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Computational Model to Determine the Efficacy of Needle Exchange Programs During an HIV Outbreak

Introduction:

In January of 2015, the Indiana Department of Public Health began an investigation of a HIV epidemic due to injection drug use in southeastern Indiana(1). By May 2nd of that year, there were 191 confirmed cases of HIV in Scott County, Indiana(2).

Circumstances created an environment that made Scott County ripe for an HIV epidemic, including high rates of poverty and the closing of the only local HIV testing center. However, the duration of the epidemic may have been shortened had measures to prevent viral spread been taken sooner. The Indiana governor at the time, Mike Pence, did not institute a needle exchange program (NEP) until March 26, 2015, after 79 cases of HIV had been confirmed(2). NEPs, where used needles can be discarded in return for clean needles and other drug paraphernalia, have been shown to be one of the most effective ways of preventing the spread of HIV through injection drug use(3).

On May 2nd, 2015, there were 191 confirmed cases of HIV in Scott County, Indiana. To determine if earlier initiation of a NEP would have resulted in fewer infected individuals by May 2nd, 2015, computational model of the epidemic was generated. This model estimates the number of individuals infected with HIV over time, with and without a NEP in place. Through use of this model, it was determined that an earlier introduction of a NEP during the 2015 HIV in Scott County would have resulted in fewer infected individuals on May 2nd, 2015.

Related work:

Modeling the transmission of HIV is difficult, in part due to the challenge of obtaining reliable data. For example, data obtained from surveys asking addicts the number of times per day they inject drugs is subject to certain biases(4). In addition, there are numerous factors that are involved in the transmission of disease, making the generation of a reliable model difficult, if not impossible(5).

Much of this work is reliant on a 1989 study by Kaplan(6). Here, Kaplan used a variety of assumptions to determine the rate of exposure to HIV due to sharing infected needles:

1. Drug injection is done in shooting galleries. There are m shooting galleries/"kits". During a visit to a shooting gallery, injection occurs once.
2. Addicts visit shooting galleries at rate λ. This action is independent from that of other addicts.
3. Equipment is infectious if used by an infected addict. If used by an uninfected addict, the equipment is "flushed" at rate θ
4. If an addict is exposed, infection will occur at rate α
5. The addict population remains the same, n
6. Fraction of infected addicts is represented by $\pi(t)$ and variability within this fraction can be ignored

These assumptions led to the generation of the following equation for $\beta(t)$, the rate of exposure to HIV:

$$\frac{d\beta(t)}{dt} = \lambda\gamma\pi(t) - \lambda\gamma\beta(t)[1 - [1 - \pi(t)](1 - \theta)]$$

where γ represents the gallery ratio, $^{n}/_{m}$.

Methods:

To determine if earlier implementation of a NEP in Scott County, Indiana could have reduced the number of HIV infected individuals during the first four months of the epidemic, a disease model was built. This model determines the number of new infections at each iteration using the following equation:

$$Number\ of\ new\ infections = \frac{d\beta(t)}{dt} \times \alpha n$$

where $\frac{d\beta(t)}{dt}$ denotes the rate of exposure as generated by Kaplan, α denotes the rate at which exposure leads to a new infection, and n denotes the addict population which shares needles (ASN).

To build the model, some values within $\beta(t)$ were based on the choices of Kaplan, or other references. The values for θ and λ were assigned as the values that Kaplan used in his study, 0.25 and 1, respectively. Scott County, Indiana has a total population of approximately 24,000 people (https://en.wikipedia.org/wiki/Scott_County,_Indiana). The number of ASN on January 11th, was assigned arbitrarily as 10% of the total population. There were 11 confirmed cases on January 11th, therefore, $\pi(0) = 0.0045$. Additionally, the rate at which exposure leads to infection α was determined by another study to be 0.0063(7).

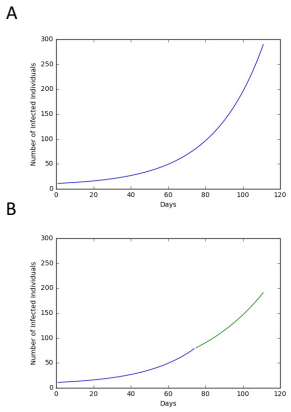

Fig. 1 The use of a NEP was effective in reducing the number of infected individuals during the 2015 epidemic. Blue indicated no NEP in use. Green indicates NEP in use (A) No NEP (B) NEP introduced on March 26th

Remaining values ($\beta(t)$, *m, n2)* were determined through model refinement to achieve a model which fit the actual events of the 2015 epidemic. Dates that were used to refine model function are March 26th (79 infected, the day the NEP started), and May 2nd (191infected). Through this method, $\beta(t)$ equals 0.01, *m* equals 400, and *n2* equals 1610. The resulting model directly mirrors infected individuals on March 26th and May 2nd during the epidemic (79 and 191 respectively). It should be noted, however, there are other possible values that would produce these results.

To model a NEP, the number of ASN was decreased on the date of institution. It stands to reason that if new needles are made available through a NEP, some ASN will leave the system, opting to make use of the NEP. If these individuals are no longer sharing needles, they are no longer at risk for developing HIV.

Results:

To determine whether institution of a NEP on March 26th was successful in reducing the number of infected cases by May 2nd during the Scott County epidemic, the number of infected individuals was determined for the instance in which a NEP was not instated at any point within the study. While there were 191 confirmed cases of HIV on May 2nd during the 2015 epidemic, the model estimates 290 infected individuals would have been infected had a NEP not been introduced. Therefore, the March 26th introduction of a NEP successfully prevented new HIV infections during the 2015 epidemic (Fig 1).

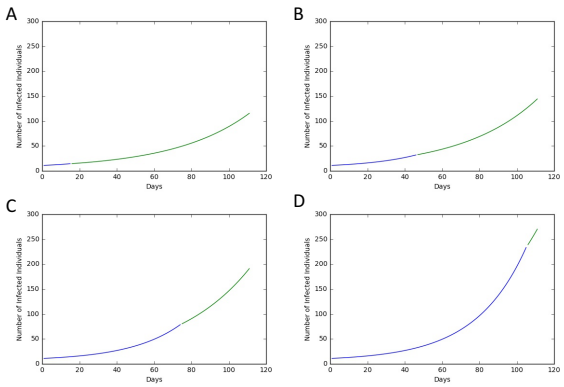

Fig. 2 Earlier implementation of a NEP results in fewer infected individuals. Blue indicated no NEP in use. Green indicates NEP in use. (A) NEP introduced on January 26th (B) NEP introduced on February 26th (C) NEP introduced on March 26th (D) NEP introduced on April 26th

To examine the effects of a prompter institution of a NEP on the number of infected individuals on May 2nd, the institution the NEP was modeled on the 26th day of January, February, and April. These models found that the total number of infected individuals was 116, 144, and 270, respectively (Fig. 2). These findings again show that the NEP was effective in preventing transmission of HIV, and comparison between all models shows that the earlier the NEP begins, the less infected cases on May 2nd (Fig. 3).

Discussion:

In this study, I show that an earlier institution of the NEP program during the 2015 Scott County HIV epidemic would have resulted in fewer infected individuals. In this instance, the political beliefs of Governor Mike Pence increased the severity of the epidemic, bringing both physical harm and monetary expense to the citizens of Indiana. Based on the presented data, the NEP should have been instituted as early as possible. While NEPs should not be the only preventative measure installed to help reduce the spread of infection, its effectiveness should not be overlooked.

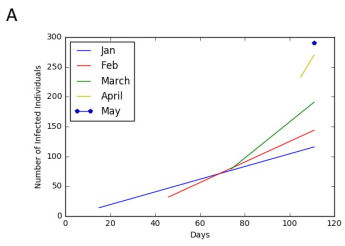

Fig. 3 Total number of infected individuals decreases with earlier NEP introduction. (A) Number of infected individuals shown at the date of NEP introduction and on May 2nd for the indicated months

Predictions generated by models are only as accurate as the model's assumptions, and while I believe that the trends produced by this model are accurate, there are some changes that could be made to $\frac{d\beta(t)}{dt}$ so that the model would more accurately represent ASN in Scotts County. Firstly, this model assumes that all addicts behave identically. There is sure to be variation in the rates at which ASN inject drugs. Greenhalgh and Hay made this modification to Kaplan's model in their 1997 paper, rationalizing that individuals who know they are HIV positive will visit shooting galleries at a lower rate than individuals who either don't know their HIV status or are uninfected(8). In addition, my model does not include Kaplan's modification to account for the effects of cleansing used needles with bleach(6). These changes may alter the rates of infections, but I do not think that these changes would affect the trends of this study.

Conclusions and Future Work:

This study was successful in providing evidence that Mike Pence's hesitance to institute the NEP during the 2015 Scott County, Indiana epidemic resulted in a greater number of citizens infected with HIV during the epidemic. It also showed that early NEP implementation would result in the lowest number of infected individuals during the epidemic. Future work would be to refine the model to increase its accuracy by including parameters to more accurately model ASN behavior, and include additional measures of transmission prevention, such as increased testing availability.

References:

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