Tropical Medicine and Health Vol. 32 No. 3, 2004, pp. 249-251
Copyright© 2004 by The Japanese Society of Tropical Medicine

A SIMULATION SHEDS A LIGHT ON THE PRESENT HIV EPIDEMIC

TARO YAMAMOTO MD. PhD[1*], YOSHIKI HAMADA MD[1], AFETSE YAWO DOTSE MD[1,2], YUJI ATAKA Ph.D[1], and KAZUHIKO MOJI Ph.D[1]
Accepted 19, August, 2004

Abstract: A hypothetical community of one million people where birth rate and death rate are equal was applied to the modified deferential equations Lipsitch and Nowak published in 1995 in order to examine the impact of partner acquisition change on the HIV epidemic over a relatively short term. The results showed that if the partner exchange rate increases from two to three per year in the population, the epidemic caused by a more virulent strain would overweigh that caused by a less virulent strain within a century. This result reveals that an increase in the rate of partner acquisition gives the more virulent strain an advantage in terms of propagating the virus in a given population, at least over a relatively short term of several decades. The partner acquisition rate also exerts an influence on the magnitude of the HIV epidemic and the time it needs to reach a peak in the hypothetical community.

These results indicate that increased sexual contact may be even more important than expected and thus shed a new light on the present HIV epidemic.

INTRODUCTION

To maintain the infectious cycle, a sexually transmitted virus has to remain infectious until at least one member of a couple engages in sexual activity outside the pair. When a sexually transmitted virus, such as HIV-1, exists in a society of relatively monogamous humans, only those pathogens that have some way to prolong infectiousness can be maintained. In other words, to extend their infectiousness, pathogens must avoid both being destroyed by the host's immune system, [1] and causing the host to die. From the evolutionary standpoint, the benefits to the virus of extending infectiousness have to be weighed against both the higher rate of infection and shorter period of infectiousness that is seen in measles, influenza and many other pathogens [2-4]. If this hypothesis is true, what keeps the slowly replicating HIV from being displaced by the rapid replicators in the HIV population as a whole?

An increase in the number of sexual partners should give HIV a chance to spread from one host to another. Even if the high replication-type virus ruins the health of the human host within a relatively short period of time, and, as a result, shortens the period of infectiousness, this disadvantage would be compensated by the increasing chance of infection through sexual contacts.

This conjecture points to a key issue, that is, the fact that the higher the sexual partner rate is, the larger the net benefits to HIV-1from rapid replication will be.

Mathematical modeling promises to provide a powerful tool to evaluate this issue. In the present paper we look at this possibility, with special focus on how much impact an increase in the number of partners exerts on the competition of two different types of HIV-1, i.e. a virulent HIV and a less virulent HIV in the population.

MATERIALS AND METHODS

Mathematical modeling

There have been several studies using mathematical modeling to deal with theoretical predictions about the evolution of parasite virulence [5-7]. Among these, the paper by Lipsitch and Nowak provides important insights into the evolution of HIV-1, investigating whether greater transmission opportunities exist for shorter-duration-of infection strains [8].

We use this mathematical model to determine which strain becomes dominant, the virulent or less virulent strain, as the rate of partner change increases. The spread of the

1. Research Center for Tropical Infectious Diseases, Institute of Tropical Medicine, Nagasaki University.
2. Ministry of Health, Togo.
*Correspondence to: Taro Yamamoto, MD.PhD,
Sakamoto1-12-4, Nagasaki 852-8523, JAPAN
Tel. +81-95-849-7869 Fax. +81-95-849-7869 E-mail: Taroy0103@aol.com

two strains was modeled on the basis of the differential equation created by Lipsitch and Nowak in 1995 [8]. One difference is that, whereas Lipsitch and Nowak applied exponential population growth, we simplify the model, applying a constant population in which birth rate is equal to death rate in order to determine the impact of a change in the acquired number of sexual partners on the competition of two different types of HIV, a virulent strain and less virulent strain, over a relatively short period of time.

The following system of differential equations is used:

$$dS/dt = u*N - (A_1 + A_2 + u)*S \quad (1)$$

$$dY_1/dt = A_1*S - m_1*Y_1 - u*Y_1 \quad (2)$$

$$dY_2/dt = A_2*S - m_2*Y_2 - u*Y_2 \quad (3)$$

Where S is the number of susceptible persons in the population, and Y_1 and Y_2 represent the number of hosts infected with strain 1 and 2, respectively. N is the total population size. New susceptibles are born to all members of the population at a rate of u. Given the prerequisite that population is constant, meaning that birthrate is equal to death rate, u is also the rate at which the hypothetical population dies. The m_i is given by mortality caused by HIV.

The A_i is the so-called “force of infection” for strain i, which is expressed by the following equation:

$$A_i = c*b_i*Y_i /N \quad (4)$$

where c is the rate of new partner acquisition per year, and bi is the probability that a susceptible person will be infected with strain i when an infected individual encounters the susceptible partner.

Hypothetical community and HIV characteristics

The equations are tested under the hypothetical condition that a total population is one million, that life expectancy at birth of the population is fifty years (with an annual death rate of 2%), and that the period of time from infection to death is 3.3 years in the virulent strain and ten years in the less virulent strain. The probability of HIV infection per contact was estimated to be 0.01, which means that an infection occurred every 100 contacts.

RESULTS AND DISCUSSION

Interesting results were obtained from the equations and are shown in Figures 1-a, b, c, and d. Given that partner acquisition rate per year is one, if a single index case of the virulent strain (strain 1) and less virulent strain (strain 2) are introduced into the totally susceptible population of one million people, no epidemic will occur (Fig. 1-a). However, if the partner acquisition rate increases from one to two on average, the less virulent strain will spread over a couple of centuries and reach a stable status, maintaining a prevalence of about seven percent whereas the virulent strain will die out after a small epidemic (Fig. 1-b). If the partner exchange rates increase from two per year to three in the same population, the epidemic caused by the more virulent strain will overweigh that caused by the less virulent strain over several centuries (Fig. 1-c). As the number of partner acquisitions increases from three per year to four, the more virulent strain will become dominant in the early stage of the epidemic in the population, with a peak of over thirty percent of prevalence (Fig. 1-d). If the partner acquisition rate increases, the epidemic caused by the virulent strain will occur only within half a century (Fig. 1-d).

This result may provide an answer to the question of why HIV-1 has become pandemic within a few decades. Although the mathematical modeling is simple, the result reveals that an increase in the rate of partner acquisition gives the virulent strain an advantage in terms of propagating the virus in a given population, at least over a short period of time. It follows that a reduction in partner acquisition rate may contribute to preventing the HIV-1 epidemic both indirectly by depriving the virulent strain of its advantage of spreading in the population and directly by reducing the ability of all strains to transmit one after another.

Furthermore, as partner acquisition rate increases, the subsequent epidemic magnifies more rapidly and less time is needed for the HIV epidemic to reach a peak (Fig. 1-a, b, c, d). In our simulation, when the partner acquisition rate is four per year on average, the HIV epidemic reaches its peak in a mere 25 years, with more than 30% of the population infected with HIV (Fig. 1-d).

Studies from Uganda have revealed that HIV-1 prevalence among young adults significantly declined as a result of behavioral change since the early 1990s. [9-11]. Among women aged 15-19 years, education and marital status-adjusted HIV-1 prevalence declined from 32.2% in 1991 to 10.3% in 1997. For 20-24-year-old women, HIV-1 prevalence decreased from 31.7% in 1993 to 21.7% in 1997. In Uganda, falls in HIV-1 prevalence have been associated with a decrease in the number of sexual partners and pregnancy rate in teenagers, and an increase in reported age at first sex and the frequency of reported condom use. Social factors, such as frequent sexual contact, may be even more important than expected.

The mathematical modeling of Lipsitch and Nowak provided information about long-term historical evolution, giving the unit of time rather than actual time frame work. However, setting the hypothetical population and applying it to our simplification of the mathematical model tells us more intuitively what impact partner acquisition change exerts on the HIV epidemic in a relatively short period of time,

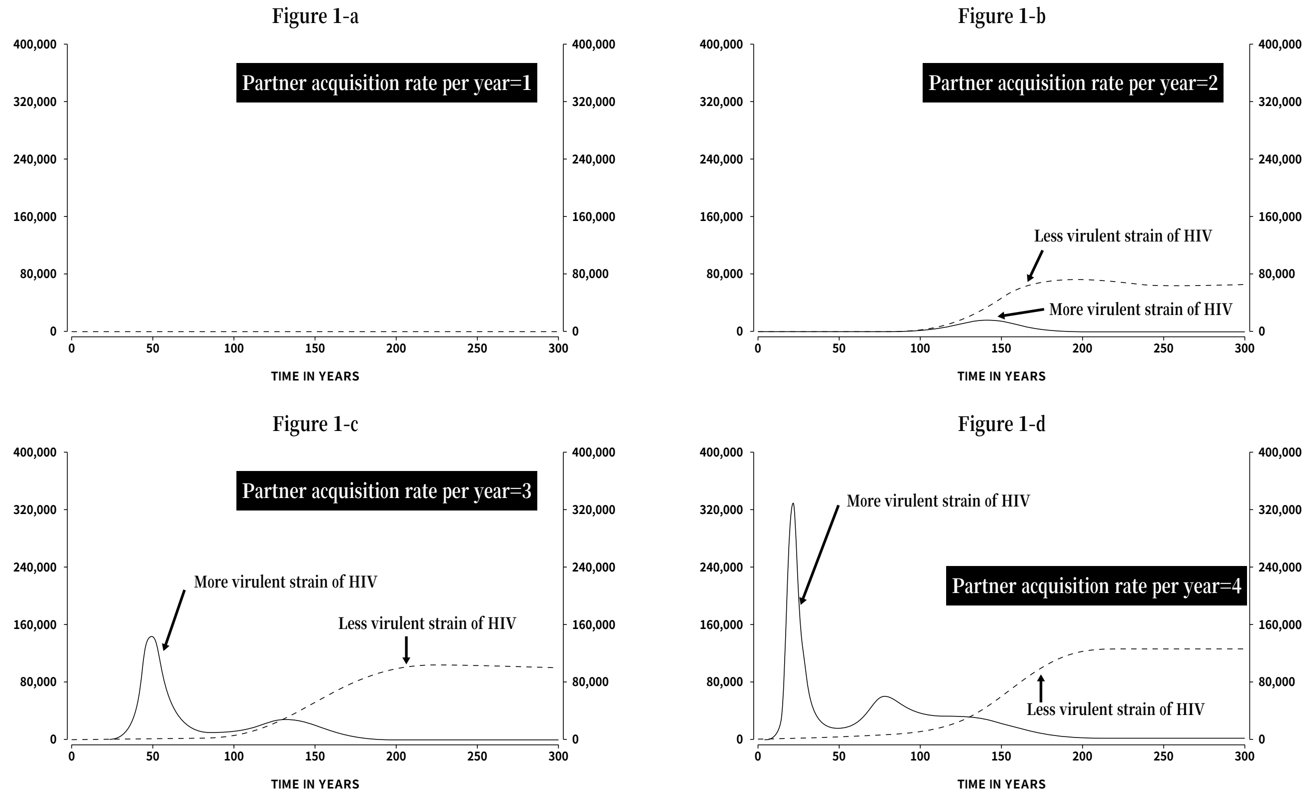

Fig. 1-a, b, c, and d.
The possible dynamical patterns in competition between two strains in a host population are shown. The x axis shows the year. The y axis is the number of individuals infected with the less virulent strain and those infected with the virulent strain. The more frequently people intermingle, the more dominant the more virulent strain will be.

i.e. several decades. Because Lipsitch and Nowak set the unit of time rather than actual time frame, or year, their model provides information about the HIV epidemic both in the short-term and long term but does not reveal the exact meaning of these time frames.

ACKNOWLEDGEMENTS

We are most grateful to the Takemi Program, which provided the opportunity to write this paper. We also express thanks to Professor Michael Reich and Dr. Marc Mitchell at the Department of International Health, Harvard School of Public Health, Boston for their useful advice and assistance in the creation of this manuscript.

REFERENCES

1. Ewald, P.W., *Evolution of Infectious Disease.* 1994, New York: Oxford Univ Press.
2. Fenner, F., *Infectious disease and social change. I.* Med J Aust, 1971. 1 (20): p.1043-7.
3. Clements, C.J. and F.T. Cutts, *The epidemiology of measles: thirty years of vaccination.* Curr Top Microbiol Immunol, 1995. 191: p.13-33.
4. McLean, A.R., *After the honeymoon in measles control.* Lancet, 1995. 345 (8945): p.272.
5. Levin, B.R. and J.J. Bull, *Short-sighted evolution and the virulence of pathogenic microorganisms.* Trends Microbiol, 1994. 2 (3): p.76-81.
6. May, R.M. and R.M. Anderson, *Epidemiology and genetics in the coevolution of parasites and hosts.* Proc R Soc Lond B Biol Sci, 1983. 219 (1216): p.281-313.
7. Ewald, P.W., *Transmission modes and the evolution of virulence: with special reference to cholera, influenza, and AIDS.* Human Nature, 1991. 2: p.1-30.
8. Lipsitch, M. and M.A. Nowak, *The evolution of virulence in sexually transmitted HIV/AIDS.* J Theor Biol, 1995. 174 (4): p.427-40.
9. Kamali, A., et al., *Seven-year trends in HIV-1 infection rates, and changes in sexual behaviour, among adults in rural Uganda.* Aids, 2000. 14 (4): p.427-34.
10. Mulder, D., et al., *Decreasing HIV-1 seroprevalence in young adults in a rural Ugandan cohort.* Bmj, 1995. 311 (7009): p.833-6.
11. Asiimwe-Okiror, G., et al., *Change in sexual behaviour and decline in HIV infection among young pregnant women in urban Uganda.* Aids, 1997. 11 (14): p.1757-63.