Infectious Disease Modelling 1 (2016) 3–10

Contents lists available at ScienceDirect

Infectious Disease Modelling

journal homepage: www.keaipublishing.com/idm

A mathematical modeling study of the HIV epidemics at two rural townships in the Liangshan Prefecture of the Sichuan Province of China

Zhimin Su [a, 1], Caiting Dong [b, 1], Ping Li [c, d], Hongxia Deng [e], Yuhan Gong [f], Shiyong Zhong [g], Min Wu [h], Yuhua Ruan [c], Guangming Qin [b], Wen Yang [b, *], Yiming Shao [c, d, *], Michael Li [a, *]

[a] Department of Mathematical and Statistical Sciences, University of Alberta, Edmonton, Alberta, T6G 2G1, Canada
[b] Sichuan Provincial Center for Disease Control and Prevention, Chengdu 610041, Sichuan Province, China
[c] State Key Laboratory of Infectious Disease Prevention and Control (SKLID), Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases, Chinese Center for Disease Control and Prevention (China CDC), Beijing 102206, China
[d] Guangxi Key Laboratory of AIDS Prevention and Treatment, School of Public Health, Guangxi Medical University, Nanning, Guangxi 530021, China
[e] Butuo Township Hospital, Butuo County, Sichuan Province, China
[f] Liangshan Prefecture Center for Disease Control and Prevention, Sichuan Province, China
[g] Butuo Center for Disease Control and Prevention, Butuo County, Sichuan Province, China
[h] Butuo People's Hospital, Butuo County, Sichuan Province, China

ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form 4 May 2016
Accepted 5 May 2016
Available online 16 May 2016

Keywords:
HIV epidemiology
HIV testing and treatment
mathematical modeling

ABSTRACT

Background: As a response to a severe HIV epidemic in the Liangshan Prefecture, one of the worst in China, population based HIV interventions, including two population-wide HIV screening, have been carried out since 2005 at two townships in a remote mountainous region of Liangshan. The objective of our mathematical modeling study is to assess the temporal dynamics of the HIV epidemic in the two townships based on the data collected in the study area during the period 2005–2010.

Methods: A mathematical model was set up to describe the population dynamics of HIV transmission in study area. The model was calibrated by fitting it to the HIV testing and treatment data from 2005 to 2008. Validation of the model was done by comparing its predicted value of HIV prevalence in 2010 to the prevalence data obtained in the 2010 population wide HIV testing. The validated model was used to produce estimation of HIV incidence, prevalence and death.

Results: Our model estimations show that population-based HIV interventions have significantly slowed down the rise of the HIV epidemic in the two townships. Over the five-year period from 2005 to 2010, the year-over-year rate of increase in HIV incidence, prevalence, and death has declined by 91.5%, 28.7%, and 52.3%, respectively.

Conclusion: Mathematical models, when integrated with epidemiological and surveillance data, can be an effective tool for predicting the temporal dynamics of HIV and assessing the impacts of HIV interventions.

Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immune deficiency syndrome; PLHIV, people living with HIV/AIDS; ART, anti-retroviral therapy; MCMC, Markov chain Monte Carlo; LHS, Latin Hypercube sampling.

* Corresponding authors.
E-mail addresses: yangwenn@yeah.net (W. Yang), yshao08@gmail.com (Y. Shao), mli@math.ualberta.ca (M. Li).

Peer review under responsibility of KeAi Communications Co., Ltd.

[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.idm.2016.05.001

1. Background

Major challenges to the effective control of the HIV epidemics in China include the heterogeneity of populations, economic conditions, social structures and local HIV transmission dynamics across its vast and diverse geographic regions. At the national level, it was estimated that about 740,000 people are living with HIV (PLHIV) in 2009, and an additional 105,000 people are surviving AIDS (CD4 count $< 200/mm^3$) (Ministry of Health, China, 2011). While all of the country's 31 provinces and autonomous regions have reported HIV cases, the top six high-prevalence provinces (Yunnan, Guangxi, Henan, Sichuan, Xinjiang, and Guangdong) in 2009 have accounted for 77.1% of the cumulative HIV reports in the country, and for over 60% of the national number of people living with HIV (PLHIV) (Ministry of Health, China, 2011). In certain remote rural townships, the HIV prevalence among adults can be 200 times higher than the national average (Li, 2013).

Liangshan Yi Autonomous Prefecture in the Sichuan Province is among the regions with the highest HIV prevalence rate, accounting for 56.4% of cumulative reported cases of HIV/AIDS in the province at the end of 2010. The severe HIV epidemic in Liangshan was attributed to the prefecture's location along one of the major drug trafficking routes to northwest and central China from the "Golden Triangle", one of the world's largest illicit heroin production and distribution centers, and to the large number of injected drug users from the remote areas in the northeastern part of the prefecture. A large migrant population of farmers, who goes to other regions and provinces to seek work and travel between home and their work places, accounts for 15% of the prefecture's 4.73 million population in 2011. National HIV surveillance data have shown that migrant workers from Liangshan have contributed to the spread of HIV to 30 other provinces. To effectively control the HIV epidemics in Liangshan, the local government has partnered with the Chinese Center for Disease Control and Prevention and the Sichuan Center for Disease Control and Prevention to start in 2005 comprehensive HIV intervention and control programs in two remote rural townships, Jiudu and Muer, with a combined population of about 10,000. The interventions included expanded methadone clinics to help people aviod injection drugs, and expanded HIV testing and ART treatment coverage. Experiences and lessons learned from these localized programs will help improve the HIV control programs in larger high-prevalence regions.

To fully understand the severity of the HIV epidemic and establish a baseline of the HIV prevalence in the Lianshan Prefecture, two population-wide HIV screening programs were carried out in 2008 and 2010 in the Jiudu and Muer townships. The 2008 screening program tested close to 50% of the population in both townships for HIV. Test data showed an HIV prevalence rate of 18.32% among adults aged between 15 and 49 (Li, 2013). In 2010, with the support from the National 11-5 Major Research Project on the Prevention and Control of HIV, Viral Hepatitis and Other Major Infectious Diseases, a population-wide physical examination was conducted in Jiudu and Muer. Baseline individual health records, including HIV status, were established for over 99% of the population in the two townships. Concurrent with the increase of HIV screening, enrollment into ART treatment programs was also greatly expanded. In 2005, there was only one HIV patient receiving ART treatment in Jiudu and Muer, and the number has risen to 166 by the end of 2010.

The extensive HIV data collected in the Jiudu and Muer townships, which were categorized and analyzed in the doctoral dissertation of Dr. Ping Li (2013), provided a unique dataset for a mathematical modeling study of temporal dynamics of the HIV epidemic. The prevalence data in year 2010 based on HIV testing of 99% of the population provided a "gold standard" for model validation.

Our mathematical model for the HIV transmission dynamics was first calibrated using the surveillance and treatment data for the period 2005–2008 collected in the two townships (Li, 2013). We validated our model by comparing its predicted value of HIV prevalence in 2010 to the prevalence data of 2010. The validated model produced estimations on the number of new HIV infections, people living with HIV (PLHIV), and HIV/AIDS related death for 2005–2010. These model estimations and their temporal trend provided the local health authorities with a better understanding of the true burden of the HIV epidemics among the studied populations, and were used to assess the impacts of HIV intervention programs.

2. Methods

2.1. Model

We constructed a deterministic transmission model that describes the process of susceptible people (in compartment S) becoming infected with HIV (in compartment I) through horizontal transmission, and being diagnosed (in compartment D) through HIV testing, and then being enrolled into ART treatment programs (in compartment T). By this categorization, people in compartment I are HIV positive but undiagnosed or unaware of their HIV status. People who were in a treatment program but experienced treatment failures or were lost to follow-up belong to compartment D. The model is depicted in the transfer diagram in Figure 1.