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<td>A SIMULATION SHEDS A LIGHT ON THE PRESENT HIV EPIDEMIC</td>
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NAOSITE: Nagasaki University’s Academic Output SITE

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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-1 from 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
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 ex-
ponential population growth, we simplify the model, apply-
ing 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 viru-
 lent strain, over a relatively short period of time.

The following system of differential equations is used:

\[
\begin{align*}
\frac{dS}{dt} &= u*N - (A_i + A_j + u)*S \\
\frac{dY_i}{dt} &= A_i*S - m_i*Y_i - u*Y_i \\
\frac{dY_j}{dt} &= A_j*S - m_j*Y_j - u*Y_j
\end{align*}
\]

Where \( S \) is the number of susceptible persons in the
population, and \( Y_i \) and \( Y_j \) represent the number of hosts in-
fected with strain 1 and 2, respectively. \( N \) is the total popu-
lation size. New susceptibles are born to all members of the
population at a rate of \( u \). Given the prerequisite that popula-
tion is constant, meaning that birthrate is equal to death rate,
\( u \) is also the rate at which the hypothetical population dies.
The \( m \) 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:

\[
A_i = c*bi*Y_i/N
\]

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

Hypothetical community and HIV characteristics

The equations are tested under the hypothetical condi-
tion that a total population is one million, that life expect-
ancy 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 in-
fec tion 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 ex-
change rates increase from two per year to three in the same
population, the epidemic caused by the more virulent strain
will outweigh that caused by the less virulent strain over
several centuries (Fig. 1-c). As the number of partner acquisi-
tions increases from three per year to four, the more viru-
 lent strain will become dominant in the early stage of the
epidemic in the population, with a peak of over thirty per-
cent 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. Al-
though the mathematical modeling is simple, the result re-
veals 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 indi-
rectly 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 preva-
lence 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 preva-
lence 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 preg-
nancy 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 ex-
erts on the HIV epidemic in a relatively short period of time,
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.

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REFERENCES


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.