Studies on the transmission model of HIV/AIDS among commercial sex workers in Thailand

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In 1990s, there were rapid increases in the number of HIV epidemics and AIDS cases in Thailand, Southeast Asia. In particular the risk of HIV infection was very high among female prostitutes who played a large part in the transmission of HIV infection. We formulated a mathematical model for the transmission of HIV in prostitutes. We carried out the model simulations to analyze the incipient spread of HIV infection and the effect of AIDS prevention methods in prostitutes. The simulation of our model indicates that even if the effect of AIDS prevention methods such as the recommendation of condom use for commercial sex workers would block the transmission at rate by 70%, the elimination of the HIV epidemic is still beyond attainment.

Key words: AIDS, HIV, prostitution, Thailand, transmission model

1. INTRODUCTION

Nowadays, HIV/AIDS continues to spread in all regions of the world. There is still no radical cure for AIDS, and therefore AIDS control is one of the most important public health problems. Particularly, there are many HIV patients and AIDS cases in Southeast Asia and Africa where an increasing number of HIV epidemics has been documented. In view of the serious situation, this paper aims to look at the prevalence of HIV/AIDS in Thailand, Southeast Asia. HIV is highly prevalent in Bangkok, the capital of Thailand and the northern region. Weniger et al. (1991) reported that in Thailand the prevalence of HIV first broke out in injecting drug users from 1988, second in female prostitutes who worked in brothels (commercial sex workers, CSW) from 1989 and

third in heterosexual men from 1989. As the CSW population plays a large part in the transmission of HIV, an important consideration is the prevention of HIV in this population. Weniger et al. (1991) also pointed out that factors in the infection CSW were: (1) greater frequency of sexual intercourse, (2) lower sexual service charge, and (3) a low condom usage rate (less than 50%).

From a theoretical point of view, Isham (1988) reviewed mathematical models of HIV transmission such as homosexual and heterosexual epidemic models as well as discussing the doubling time of the epidemic and the incubation period for these models. Anderson (1988) also studied the dynamics of HIV transmission as well as the incubation and infectious periods on the basis of homosexual or heterosexual activities in the United Kingdom. A mathematical model for the transmission of HIV in the CSW population is formulated in this paper. We focused on the incipient spread of HIV infection and the effect of AIDS prevention methods on the HIV prevalence in the CSW population of northern Thailand. This paper attempts to analyze the above situations by carrying out simulations of the model. The simulation of the model indicates that the effect of AIDS prevention

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methods such as the recommendation of condom use for CSW would only block the transmission rate by 70%, and in this situation the elimination of the HIV epidemic is beyond attainment. Thus for the elimination of HIV in Thailand, it is necessary to carry out more exhaustive transmission - blocking strategies.

2. MATERIALS AND METHODS

2.1. Study Area

Thailand is located in Southeast Asia, and is roughly divided into the central region (around Bangkok, the capital of Thailand), the northern region (on the border of Myanmar and Laos), the northeast region and the south region. Nowadays the spread of HIV/AIDS has been observed in all over the country, but especially in the central and northern regions where HIV is prevalent at a high rate (Weniger et al., 1991). Tables 1 and 2 show the number of AIDS cases in Thailand, and the HIV infection rates among 21-year old men in Thailand, respectively. One of the features of HIV/AIDS in Thailand is that commercial sex workers plays a large part in the transmission. This paper aims at investigating the prevalence of HIV/AIDS in CSW. The HIV infection in CSW was found in 1989, and thereafter it spread rapidly among this group (Weniger et al., 1991). It was reported that HIV/AIDS was prevalent at the rate of 15-40% in CSW of the central and northern regions, with a

Table 1 The number of AIDS cases in Thailand

Year	AIDS (male)	AIDS (female)	AIDS (total)
1991	479	80	559
1992	1450	238	1688
1993	5765	965	6730
1994	11475	2101	13576
1995	14400	3542	17942
1996	18702	4722	23424
1997	20136	6289	26713
1998	19782	6986	27128
1999	17968	7710	26003
2000	15615	7350	23352

(Derived from Thailand Health Profile 1997-1998, MOPH and Epidemiological fact sheets on HIV/AIDS and sexually transmitted infections, Thailand, 2002 update, WHO)

prevalence rate of over 40% being observed in some villages of the northern region (Weniger et al., 1991). In 1990, Weniger et al. (1991) reported that 10241 CSWs in 1290 establishments worked in the northern region, while in the whole country there were 86494 CSWs in 6160 establishment. Tables 3 and 4 show the prevalence rate of HIV infection among CSW throughout the whole country and in the northern region only.

2.2. Epidemiological parameters

To construct a model for the dynamics of the HIV/AIDS transmission, we have to introduce three epidemiological parameters. β_m denotes the transmission coefficient from a man infected with HIV to a susceptible CSW; v_w denotes the rate of developing AIDS from an

Table 2 HIV infection rates among 21-year-old Thai men selected for conscription by lottery

Year	Number tested	Prevalence rate (%)
November 1989	19131	0.5
May 1990	31638	1.7
November 1990	24272	2.1
May 1991	31230	2.9

(Derived from Weniger et al., 1991)

Table 3 HIV infection rates among CSW in Thailand

Year	Prevalence rate (%)
1989	3.12
1990	9.33
1991	15.24
1992	22.97
1993	28.03
1994	27.00
1995	33.15
1996	28.17
1997	27.78
1998	21.06

(Derived from Epidemiology division, MOPH)

Table 4 The number of serosurveys for HIV among commercial sex workers in Northern Thailand

Year	Location	Number tested	Number positive	Prevalence rate (%)
1987	Chiang Rai [a]	40	0	0
1987	Chiang Mai [b]	101	0	0
1988	Chiang Rai [a]	683	3	0.5
1988-1989	Chiang Mai [c]	1092	4	0.4
1989	Chiang Mai [a]	238	87	37

(Derived from [a]: Epidemiology of AIDS in Chiang Rai, Thailand, Limpakarnjanarat K, 1991, [b]: Epidemiological assessment of anti-HIV antibodies in Thailand, Thongkrajai et al., 1988,[c]: Seroprevalence of antibody to human immunodeficiency virus HIV-1 in a high-risk group in 4 provinces with tourist attractions, Traisupa et al., 1990)

infection with HIV in CSWs per month, which is estimated as $1/D$ (D standing for the mean incubation period for AIDS); and α_w denotes the mortality rate of CSWs caused by AIDS per month.

Wannamethee et al. (1998) reported that the incubation period was 6.5-13 years in western cohorts and that this was comparable to Thailand. The mean survival time after developing AIDS was 6 months nationwide in Thailand (Weniger et al., 1991), and 7 months in northern Thailand (Kitayaporn et al., 1996). We have adopted the values for the above parameters as $D=96$, $v_w =1/96$, and $\alpha_w =1/6$. Since there is little detailed data on the transmission coefficient (β_m), it is difficult to determine its value precisely. We will estimate the value appropriately through simulations of the model.

2.3. Parameters for the sexual activities in Thailand

In this section, we will introduce three parameters for sexual activities. κ_w denotes the mean number of male partners that a prostitute acquires a month; e denotes the rate for young females from the population becoming a prostitute in a month and m, the rate of withdrawal from a prostitution a month.

It is reasonable to assume that a prostitute will acquire at least one male almost every day. Therefore, κ_w is estimated as $30 \times 0.8=24$ with the acquiring rate as 0.8 per day. The average time in the profession was less than 2 (Suputhithada et al., 1991), or 3 years (Sakhondhavat et al., 1991). In this paper, the CSW population is assumed to maintain a constant size. We have adopted the average time in the profession as $3 \times 12=36$ months and m as

$1/36$, which is equal to the inverse of that time. e can be estimated by the CSW population dynamics. Let n_w and n_f be the population of CSW and that of young females (age 15-29) respectively. The rate of CSW in the young female population was estimated to be 2.4% in 1991 (Weniger et al., 1991), so we have adopted n_w/n_f as 0.024. The dynamics can be written by the following equation:

$$\frac{dn_w}{dt} = en_f - mn_w$$

As the equilibrium of n_w in the above equation becomes to be en_f / m, e is estimated as $m(n_w / n_f)$, whose value can be assessed as 6.6×10^{-4}.

2.4. Control of the HIV/AIDS transmission

In response to the rapid increase of the HIV/AIDS prevalence in Thailand, short-term and medium-term plans for AIDS prevention and control were established in 1988 and 1989 by the Ministry of Public Health, Thailand (MOPH) with support from WHO. By the way of prevention against HIV/AIDS transmission, condom usage was promoted and condoms were distributed free by government agencies and non-governmental organizations. Public health education was also carried out for CSW by public-health care workers (Weniger et al., 1991). As a result, the condom usage rate in Chiang Mai, northern Thailand rose from 10-20% in early 1989 to 80-90% in late 1990 (Thanprasertsuk et al., 1991; Meyer, 1990).

We have also investigated the efficacy of the control measures. The probability of the HIV transmission being interrupted by control measures stands for c. In this case, β_m should be replaced by $(1-c)$ β_m. As the usage of

condoms spread, male gonococcal urethritis cases at the public STD clinic declined from a mean of 540 per month in the period from October 1988 through September 1989 to a mean of 306 per month from October 1989 through November 1990 (Weniger *et al.*, 1991). Thus the efficacy of the control by condoms usage was shown by the decline in the sexually transmitted disease among Royal Thai Army and Air force conscripts, as is shown in Table 5.

Table 5 HIV incidence per 100 people/year among Royal Thai Army and Air force conscripts, in northern Thailand, for 1991-1993 and 1993-1995.

Term	Incidence rate per 100 people/years
1991-1993	2.48
1993-1995	0.55

(Derived from Decreasing incidence of HIV and sexually transmitted diseases in young Thai men: evidence for success of the HIV/AIDS control and prevention program, Celentano *et al.*, 1998)

2.5. Dynamics of HIV/AIDS

In this section, we have made a mathematical model of the prevalence with HIV in the CSW population. When a CSW acquires male clients who are infected with HIV, she also may be infected with HIV. It is assumed that a CSW is infected with HIV when she has contacts with male clients in the brothel, while other channels are ignored. A new prostitute is assumed to be susceptible. In the model, AIDS cases are distinguished from HIV infection. The CSW population is divided into 3 classes for the status of infection; susceptible, HIV cases without symptoms (HIV infection), and AIDS cases, that are symbolized by x_w, y_w and z_w respectively. When an individual of HIV infection class develops AIDS symptoms, she moves to the AIDS cases class. An individual is removed from all classes upon death, while she is removed from only susceptible and HIV infection classes by withdrawal from prostitution. Let p_m be the rate of males infected with HIV, which is considered as external variable in the model. The probability of new infections with HIV a year in the CSW population is assessed at β_m κ_w p_m because the monthly infectious

contacts per CSW amount to $\kappa_w p_m$. Therefore, the model is described by the following differential equations:

$$\frac{dx_w}{dt} = en_f - \beta_m \kappa_w p_m x_w - mx_w$$

$$\frac{dy_w}{dt} = \beta_m \kappa_w p_m x_w - (m + v_w)y_w$$

$$\frac{dz_w}{dt} = v_w y_w - \alpha_w z_w$$

3. RESULTS

3.1. Estimation of transmission coefficient

To investigate the incipient spread of HIV infection in the CSW population of northern Thailand we need to estimate the transmission coefficient (β_m). The value of the coefficient was detected in the range from 0.005 to 0.035 in steps of 0.005 through simulations of the model where the male prevalence rate (p_m) was assumed to be stable at the average of November 1989 - May 1991 (Table 2) in the early stage of the epidemic. The curves were compared with the AIDS surveillance data for the CSW in Thailand (Fig. 1). The allowable boundary was estimated to be (0.015 - 0.025) if tolerance error to the surveillance data at the beginning of 1990 or 1991 was allowed to be 2.5% or 5% respectively.
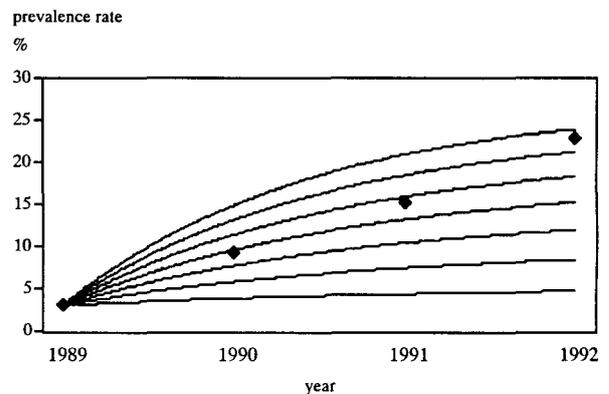

Fig. 1 Transitions of the HIV prevalence rate among CSW. p_m is selected as 0.018. 1st, 2nd, 3rd, to 7th lines from the bottom show the prevalence curve according to the values 0.005, 0.01, 0.015, to 0.035 of the transmission coefficient respectively, while ◆ shows the actual data.

3.2. Simulations for the prevalence of HIV in commercial sex workers

Firstly, to investigate the incipient spread of HIV infection among the CSW population, we planned the simulation in situations where the male prevalence rates was sorted into half a year periods, whose values were given as 0.005, 0.018, 0.021, 0.029, 0.032, 0.0345, 0.037, 0.04, 0.043, 0.046, 0.049, 0.053, 0.056, 0.06, 0.065, 0.07 according to the interval of November 1989 - May 1990, May 1990 - November 1990, and November 1997 - May 1998. The transmission coefficient (β_m) from male to CSW was adopted as 0.02. The prevalence curve among the CSW population obtained by the above simulation is shown in Fig. 2.
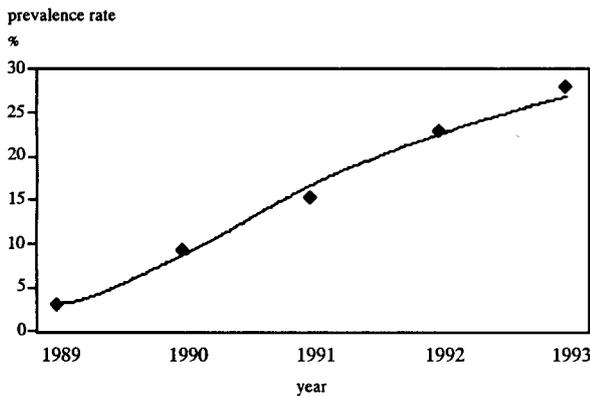
prevalence rate
%

Fig. 2 Comparison of the transition for the HIV prevalence rate in CSW to HIV surveillance data. The black line being the values estimated by our model and ◆ being the actual data.
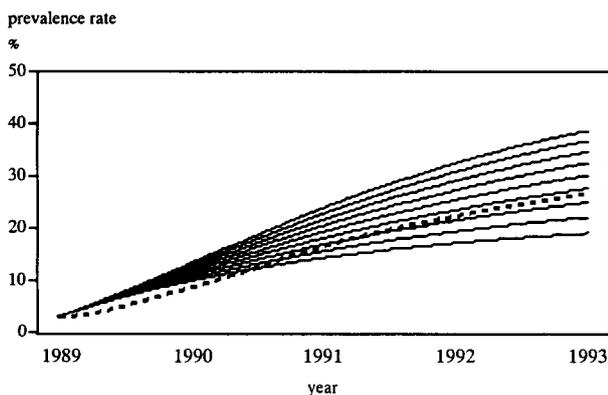
prevalence rate
%

Fig. 3 Transitions of the prevalence curve for HIV among CSW. 1st, 2nd, to 9th lines from the bottom show the prevalence curve obtained from the self determined system of the male prevalence according to the values 0.01, 0.015, to 0.05 for the transmission coefficient (β_w) respectively. The dotted line shows the prevalence curve obtained from the model of 2.5.

Secondly, to study the epidemics of HIV among the CSW population by the comparative method we planned simulations of the modified model in which the male prevalence rate was self-determined in the system of equations. The simulations were carried out for nine values of the transmission coefficient (β_w) from CSW to males which was varied from 0.01 to 0.05 in steps of 0.005 (Fig. 3).

3.3. Simulations for the prevalence of HIV with the transmission blocking method

Finally, we estimated the effect of the HIV transmission blocking method, that is, the recommendation of condoms usage for CSW. The simulations were carried out for two situations; one situation (a) that the transmission blocking method has been introduced since 1991 at a settled effective rate which is selected from 5% to 40% in steps of 5% and the other situation (b) that it was introduced at the effective rate of 5% in 1991 and then strengthened at a higher rate than the initial rate since 1995, which is selected from 30% to 70% in steps of 10% (Fig. 4a, b).

4. DISCUSSION

In view of the seriousness of the HIV epidemic in Thailand, it is very important to appraise the effect of the AIDS prevention campaign in the CSW population which is one of the major source of infection and also to predict the transition of HIV epidemics among them for the future.

The transmission coefficient (β_m) from male to CSW cannot be determined by the epidemiological data. It was estimated as 0.020 ± 0.005 when tolerance error of the prevalence rate among the CSW population would be 2.5% and 5% for 1990 and 1991 surveillance data respectively in the pre-control period. The prevalence curve which was obtained by our model with the median (0.020) of the allowance boundary coincided well with the surveillance data in 1989-93 (Fig. 2). Therefore it seems reasonable to adopt the value of (β_m) as 0.020.

We made a comparison between two transmission models, self contained and not self contained models. Adult Thai men are infected with HIV by sexual contact
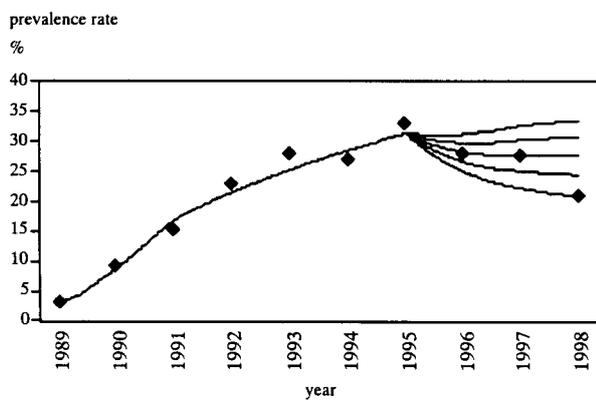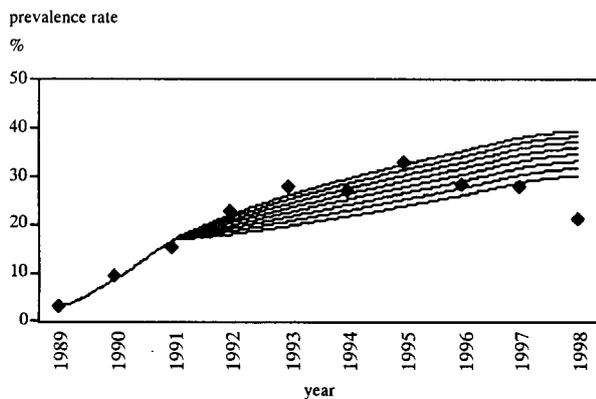
Fig. 4a, b Comparison of the transition for the HIV prevalence rate in CSW to the surveillance data. For case (a), 1st, 2nd, to 8th lines from the top show the prevalence curve corresponding to the values 5%, 10%, to 40% for the effective rate of the transmission blocking method respectively. For case (b), 1st, 2nd, to 5th lines from the top show the prevalence corresponding to the values 30%, 40%, to 70% for the effective rate for the transmission blocking method respectively. ◆ shows the actual data.

with CSW as well as heterosexual contact with girl friends and wives, homosexual contacts including bisexual contacts and injecting drug use. Therefore, the assumption that the male prevalence rate would be determined by only sexual contact with CSW may be at variance with reality. However, the above two models made little difference to the simulations for the incipient period of HIV infection, which was due to CSW playing a greater part of infectious contacts with adult Thai men.

In regard to the transmission coefficient (β_w) from CSW to man, the simulations estimated the allowance boundary as 0.010 - 0.020 if a tolerance error of 5% was allowed between the prevalence rate obtained by the model and the surveillance data in 1992-93. However we

cannot know if its estimation is a real value due to the multiple routes of HIV infection in males.

In 1990s, even although condoms were distributed free for CSW, their usage was unacceptable in the beginning. The simulations showed that after 1995, the control method suppressed an increase in the prevalence rate among the CSW population and thereafter this rate decreased (Fig. 4b), however it could not decrease the HIV epidemic among CSW until 1995 (Fig. 4a). The effective rate of the transmission - blocking method was estimated as 5% for 1991-95 and 50%-70% for 1995-98 (Fig. 4b). The simulations indicate that, if the effective rate of transmission-blocking through the control method could attain a level of 50%, it cannot reduce the prevalence among the CSW population and that, even if it could attain a level of 70%, it can hardly eliminate the HIV epidemic among them. In conclusion, for the elimination of the HIV epidemic in Thailand, particularly among the CSW population, it is necessary to carry out more exhaustive HIV/AIDS prevention strategies which can attain an effective rate of transmission - blocking which is higher than 90%.

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