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# HIV SPREAD : SOME STATISTICAL RESULTS

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## Abstract

The spread of AIDS causative agent HIV has now entered the third decade. The infection was first noticed in 1981 in the USA. Within 2 decades, it has quickly grown to the level of an endemic. Unlike several other infectious diseases, AIDS endemiology is interdisciplinary, surrounded by many complex socio-economic, psychological, legal, behavioural and statistical issues. Knowledge of HIV incidence is important to formulate sensible intervention strategies aimed at its control.

This article discusses :

i) Important special features of the spread mechanism which render the syndrome a lethal and silent killer,

ii) a method to evaluate probability of infection in a heterosexual relation,

iii) a method for estimating HIV infections in perinatal transmission, and

iv) the Indian HIV perspective and makes a few suggestions to control the reckless spread of HIV across the country.

**Key words :** AIDS, Estimation, Heterosexuality, HIV, Transmission.

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## Introduction

Acquired Immuno Deficiency Syndrome (AIDS), is the most dreaded human misery at the present with its impact felt in almost all countries of the world. There is an element of mystery in tracing the origin of this modern silent killer. AIDS, caused by infection due to retrovirus HIV is a condition in which the inbuilt defence system (immune cells) of the human body breaks down completely. AIDS was first noted in the United States in 1981 (CDC, 1982) and in India later in 1986 (NACO, 1994). Since then the spread has been rapid to all sections of human society including women and children and has become a pandemic in a short span of time. Based on the intensity and magnitude of spread, the countries can be categorised into 3 types as in Table-1.

**Table 1 :**
**Classification of countries based on intensity of HIV spread**

| Group | Characteristics | Examples of Countries |
|---|---|---|
| A (Worst hit) | • Underdeveloped regions<br>• Already major havoc caused by AIDS | South Africa, Uganda Zimbabwe and a few other sub-Saharan countries |
| B (Recovering) | • Declining number of AIDS deaths<br>• Signs of recovery are seen<br>• Effective awareness campaigns<br>• Higher rate of literacy<br>• I.V.drug use and homosexuality are the major causes | Western European countries and the USA |
| C (Grim future) | • Late start of the epidemic<br>• Developing economics<br>• Serious impact is yet to be felt.<br>• Fast spread due to heterogeneity in population structure.<br>• Low awareness due to ineffective interventions.<br>• Poverty and low social status of women.<br>• Commercial sex is the major cause of spread. | India, Sri Lanka, Malaysia, Indonesia & some other Asian countries. |

Scientific understanding of the disease is still incomplete and invention of vaccine is only underway. AIDS is now posing the biggest challenge to the public in general and health planners and researchers in particular. The following section discusses some important features of HIV epidemic in contrast to other diseases.

## Special Features of HIV Transmission

So far only 4 modes of HIV transmission have been documented. These are (i) unprotected hetero/homosexuality, (ii) infected blood transfusion, (iii)infected needles (mainly drug abuse) and (iv) infection from mother to newborn (perinatal).

In many countries cause (i) is primary mode of spread followed by cause (ii). There can be a two way spread of virus in mode (i) while the others are unidirectional. The occurrence of infections in sexual act which is natural and one of the basic human instincts, has lead to the fast and uncontrolled spread of HIV in the general population. It can be pointed out that the spread of HIV is weather and season independent but it depends on age and to some extent, on sex. AIDS kills people in their prime and productive age group of (20-40) years which is one of its striking features. A few other notable characteristics of AIDS are : involvement of confidentiality and social stigma, very long and variable incubation period as the virus is slow acting, presence of opportunistic infections such as tuberculosis and pneumonia which makes the diagnosis complicated and non-availability of cure so far. However, it may be noted that HIV does not spread through kissing, hand shake, use of common toilet, saliva, water or air as misconceived sometimes.

**Risk groups :** The major risk groups prone to HIV infection include : commercial sex workers, blood donors/recipients, intravenous drug abusers, slum dwellers, hostelites, tourists, travelling salesmen, truck drivers and more generally, sexually active youth. It is noted that there is a rising trend of HIV infection in blood transfusion. Extensive studies regarding the behaviour of these groups are necessary in order to control the fast spread of HIV. The next section develops a method for evaluating the probability of HIV infection in heterosexual transmission.

The paper develops a method for estimating the probability of HIV transmission in heterosexual relations by enumerating the effective number of adult pairs (A(t)) and the size of the subset at risk ($A_1$(t)). The ratio $A_1$(t) / A(t) is taken as the estimate. It also obtains perinatal (mother to child) transmission probability by computing the ratio of expected number of HIV infected births ($B_1$(t)) to the total number of births (B(t)). The standard age specific fertility rates are applied to number of women in child bearing ages for computing B(t), which is then adjusted for still births as well as infant mortality.

## Probability of Infection

Consider a heterosexual HIV risk population of size N consisting of three categories of persons viz.

a) Sexually active young males (y).

b) Sexually active young females (x). and

c) Commercial sex workers (z).

Categories (a) and (b) are divided into married (m) and unmarried (u), each of which is further subdivided into susceptible (0) and infective (1), while category (c) is divided into males ($Z_y$) and females ($Z_x$) which is further split into susceptible and infective. At any time t, the number of persons in each of the above groups is denoted by using the subcategory notation as subscript, for example, $Y_{u0}$ denotes the number of susceptible unmarried males. Let M denote the number of married couples. The objective is to estimate the probability of infection by computing the number of infected pairs and the number of possible pairs and taking their ratio. Assuming heterosexuality, a simple accounting of possible pairs is given by : $A(t) = Y_u.Z_x + Z_u \cdot Z_y + M$ (1)

In reality, heterosexuality is an intentional act and is subject to social norms attitudes and behaviour. Further, in many societies there is no free mixing of the sexes. Thus the materialized number of pairs is to be computed by applying suitable discounting factors $f_1$ and $f_2$ ($0 \leq f_i < 1$; i = 1, 2) to the first two terms on the right side of (1). Closeness of $f_i$ to 0 will indicate higher discounting while closeness to 1 will mean the opposite. Applying these factors and assuming faithful partnership among the married, expression (1) reduces to

$$A(t) = (Y_u \cdot Z_x) f_i + (X_u \cdot Z_y) f_2 + M \tag{2}$$

which represents the effective number of pairs. With a reasoning that for a *new* infection, a pair should have precisely one infected person, the total number of infected pairs $A_1(t)$ is evaluated as a sum as follows :

$$A_1(t)=[(Y_{u0} \cdot Z_{x1}) + (Y_{u1} \cdot Z_{x0})] f_1 + [(X_{u0} \cdot Z_{y1}) + (X_{u1} \cdot Z_{y0})] f_2 + M_x + M_y, \tag{3}$$

where $M_x$ and $M_y$ respectively denote the number of married pairs in which only female and male members are infected.

The proportion of infected pairs p(t) with only one infected member is therefore obtained by dividing $A_1(t)$ by A(t). To estimate probability of HIV infection, we have to consider the rate of transmission (q) as well as the frequency of contact per unit time (C).

It is noted in literature that male and females have different transmission rates. Let these be $\theta_m$ and $\theta_f$ respectively. Accordingly, the combinations in (3) are segregated into 'female only' and 'male only' infected groups and the rates $\theta_f$ and $\theta_m$ are applied. Then

$$\hat{P}_I(t) = \frac{C[((Y_{u0}.Z_{x1} + X_{u1}.Z_{y0})f_1 + M_x)\theta_f + ((Y_{u1}.Z_{x0} + X_{u0}.Z_{y1})f_2 + M_y)\theta_m]/A(t)}{A(t)} \quad (4)$$

In turn, this probability can be applied to susceptible group $(N_1(t) = X_0 + Y_0 + Z_0)$ to give the expected number of new infections during the period. Thus

$$\hat{n}_I(t) = N_I(t) \,.\, \hat{P}_I(t) \quad (5)$$

## Knowledge of parameters

The data on the variables X, Y, Z & M in the model are generally available from census and other demographic records. The parameters $\theta_m$, $\theta_f$ and C can be taken from the African study (Bongaarts, 1989) as follows :

$\theta_m$ : male to female transmission probability = 0.001.

$\theta_f$ : female to male transmission probability = 0.0005.

$C_p$ : monthly frequency of sexual contacts between individuals in a pair = 8.

The discounting factors may be computed by $f_1 = Z_x / Y_u$ & $f_2 = Z_y / X_u$. These values of f may also be assessed by special behavioural studies.

## Illustration I

Consider a hypothetical heterosexual population of size N = 1000 with the following break-up :

$Y = 500;\ X = 470;\ Z = 30.$

$$\begin{bmatrix} Y_{u0} = 225, & Y_{m0} = 200 \\ Y_{u1} = 25, & Y_{m1} = 50 \end{bmatrix} \quad \begin{bmatrix} X_{u0} = 250, & X_{m0} = 170 \\ X_{u1} = 20, & X_{m1} = 30 \end{bmatrix}$$

| | |
|---|---|
| t = one year<br>C = 96/year<br>θm = 0.001<br>θf = 0.0005 | $Z_{yo} = 3$<br>$Z_{y1} = 7$<br>$Z_{xo} = 5$<br>$Z_{z1} = 15$<br>$f_1 = 0.08$<br>$f_2 = 0.037$ |

Then on using expressions (2) and (3) respectively, we get A(t) = 700 and $A_1(t) = 428$. The proportion of infected pairs is p(t) = 0.61. The use of expression (4) results in the estimated probability of HIV infection, $\hat{P}_1(t) = 0.037$ and expression (5) gives $\hat{n}_1(t) = 31$.

## Perinatal Transmission

Mode wise projection of HIV and AIDS cases is useful for predicting the path and interventions separately. With the four modes of HIV spread as mentioned in Sec.2, it is likely that a few may be exposed to the risk from more than one mode leading to overlapping of cases. This factor will be absent in perinatal transmission. Thus, a person involved in unprotected sexual act may also be a drug abuser and a blood recipient and vice versa whereas for a new born with HIV infection there is no risk of further infection from any other cause except for possibility of receiving blood, since it will not survive until adulthood. The HIV projection methods and the problem of overlap have been discussed by Rao and Srivenkataramana (1999). Modelling for the spread of HIV separately in heterosexual population, blood transfusion and drug abuse has been attempted by Rao and Srivenkataramana (2001,2002a,b). In this section we pursue estimation in perinatal spread.

## A Model for HIV in Perinatal Transmission

The notations used are as follows :

t : unit time.

x : Age of mother in years; $15 \leq x \leq 49$. (Reproductive age group) :

W(x,t): Number of women aged 'x' years at time t.

f(x,t) : Age specific fertility rate.

$r_1(x,t)$ : Prevalence of HIV infection among W(x,t).

q : Probability of HIV transmission from infected mother to child.

B(t) : Total number of births during the period (t, t+1).

$B_1(t)$ : Total number of births with HIV infection.

$r_2(t)$ : Infant mortality rate.

Then estimated number of births is

$B(t) = \sum_{x=15}^{49} W(x,t)\, f(x,t)$ and the estimated number of births with HIV infection is :

$$\hat{B}_1(t) = q.\sum_{x=15}^{49} W(x,t)\, f(x,t)\, .\, r_1(x,t) \tag{6}$$

The probability $P_2(t)$ of a baby being born with HIV infection at time t can be estimated by

$$\hat{P}_2(t) = \hat{B}_1(t) / B(t)$$

In this setting there are two practical aspects of interest :

a. Health care for mothers.

b. Health care for children.

$\hat{P}_2(t)$ is an indicator of infection status among mother and hence in the general population. This probability will help for planning health care for mothers. But, for (b) an adjustment for still births and IMR (whose combined effect may not be negligible) may first be made to get the net number of children with perinatal infection. In order to do this, $B_1(t)$ should be adjusted for still birth as well as infant mortality. Still births are estimated by :

$$\hat{S}(t) = s(t) \,.\, \hat{P}_2(t)\, B(t) \tag{7}$$

where s(t) is the rate of still births which can be computed from hospital records. The estimated number of deaths under age 1 among the children born with HIV is given by :

$$\hat{D}(t) = r_2(t)\, \hat{P}_2(t)\, B(t) \tag{8}$$

Thus, the estimated number of HIV infected due to perinatal transmission is obtained as

$$\hat{n}_2(t) = B_1(t) - (\hat{S}(t) + \hat{D}(t)) \tag{9}$$

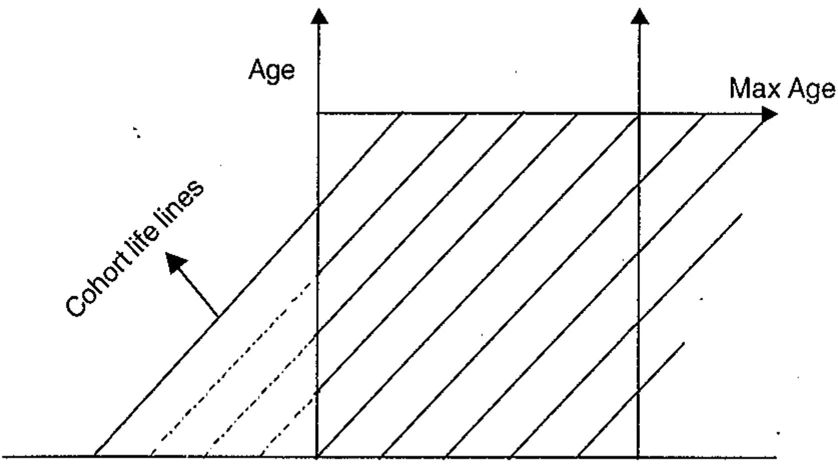
## Remarks

1. In geographically large countries like India, computation of $P_2(t)$ may be tedious. However, the same may be estimated for different regions and then pooled.

2. The HIV prevalence rate $r_1(t)$ among women is likely to vary over regions (eg., rural/urban/metropolitan). If information on $r_2(t)$ is available we may use the estimation formula (9) region-wise and then pool the estimates.

**Follow-up :** To have a follow-up of the HIV infected perinatal, the AIDS forecasting model (Bongaarts, 1989), which mimics the standard demographic cohort component technique may be used. Each group of individuals born in a given year (birth cohort) is followed from birth to death and all necessary events are recorded over the life cycle. The following lexis diagram plots life lines of successive cohorts by age and calendar time.

Fig. 1 : Lexis Diagram




To obtain estimates of key variables like the number of AIDS cases in a given year t, it is necessary to combine the numbers from all cohorts at that time. Since single year cohorts are used in the model, the total number of cohorts that have to be taken into account in a given year equals the maximum number of years lived by individuals.

Illustration 2 : Consider the following hypothetical set-up :

| | |
|---|---|
| $W(x,t) = 1{,}00{,}000$ | $q = 0.9$ |
| $f(x,t) = 90/1000 = 0.09$ | $r_2(t) = 100/1000 = 0.1$ |
| $r_1(x,t) = 2\%$ | $s(t) = 40/1000 = 0.04$ |

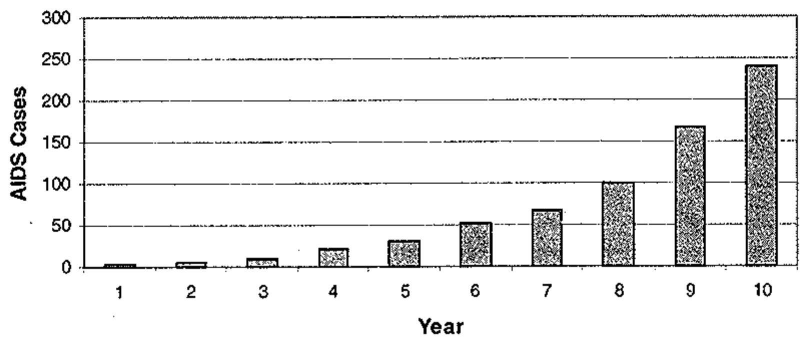
We obtain the following results on using expressions (5) to (9).

| | |
|---|---|
| $\hat{B}_1(t) = 162$ | $\hat{D}(t) = (16)$ |
| $\hat{P}_2(t) = 0.018$ | $\hat{n}_2(t) = 0$ 140 infections |
| $\hat{S}(t) = 6\,\hat{D}(t)$ | |

## INDIAN HIV SCENARIO : Perspective and prospects

The developing countries including India are placed under the category 'Grim future'. Though there is a late start of this epidemic in India, its impact is felt in all the states. Heterosexuality, mainly the commercial sex is the dominant mode followed by blood transfusion. So far, more than 4 million blood bottles have been tested for HIV out of which atleast 0.1 million were found to be HIV positive. Though the seroprevalence is estimated to be in the range (5-10) million, only about 24,000 AIDS cases have been reported to National AIDS control organisation (NACO). Fig.2 gives the annual cumulative number of AIDS cases reported to NACO in the years 1992-2001.

**Fig.2 : Reported No. of AIDS cases (in Hundreds)**




HIV infections do not appear to be uniformly distributed over the country. Using the projected seropositivity rates (r(t)), Rao and Srivenkataramana (2001) have estimated HIV infections in India among adults for a few select years as shown in Table 2.

Table 2. HIV projections in India (Figures in Lakhs)

| Year | Project adult Population | Projected *r*(t) | Number HIV Infected M | Number HIV Infected F | Number HIV Infected T | % infected among adults |
|---|---|---|---|---|---|---|
| 2000 | 5112 | 34.4* | 117 | 58 | 175 | 3.4 |
| 2001 | 5260 | 37.78 | 130 | 68 | 198 | 3.7 |
| 2002 | 5413 | 41.10 | 149 | 75 | 224 | 4.1 |
| 2008 | 6231 | 61.60 | 256 | 128 | 384 | 6.2 |
| 2012 | 6626 | 75.70 | 334 | 167 | 501 | 7.6 |

It is noted that the Southern states are 1-5% seropositive while the Northern states are less than 1% seropositive. This difference may be attributed to many factors including inadequate and inefficient reporting system and intentional wrong reporting. The urban centres like Mumbai, Kolkata, Chennai, New Delhi and Imphal are most affected and the infection is now spreading to rural areas as well. Mumbai city alone is reported to have more than 0.2 million sex workers and at least 60% of them are HIV infected.

Due to the social stigma associated with AIDS and ineffective and inadequate AIDS data gathering and reporting systems in India, considerable percentage of infections go undetected. In this context, Rao and Srivenkataramana (2002) have suggested a computer networking for HIV-AIDS database in the country, which is feasible and is expected to solve many AIDS data problems confronting health planners and AIDS researchers.

Many researchers fear that by the end of present decade India may have 25% of the world's total seropositive. This may materialize in the absence of vaccine and effective awareness. Stepping up of awareness programmes and hope for vaccines will definitely retard the growth of the epidemic. Further, India which is yet to feel the adverse impact of AIDS may very well learn from the experiences of other nations which have suffered or are recovering.

**Need of the hour :** The following suggestions are made, for the effective management of AIDS in India.

- Scientific understanding of HIV spread mechanism in different transmission modes.
- Special behavioural studies of high risk groups.
- Evaluation of risk behaviour change by adopting counselling and testing.
- Mandatory check-up for HIV seropositivity for persons with high risk activities.
- Introduction of sex-education in colleges.
- Setting up of hitech testing labs, specially in rural areas.
- Adequate training of physicians and other medical professionals.
- High publicity for the use of contraceptives.
- Strict population control measures.

- Evolving methods to deal with opportunistic diseases, especially at the time of AIDS diagnosis.
- Adequate and effective awareness campaigns.
- Improving social status of women in society.
- Extensive clinical longitudinal studies on AIDS for invention of vaccines.
- Organization of full fledged HIV-AIDS database in the country.
- Stringent laws to govern blood banks.
- Control over drug trafficking in border areas.
- Design and implementation of needle exchange programmes.

Ultimately, the communities, organizations, groups of persons and individuals should wake up to the dangers of AIDS.

## Discussion

AIDS endemiology is a relatively new field of research which poses several challenges. The impact of HIV in different parts of the world including India is analysed and presented. Understanding the HIV transmission phenomenon is the first step towards controlling the virus spread. Unlike many other infections, HIV infection and its manifestation to AIDS involves several novel features.

The probability of HIV infection is important in many AIDS related statistical studies. A method to evaluate this in heterosexual transmission has been outlined using classical approach and a few key parameters of the spread mechanism. This probability is shown to be useful in estimating the number HIV infected for this mode of spread. More and more children have been HIV infected over the years. There is very little work done with regard to perinatal infections. A method based on vital rates is outlined in Sec.4 for estimating the spread of HIV in perinatal transmission. This will help health planners to design appropriate interventions for this section of the population.

Finally, Indian prospect in the coming decade in respect of HIV/AIDS is outlined and a few suggestions are made to combat spread of AIDS virus in the dense and highly heterogeneous Indian population.

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