Expanding HAART to Control the Spread of HIV Among Injection Drug Users
A Mathematical Model

N Richardson, AR Rutherford, B Ramadanovic, B Marshall, A Kaida, P Bastani, A van der Waall, JSG Montaner, VD Lima, K Fernandes, RS Hogg, P Borwein, K Vasarhelyi

The IMPACT-HIV Group
A collaboration of the
BC Centre for Excellence In HIV/AIDS, Vancouver, Canada and the
Complex Systems Modelling Group, Simon Fraser University, Burnaby, Canada

CECM Day 2009 – IRMACS

1 Background

Expanding antiretroviral therapy is considered a potential strategy for controlling the global HIV epidemic. Measurable drops in viral load and HIV incidence correlate with the Introduction of HAART (Highly Active Antiretroviral Therapy). Mathematical models show that HAART can be an effective prevention strategy at the population level, but also raise concerns about unintended increases in HIV risk behaviours when HAART is widely available.

HIV epidemics can become extinct in the presence of social influences modifying risk behaviours. We previously showed, using a risk behaviour-driven, individual-based (cellular automaton) model of injection drug users (IDU), that HIV is rapidly eliminated if social influence to discourage needle sharing reaches a threshold level (Dabbaghian et al., IAS 2008). This effect is similar to herd immunity. We incorporated HAART into this model to examine the impact of a biomedical intervention on the threshold. Therapy was implemented with or without a behavioural intervention to reduce needle-sharing among HAART recipients. We also tested the effect of initiating therapy early.

Our goal is to understand how epidemics are generated in differing risk environments and how interventions can impact this process. Epidemics were simulated over the entire range of social influence parameters and for 10 HAART coverage levels from 0 to 100%.

2 Model Structure and Simulations

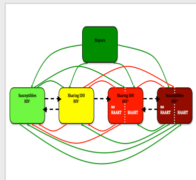


Figure 1. *Model of a Risk behaviour-driven HIV Epidemic Among Injection Drug Users*

The model is based on a Mover-Stayer compartmental model and a cellular automaton (CA). CA simulate individual risk behaviour. Boxes are types of individuals: Stayers, HIV+ and HIV- Susceptibles, HIV+ and HIV- IDU.

Arrows show social influences and transitions. Red arrows encourage, green arrows discourage needle sharing. All except Stayers accumulate social influences from their neighbours. Once a threshold is reached, needle-sharing stops or begins (double dashed arrows). HIV is transmitted at a disease stage-specific probability. (single dashed arrow).

HAART is allocated at eligible individuals at the specified HAART Coverage Level. For each level, 121 (11x11) simulations are run to map the region in the social influence plane where HIV is endemic. A needle-sharing epidemic is mapped similarly.

3 Scenarios and Parameters

Scenario I	Scenario II	Scenario III
Eligible for HAART after 5 years	Eligible for HAART after 5 years	Eligible for HAART after 1 year
No behaviour change when starting HAART	All those initiating HAART stop needle-sharing permanently	All those initiating HAART stop needle-sharing permanently
HAART Coverage 10-100% in steps of 10	HAART Coverage 10-100% in steps of 10	HAART Coverage 10-100% in steps of 10

Parameter[1]		Value
HIV transmission probability	Stage I (2 months) Stage II (7 years) Stage III (1 year)	0.05 0.001 0.01
Needle-sharing rate	Number shared / month	25
Life expectancy	Stayers HIV- Susceptibles All on HAART HIV+ not on HAART, after infection	75 years 55 years 55 years 10 years
Initial Population[2]	Stayers HIV- Susceptibles HIV- Sharing IDU HIV+ Sharing IDU+Susceptibles	5% 67% 17% 5-50%

1 Parameters based on Vancouver's Downtown Eastside
2 Our analytical results show that initial proportions do not influence model results.

4 Results

Scenario I
HAART only
Late initiation

Scenario II
HAART +
Behaviour Change
Late initiation

Scenario III
HAART +
Beahviour Change
Early initiation

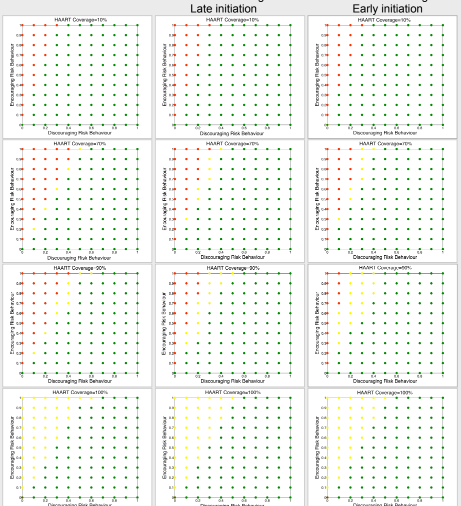


Figure 2. *Simulations of HAART Intervention Scenarios*

100% HAART coverage eliminates epidemics even in the highest risk environments. Each phase diagram above depicts where in the social interaction plane HIV becomes extinct (green) or endemic (red). Yellow dots show needle-sharing epidemics. Simulations were continued until equilibrium was reached, where HIV prevalence is constant in all scenarios (~ 40%). If those on HAART continue to share needles, HIV becomes endemic more easily (Scenario I). If those starting HAART stop sharing needles permanently, this effect is prevented completely (Scenario II). Initiating HAART earlier further magnifies this positive effect (Scenario III).

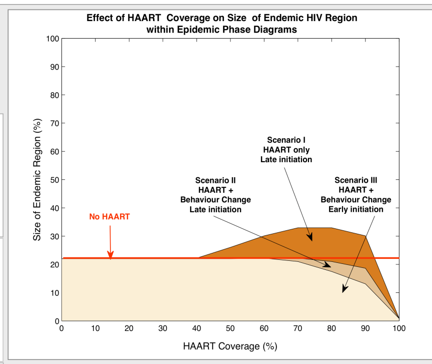


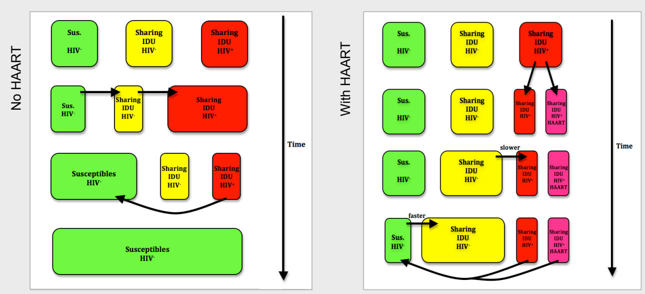
Figure 3. *Changes in the HIV Endemic Region with Increasing HAART Coverage*

Low HAART coverage levels have no effect on how social interactions drive HIV to become endemic. This summarises results in Figure 2. In Scenario I, the endemic region expands for HAART coverage of 40-90%. This is explained in part (see figure 4) by the longer life expectancy of needle-sharing IDU on HAART, who no longer transmit HIV, but continue to encourage others to engage in needle-sharing. This leads to more needle-sharing and HIV transmission.

If HAART recipients stop sharing needles, HAART leads to some reduction of the endemic region. Scenarios II and III may be more realistic because HAART is generally administered within programs that support patients in the therapy process. In these scenarios the endemic regions are reduced below the level seen without HAART.

Figure 4. *How can needle-sharing increase in Scenario I?*

100% HAART coverage eliminates HIV in the model, but needle-sharing epidemics remain. The figures below provide an explanation. If no HAART is applied (below left), HIV transmission keeps the HIV- Sharing IDU category small. Depending on social influence, the entire population becomes either HIV+ or Susceptible. With HAART (below right), fewer HIV infections occur, which keeps the HIV- Sharing IDU category larger. In a positive feedback, this group draws in more Susceptibles by encouraging them to share needles. This effect is more pronounced if HAART is used without behavioural interventions for HAART recipients.



5 Conclusions

Our modelling suggests that HAART has a positive impact on the HIV epidemic. Expanding HAART can potentially eliminate HIV, but in very high risk settings, 100% or close to 100% coverage may be required.

Our results support previous suggestions that HAART should be implemented in combination with behavioural interventions. In our pessimistic scenario, with no change in risk behaviour in HAART recipients, HAART leads to increased HIV prevalence. This scenario is likely to be unrealistic for many drug treatment programs, where support is provided that may reduce risk behaviour. Nonetheless, the results underline the importance of targeting risk behaviour in HAART recipients.

Measuring incidence may provide more complete information on the impact of HAART. We found previously that in the endemic regions prevalence was constant at close to 40%. This was confirmed for all endemic regions in this study. Since HIV transmission and death rate are reduced, while life expectancy increases substantially for HAART recipients, we may find that incidence drops when HAART is implemented. Therefore, incidence should also be included in an assessment of the impact of HAART on the HIV epidemic.

Earlier initiation of HAART appear to have a beneficial effect on the epidemic.

6 Next Steps

Measuring incidence – We will modify the model so that new infections are tracked to provide an improved measure of any intervention to control the HIV epidemic.

Behavioural interventions for those not on HAART – We did not include behavioural interventions for anyone not entering a HAART program. Expanding behavioural interventions along with expansion of HAART will be tested in the future.

Imperfect scenarios – We assume 100% adherence to HAART in the current model. Variations in adherence will be considered in future versions.

Timing of HAART – To fully understand the impact of timing, we will develop more complex timing scenarios for testing.

Social influence scale – Our social influence scale is an abstract conceptualisation of influences that are likely to drive risk behaviours among IDU. We intend to work with social scientists to find or develop measurable social influence scales that can be used to inform the model.

For more information please contact
Natasha Richardson at
nmr@sfu.ca

IMPACT-HIV
impact-hiv@irmacs.sfu.ca

CSMG
http://csmg.irmacs.sfu.ca

British Columbia Centre for Excellence In HIV/AIDS

Complex Systems Modelling Group

This research is supported by grants from the Canadian Institutes for Health Research and the Natural Sciences and Engineering Council of Canada