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Research article

Influence of media intervention on AIDS transmission in MSM groups

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Abstract: To explore the effects of propaganda and education on the prevention and control of AIDS infection, a model of AIDS transmission in MSM population is proposed and theoretically analyzed by introducing media impact factors. The basic reproduction number of AIDS transmission in MSM group without media intervention $R_0 = 1.5447$ is obtained. Based on the comparison of the implementation of three different detection and treatment measures, it can be concluded that the promotion of condom use is more effective than other strategies, and using condoms with a fixed partner can reduce the value of R_0 more quickly.

Keywords: MSM; HIV/AIDS; media impact factor

1. Introduction

The acquired immunodeficiency syndrome (AIDS) caused by the human immunodeficiency virus (HIV), has become increasingly prevalent in China [1]. Beijing reported the first Chinese AIDS case in 1985. By the end of October 2018, a total of 29063 HIV/AIDS cases have been reported. Among all HIV-infected individuals, 26697 cases (91.86%) were sexually transmitted, of which 19586 cases (67.39%) were homosexual transmission and 7111 cases (24.47%) were heterosexual transmission. From January to October 2018, 2874 HIV/AIDS cases were reported in Beijing, down 5.86% from the same period last year. Of the newly reported cases from January to October 2018, 2784 cases (96.87%) were sexually transmitted, where 777 cases (27.04%) were heterosexually transmitted and 2007 cases (69.83%) were homosexual transmitted [2]. On the one hand, the overall epidemic situation is at a low epidemic level, and the number of newly reported cases is steadily declining. At the same time, men who have sex with men (MSM) are showing a high epidemic trend. Transmission through sexual contact, especially male-to-male sexual transmission, is the main route of AIDS transmission in Beijing. The proportion of new HIV infections per year due to male homosexual transmission increased from 0.3% during 1985-2005 to 69.83% in 2018 [3].

MSM group has always been a high-risk group of HIV infection and also one of the fastest growing groups of HIV infection in China in recent years. MSM population has the characteristics of high-risk sexual behavior, low rate of condom use, and many sexual partners [4]. A survey of 550 MSM people in China showed that in the past three months, 37.8% of MSM had one partner, 50.4% of MSM had two to five partners, 11.8% of MSM had more than five partners, and even 0.9% of them had commercial homosexual sex [5]. In the MSM population, due to the trust in fixed partners, protective measures are rarely used. The results of [5] show that 59.2% of MSM had unprotected high-risk sexual behavior with fixed partners in the past month, which laid a huge hidden danger for the spread of AIDS in the MSM population. Therefore, it is of great practical significance to further study the influence of fixed and non-fixed partners on HIV transmission in MSM population.

Under the constraints of traditional Chinese culture, the target population of MSM is generally concealed. In reality, it is very difficult to carry out propaganda and education for MSM population. However, in recent years, with the rapid development of new media, especially the popularity of smart phones, emerging dating software has gradually become the main way of MSM dating. Centers for Disease Control and Prevention (CDC) is more likely to use the new media platform to locate MSM groups and implement targeted interventions. A domestic survey [6] had shown that 89.5% of MSM chose emerging media (Blued, WeChat, etc.) to communicate. As of February 2018, Blued, a gay dating app, had more than 40 million registered users in 193 countries and regions around the world, of which 30% were overseas users [7]. Therefore, in the new media era, media intervention as the main strategy to control the AIDS epidemic can play a greater role in education and guidance.

In 2014, Lou et al. [8] divided the MSM patients into two categories according to whether the CD4 cell count in the body is greater than 350/mm^3, and discussed the influence of expanding treatment and increasing the use of condoms on reducing the number of new HIV infections in the MSM population every year. In 2015, Luo et al. [9] divided the MSM patients into three categories according to their CD4 count, which were respective AIDS patients with CD4 count > 350 cells/mm^3, 200 cells/mm^3 < CD4 count < 350 cells/mm^3 and CD4 count < 200 cells/mm^3. They also discussed the influence of expanding testing and expanding treatment on the number of new AIDS cases every year. In this paper, based on [9], the heterogeneous factor of fixed and non-fixed sexual partners in MSM population will be discussed. Furthermore, media factors will be introduced into the established HIV model to analyze the influence of publicity and education on the HIV transmission of MSM groups in different interventions.

2. Model establishment

First, according to the situation of AIDS infection and treatment, MSM population is classified into four categories: HIV-susceptible, HIV-infected, HIV-treated and HIV-related deaths. Because CD4 cell count can reflect the disease process of HIV-infected persons, then all HIV-infected persons are divided into four sub-groups in terms of the disease process and the changes of CD4 cells. At the early stage of infection, CD4 cells undergo a dramatic change, and then gradually decrease over time. Finally MSM population are divided into the following nine groups (i.e. nine compartments):

1. HIV-susceptible individuals: The number of HIV-susceptible individuals is $S(t)$, which indicates

the number of MSM who are not infected at time t but are likely to be infected.

2. Individuals with acute HIV infection: The number of HIV patients in acute infection period is recorded as $I_1(t)$, indicating that the time of t is the beginning of infection, and the number of CD_4 cells change dramatically.
3. HIV-infected individuals in early latent infection stage: The number of HIV- infected individuals in early latent infection stage is $I_2(t)$, indicating that the number of CD_4 cells at time t is more than 350 cells/mm^3.
4. HIV-infected individuals in later latent infection stage: The number of HIV-infected individuals in later latent infection stage is $I_3(t)$, indicating that the number of CD_4 cells at time t is between 200 cells/mm^3 and 350 cells/mm^3.
5. AIDS patients: The number of AIDS patients is $I_4(t)$, indicating that the number of CD_4 cells at time t is under 200 cells/mm^3.
6. HIV-infected individuals on antiretroviral therapy (ART) in early latent stage of HIV infection: The number of people participating in the treatment of HIV early latent stage is recorded as $A_2(t)$, indicating the number of people who start ART when the cell count is more than 350 cells/mm^3.
7. HIV-infected individuals on ART in later latent stage of HIV infection: The number of people participating in the treatment of HIV later latent stage is recorded as $A_2(t)$, indicating that people who start ART when the cell count is between 200 cells/mm^3 and 350 cells/mm^3.
8. HIV-infected individuals on ART in AIDS stage: The number of HIV-infected individuals on ART in AIDS stage is recorded as $A_3(t)$, indicating the number of people who start ART when the cell count is less than 200 cells/mm^3.
9. Deceased individuals due to AIDS: The number of people who died of AIDS is recorded as $D(t)$.

In the following, some notations and assumptions are given.

Let π_{NR} and C_{NR} represent condom use rate and high-risk sexual behavior frequency in fixed MSM population, respectively; π_{NC} and C_{NC} represent condom use rate and high-risk sexual behavior frequency in non-fixed MSM population, respectively. The total population of MSM population is assumed as $N(t) = S(t) + I_1(t) + I_2(t) + I_3(t) + I_4(t) + A_2(t) + A_3(t) + A_4(t)$. In order to further explore the influence of media on different interventions, we define the media impact factors: g_1 and g_2, where g_1 embodies the influence of media publicity on condom use ($g_1 \in [0, 1]$); g_2 reflects the influence of media publicity on the rate of participation in treatment ($g_2 \in [1, 1.23]$). When $g_1 = g_2 = 1$, there is no media influence.

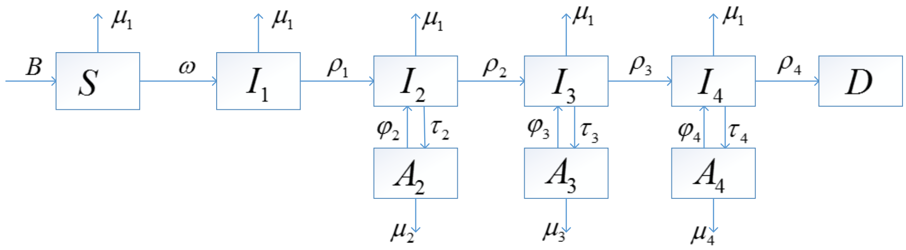

Figure 1. Transfer diagram for AIDS transmission in MSM population.

On the basis of the above assumptions (see Figure 1), the model is proposed as follows:

$$\begin{cases} \dfrac{dS}{dt} = B - \omega S - \mu_1 S, \\ \dfrac{dI_1}{dt} = \omega S - \rho_1 I_1 - \mu_1 I_1, \\ \dfrac{dI_2}{dt} = \rho_1 I_1 + \varphi_2 A_2 - (g_2\tau_2 + \mu_1 + \rho_2) I_2, \\ \dfrac{dI_3}{dt} = \rho_2 I_2 + \varphi_3 A_3 - (g_2\tau_3 + \mu_1 + \rho_3) I_3, \\ \dfrac{dI_4}{dt} = \rho_3 I_3 + \varphi_4 A_4 - (g_2\tau_4 + \mu_1 + \rho_4) I_4, \\ \dfrac{dA_2}{dt} = g_2\tau_2 I_2 - (\varphi_2 + \mu_2) A_2, \\ \dfrac{dA_3}{dt} = g_2\tau_3 I_3 - (\varphi_3 + \mu_3) A_3, \\ \dfrac{dA_4}{dt} = g_2\tau_4 I_4 - (\varphi_4 + \mu_4) A_4, \end{cases} \tag{2.1}$$

where

$$\omega = [g_1(1-\pi_{NC})C_{NC} + g_1(1-\pi_{NR})C_{NR}]\beta(q_1 I_1 + q_2 I_2 + q_3 I_3 + q_4 I_4 + \varepsilon q_2 A_2 + \varepsilon q_3 A_3 + \varepsilon q_4 A_4)/N,$$

and the descriptions of other parameters of model (2.1) are listed in Table 1.

From model (2.1), we can get $dN/dt = B - \mu_1 N - \rho_4 I_4 \leq B - \mu_1 N$. By using the comparison principle, $N(t)$ is ultimately bounded. The feasible domain of model (2.1) is

$$\Omega = \left\{ (S, I_1, I_2, I_3, I_4, A_2, A_3, A_4) \in R_+^8 : N \leq \frac{B}{\mu_1} \right\}. \tag{2.2}$$

It is not difficult to verify that Ω is a positive invariant set of model (2.1).

3. Model analysis

The disease-free equilibrium E_0 of model (2.1) is $(B/\mu_1, 0, 0, 0, 0, 0, 0, 0)$. Using the method presented by Van den Driessche and Watmough [10] to calculate the next generation matrix, there follow

$$F = \beta \cdot \begin{pmatrix} kq_1 & kq_2 & kq_3 & kq_4 & k\varepsilon q_2 & k\varepsilon q_3 & k\varepsilon q_4 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

and

$$V = \begin{pmatrix} \rho_1+\mu_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\rho_1 & g_2\tau_2+\mu_1+\rho_2 & 0 & 0 & -\varphi_2 & 0 & 0 \\ 0 & -\rho_2 & g_2\tau_3+\mu_1+\rho_3 & 0 & 0 & -\varphi_3 & 0 \\ 0 & 0 & -\rho_3 & g_2\tau_4+\mu_1+\rho_4 & 0 & 0 & -\varphi_4 \\ 0 & -g_2\tau_2 & 0 & 0 & \varphi_2+\mu_2 & 0 & 0 \\ 0 & 0 & -g_2\tau_3 & 0 & 0 & \varphi_3+\mu_3 & 0 \\ 0 & 0 & 0 & -g_2\tau_4 & 0 & 0 & \varphi_4+\mu_4 \end{pmatrix}.$$

The basic reproduction number is $R_0 = \rho(FV^{-1})$ where ρ represents the spectral radius of the regeneration matrix FV^{-1}. Hence, we can obtain

$$R_0 = k(M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7),$$

where $k = g_1(1-\pi_{NC})C_{NC} + g_1(1-\pi_{NR})C_{NR}$,

$$\begin{aligned}
M_1 &= \frac{q_1\beta}{\rho_1+\mu_1},\\
M_2 &= \frac{\rho_1}{\mu_1+\rho_1}\cdot\frac{q_2\beta}{\mu_1+\rho_2+\frac{g_2\tau_2\mu_2}{\varphi_2+\mu_2}},\\
M_3 &= \frac{\rho_1}{\mu_1+\rho_1}\cdot\frac{\rho_2}{\mu_1+\rho_2+\frac{g_2\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{q_3\beta}{\mu_1+\rho_3+\frac{g_2\tau_3\mu_3}{\varphi_3+\mu_3}},\\
M_4 &= \frac{\rho_1}{\mu_1+\rho_1}\cdot\frac{\rho_2}{\mu_1+\rho_2+\frac{g_2\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\rho_3}{\mu_1+\rho_3+\frac{g_2\tau_3\mu_3}{\varphi_3+\mu_3}}\cdot\frac{q_4\beta}{\mu_1+\rho_4+\frac{g_2\tau_4\mu_4}{\varphi_4+\mu_4}},\\
M_5 &= \frac{\rho_1}{\mu_1+\rho_1}\cdot\frac{g_2\tau_2}{\mu_1+\rho_2+\frac{g_2\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\varepsilon q_2\beta}{\varphi_2+\mu_2},\\
M_6 &= \frac{\rho_1}{\mu_1+\rho_1}\cdot\frac{\rho_2}{\mu_1+\rho_2+\frac{g_2\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{g_2\tau_3}{\mu_1+\rho_3+\frac{g_2\tau_3\mu_3}{\varphi_3+\mu_3}}\cdot\frac{\varepsilon q_3\beta}{\varphi_3+\mu_3},\\
M_7 &= \frac{\rho_1}{\mu_1+\rho_1}\cdot\frac{\rho_2}{\mu_1+\rho_2+\frac{g_2\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\rho_3}{\mu_1+\rho_3+\frac{g_2\tau_3\mu_3}{\varphi_3+\mu_3}}\cdot\frac{g_2\tau_4}{\mu_1+\rho_4+\frac{g_2\tau_4\mu_4}{\varphi_4+\mu_4}}\cdot\frac{\varepsilon q_4\beta}{\varphi_4+\mu_4}.
\end{aligned}$$

The compartment I_1 means that when a new MSM infector enters I_1 the average time in I_1 is $1/(\rho_1 + \mu_1)$, and the infection rate is $q_1\beta$, thus the number of people infected by a new MSM infector in I_1 is kM_1. The compartment I_2 means that the infected persons in I_1 enter compartment in the proportion of $\rho_1/(k_2 + \rho_1 + \mu)$, the average time in I_2 is $1/(\rho_2 + \mu_1 + (\mu_2 g_2\tau_2/\varphi_2 + \mu_2))$, and the infection rate is $q_2\beta$, hence kM_2 means that the number of people infected during the stay time in I_2. The biological meanings of other compartments can be obtained similarly.

Theorem 3.1. *If $R_0 < 1$, the disease-free equilibrium E_0 is globally attractive.*

Proof. By model (2.1), we have

$$\frac{dI_1}{dt} + (\rho_1 + \mu_1)I_1 = \omega S,$$

and then $[I_1 e^{(\rho_1+\mu_1)t}]' = \omega S e^{(\rho_1+\mu_1)t}$, consequently,

$$I_1(t) = I_1(0)e^{-(\rho_1+\mu_1)t} + e^{-(\rho_1+\mu_1)t}\int_0^t \omega S e^{(\rho_1+\mu_1)u} du.$$

Taking the upper limit on both sides of the above equation,

$$\begin{aligned}
&\limsup_{t\to\infty} I_1(t)\\
=&\limsup_{t\to\infty}\left[I_1(0)e^{-(\rho_1+\mu_1)t} + e^{-(\rho_1+\mu_1)t}\int_0^t \omega S e^{(\rho_1+\mu_1)u} du\right]\\
=&\limsup_{t\to\infty}\left[\omega(\xi(t))S(\xi(t))e^{-(\rho_1+\mu_1)t}\int_0^{\frac{t}{2}} e^{(\rho_1+\mu_1)u} du + \omega(\eta(t))S(\eta(t))e^{-(\rho_1+\mu_1)t}\int_{\frac{t}{2}}^t e^{(\rho_1+\mu_1)u} du\right]\\
\le&\limsup_{t\to\infty}\frac{\omega(\xi(t))S(\xi(t))}{\rho_1+\mu_1}\left[e^{-(\rho_1+\mu_1)\frac{t}{2}} - e^{-(\rho_1+\mu_1)t}\right] + \limsup_{t\to\infty}\frac{\omega(\eta(t))S(\eta(t))}{\rho_1+\mu_1}\left[1 - e^{-(\rho_1+\mu_1)\frac{t}{2}}\right] \qquad (3.1)\\
\le&\limsup_{t\to\infty}\frac{\omega(t)S(t)}{\rho_1+\mu_1}\\
\le&\frac{k}{\rho_1+\mu_1}(q_1\beta\limsup_{t\to\infty} I_1(t) + q_2\beta\limsup_{t\to\infty} I_2(t) + q_3\beta\limsup_{t\to\infty} I_3(t) + q_4\beta\limsup_{t\to\infty} I_4(t)\\
&+ \varepsilon q_2\beta\limsup_{t\to\infty} A_2(t) + \varepsilon q_3\beta\limsup_{t\to\infty} A_3(t) + \varepsilon q_4\beta\limsup_{t\to\infty} A_4(t))
\end{aligned}$$

In the same way, the following results can be obtained,

$$\begin{aligned}
\limsup_{t\to\infty} I_2(t) &\le \frac{\rho_1}{\tau_2+\mu_1+\rho_2}\limsup_{t\to\infty} I_1(t) + \frac{\varphi_2}{\tau_2+\mu_1+\rho_2}\limsup_{t\to\infty} A_2(t),\\
\limsup_{t\to\infty} I_3(t) &\le \frac{\rho_2}{\tau_3+\mu_1+\rho_3}\limsup_{t\to\infty} I_2(t) + \frac{\varphi_3}{\tau_3+\mu_1+\rho_3}\limsup_{t\to\infty} A_3(t),\\
\limsup_{t\to\infty} I_4(t) &\le \frac{\rho_3}{\tau_4+\mu_1+\rho_4}\limsup_{t\to\infty} I_3(t) + \frac{\varphi_4}{\tau_4+\mu_1+\rho_4}\limsup_{t\to\infty} A_4(t),\\
\limsup_{t\to\infty} A_2(t) &\le \frac{\tau_2}{\varphi_2+\mu_2}\limsup_{t\to\infty} I_2(t),\\
\limsup_{t\to\infty} A_3(t) &\le \frac{\tau_3}{\varphi_3+\mu_3}\limsup_{t\to\infty} I_3(t),\\
\limsup_{t\to\infty} A_4(t) &\le \frac{\tau_4}{\varphi_4+\mu_4}\limsup_{t\to\infty} I_4(t),
\end{aligned}$$

Tidy up the formulas above, we can get the following results,

$$\limsup_{t\to\infty} I_2(t) \le \frac{\rho_1}{\mu_1+\rho_2+\frac{\tau_2\mu_2}{\varphi_2+\mu_2}}\limsup_{t\to\infty} I_1(t), \qquad (3.2)$$

$$\limsup_{t\to\infty} I_3(t) \le \frac{\rho_1}{\mu_1+\rho_2+\frac{\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\rho_2}{\mu_1+\rho_3+\frac{\tau_3\mu_3}{\varphi_3+\mu_3}}\limsup_{t\to\infty} I_1(t), \qquad (3.3)$$

$$\limsup_{t\to\infty} I_4(t) \le \frac{\rho_1}{\mu_1+\rho_2+\frac{\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\rho_2}{\mu_1+\rho_3+\frac{\tau_3\mu_3}{\varphi_3+\mu_3}}\cdot\frac{\rho_3}{\mu_1+\rho_4+\frac{\tau_4\mu_4}{\varphi_4+\mu_4}}\limsup_{t\to\infty} I_1(t), \qquad (3.4)$$

$$\limsup_{t\to\infty} A_2(t) \le \frac{\rho_1}{\mu_1+\rho_2+\frac{\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\tau_2}{\varphi_2+\mu_2}\limsup_{t\to\infty} I_1(t), \qquad (3.5)$$

$$\limsup_{t\to\infty} A_3(t) \le \frac{\rho_1}{\mu_1+\rho_2+\frac{\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\rho_2}{\mu_1+\rho_3+\frac{\tau_3\mu_3}{\varphi_3+\mu_3}}\cdot\frac{\tau_3}{\varphi_3+\mu_3}\limsup_{t\to\infty} I_1(t), \tag{3.6}$$

$$\limsup_{t\to\infty} A_4(t) \le \frac{\rho_1}{\mu_1+\rho_2+\frac{\tau_2\mu_2}{\varphi_2+\mu_2}}\cdot\frac{\rho_2}{\mu_1+\rho_3+\frac{\tau_3\mu_3}{\varphi_3+\mu_3}}\cdot\frac{\rho_3}{\mu_1+\rho_4+\frac{\tau_4\mu_4}{\varphi_4+\mu_4}}\cdot\frac{\tau_4}{\varphi_4+\mu_4}\limsup_{t\to\infty} I_1(t). \tag{3.7}$$

Substituting (3.2)-(3.7) into (3.1), we can get

$$\limsup_{t\to\infty} I_1(t) \le k(M_1+M_2+M_3+M_4+M_5+M_6+M_7)\limsup_{t\to\infty} I_1(t) = R_0\limsup_{t\to\infty} I_1(t).$$

Therefore, it holds $\limsup_{t\to\infty} I_1(t) \le 0$ since $R_0 < 1$, and it follows $\lim_{t\to\infty} I_1(t) = 0$. Immediately, we have

$$\lim_{t\to\infty} I_2(t) = 0,\quad \lim_{t\to\infty} I_3(t) = 0,\quad \lim_{t\to\infty} I_4(t) = 0,$$
$$\lim_{t\to\infty} A_2(t) = 0,\quad \lim_{t\to\infty} A_3(t) = 0,\quad \lim_{t\to\infty} A_4(t) = 0.$$

By [11, Lemma 5.1], we can obtain $\liminf_{t\to\infty} S(t) \ge B/\mu_1$. Thus, it follows from (2.2) that $\lim_{t\to\infty} S(t) = B/\mu_1$. Therefore, the disease-free equilibrium E_0 is globally attractive if $R_0 < 1$. □

4. Numerical simulation

Initial data are substituted into model (2.1), the parameter values in numerical intervals are taken randomly 1000 times, and then the model is simulated 1000 times, see Table 1 and Table 2. It is concluded that under the current measures (without media factors), the number of new HIV infections in MSM population in Beijing will increase persistently every year, as shown in Figure 2.

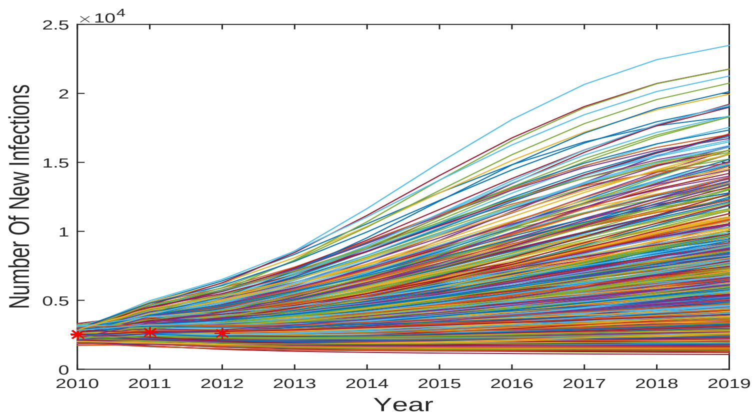

Figure 2. Numerical simulations of AIDS cases in Beijing MSM from 2010 to 2019.

Based on the established model and estimated parameters, we may conclude that by 2019, there will be 4107 new MSM infection cases, which will form a huge "hidden danger" of AIDS transmission. It is worth mentioning that the star "∗" in Figure 2 indicates the number of new HIV/AIDS cases found by CDC or medical departments every year. While some infected persons still have not been found. This is because MSM population is more difficult to find than other groups. These undetected infectors, on the one hand, do not get timely and effective treatment, on the other hand, they do not know their own infection situation, will infect more susceptible people.

Table 1. Descriptions and values of parameters for model (2.1).

Description of parameter	Value	Source
B: MSM annual increase in population	4463-8925	[12]
ρ_1: Probability of HIV infection progressing to pre-incubation in acute infection	4	[12]
ρ_2: Probability of progression to later latency in untreated HIV infections at pre-incubation stage	0.2301	[12]
ρ_3: Probability of progression from untreated HIV infections to AIDS in later latency	0.3755	[12]
ρ_4: Probability of death in HIV patients with untreated infection during AIDS	0.5	[12]
μ_1Probability of HIV-susceptible and untreated HIV-infected people dying or not having homosexual behavior every year due to non-AIDS causes	0.0343	[12]
μ_2: Probability of death or no longer homosexual behavior in infected individuals who begin treatment in the early stages of HIV incubation	0.0343	[12]
μ_3: Probability of death or no longer homosexual behavior in infected individuals who begin treatment in the later stages of HIV incubation	0.0514	[12]
μ_4: Probability of death or no longer homosexual behavior in infected individuals who begin treatment in AIDS stage	0.0668	[12]
τ_2: Probability of new annual participation in treatment for those who have not received ART in the early stage of HIV incubation	0, 0.49, 0.81	[12]
τ_3: Probability of new participation in treatment for those who have not received ART in the later stage of HIV latent	0.39, 0.49, 0.81	[12]
τ_4: Probability of new participation in treatment for those who have not received ART in AIDS stage	0.39, 0.49, 0.81	[12]
φ_2: Probability of withdrawal from ART annually for HIV-infected patients in the pre-incubation period	0.03-0.07	[12]
φ_3: Probability of withdrawal from ART annually in the later latent stage of HIV infection	0.03-0.07	[12]
φ_4: Probability of annual withdrawal from ART in AIDS patients	0.03-0.07	[12]
π_{NC}: Probability of condom use between HIV-infected persons and non-fixed sexual partners	37.7%	[13, 14, 15]
C_{NC}: Times of high-risk sexual behaviors between HIV-infected persons and non-fixed sex partners	18.2	[13, 14, 15]
π_{NR}: Probability of condom use between HIV-infected persons and fixed sexual partners	30.7%	[13, 14, 15]
C_{NR}: Times of high-risk sexual behaviors between HIV-infected persons and fixed sex partners	36.5	[13, 14, 15]
S: Number of HIV susceptible people in MSM population in Beijing in 2010	101412-202824	[12]
β: The probability of each high-risk sexual behaviors being infected	0.00335	Calculation
N: MSM population size in Beijing in 2010	108000-216000	[12]
q_1: Infectious capacity of untreated patients with acute HIV infection	10	[12]
q_2: Infectious capacity of untreated pre-incubation HIV patients	1	[12]
q_3: Infectious capacity of untreated patients with later latency of HIV	2	[12]
q_4: Infectious capacity of untreated HIV patients	5	[12]
ε: The rate at which HIV patients' ability to become infected declines after treatment	0.04-0.1	[12]

Table 2. Initial data of model (2.1) from Beijing.

Compartment	Initial value	Compartment	Initial value
S	101412-202824	I_4	1027-2054
I_1	179-358	A_2	19
I_2	3067-6134	A_3	170
I_3	1727-3754	A_4	399

5. Results and discussion

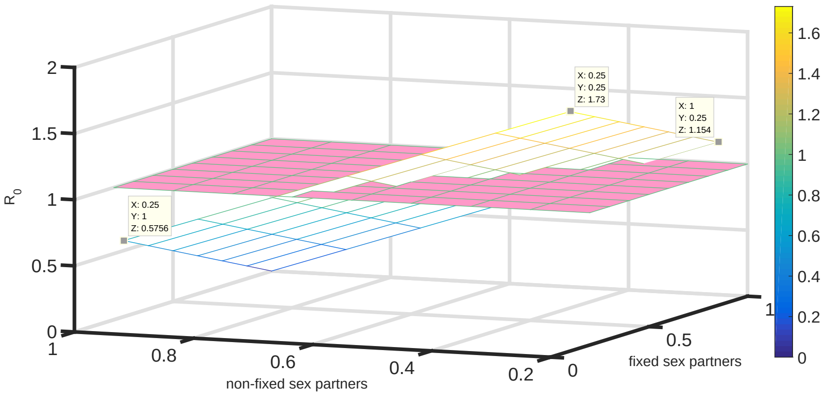

Figure 3. Relationship between condom usage and R_0.

At the same time, the influence of the simultaneous change of condom use rate between MSM non-fixed partners and fixed partners on the basic reproduction number R_0 has been analyzed. From Figure 3, it can be seen that with the increase of condom use rate between MSM fixed partners and non-fixed partners from 25% to 100%, R_0 will gradually decrease from its maximum value 1.73 to 0, consequently, the range of $R_0 < 1$ can be obtained. In addition, Figure 3 shows that when the condom use rate with fixed partner is 100%, and with non-fixed partner is 25%, R_0 decreases to 0.5756; while fixed partner condom use rate is 25%, non-fixed partner condom use rate is 100%, R_0 decreases to 1.154. A conclusion can be drawn that improving the condom use rate with fixed partner can reduce the value of R_0 more effectively.

In order to further explore the influence of media factors on the detection and treatment measures, the number of new HIV cases is compared under three measures: take no account of media impact factors, denoted by S_1; the media factors affect the detection and treatment, denoted by S_2; the media factors act on condom use, denoted by S_3. In the measure S_2, with the help of publicity and education, the detection and treatment rate can be increased by $g_2\tau_i$ $(i = 2, 3, 4)$, where τ_i indicates the detection and treatment rate of the original infected persons. The three schemes are introduced into the model and then numerical simulation is carried out, where the media impact factors are taken as $g_1 = 0.92$ and $g_2 = 1.2$.

When the detection rate of HIV infected persons is 50%, the proportion of pre-treatment of HIV-infected individuals is 0%; the proportion of HIV treatment at the later stage is 78%, and when it at the AIDS stage is 78%, we take $\tau_2 = 0$, $\tau_3 = 0.39$, $\tau_4 = 0.39$. The numerical simulation results show that the number of new HIV cases in MSM will be around 4107 in 2019 without media factors, as shown in Figure 4. If media factors act on condom usage, the number of new HIV cases in MSM will reach 3260, compared with no media factors, which will be reduced by 20.62%. If the media factors act on the detection and treatment, the number of new HIV cases in MSM will reach 3744, compared with no media factors, which will decrease by 8.84%. Therefore, the effect of the measure S_3 is obviously stronger than other measures, MSM has the lowest number of new HIV infections per year.

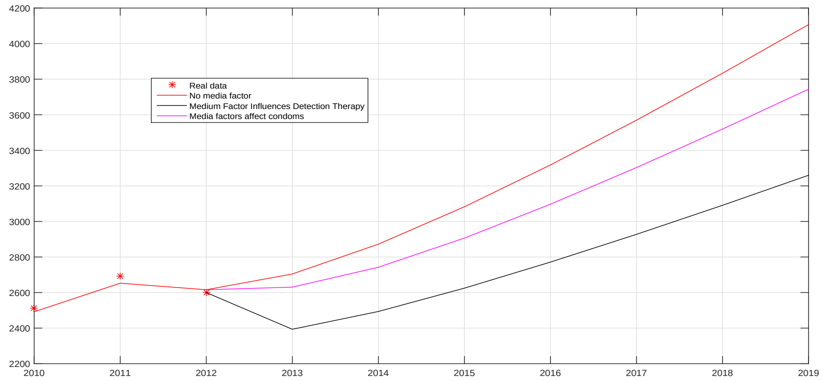

Figure 4. Effect of different media propaganda interventions.

If detection rate of HIV infection is 70%, the pre-incubation treatment proportion is 70%, the post-incubation treatment proportion is 70%. If the proportion of AIDS treatment is 70%, we take $\tau_2 = 0.49$, $\tau_3 = 0.49$, $\tau_4 = 0.49$. The numerical simulation results show that the number of new HIV cases in MSM will reach 1010 in 2019 without media factors, as shown in Figure 5. If media factors act on condom usage, the number of new HIV cases in MSM will reach 740, which will be reduced by 26.73% compared with no media factors. If the media factors affect the detection and treatment, the number of new HIV cases in MSM will reach 825, which will be decreased by 18.32% compared with no media factors. Therefore, the effect of the measure S_3 is more significant than other measures, MSM has the lowest number of new HIV infections per year.

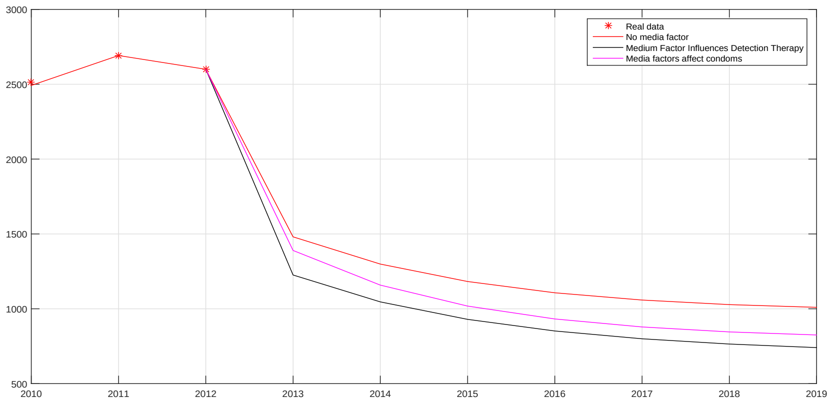

Figure 5. Effect of different media propaganda interventions.

When detection rate of HIV-infected persons is 90%, the pre-latent treatment proportion is 90%, the post-latent treatment proportion is 90% , and if the proportion of AIDS treatment is 90%, we take $\tau_2 = 0.81$, $\tau_3 = 0.81$, $\tau_4 = 0.81$. The numerical simulation results show that the number of new HIV cases in MSM will reach 542 in 2019 without media impact factors, as shown in Figure 6. If media factors act on condom use, the number of new HIV cases in MSM will reach 417, which will be reduced by 23.06% compared with no media factors. If the media factors affect the detection and treatment, the number of new HIV cases in MSM will reach 468, it follows a decrease of 13.65% compared with no media factors. Therefore, the effect of the measure S_3 is also more obvious than other measures, MSM has the lowest number of new HIV infections per year.

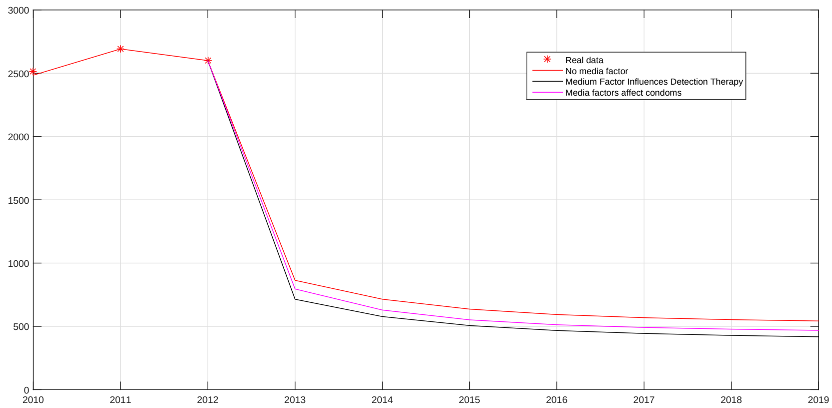

Figure 6. Effect of different media propaganda interventions.

With the comparison of the above three cases, it can be concluded that increasing the intensity of detection and treatment can rapidly reduce the number of new HIV infections in MSM population. Each kind of detection and treatment, propaganda of detection and treatment can partly reduce the number of new HIV infections in MSM population. Furthermore, propaganda of condom use can greatly reduce the number of new HIV infections in MSM population. In consequence, we know that the measure S_3 will be more effective.

6. Conclusion

Based on the heterogeneity of fixed and non-fixed partners in MSM population, we have proposed a model of AIDS transmission in MSM population in Beijing, employing the data of new HIV cases of MSM in Beijing from 2010 to 2012, our model can reflect the mechanisms of AIDS transmission in MSM population. In the absence of any measures, the basic reproduction number $R_0 = 1.5447 > 1$, which indicates the new AIDS infections among MSM population in Beijing will be persistent in the future.

Increasing the rate of condom use with fixed partners will be of significant measure on the basic reproduction number R_0. Strengthening the publicity of condom use with fixed partners is more effective in controlling the spread of AIDS. With the above discussion of the effect of media factors on different measures under three different detection and treatment intensity, it shows that the effect of media promotion on condom use is better than that of other measures.

To sum up, CDC should strengthen the detection and treatment, and emphasize the use of condoms when using new media platforms for publicity and education, so as to curb the further spread of AIDS in the MSM community. Increasing the use of condoms in MSM population, especially the use of condoms with fixed partners, can be more effective in preventing AIDS. In the process of MSM sexual behavior, the use of condoms should not be neglected because of the fixed partner's trust, otherwise it will increase the risk of AIDS. In addition, the HIV detection rate of MSM population should be further increased such that more MSM know their own infection situation, and with the aid of media intervention and other measures, the risk of AIDS transmission can be reduced.

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Conflict of interest

The authors declare there is no conflict of interest in this paper.

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