Optimal Placement of Syringe-Exchange Programs

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ABSTRACT *Syringe-exchange programs (SEPs) will likely play a major role in slowing the spread of acquired immunodeficiency syndrome (AIDS) among injecting drug users (IDUs), but the success of any single SEP will depend to a large extent on where it is located. We show how the optimal position for a new SEP can be chosen given accurate knowledge of where IDUs live and how far they are willing to travel to an SEP. This information is not normally available, and one of our major points is that SEPs will necessarily be placed in suboptimal locations and will serve fewer IDUs than they otherwise might until it becomes available. Our method for choosing the best SEP placement is illustrated with Manhattan as an idealized example.*

KEYWORDS *Acquired immunodeficiency syndrome (AIDS), Geographic information systems, Health planning, Health policy, HIV, Intravenous drug user, Syringe-exchange programs.*

INTRODUCTION

Intravenous drug use fuels the acquired immunodeficiency syndrome (AIDS) epidemic. Although New York City's estimated 200,000 intravenous drug users (IDUs) comprise only 2% of its population, between 1994 and 1997 they accounted for more than 50% of its AIDS cases.¹⁻³ In the United States as a whole, more than one third of the reported new AIDS cases in 1999 were IDU associated.⁴ A similarly large fraction of AIDS cases is associated with intravenous drug use in many urban areas throughout the developed world.⁵ Successful strategies for containing the epidemic will have to target the population of IDUs.

Numerous studies have shown that syringe-exchange programs (SEPs) help reduce the spread of HIV among IDUs.⁶⁻⁸ Des Jarlais et al.⁷ found that IDUs who use SEPs are three times less likely to become infected with HIV than those who do not. Because SEPs provide one of the few effective ways of slowing HIV transmission among IDUs, they are rapidly being established throughout the United States. Between 1996 and 2002, there was an increase from 113 to 211 in the number of SEPs in the United States and Puerto Rico.⁹

Despite the rapid growth in number of SEPs, however, only a small fraction of IDUs currently have access to an SEP. Finkelstein and Vogel¹⁰ estimated, for example, that less than 2% of the IDU population in New York was served by SEPs in 1998. It is likely that many more SEPs will be established in the effort to contain the spread of AIDS among IDUs.

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The success of future SEPs in combating AIDS will depend to a large extent on where they are placed. Rockwell et al.¹¹ showed that IDUs were significantly more likely to use an SEP if it was located within a 10-minute walk. Proximity to an SEP was the dominant factor in determining usage rates in their study. Race, age, gender, education level, or frequency of drug use were not important in determining whether an IDU would make use of an SEP.

This article presents a general framework that health planners can use in determining where to place new SEPs to maximize their benefit. We describe the framework and apply it to Manhattan as an example. The result is a map of the likely number of IDUs who would be helped depending on the geographic placement of the syringe exchange in Manhattan. We discuss the limitations of our estimate. The limitations are because of our poor knowledge of where IDUs reside and how IDUs will respond to a new SEP placed near them. We describe the sort of data collection that would remove these limitations and allow policymakers to place new SEPs in a way that maximizes their effectiveness in fighting AIDS.

METHODS

Let $n(x,y)dx dy$ be equal to the number of IDUs who live in a small region centered at position (x,y) , and let $P(x,y,x',y')$ be the probability that an IDU who lives at (x,y) does not currently visit any SEP, but would start visiting a new SEP if it were placed at (x',y') . Then, the expected number of IDUs who would begin using an SEP if a new SEP was placed at (x',y') is

$$g(x',y') = \int_{\text{Manhattan}} dx dy n(x,y) P(x,y,x',y') \quad (1)$$

The ideal position (x',y') for a new SEP is the one that maximizes $g(x',y')$. Equation 1 shows that we will be able to determine the ideal placement only if we have accurate knowledge of where IDUs live and how far they are willing to travel to an SEP. One of the major points of our article is that this important knowledge is not available. SEPs will necessarily be placed in suboptimal locations and will consequently prevent fewer AIDS cases than they otherwise might until further research determines where IDUs live and how far they are willing to walk. The point will be easier to appreciate if we continue with the analysis by adopting plausible (but almost certainly incorrect) models for $n(x,y)$ and $P(x,y,x',y')$.

To estimate the IDU number density $n(x,y)$, we began with the 1999 New York City Department of Health's report of the number of AIDS cases among IDUs in each of the 10 United Hospital Fund (UHF) neighborhoods in Manhattan.¹² If the observed 20% prevalence of AIDS among methadone treatment patients¹³ is similar to the prevalence among all IDUs, then the total number of IDUs in each UHF neighborhood will be roughly five times higher than the reported number of IDUs with AIDS. To estimate $n(x,y)$, we assumed first that the total number of IDUs in each UHF neighborhood was equal to five times the number of IDUs with AIDS, and second that IDUs were uniformly distributed within each neighborhood:

$$n(x,y) = \frac{N(x,y)}{fA(x,y)} \quad (2)$$

where $N(x,y)$ is the total number of IDUs with AIDS in the UHF neighborhood that contains point (x,y) , f is the estimated fraction (0.2) of IDUs who have AIDS, and $A(x,y)$ is the area of the UHF neighborhood that contains point (x,y) . Our assumption that the spatial density of IDUs is constant within each UHF neighborhood is likely to be poor, but UHF neighborhoods were the smallest geographic unit for which data were available,¹⁴ and without better data collection and reporting, this assumption cannot easily be improved.

Our model for $P(x,y,x',y')$ is founded on the observation of Rockwell et al. that proximity plays a dominant role in determining whether an IDU will use an SEP.¹¹ We assumed that $P(x,y,x',y')$ would depend only on the distance between (x,y) and (x',y') . Presumably, $P(x,y,x',y')$ should be a smoothly declining function of the distance between x,y and x',y' , with IDUs very likely to use an SEP if it is next door, but less and less likely to use the SEP as it is moved farther away. Unfortunately, there has been (to our knowledge) no study sufficient to determine the functional form of $P(x,y,x',y')$. Given only the report of Rockwell et al.¹¹ that 81% of New York City IDUs will use an SEP if it lies within a 10-minute walk and 59% will use an SEP otherwise, we adopted the following model:

$$P(x,y,x',y') = \begin{cases} 0.22, & \text{if } x,y \text{ is within 1500 feet of } x',y' \text{ and not within 1500 feet of an existing SEP} \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

Here, 1,500 feet is our approximation of a 10-minute walk and $0.22 = 0.81 - 0.59$ is the fraction of IDUs whose behavior would be modified by the addition of a new SEP in their vicinity. We are assuming that IDUs who do not use an existing SEP within 1,500 feet would also not use a new SEP within 1,500 feet. The assumptions behind our model are crude, but the available data do not seem to justify anything more sophisticated.

Locations of existing SEPs were taken from the work of Finkelstein and Vogel.¹⁰ We geocoded the published street addresses of existing SEPs onto existing TIGER/Line streets data from the 2000 US Census.¹⁵ One mobile clinic, a group of roving teams from the Lower East Side Harm Reduction Center, which operated on the Lower East Side, was excluded because of its large geographic area of operation; other mobile units restricted their operations to areas that were small compared to 1,500 feet and were treated as fixed SEPs located at the center of their range of travel.

The analysis was straightforward after the models for $n(x,y)$ and $P(x,y,x',y')$ had been adopted. We obtained a map of Manhattan and its ZIP codes (because UHF neighborhoods are groups of ZIP codes) from the Environmental Systems Research Institute CD-ROM of domestic data,¹⁶ updated in 2002. This map divided Manhattan into a large number ($> 20,000$) of rectangular cells, each 135 feet by 175 feet. We continued to use these cells in the subsequent analysis. A number of IDUs $n(x,y)\Delta x\Delta y$ were associated with each cell based on the model for $n(x,y)$ shown in Equation 2, according to which $n(x,y)\Delta x\Delta y$ for each cell in (say) Central Harlem is equal to the estimated total number of IDUs in Central Harlem divided by the number of cells in Central Harlem.

We then used Equation 3 to estimate the number of IDUs in each cell who would modify their behavior if a new SEP was placed sufficiently close to them. We calculated the number of these "receptive" IDUs per cell by multiplying the cell's total number of IDUs $n(x,y)\Delta x\Delta y$ by 0.22 if no existing SEP lay within 1,500 feet and by 0 otherwise.

Finally, the total number of IDUs who would be helped by the placement of a new SEP in a given cell was calculated by summing the number of receptive IDUs in every cell with a center within 1,500 feet of the center of the potential SEP's cell. This gave us an estimate of the benefit of placing a new SEP at that single location in Manhattan. By repeating this process numerous times, with the potential SEP placed in a different cell each time, we made a map of the estimated benefit of placing a new SEP at any point in Manhattan. Figs. 1 and 2 illustrate the procedure.

The accuracy of the calculation will improve as the cell size is made smaller and smaller because then the set of cells with centers that lie within 1,500 feet of a given SEP will have a perimeter that is more nearly circular. There is little need, however,

FIGURE 1. (a) The estimated number of IDUs per cell $n(x,y)\Delta x\Delta y$ calculated by dividing each neighborhood's estimated total number of IDUs by the number of cells it contains (Equation 2). (b) The approximation of Equation 3 implies that 22% of IDUs would begin using SEPs if a new one was placed within 1,500 feet unless they already live within 1,500 feet of an existing SEP. In that case, we assume that the addition of a new SEP would not alter their behavior, and so the benefit to them of a new SEP is 0. Panel b shows the result of multiplying panel a by a function that is either 0.22 or 0 according to this prescription. The map in this panel shows the number of receptive IDUs in each cell.

FIGURE 2. (a) A copy of Fig. 1b, shown for reference. The area within the square outline is shown enlarged in panel b. (b) Cell boundaries have been drawn around all the cells that lie within 1,500 feet of the blackened cell in the center. According to the approximation of Equation 3, IDUs within only these cells would be willing to walk to a new SEP placed in the central blackened cell at (x',y') . Our estimate of the number of IDUs who would be served by the new SEP is equal to the sum of the number of receptive IDUs in the outlined cells. Star icons show current SEP locations (x,y) . (c) An enlargement of the boxed area in panel b. The assumed number of receptive SEPs in each cell has been written in the cell. Cells in the top left corner contain the value 0 because they fall within 1,500 feet of existing SEP locations. Cells in the lower right are blank because they fall in Central Park. For this idealized case, we are assuming, unrealistically, that the number of receptive IDUs will change sharply at neighborhood boundaries. The transition from 0.7 to 1.1 receptive IDUs per cell occurs at the boundary of Central Harlem.

to make the cells arbitrarily small because reasonable accuracy will be achieved, in this example, as long as the cells are small compared to 1,500 feet. Monte Carlo simulations show the cells with centers that lie within 1,500 feet of a given point will have a total area that differs from the correct answer (πr^2) by only 0.5% (root-mean-square) when the size of the cells is the same as ours (135 feet by 175 feet). This level of accuracy is more than adequate for our purposes.

It would have been easy to incorporate additional information into the analysis. If, for example, unusual demographics or good access to syringes through other channels cause IDUs living in a given cell to be only half as likely as random IDUs to use an SEP, the number of “receptive” IDUs in that cell could be divided by 2 before calculating the sums that led to Fig. 3. Some cells, perhaps those near subway stations, might draw IDUs from an unusually large radius if they were the site of a new SEP. This could be incorporated by allowing the SEP usage radius to vary with spatial position rather than being held fixed at 1,500 feet. Differences from one neighborhood to the next in ease of movement or in IDUs’ willingness to travel could be accounted for in a similar way.

FIGURE 3. An example of our method’s output. The number of IDUs who would begin using SEPs if a new SEP were placed at a given position (x', y') was calculated by summing the number of receptive IDUs $n(x, y)$ within a 1,500-foot radius (i.e., a 10-minute walk) of (x', y') . See Fig. 2 for a detailed view. Repeating this procedure for every cell center (x', y') in Manhattan produced the map shown. The map is a visual representation of the function we called $g(x', y')$ in Equation 1; our procedure for creating the map is equivalent to a numerical solution of Equation 1 given the approximations of Equations 2 and 3.

Arbitrarily complex information could be incorporated if one were willing to abandon the simplifying assumption that $P(x,y,x',y')$ depends solely on the distance between x,y and x',y' and instead calculate the benefit of a new SEP from the general form of Equation 1.

If the presence of a police station or especially hostile streets made IDUs unwilling to travel from $x=a, y=b$ to an SEP at $x'=a', y'=b'$, for example, the probability $P(a,b,a',b')$ could be set to zero in Equation 1.

We chose to ignore these and other complications for the simplified analysis of this article, but the method we present could have handled them with ease.

RESULTS

Figure 3 shows the result of our simplified analysis. Each point on the map is color coded to indicate the number of IDUs who would be helped if a new SEP were placed at that location. Maps similar to this would be the output of our method applied in other situations. The map suggests that the best locations for new SEPs in Manhattan lie primarily within the neighborhoods of Central Harlem, East Harlem, and Union Square; a new SEP in any of these neighborhoods would serve 300 or more IDUs. Although our analysis was based on questionable assumptions and was mainly intended to illustrate how our method could be applied in an idealized situation, the final output does not seem completely unreasonable. Existing SEPs in Manhattan, which are mainly located within the areas of greatest need, typically serve a mean of 377 IDUs per month.¹⁰ Our methodology would have predicted roughly this number of clients for them.

The main result of this article is not Fig. 3 itself, however, but the approach that let us produce the figure. As better data become available and our assumptions about $n(x,y)$ and $P(x,y,x',y')$ can be improved, this approach will allow SEP locations to be chosen in a way that is closer and closer to optimal. We will soon discuss the sort of data that should be taken to help us reach this goal.

SUMMARY AND DISCUSSION

SEPs appear to provide a powerful way to slow the spread of AIDS in the developed world, but the political and financial support for them is limited.

Existing SEPs distribute only a small fraction of the syringes used by IDUs¹⁰; a significant fraction of new AIDS cases continues to be caused by reuse of infected syringes by IDUs.⁴ Further documentation of the success of SEPs in combating AIDS may ultimately result in the establishment of enough SEPs to meet the needs of IDUs, but in the meantime, it may sometimes be easier to distribute clean needles to (say) 20% more IDUs by increasing the usage of existing SEPs rather than by lobbying for a 20% increase in the number of SEPs.

Because the willingness of IDUs to use an SEP is strongly influenced by the SEP's location,¹¹ minor changes to an SEP's location can easily affect its number of clients by 20% or more (see, e.g., Fig. 3). The goal of this article was to show how decisions about the placements of SEPs should be made if we want to maximize their effectiveness in fighting AIDS.

We presented, in Equation 1, the mathematical formula to determine the optimal placement of SEPs in an ideal world of perfect information. We do not live in an ideal world, but the value of the formula is that it shows the sort of information needed in order for SEPs to be placed as intelligently as possible.

The information consists of two parts. First is the spatial distribution of IDUs. Research suggests that the willingness of IDUs to use an SEP declines significantly if the SEP is more distant than a 10-minute walk.¹¹ It is therefore important that we know where IDUs reside with a precision that is better than about 1,500 feet. Information with this precision does not appear to be available in the literature, but it must be made available to policymakers if they hope to maximize the benefit of SEPs.

Second is $P(x,y,x',y')$, the probability that an IDU who lives at position x,y does not currently use SEPs but would start if a new SEP is placed at x',y' . The definition of $P(x,y,x',y')$ is general and flexible. This is a mixed blessing. On the one hand, it is easy to incorporate into $P(x,y,x',y')$ any information about IDUs that becomes available. We show at the end of the Results section how to incorporate geographical changes in IDU demographics, in the ease of transportation, in the availability of clean syringes through other channels, and so on. The mathematical apparatus of Equation 1 will then guarantee that this information influences the choice of SEP placement in the appropriate way.

On the other hand, the potential complexity of $P(x,y,x',y')$ means that it may be hard to determine in practice. We may never know precisely how likely it is that the IDUs in a particular block of Chelsea would make use of a new SEP placed next to the 81st Street subway station, but this is the kind of information that a full model for $P(x,y,x',y')$ demands. Fortunately, the data of Rockwell et al.¹¹ suggested that distance plays a dominant role in the willingness of IDUs to make use of an SEP, and we may be able to obtain a reasonable approximation to $P(x,y,x',y')$ by assuming that it depends solely on the distance between the IDU position (x,y) and the SEP position (x',y') . The dependence of SEP usage on distance would not be difficult to measure.

Rockwell et al.¹¹ took an important first step by comparing the SEP usage rates of IDUs who lived within a 10-minute walk of an SEP to those of IDUs who lived farther away, but their arbitrary break at the distance of a 10-minute walk led us to adopt the nonsensical assumption that IDUs who lived 1,499 feet from an SEP would be willing to use it, but those who lived 1,501 feet away would not. Further study of precisely how IDUs' willingness to use an SEP declines with distance will be required if one is to choose SEP's locations in the optimal way; the ideal result would be a function $P(r)$ showing how SEP usage depends on distance, not a binary comparison of usage rates inside and outside some fixed radius. It will also be important to extend the work of Rockwell et al.¹¹ by showing that factors other than distance can be safely neglected in modeling IDUs' willingness to use SEPs.

After presenting our method for selecting the optimal SEP locations, we illustrated how the method works by applying it to a simple test case. This test case was based on Manhattan, but was highly idealized. Our map of the SEP suitability of different Manhattan locations (Fig. 3) is an example of the output that our method produces, but should not be taken literally.

The map is rendered questionable first by the poor assumptions about IDUs' locations and willingness to travel that we were forced to make and second by our neglect of the Expanded Syringe Access Demonstration Project (ESAP), with 250 participating pharmacies in Manhattan that provide access to sterile syringes without a prescription.¹⁷ These ESAP pharmacies affect the geographic availability of clean syringes in a major way. Studies suggested that different types of IDUs make use of different syringe distribution channels¹⁸ and indicated that the additional services provided by many SEPs are especially important in combating AIDS,¹⁹ so

our neglect of ESAP pharmacies is justified to some extent. Nevertheless, they would have to be taken into account in a more realistic treatment. Our current model probably overestimates the number of IDUs served by the placement of a new SEP.

We emphasize, in conclusion, that the primary result of this article is not Fig. 3, but is instead our method for choosing SEP locations and the need for better data that it pointed out. The battle against AIDS will be fought on many fronts. We hope that this article will contribute by slowing its spread among vulnerable populations.

ACKNOWLEDGEMENT

We would like to acknowledge the information provided by the New York City Department of Health, Office of AIDS Surveillance. We would also like to express our gratitude for the intellectual contributions of David Vlahov, Richard Hoskins, Sandro Galea, and Adam Cabrera to this project.

The following software programs were used in development of this article: ArcGIS 8.1, Environmental Systems Research Institute; Maptitude 4.5, Caliper Corporation; Microsoft Word, Microsoft Corporation; Supermongo plotting program, created by R. H. Lupton; and custom software written in Perl by K. L. Adelberger.

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