An Age-Structured Model for the Potential Impact of Generalized Access to Antiretrovirals on the South African HIV Epidemic

Nicolas Bacaër, Carel Pretorius, Bertran Auvert

IRD (Institut de Recherche pour le Développement), 32 avenue Henri Varagnat, 93143 Bondy, France
SACEMA, DST/NRF Centre of Excellence in Epidemiological Modelling and Analysis, Stellenbosch University, Stellenbosch, South Africa
Assistance Publique-Hôpitaux de Paris, University of Versailles, INSERM U687, Paris, France

Received: 5 October 2009 / Accepted: 9 March 2010 / Published online: 27 March 2010
© Society for Mathematical Biology 2010

Abstract A simple mathematical model (Granich et al., Lancet 373:48–57, 2009) suggested recently that annual HIV testing of the population, with all detected HIV+ individuals immediately treated with antiretrovirals, could lead to the long-term decline of HIV in South Africa and could save millions of lives in the next few years. However, the model suggested that the long-term decline of HIV could not be achieved with less frequent HIV testing. Many observers argued that an annual testing rate was very difficult in practice. Small scale trials are nevertheless in preparation. In this paper, we use a more realistic age-structured model, which suggests that the recent high levels of reported condom use could already lead to a long-term decline of HIV in South Africa. The model therefore suggests that trials with for example 20% of the population tested each year would also be interesting. They would have similar (though smaller) advantages in terms of reduction of mortality and incidence, would be much easier to generalize to larger populations, and would not lead to long term persistence of HIV. Our model simulations also suggest that the age distribution of incidence has changed considerably over the past 20 years in South Africa. This raises some concern about an assumption presently used in EPP/Spectrum, the software used by UNAIDS for its estimates.

Keywords HIV · Antiretrovirals · Mathematical model · Age structure

1. Introduction

There are now more than 5 million HIV+ individuals in South Africa alone (Department of Health of South Africa, 2009, p. 35). More than 300,000 AIDS-related deaths occur
An Age-Structured Model for the Potential Impact of Generalized

each year (Department of Health of South Africa, 2009, p. 35) despite the current ART
program, which provides treatment for detected HIV+ people with a CD4 count less than
200. Although the South African treatment guidelines are likely to put this threshold at
350 in the near future, the problem is that many HIV+ people don’t know their HIV status
and go to the hospital at a very late stage of infection when their CD4 count is already
much less than 350 or 200.

Recent modeling work (Granich et al., 2009) suggested that annual HIV testing, with
all detected HIV+ individuals immediately treated with antiretroviral therapy (ART)
whatever the CD4 count, could lead to the long term decline of the HIV epidemic in
South Africa and save millions of lives. The model also suggested that a less frequent
testing rate could not lead to the long-term decline of HIV, but could still save a consid-
erable number of lives. The model used in Granich et al. (2009) was relatively simple
in structure and the assumptions somewhat optimistic. Nevertheless, the modeling results
were striking enough to make a number of experts start considering ART not only as a
treatment but also as a possible prevention method, like condoms or circumcision.

In 2009, the World Health Organization organized several meetings aimed at getting
a better understanding of the various costs and advantages of the strategy advocated in
Granich et al. (2009). ART (including medical follow-up) costs several hundred dollars a
year for each patient (Granich et al., 2009). Even if the new “test and treat” strategy could
save millions of lives, it would cost several billion dollars per year during at least a decade
or two after deployment. To help funding agencies, decide whether such a costly project
is worth trying; modeling can help produce a clearer picture of the situation and how it
can evolve.

In this paper, we use an age-structured model to investigate the “test and treat” strategy
of Granich et al. (2009). We consider a hypothetical average community in which the
age pyramid, HIV prevalence, and overall mortality statistics would be equal to those
of South Africa at the national level. The model also includes a variable for time since
HIV infection and various parameters taking into account the history of interventions
against HIV. Of course, the question of which ingredients are to be put in the model
is controversial. There is no general agreement as to why the HIV epidemic spread so
fast in South Africa when compared to Central or Western Africa. Some argue that the
large migrant male population working in mines and the associated female sex workers
were a key factor (Hargrove, 2008), a possibility which would require in principle a model
different from ours with several risk groups (however, we shall take a relatively high initial
HIV prevalence arguing that this was the result of a subepidemic among sex workers
and their clients). Others emphasize the low level of male circumcision (Williams et al.,
2006) or the fact that age at first marriage is relatively high (Bongaarts, 2007). The latter
factors are taken only implicitly into account in our model through the HIV transmission
probabilities and through the age-specific turnover of sexual partners.

A number of age-structured HIV models have already been developed (see, e.g., An-
derson and May, 1990; Johnson and Dorrington, 2006; Johnson et al., 2009; Stover, 2009).
Our goal was to try to develop the simplest possible age-structured model that could fit
the age-specific HIV and mortality data from South Africa, including the 2008 population
survey (Shisana et al., 2008). The result is therefore of intermediate complexity, including
antiretrovirals unlike the earlier models (Anderson and May, 1990), avoiding risk groups
as in Johnson and Dorrington (2006) or partnership formation as in Johnson et al. (2009),
but relying on a mechanistic assumption for the incidence unlike (Stover, 2009). One of