial data collection and analysis has evolved, we have been able to gain far more meaningful insights into the provision of HIV prevention, care, and treatment. As satellite imagery, social media, and smartphone technology have become ubiquitous and more accessible, patterns of human mobility can be identified to expand our understanding of where and when individuals may congregate and navigate themselves throughout their communities and environments, ultimately improving our understanding of the role community plays in health behaviors, outcomes, and care. As geospatial data has begun to present a more comprehensive image of the world around us from above the earth through the ground below our communities, there is need to develop innovative and applicable methodologies to derive and interpret meaningful findings. The guiding purpose of incorporating geospatial analyses into public health and health care issues is to better provide insights into how individuals live, work, and play. This narrative review explores recent research incorporating geospatial science into the study of HIV infection with the goals of improving equity and creating opportunities to reduce new infections through better understanding and using the technology available to best reach individuals throughout our communities, and, ultimately, end the epidemic. The review is structured in a manner that outlines different geospatial technologies that have been or are yet to be applied to HIV research and practice.

Geospatial Network Analyses

Much of the geospatial research that has been conducted related to individuals at risk of and living with HIV has focused on accessibility; in particular, to medical clinics, pharmacies, HIV/STI testing sites, and prevention services (i.e., PrEP) [18–20]. These studies consistently identify that nearly 1 in 5 people with HIV live within a suboptimal distance to HIV care and treatment and thus, more likely to experience challenges in care [21]. In addition to the network, or physical distance, a number of community and social factors have also been noted as creating challenges in daily medication adherence among those living with HIV [22]. An earlier geospatial study identified that even when having access to health care and medical case management through the Ryan White Care funding, individuals with HIV that lived in more economically disadvantaged neighborhoods experience barriers and challenges in treatment adherence [23]. The prominent role that distance to clinic and home environment plays in HIV management, and more broadly other health outcomes, is often revealed through the application of spatial network analysis.

Spatial network analysis explains the relationships between nodes, (e.g. individuals, events, locations) in the context of location using deep learning theory [24]. Health research that utilizes network analysis typically highlights the important role of distance between these nodes by identifying the nearest, the fastest route, or, for temporally integrated studies, the order that nodes occur throughout environments. Specifically, these studies have been useful in determining disparities in availability and accessibility to health-related resources [25]. While critical to understanding land use, physical water, soil, and air infrastructure, as well as social and policy development, results from these studies often highlight that distance to health resource is one component of a complex interaction of home environment and healthcare, especially in urban environments where more numerous healthcare service options may exist [26, 27••]. A number of studies have determined that patients do and would travel farther distances for perceived better care or for care locations that are more culturally competent [28–30]. Thus, a better understanding beyond spatial networks is needed to better understand the support that HIV care services can provide throughout daily lives.

The reach of HIV prevention efforts and treatment locations are spatial in nature. Studies have explored the distances between home and clinic, ultimately identifying challenges of transportation for clinic visits in the USA as well as international settings. While Ryan White Care Act funds cover transportation to clinic in the USA, the distance may be challenging to overcome beyond the associated costs. Measures of "reach," taken from the RE-AIM Framework [31], the number and proportion of individuals at risk for and living with HIV infection in a given spatial area. This is difficult to assess when considering the burden of HIV infection, particularly among those at risk for HIV infections. While not more than 1% of the US population is estimated to live with the infection, the patterns of infection are spatial. Much of the HIV infections are concentrated in more urban environment, yet rural communities continue to have delays in diagnosis of HIV infections [32••]. Identifying locations may require some additionally spatially informed data sets including data from dating apps, anonymized smartphones, and assessing substance use treatment services and needs to better reach the needs of the population at risk for and living with HIV.

Lifespace Measurement

Lifespace measurement is the study of how individuals engage in the physical environment around them, from their homes and throughout the community [33]. Much of the lifespace measurement can be conceptualized as social determinants of health, which have been assessed with indices including social vulnerability and area deprivation where individuals at risk for and living with HIV reside [34]. Residential measures of poverty are included in the lifespace measurement. Lifespace measurement is more expansive than these indices, though measuring that space has been challenging, and continues to be underutilized.

The online application Google Street View presents one such opportunity to more accurately classify types of environments and has the ability to be leveraged to develop lifespace measurements. Previous studies, focused on health delivery locations such as HIV testing centers, PrEP providers, grocery stores, pharmacies, and locations that sell condoms, will often rely on Google Street View to describe the environment in which these locations exist [35, 36, 37••]. Often using tools such as Google to retrieve listings of diverse healthcare settings (including HIV testing centers, PrEP clinics, grocery stores, pharmacies, condom-selling establishments, and others) [18, 38]. These studies have established the distance and density of these types of resources around the home environment of community members and also patients. Food deserts have been defined in this manner, with additional variables such as car ownership to guide these measures [42]. In a recent study examining spatial accessibility of HIV prevention and treatment services, populations of risk were categorized as MSM (men who have sex with men), people living with HIV (PLWHA), and general population of 18–64 years of age, and their distances from their home neighborhoods to prevention and treatment services was calculated. Spatial accessibility was highest to testing sites in the Chicago area, but not the rest of the state. Furthermore, a study exploring HIV infection patterns in Brazil identified concentrated areas where individuals in concentrated geographic areas that had fewer healthcare providers and lower education attainment [43]. Similar methods were used in Burundi that found HIV infection spatial clusters in and around urban communities, rather than the rural areas [44]. These studies highlight the opportunities to leverage location data and identify where to place This study was able to identify which resources were needed where to assist the End the HIV Epidemic efforts [45].

Anonymized smartphone data have provided broader lifespace insights, with the ability to identify geomobility throughout and across communities. While anonymized, there is little that can be identified with specific note of HIV infection, without particular focused attention. Yet, one study examined how PrEP clinics can address the populations in need where unmarried same-sex households live, in particular that access was challenged during an infectious disease pandemic [41]. These types of sights provides great opportunity to examine where individuals live, the types of needs they may express by the manner in which they live, work, and play. These indicators are not like those traditionally measured by standardized, self-reported surveys; geospatial insights can provide these deeper insights. Utilizing these types of data may provide insights to patterns of mobility that are related to healthcare-seeking, sexual health, and/or substance use seeking and treatment patterns.

Mobile Technologies for E-Health Extension

In order to improve continued care of HIV, clinic-based mobile technologies have been implemented to engage patients between appointments. These technologies, often delivered through mobile applications, have been shown to reduce missed appointments and increase medication adherence [46, 47–49]. These have been tested in many environments with patients who have expressed specific barriers to continued care, and shown to improve health outcomes [48, 49]. Often, these technologies can be as simple as notifying or reminding users of appointment and medication times; practices, long validated by HIV research. These mobile tools remain especially important among those with housing instability, those with substance use disorder [50], and adolescents [48] due to higher risk of HIV infection and decreased likelihood of treatment adherence [51, 52]. This has served as an extension of both data collection to better understand the patterns of behavior and mood that drive health outcomes often among those engaged in care, as well as provision of healthcare through connections with patients and clients to feeling engaged and providing real-time intervention when needed. Use of these mobile-technology interventions have been shown to reduce drug, alcohol, and risky sex behaviors through addressing, or bringing into context, social and environmental stressors and thus reduce risk of new HIV infections [53, 54••]. It seems that the reminder, as well as social connection, have been useful for continued engagement with clinic staff, thus improving adherence to medical care [49]. Furthermore, among those in substance use treatment, these connections with clinic staff have been shown to lead to higher rates of continuous engagement in treatment services [55]. In addition, older individuals living with HIV have benefitted from these types of extension healthcare services where social isolation has served a more comprehensive opportunity to provide care and check in with patients between clinic vists [56].

HIV-related studies have relied on using medication electronic monitoring systems (MEMSCAPS) to identify patterns of delayed or missed medication by providing a date-time stamp of each time the pill bottle is opened [57]. More recently, advances in ingestible-sensors within pills have been used to more thoroughly identify medication adherence patterns [58]. Identification of common medication adherence patterns has revealed insights into the influence of spatial, social, and temporal factors on HIV outcomes and how they differ among populations. These efforts help monitor the medication adherence patterns, coupled with mobile extension health care, can provide greater insight into addressing barriers and needs in the management of HIV infection.

Beyond clinic-based, app-collected and delivered data collection and intervention, research leveraging geospatial data, or more lifespace examinations, have occurred most often among populations of men who have sex with men (MS), or cis-gender men who identify as homosexual. These studies have incorporated the use of location devices to better identify where, when, and how MSM are interacting within their communities, travel, and how they interact with health resources [54, 59]. One recent study explored the lifespace of individuals who are HIV negative and identify as MSM and corroborated previous findings showing individuals that were more mobile were at higher risk for HIV infection [60, 61]. While these studies asked participants to carry GPS units for 2 weeks or retrospectively asked where individuals were traveling to meet sex partners, these insights provide opportunities to establish the acceptability of smartphone technology to track location, and even more promising opportunities to provide real-time HIV interventions in natural environments [62]. Leveraging app-based data collection and geofenced real-time intervention may provide support individuals with HIV need in their natural environments.The opportunities to explore how lifespace and in particular, the overlapping use of geosocial network apps, may provide insights to interventional needs for HIV and other sexually transmitted infections [63].

Social Media and Mobile Dating Apps

Location has long played a prominent role in gay culture and the culture of sexual risk behavior. This includes the establishment of gay neighborhoods and communities, gay bars and clubs, and bathhouses and theaters or sexual "hook-up" locations [64–66]. Often, these locations serve as engagement points and points of HIV intervention. As further subcultural division occurs among the broader gay community, spatial science is poised to play an important role in better understanding these groups and associated HIV risks.

Much of the spatial tools leveraged more recently have focused heavily on mobile dating apps. Research into these applications, whose use is centered on distance and location of potential sex partners, have informed understanding on how HIV and STIs are transmitted in diverse locations, outside of urban environments as previously understood in the USA, identifying how individuals are becoming more mobile using these tools to meet sex partners [67, 68]. Previous studies have identified that the use of geosocial dating network apps as risk behaviors for STI [69, 70], yet few have fully explored how the apps may be used to promote health in the USA. For instance, individuals who had reported using MSM-specific geosocial networking apps were more likely to have had HIV tests. The advertising opportunities and communication strategies that have been more common among MSM-specific dating apps may likely to better be promoted as tools for sexual health. Given their focus on location, geosocial networking apps are well-positioned to be used for partner sexually transmitted infection (STI) and HIV notification or used for alerts during possible outbreaks.

Furthermore, social media provides an opportunity for a geolocated assessment of location-specific attitudes, beliefs, norms, and behaviors. Using social media to provide insights on where and what types of sexual health interventions may need to be implemented based on the discussions shared online, including different considerations of drug use, sex partner seeking, condom use, and other behavior that place individuals at HIV risk. Previous studies have explored the feasibility of sexual health promotion, as large populations are using these tools to communicate [71]. Yet, these communication strategies are likely to be difficult due to the fast-changing preferences of users in combination with differing risk and message uptake dependent on the application and policy. The spatial aspects of social media and dating applications, while useful, are not without limitations. Much of the research focused on social media and applications has focused on specific subpopulations that experience HIV treatment barriers and challenges that are very specific to locations, and thus, less generalizable. Still, the implementation of these types of apps and other health extension interventions are shown to improve HIV care engagement and reduce lost-to-follow-up [13, 72, 73]. These types of technology-based and location-enabled interventions should be implemented as standard of care practices. The opportunity to support health behaviors outside of patient encounters in clinic settings is urgent. This type of research and practice needs to complement the existing network analyses that have explained levels of clinic accessibility with patient populations. Yet, these social media-based conversations can be geolocated and utilized to identify focused HIV/STI testing, prevention efforts, and even build opportunities to grow better models of informing emerging infectious diseases, such as the emerging monkeypox infections [73]. Further

exploration, using implementation science strategies, is needed to better understand how clinicians and practitioners might leverage app-based connectivity and anonymized smartphone location data that make up lifespace as a predictor of health outcomes [72].

Satellite Imagery Identification and Analysis

Imagery has provided great opportunities for analysis and understanding community patterns and lifespace. Webcams have been used to better describe neighborhoods and human interaction. These types of data and analyses began with human raters determining points of interest, whether the measure is human interaction in physical spaces that focus on walking or biking policies within cities [74] or identification of drug use and selling patterns [75]. Limited research has been done related to the use of webcams and its opportunity to measure lifespace, thus serves as an opportunity as the webcam data are able to be leveraged with machine learning/artificial intelligence algorithms to identify patterns of community behavior, rather than human coding [76]. The patterns of community engagement among individuals, particularly those with HIV infection or at risk for infection, could have great implications for development of behavioral and social interventions to address adherence to medication and care, social isolation, and managing other co-morbidities. The importance of these factors are compounded by the need to engage community members, as scientists work to further investigate social determinants tangentially associated with geospatial data and insights in order to understand the community patterns. Community-based insights driven by the cultural knowledge and lived experiences of its members, in tandem with evidence-based research, have great potential to inform the development of effective interventions that reduce new HIV infections.

Another area of geospatial research is the development and application of satellite imagery to answer questions of existence and types of resources present or patterns of mobility. In explorations of health-related applications of imagery, there have been studies focused on identifying numbers of cars in parking lots [77], air pollution plumes [78], or reductions in water concentration, and how they may relate to health outcomes of a population. Specific HIV-related research has been limited in this scope thus far. Initial studies have outlined a conceptual framework exploring how climate change will influence HIV rates throughout the world [79]. Changes in climate will need a multi-pronged examination of the multiple factors that they influence to impact HIV risk and disease management. While not specific to populations with HIV, urban areas have been identified as heat islands [80, 81], where there is increased likelihood of death related to heat and the role of an immunological infection in combination of other common co-morbidities are likely [82]. Thus, this is a burgeoning field and needed area of exploration and future intervention to address the needs of populations with and at risk of HIV infection. Initial studies of the relationship of climate change and HIV infections have identified that limited food and water security impacts livelihoods, particularly careers of farming and fishing that may disappear as climates become hotter and drier. Furthermore, exchanging sex for these basic needs seem to be occurring more commonly in these resource-challenged regions of the world [83••, 84].

In particular, the future of spatial technology's integration into HIV research is likely to involve the more effective and efficient delivery of medications using unmanned aerial vehicles (drones). Preliminary studies have shown positive feasibility utilizing flying delivery services to delivery important medications throughout multiple countries around the world [85, 86]. While it is currently unclear how social and privacy considerations will need to be addressed in delivering HIV medications, the practice is likely to be adopted sooner rather than later.

Conclusion

The purpose of this narrative review was to identify the current state of geospatial science and application in the field of HIV research. This summary identifies that as the geospatial core sciences evolve, the application of these tools have yet to be fully actualized in research and practice. In many research studies, geospatial technology has been used to leverage app-based data collection and interventions, though this has yet to be implemented as a standard of care in most clinic and community settings throughout the USA. Furthermore, our understanding and practices in the field of HIV are traditionally community-led, thus inherently, geospatial in its lens. As a field, HIV researchers and practitioners work better when we understand our communities more deeply; geospatial science helps the field know more, and use that knowledge to complement the community engaged work that is done, including listening to the challenges and assets that exist in communities in which we serve. It is those lessons that should guide how our policies and practices deliver prevention and treatment efforts. Geospatial analyses are able to better inform how enacted policies may impact community members in spatially differential ways. Geospatial data and community members need to be involved to incorporate how to overcome inequitable policies that likely hit communities in which people at risk for or those living with HIV are living within. Centering this effort of using nontraditional data sourced needs to be community-engaged, as the use of geospatial data and analysis may be especially sensitive to potentially violate privacy of the identity of individuals who are either living with HIV or engaging in behaviors

that place them at risk. While these data are not necessary identified as HIPAA-protected, (Health Insurance Portability and Accountability Act of 1996), they may elucidate health-related data about an individual. The ethical use of these data are imperative, the development of regulations to manage this risk are still slow to develop and implement. HIV infection has been inequitable from the start of the epidemic and disparities continue to persist. Inequitable environments exist in each of the stages of the continuum of care: those who become infected, those who are able to access care, and those who are able to adhere to care. Using and leveraging the opportunities that location-enriched data can provide should be prioritized in the implementation of our best science.

Geographic determinants influence how individuals are able to engage in health-promoting behaviors, are exposed to different and dangerous pollutants, and accessibility to needed resources [87, 88]. Furthermore, as physical and social environments differ across communities, individuals encounter drastic variations in health promoting and compromising influences throughout their daily lives. As such, there has been a significant shift to incorporate these location-fixed determinants of health in research and practice. There is also a need to understand that "geospatial" is a broad term, and space can be defined as residences, routes of mobility, community, built environment, policy environment, service area, and many other variations.

The current practices in the USA most often utilize HIV prevention efforts delivered by local departments of public health and contracted external organizations. There is a great opportunity for researchers to more actively collaborate with practitioners to better deliver prevention and care efforts throughout our communities, and to use the best location-informed data to complement community-based efforts. The practice of HIV care and prevention is well-established throughout the USA through clinic and departments of public health with the support of federal agencies including HRSA and CDC. Thus, incorporating geospatial data to better inform needed prevention and care services needs to be purposeful. With the development and application of geospatial sciences, the growth in these insights will continue to grow. The field of HIV care and prevention continues to experience gaps in understanding the ways in which community members live, work, and play to expand our ability to identify where and when and how environmental factors impact our behaviors and outcomes as we move through our communities within and across days and seasons of life.

Declarations

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Conflict of Interest The authors declare no competing interests.

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Papers of particular interest, published recently, have been highlighted as:
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