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Geographic area-based rate as a novel indicator to enhance research and precision intervention for more effective HIV/AIDS control

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ABSTRACT

Ending the HIV epidemic needs additional methods to better assess the incidence and prevalence of HIV infection. In this study, a new indicator — G-rate was developed for the evaluation of HIV epidemics across regions with regard to geographic area size. Different from the commonly used incidence and prevalence rates that assess the HIV epidemic with reference to population (termed as P rate in this study), G rate measures the number of new infections (incidence) or cases (prevalence) over a unit land area in one year. We demonstrated the utility of G rates using officially reported data on new HIV infections and persons living with HIV in the United States during 2000–2012. Findings of our analysis indicate that relative to P rates, G rates indicated a quicker increase in the HIV epidemic in the United States during the study period. In 2012, 4.6 persons were newly infected and 101.4 persons lived with HIV per 1000 km^2 land area. The five states with both highest P prevalence rates and highest G prevalence rates were Florida, Maryland, New York, New Jersey and Washington DC, which included New Jersey ranked 8th by P rate and excluded Massachusetts ranked 5th by G rate. In conclusion, adding G rates extends the conventional measurement system that consists of case count and P rate. Combining G rates with P rates provides a new approach for information extraction to support precision intervention strategy toward the goal of creating an AIDS-Free Generation.

1. Introduction

We have been living under the threat of the acquired immunodeficiency syndrome (AIDS) for more than three decades (UNAIDS) since the first reported AIDS case among homosexual men in 1981 in the United States (Gottlieb et al., 1981). AIDS is an infectious disease caused by the human immunodeficiency virus (HIV) (Alistar and Brandeau, 2012), and transmitted through sex, blood transfusion, and mother-child during pregnancy, child birth and breastfeeding. To end the HIV epidemic, the U.S. President's Emergency for AIDS Relief (PEPFAR), an initiative of the U.S. Government, has established a blueprint to create an AIDS-Free Generation (U.S. Department of State, 2012). In 2015, the United Nation adopted the strategy proposed by Jointed United Nations Programme on HIV/AIDS to end the AIDS epidemic by 2030 (UNAIDS, 2015). To achieve these great and ambitious goals, more comprehensive methods are needed to gauge the HIV/AIDS epidemic. Such methods should be able to add new information to better inform evidence-based decision making and to optimize resource allocation for best outcomes. Traditional epidemiologic measures provide data on total number of infections, incidence, prevalence, as well as time trends of these measures; however, no data are available about the epidemic with regard to geographic area size.

To control the HIV epidemic, it is important to know *the total number* of persons who have already been infected with HIV and who are newly infected. It provides basic data for public health decision-makers to estimate the amount of money and resources needed to successfully fight the epidemic. For example, data from World Health Organization (WHO) indicate that globally approximately 37 million persons live with HIV (PLWH), of whom 1.2 million are in the United States. If $1000 per PLWH per year is needed for HIV/AIDS control, a total of $37 billion must be budgeted worldwide and $1.2 billion for the United States alone. However, as an indicator of HIV epidemic, the total count of PLWH or new infections is inadequate. Although a larger number indicates a higher risk of HIV infection, the total count is affected by population size that varies dramatically across countries and regions. Given the same level of an epidemic, a country with a larger population will have a greater count of PLWH and new infections such as the United States than a country with a smaller population, such as Australia, Spain and Netherlands.

Prevalence and incidence are the two most commonly used measures in epidemiology. Prevalence measures the number of existing infections among a unit of at-risk population (e.g., 1000 or 100,000) in one year and incidence measures the number of new infections in the same period. Relative to total count, a population-based rate (termed as P rate

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thereafter), including *P prevalence* and *P incidence* provides new information regarding the HIV/AIDS epidemic. For example, data from the Centers for Disease Control and Prevention (CDC) indicated that 1.218 million PLWH in the United States in 2014, a very large number; but the P prevalence rate was only 18.5/100,000 (CDC, 2016); while data from UNAIDS indicated an estimate of 0.039 million in Botswana in 2014, a much smaller number; but the prevalence rate was as high as 25,200/100,000. In addition to describing levels of the HIV/AIDS epidemic, information from P rates can be used by decision-makers to prioritizing countries/places for intervention in order to achieve a predetermined goal.

Inclusion of P rates strengthens the total count of persons living with HIV to inform decision-making and strategic planning for HIV control by factoring in population size; however, the size of geographic area where the population resides is ignored. Geographic area size plays a crucial role in the HIV epidemic. Given the same P rate, the likelihood is much greater for HIV to spread from one to another in a population residing in a crowed urban area than the same number of population residing in a large rural area (Sattenspiel, 2009). Simply mapping a P rate by geographic areas does not provide complete information about geographic differences of the HIV/AIDS epidemic, underscoring the need for new measures.

In this study, we reported our work attempting a new indicator by factoring in geographic area sizes. We demonstrated the new indicator using reported data on number of new infections as well as PLWH by states in the United States. Our purpose is to expand the current total count and P rate system in epidemiology by adding a geographic area-based measure.

2. Methods

2.1. Geographic area-based rate

We defined the geographic area-based rate (G rate) as the number of persons N with an event (e.g. newly infected or living with HIV) in one year within a jurisdiction (e.g. a district, a state, or a nation) over the total geographic area A of the jurisdiction:

$$\text{G rate} = N/A \tag{1}$$

This defined G rate was used to assess incidence and prevalence of HIV in the United States, overall and by the 50 states and the District of Columbia (DC). For each state, G incidence rate was computed as the number of newly infected HIV cases in a state during one year over the total area size A of the state:

$$\text{G incidence rate} = \textit{Number of new cases detected in one year}/A\left(1000\ \text{km}^2\right) \tag{2}$$

As Eq. (2) indicates, G incidence rate measures the number of new infections in a unit time over a unit geographic area, a higher G rate indicates more new infections in a jurisdiction. For convenience of reporting, two geographic units were used, 100 km^2 and 1000 km^2.

Likewise, the G prevalence rate of HIV was estimated as the number of PLWH in a state in one year over the total area size A of the state:

$$\text{G prevalence rate} = \textit{Number of infected persons in one year}/A\left(1000\ \text{km}^2\right) \tag{3}$$

As Eq. (3) indicates, a higher G prevalence rate means more PLWH in a unit time and area of a jurisdiction.

It is worth noting that the G rate we defined in this study is conceptually a measurement of geographic density of a disease. However, we elected not using the term *density rate* to avoid term duplication. The term incidence density was introduced in the 1980s by other researchers to measure the number of new disease cases for a population over a unit of time (but not area size) (Beaumont et al., 1985; Mutgi et al., 1988). This measure has been frequently used in sampling and epidemiological research (Greenland, 2013; Liu et al., 2015) although it has little to do with geographic density.

2.2. Population-based rates and other measures

To illustrate the significance of G rates, additional indicators included were: count of persons living with HIV and newly infected, overall and by states, and two population-based P rates that are commonly used in epidemiology:

$$\text{P incidence rate} = \textit{Newly infected cases in a year}/\textit{Population at risk}(100,000) \tag{4}$$

$$\text{P prevalence rate} = \textit{All infected persons in a year}/\textit{Population at risk}(100,000) \tag{5}$$

In addition to total count, P rate and G rate, we also examined another indicator by dividing G rate with population size and termed it as D rate. D rates measure the number of infected persons per unit population per geographic area. It can be considered as indicator not affected by population density. To focus on G rate in this study, we elected not to show the details about D Rate. Interested readers can investigate D rate by following our discussion on G rate in this study.

2.3. Sources of data

Data regarding the number of new HIV infections and number of PLWH (aged 13 and above) in the United States were derived from CDC's reports (CDC, 2008, 2016; U.S. Department of State, 2012; UNAIDS, 2015), overall from 2000 to 2012 and by single states for 2012. Data for annual population from 2000 to 2012 (aged 13 and above) and land area size (km^2), overall and by states were derived from the US Census Bureau (2012). These data were directly downloaded from the websites and organized using the excel file for further analysis.

2.4. Statistical analysis

Data analysis was conducted in four steps. We first computed the G incidence rate and G prevalence rate using Eqs. (2) and (3) and P incidence and P prevalence using Eqs. (4) and (5). We then plotted the estimated incidence and prevalence of G rates and P rates respectively by year across the 2000–12 to compare the temporal trends. Followed the plotting step, we ranked and compared the 2012 G prevalence rates with P rates of individual states to illustrate the role of the new indicators in extracting additional information regarding the disease epidemiology. Lastly, we cross-plotted the ranks of G prevalence rates with those of P rates to illustrate the significance in combining the two indicators to better and more precisely informing public health planning and decision-making. Statistical analyses were conducted using the commercial software of MS Excel (Version 2010, Microsoft, Seattle, WA) and SAS version 9.4 (SAS Institute, Inc. Carry, NC).

3. Results

3.1. Time trends in the HIV epidemic

Fig. 1 depicts the time trends in the HIV epidemic in the United States during 2000–12 using both G rate and P rate. Results from panel A of Fig. 1 indicate that according to G rates, in 2000 there were 30.9 PLWH per 100 km^2 in the United States; and this number increased to 101.4 in 2012. Although both P rates and G rates captured the ups and downs of the HIV epidemic over time, G rates showed a quicker increase