Viral load monitoring of antiretroviral therapy, cohort viral load and HIV transmission in Southern Africa: A mathematical modelling analysis

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Abstract

Objectives—In low-income settings treatment failure is often identified using CD4 cell count monitoring. Consequently, patients remain on a failing regimen, resulting in a higher risk of transmission. We investigated the benefit of routine viral load monitoring for reducing HIV transmission.

Design—Mathematical model

Methods—We developed a stochastic mathematical model representing the course of individual viral load, immunological response and survival in a cohort of 1,000 HIV infected patients receiving antiretroviral therapy (ART) in southern Africa. We calculated cohort viral load (sum of individual viral loads) and used a mathematical relationship between individual viral load values and transmission probability to estimate the number of new HIV infections. Our model was parameterized with data from the IeDEA Southern African collaboration. Sensitivity analyses were performed to assess the validity of the results in a universal 'test and treat' scenario where patients start ART earlier after HIV infection.

Results—If CD4 cell count alone was regularly monitored, the cohort viral load was 2.6×10^6 copies/mL and the treated patients transmitted on average 6.3 infections each year. With routine viral load monitoring, both cohort viral load and transmissions were reduced by 31% to 1.7×10^6 copies/mL and 4.3 transmissions, respectively. The relative reduction of 31% between monitoring strategies remained similar for different scenarios.

Conclusions—While routine viral load monitoring enhances the preventive effect of ART, the provision of ART to everyone in need should remain the highest priority.

Keywords

mathematical model; Southern Africa; HIV transmission; viral load monitoring; therapy failure; second-line therapy; test and treat

Introduction

In the year 2010, 2.7 million people were newly infected with human immunodeficiency virus (HIV) [1]. The majority of infections occur in sub-Saharan Africa, where resources for patient management remain limited. There is a strong association between plasma HIV viral load and the risk of HIV transmission [2]: meta-analyses of studies of serodiscordant couples showed that patients who were treated with antiretroviral therapy (ART) and had undetectable viral load did not transmit HIV [3, 4]. A more recent randomized controlled trial showed that early initiation of ART reduced transmission of HIV [5]. 'Test and treat', which involves large-scale testing for HIV infection and immediate ART, is a subject of debate [6–8]. The acceptability and feasibility of universal testing and treatment is unclear, and modelling studies have yielded conflicting results [6, 9, 10]. In particular, it may be difficult to achieve the necessary high levels of adherence to therapy and high-risk sexual behaviours might increase.

Relatively little attention has been paid to the fact that with a 'test and treat' approach, not only the number of people on ART, but the number of individuals failing ART will increase. In high-income settings viral load is measured regularly to detect treatment failure and counsel patients on adherence [11]. In sub-Saharan Africa and other low-income settings, viral load monitoring is not generally available and ART programmes therefore rely on immunological and clinical criteria to identify treatment failure [11]. The World Health Organization (WHO) CD4 count criteria are, however, inaccurate predictors of virological failure [12, 13]. In Malawi and Zambia, where monitoring is based on CD4 cell counts, a study showed that few patients switched to second-line ART and many more remained on a failing first-line regimen compared to ART programmes monitoring viral load in South Africa [14]. Routine viral load monitoring may thus help to prevent new HIV infections by reducing the number of patients on failing first-line regimens.

We developed an individual-based mathematical model to study the importance of routine viral load monitoring versus CD4 cell monitoring on cohort viral load (CVL) and HIV transmission in Southern Africa. We analyzed data from two sites participating in a collaboration of HIV treatment programmes in Southern Africa to parameterize the model and the results of these analyses are also presented.

Methods

Data sources, eligibility and definitions

The International epidemiological Databases to Evaluate AIDS in Southern Africa (IeDEA-SA) is a collaboration of ART programmes in six countries in Southern Africa [15]. Data are collected at ART initiation (baseline) and each follow-up visit, using standardized instruments. All sites have ethical approval to collect data and participate in IeDEA-SA.

We restricted our analyses to the Gugulethu and Khayelitsha ART programmes in Cape Town, South Africa, where viral load and CD4 counts are measured regularly. All treatment-naïve patients aged ≥16 years who had started ART with at least two nucleoside

reverse transcriptase inhibitors (NRTI) and one non-nucleoside reverse transcriptase inhibitor (NNRTI) were included. Second-line ART was defined as a switch from an NNRTI-based regimen to a protease inhibitor (PI)-based regimen, with at least one NRTI changed.

We conducted statistical analyses on the cohort data and did literature searches to estimate parameters. We used parametric and semiparametric models to estimate time to virological failure (viral load over 1,000 copies/mL), immunological failure (according to WHO criteria [16]), death or loss to follow-up. Observed mortality, loss to follow-up and non-HIV background mortality according to the ASSA2008 model for Africans in Western Cape in 2007 [17] were used to calculate the corrected estimate for HIV-related mortality. Details on the statistical and mathematical methods are given in the web appendix (1.1–1.2).

Mathematical model

We adapted a published model that simulated disease progression in a hypothetical cohort of 1,000 HIV-infected patients prior to starting ART [18]. In our model, individuals were simulated independently of each other and the properties of the individual and the timing of events were calculated probabilistically based on a series of rules and parametric distributions. The model included a description of the time period before start of ART and a detailed description of the time from ART start to either death or a fixed maximum follow-up time. In the following paragraph we give a brief explanation of the structure of the model: more details are found in the web appendix (3.1–3.2).

Modelling of treatment response and mortality—Each patient was assigned a baseline age and gender and, based on these, an HIV-free life expectancy was determined. Times of virological and immunological failure were defined by simulating from distributions parameterized by the data. Depending on the chosen monitoring strategy either viral load or CD4 cell count is measured every 6 months. Failures are observed at the next visit after the true unobserved failure and confirmed in a second measurement three months later. Once failure is observed, the patient switches to second-line ART. Second-line failures are defined in the same way as first-line failures using parameters from data, but their probability additionally depends on the time spent on a virologically failing first-line therapy and the first-line immunological response.

Failure and switching events split the patient's follow-up time into different portions, as illustrated in Figure 1. Each patient spends the first three months in the initial stage, after which she either enters a phase of successful treatment or she experiences immunological or virological failure. After virological failure, the hazard of death is assumed to increase over time [19]. Similarly, immunological failure increases the risk of death. After starting second-line therapy the patient enters a three-month period during which the hazard of HIV-related death returns to the level before failure, unless second-line failure occurs. The timing of failures and switching define the mortality hazard, which again determines the time of HIV-related death. To evaluate the level of viral load at the different stages of ART, we analysed data from the two cohorts. The methods and results of these analyses are described in the web appendix (1.4).

Cohort viral load and number of new infections—We calculated two measures for potential transmission. We defined the cohort viral load (CVL) in a manner similar to the community viral load by Das *et al* [20]. An explicit number of expected HIV transmissions was calculated according to a relationship between individual viral load values and infectiousness [2, 21]. Both methods are presented in more detail in the web appendix (2.1–2.3).

Main analysis—We ran 1,000 simulations for both monitoring strategies (CD4 monitoring and routine viral load monitoring) and used the point estimates of the statistical analyses as parameters. In both strategies, patients had measurements every six months. If failure was observed, another measurement was taken three months afterwards. We calculated annual CVL and transmission, from the last year before ART until the fifth year on ART. Mean values were calculated over the five years on ART, which were used to estimate the relative reduction in CVL and transmission for routine viral load monitoring compared to CD4 cell monitoring. The results were presented as mean values over the 1,000 simulations with 95% confidence intervals.

Sensitivity and uncertainty analyses—We conducted a range of sensitivity analyses to explore the impact of our assumptions on the results (Table 1). In the first three analyses we varied the assumptions about the course of the individual viral load values over time. In two additional analyses we explored the consequences of earlier ART initiation, i.e. we assumed lower early mortality rates and lower failure rates. In two final sensitivity analyses we assumed that the time spent on a failing first line regimen would not affect the risk of second-line failure and we changed our assumptions about the effect of virological failure on mortality. To assess the impact of the variability of key parameter estimates on the results we performed an uncertainty analysis, where we sampled key parameter values before each simulation using Latin Hypercube Sampling. Details of this analysis are presented in web appendix (4.2).

Results

We describe the outcomes of the mathematical model including all sensitivity analyses, where hypothetical cohorts of 1,000 patients were simulated with either routine viral load or CD4 monitoring to compare transmission. The baseline characteristics of the data are shown in the web appendix (1.3; Table S1). The results of the statistical analyses and parameters for the distributions of time to virological and immunological failure, time to switching to second-line ART, and time to death are shown in Table 2. The hazard ratios for mortality associated with virological and immunological failure are also shown.

Cohort viral load and number of transmissions

The results during the first 5 years on ART are shown in Figure 2. We assumed six-monthly CD4 monitoring alone (left panels) or routine viral load monitoring (right panels). The top panel A shows the number of patients alive at the beginning of each year in three viral load categories, panel B shows CVL, and panel C the expected number of new infections. In the last year before starting ART, CVL was 4.0×10^8 copies/mL, with most patients (99%) having viral load values above 10,000 copies/mL (results not shown). During the first year on ART CVL was similar with both monitoring strategies (7.6×10^6 copies/mL). During subsequent years, CVL ranged between 1.0×10^6 and 1.5×10^6 copies/mL with CD4 monitoring and between 2.3×10^5 and 2.9×10^5 copies/mL with routine viral load monitoring. The annual number of transmissions dropped from over 110 during the pre-ART period to approximately 9 during the first year of ART. After this, the number of annual new infections ranged between 3 and 4 with routine viral load monitoring and 5 and 6 with CD4 monitoring. Routine viral load monitoring therefore reduced the number of new infections by about 30% (Table 3).

Sensitivity and uncertainty analyses

Of the various sensitivity analyses (Table 3), the assumed level of the viral load value after failure (analysis 2) had the largest impact on the benefit of viral load monitoring relative to CD4 monitoring: Assuming 1,000 copies after failure resulted in a 5% reduction in CVL and

a 16% reduction in number of new infections, relative to CD4 monitoring. If the viral load at failure was assumed to be similar to that at ART start, the corresponding reductions were 65% and 45%. Increasing the level of undetectable viral load to 100 copies/mL (analysis 1) led to an increase in CVL and the number of new infections. The benefit of routine viral load monitoring decreased: instead of 31% only 18% of infections were prevented, while the CVL decreased only slightly from 31% to 29%. The time that viral load started to increase before reaching the failure threshold value did not affect CVL or number of transmissions (analysis 3).

Lower mortality, which would be more realistic in a universal 'test and treat' strategy, did not affect CVL or number of transmissions (analysis 4). If failure rates were lower, both CVL and transmissions were reduced (analysis 5). If failure rates were assumed to be equally low in CD4 and viral load sites, 21% of transmissions were prevented and the reduction in CVL dropped to 22%. Assuming a lower failure rate in sites with routine viral load monitoring only, would prevent 37% of infections and lead to a 40% reduction in CVL.

The results of the two remaining sensitivity analyses (analyses S1 and S2) and the uncertainty analysis are shown in the web appendix (4.1–4.2).

Discussion

There is an ongoing debate on the benefit of routine viral load monitoring. Regular viral load measurements help to detect treatment failure earlier and may therefore reduce mortality and HIV transmission. Our model shows that routine viral load monitoring reduces cohort viral load substantially as compared to CD4 monitoring (currently the standard of care in many low-income countries [22, 23]). Compared to CD4 monitoring, viral load measurements reduced the average cohort viral load by more than 30% over five years, and the reduction in transmissions was similar.

At the end of 2009, ART coverage was below 40% in sub-Saharan Africa [24]. The time from HIV infection to ART eligibility is typically several years [25]: most people are tested too late for HIV [26] and the majority of the HIV infected population remains untreated. The proportion of new infections from treated individuals is therefore small, and even large reductions in transmission from treated individuals would hardly reduce the viral load at the population level. However, there is a trend towards earlier ART initiation: recently, WHO increased the CD4 threshold for ART eligibility from 200 to 350 cells/μL [16], and there is evidence of clinical benefits for starting ART with CD4 values above 350 [27–29]. An even more fundamental change to the treatment policy would be the implementation of the 'test and treat' strategy [6–8].

Our results should also be valid in a 'test and treat' situation. Although they are based on patients starting ART with low CD4 values, the sensitivity analyses showed that similar benefits can be achieved when patients start ART earlier. Lower mortality did not have an impact on the benefit of routine viral load monitoring. Decreasing the rate of virological failure reduced the benefit of viral load monitoring but this was offset by better adherence with viral load monitoring. Due to the current WHO guidelines, to our knowledge no data on mortality and virological failure rates have been published for people starting ART shortly after diagnosis of HIV. The available data do however suggest that the reduction in mortality due to higher CD4 count becomes minimal above 350 cells/μL [30], and several studies have found no association between baseline CD4 cell counts and risk of virological failure [31, 32].

We investigated two different ways of estimating HIV transmission and both have advantages and disadvantages. Correlation between community viral load and HIV

incidence has been described by Das *et al* in San Francisco [20]. However, it is not clear if community viral load is a good proxy for HIV incidence in low-income settings, especially when assuming that most patients would be treated. The main advantages of cohort viral load (CVL) are that it is easy to calculate and it is independent of risk behaviour. One of the main limitations is that CVL does not take into account the number of individuals: 100,000 patients with undetectable viral load (of 10 copies/mL), 1,000 patients with a detectable viral load of 1,000 copies/mL and one patient with a very high viral load of 1,000,000 copies/mL will all contribute the same amount to CVL, but the transmission potential will probably differ. The actual numbers of transmissions may therefore vary substantially between cohorts with similar CVL but different viral load distributions.

The other method we used to calculate transmissions assumes a linear relationship between log10 viral load values and HIV transmission. The resulting number of new infections is more intuitive than CVL. It can, for example, be directly transformed into costs, or other measures including the number needed to treat (NNT) or the cost of preventing one HIV infection. However, calculating the absolute number of prevented transmissions is challenging as it is highly sensitive to behavioural factors, which often are difficult to estimate.

Furthermore, the approximate reduction of 30% in transmissions should be applicable for different risk behaviour scenarios. In our calculations we assumed relatively high risk behaviour. Individuals with fewer sexual acts and higher rate of condom use would transmit less, but the relative reduction would remain the same. The rate of partner change is also not a key factor, since the per-act transmission probabilities are low (see web appendix, 2.3 for more details).

Our model focused on a group of treated patients without considering the entire population, and this approach limited us in several ways. Because the main focus was on comparing monitoring strategies on ART, we did not model the pre-ART period in detail. Therefore our results remain dependent on local characteristics, including HIV prevalence, ART coverage and ART eligibility criteria.

Transmission during the acute stage of infection has recently been estimated to contribute to about 38% of new infections [33] but various other estimates exist [34] and the acute phase may remain an important source of transmission in a 'test and treat' strategy. We did not take into account an increase in risk behaviour after ART start [35] and we did not consider behavioural differences that could result from different monitoring strategies apart from adherence. For example, patients from CD4 monitoring sites with unobserved virological failure and high CD4 counts may be more likely to engage in unprotected sex because they are unaware of the risk of transmitting the virus. If this was taken into account, probably even more infections could be prevented by viral load monitoring.

Similarly we did not investigate the effect of possible worse adherence in patients starting ART with higher CD4 cell counts. The higher virological failure rates, which remain partly undetected in CD4 sites, would increase the benefit of viral load monitoring. We also did not consider (primary) drug resistance that could complicate the treatment of newly infected individuals [36]. The assumption that the virologic failure rate, due to improved adherence counselling, would be 50% lower in viral load sites compared to sites without viral monitoring may appear high. It was an arbitrary choice that cannot be verified in our data. But a recent systematic review has shown that virologic failure rates vary substantially in sub-Saharan Africa [37] and they are also highly variable in viral load sites of the IeDEA-SA collaboration. Our results are only applicable short term. To investigate the longer term

evolution of the epidemic, one would need a dynamic transmission model in which susceptible people get HIV infected and partnerships are modelled.

Our study was based on almost 10,000 adult patients from two public sector treatment programmes in South Africa. Results should therefore be applicable to many other patients in the region most heavily affected by HIV. We acknowledge that these treatment programmes will not be representative of all programmes in southern Africa: they are located in urban areas, are equipped with electronic medical record systems, and have access to regular CD4 cell determination, viral load monitoring and second-line therapy.

The availability of viral load monitoring may have led to an underestimation of immunologic failure rates, since patients should have switched after detection of virological failure. However, many patients never switched and the median time to switching from the estimated time of failure was 22 months. Moreover, limitations in the data required us to make assumptions about factors such as the effect of virological failure on mortality and the effect of the delay between failure and switching on second-line efficacy. However, in sensitivity analyses we found that these assumptions had little effect on the results (see web appendix, 4.1 for details).

The main barrier in providing routine viral load monitoring is its high cost. A recent randomized controlled trial estimated the difference in the unit cost between viral load and CD4 measurement to be approximately $25. Therefore, the extra annual cost of treating 1,000 patients with two viral loads instead of CD4 measurements per year would be about $50,000. The net cost of preventing a new infection depends on the number of infections that can be prevented, as well as the total cost of treating and managing a new HIV infected patient. In the United States, the discounted lifetime cost of a new HIV infection has been estimated to be over $300,000 [38]. In low-income countries, these costs are much lower: for example, in Uganda, the total cost of treating a patient with ART and CD4 monitoring for a year is $467. Assuming that patients spend on average at least 20 years on ART [39], the lifetime treatment costs would be around $10,000. A detailed cost-effectiveness analysis is needed to evaluate whether routine viral load monitoring would be cost-effective or even cost-saving in the long term. Such an analysis would however require more detailed information on sexual behaviour.

Conclusions

After 15 years of antiretroviral therapy and close to a decade of widespread ART use in low-income settings it is still not clear if, when and how often viral load should be measured to optimize treatment outcomes. We found that viral load monitoring could be an important factor in reducing mortality [14], and could prevent HIV infections. Continuous evaluation of the role of routine viral load monitoring in terms of costs and effectiveness is necessary as new technologies are developed and new research findings become available. We emphasize that while the first priority should be providing ART, viral load monitoring could provide an additional benefit for ART as a preventative measure.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Abbreviations

ART	antiretroviral therapy
CVL	cohort viral load
HIV	human immunodeficiency virus
IeDEA-SA	International epidemiological Databases to Evaluate AIDS Southern Africa
NRTI	nucleoside reverse transcriptase inhibitor
NNRTI	non-nucleoside reverse transcriptase inhibitor
PI	protease inhibitor
WHO	World Health Organization

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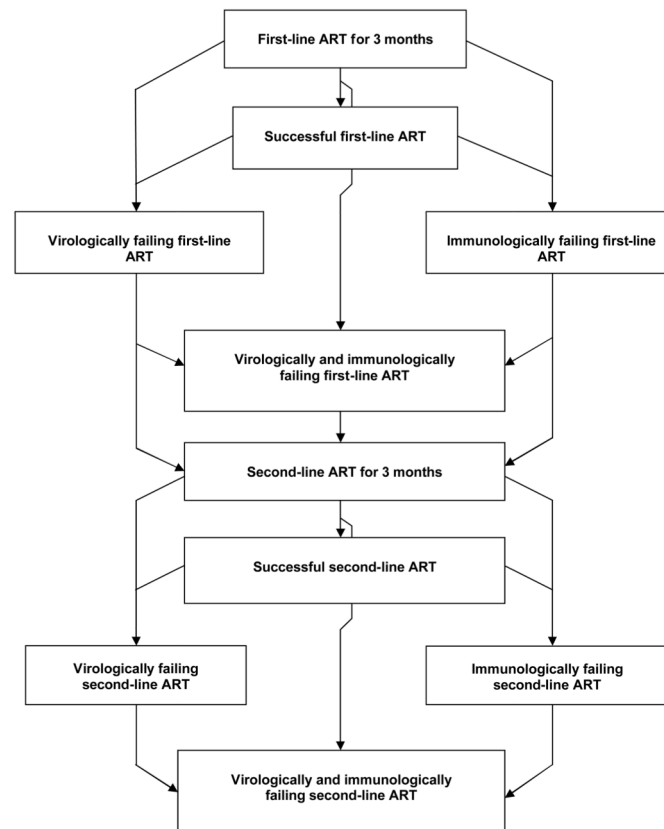
Figure 1. Flow chart showing possible transitions between risk stages after start of antiretroviral therapy (ART)

In each stage, the patient is exposed to specific risk of death and loss to follow up. Transitions between stages are assigned randomly according to the failure and switching rates observed in the Gugulethu and Khayelitsha ART programmes in Cape Town, South Africa. The flow chart is simplified: the nature of immunological failure (with or without preceding virological failure) will influence outcome of second-line ART. As treatment failures are rare, most patients stay on successful first-line ART during the entire follow-up period.

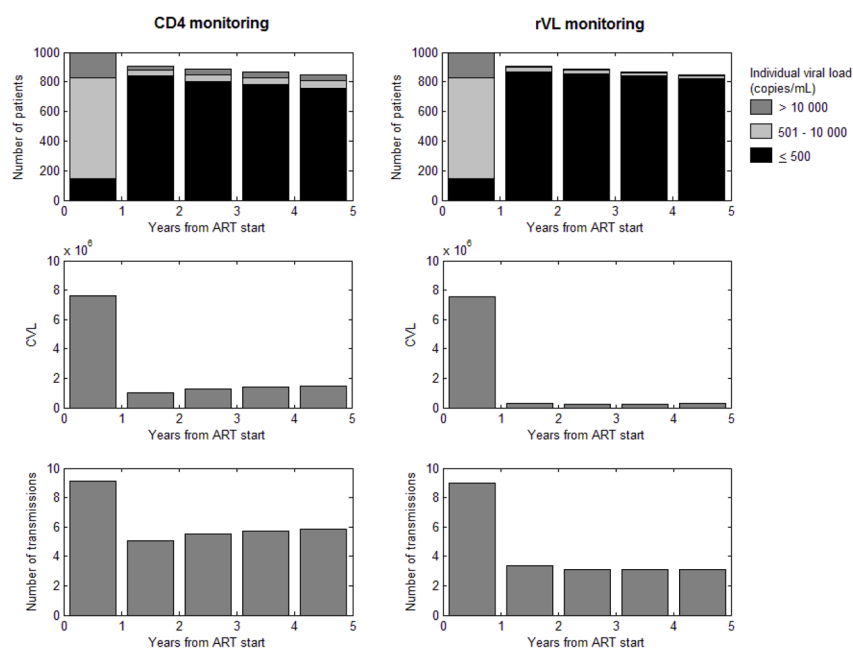**Figure 2. Number of patients in different viral load categories (A)*, cohort viral load (B) and expected number of new infections (C)**

rVL, routine viral load; CVL, cohort viral load; ART, antiretroviral therapy.

*) The same individuals were followed up through the entire 5 years, and because of mortality the total number of patients decreases over time.

Table 1
Key assumptions of main and sensitivity analyses

For results of analyses S1 and S2, see web appendix (4.1). The parameter values of the main analyses are shown in Table 2.

1)	**Level of undetectable viral load**
	Main scenario: undetectable viral load is 10 copies/mL
	Sensitivity analysis: undetectable viral load is 100 copies/mL
2)	**Level of viral load after failure**
	Main scenario: the median viral load after failure is 10,000 copies/mL
	Sensitivity analyses: the median viral load after failure is either 1,000 copies/mL or 100,000 copies/mL
3)	**Time from undetectable viral load until reaching failure threshold**
	Main scenario: viral load starts to increase 3 months before reaching failure threshold of 1,000 copies/mL
	Sensitivity analysis: viral load starts to increase 1 month before reaching failure threshold 1,000 copies/mL
4)	**Mortality (HIV related)**
	Main scenario: Time to HIV related death is estimated from the cohorts; a double Weibull distribution (weighted sum of two Weibull distributions: one with decreasing, one with constant or increasing hazard) is used to reflect the high mortality early after ART start
	Sensitivity analysis: Time to HIV related death is estimated from the cohorts, but the first component of the double Weibull distribution, which represents the high risk of death in the first months after ART initiation, is omitted
5)	**Virological failure**
	Main scenario: Time to virological failure is estimated from the cohorts; a Weibull distribution is used
	Sensitivity analysis: Time to virological failure is estimated from the cohorts, but the scale parameter of the Weibull distribution is increased to correspond to a 50% lower hazard than in the main analysis. This is in accordance with studies showing a lower risk of virologic failure in people starting ART earlier with higher CD4 cell counts [40]
S1)	**Resistance penalty for risk of second line failure**
	Main scenario: The time from switching to second line failure depends on the amount of time spent on a failing first line ART regimen (i.e. assuming a resistance penalty)
	Sensitivity analysis: No resistance penalty is included (i.e. risk of 2nd line failure after switching is the same as the risk of 1st line failure after ART start)
S2)	**Effect of virological failure on mortality**
	Main scenario: Hazard ratio of HIV-related mortality (virologically failing compared to successful ART) increases over time
	Sensitivity analysis: Hazard ratio of HIV-related mortality (virologically failing compared to successful ART) is constant over time

Table 2

Model parameters and data sources

Distributions of times to event were assumed to be exponential, Weibull or double Weibull distributed, based on the cohort data. Cohort data are from the Khayelitsha and Gugulethu ART programmes in Cape Town, South Africa.

Outcome	Source	Statistical model	Starting	Censoring	Value (95% CI)	Dimension	Risk
1) Time to virological failure							
	Cohorts	Parametric Weibull	3 months from ART start	Death, LTFU, switch to 2nd line	0.47 (0.43–0.50)	Shape	5.6% (1 year after ART start)
					3.30 (2.77–3.95)	Scale (100 years)	
2) Time to immunological failure							
(a) After virological failure	Cohorts	Parametric exponential	Virological failure	Death, LTFU, switch to 2nd line	12.72 (9.59–16.88)	Mean (years)	7.6% (1 year after virol. failure)
(b) Before virological failure	Cohorts	Parametric Weibull	3 months from ART start	Death, LTFU, switch to 2nd line, virological failure	0.22 (0.20–0.25)	Shape	3.0% (1 year after ART start)
					5.46 (3.14–9.51)	Scale (10^6 years)	
3) Time to death and LTFU							
(a) Background mortality, male	ASSA2008 [17]	parametric Weibull	Age of 5 years	n/a	6.36	Shape	5.9% (at age of 50) *****
					69.89	Scale (years)	
(b) Background mortality, female	ASSA2008 [17]	parametric Weibull	Age of 5 years	n/a	7.09	Shape	3.0% (at age of 50) *****
					73.60	Scale (years)	
(c) Observed mortality	Cohorts	No specific model (competing risk analysis)	ART start	Virological or immunological failure, switch to 2nd line	****		
(d) Observed LTFU	Cohorts	No specific model (competing risk analysis)	ART start	Virological or immunological failure, switch to 2nd line	****		
(e) Mortality among LTFU	Analysis 3d, Egger [41]	No specific model (theoretical calculation)	n/a	n/a	****		n/a

Outcome	Source	Statistical model	Starting	Censoring	Value (95% CI)	Dimension	Risk
(f) HIV-related mortality	Analyses 3a, 3b, 3c, 3e	Theoretical calculation, double Weibull *)	ART start	n/a	0.88 (0.88–0.90)	Shape 1	8.4% (1 year after ART start)
					0.35 (0.32–0.39)	Scale 1 (years)	
					1.00 (1.00–1.00)	Shape 2	
					64.60 (54.52–76.55)	Scale 2 (years)	
					0.08 (0.08–0.08)	Weight (1st component)	
(g) Extra hazard after immunological failure	Cohorts	Cox regression	Immunological failure **)	Switch to 2nd line ***)	1.75 (1.15–2.67)	HR, constant over time	n/a
(h) Extra hazard after virological failure	Petersen [19], cohorts	Cox regression ******)	Virological failure **)	Switch to 2nd line	1.07 (0.91–1.26)	HR per each 3 months	n/a

CI, confidence interval; ART, antiretroviral therapy; HR, hazard ratio; ASSA, Actuarial Society of South Africa; n/a, not applicable

*) Analysis was done by fitting the theoretically calculated cumulative incidence to a double Weibull model using the Matlab curve fitting tool.

**) Analysis was started from ART start, but the hazard ratio is only applied from this time point onwards

***) Not applicable if failure is happens according to the risk described in 2b

****) The results are given as a cumulative incidence function (without closed parametric form)

*****) Excluding mortality before age of 5 (i.e. the risk of dying between the ages of 5 and 50)

******) Estimated by comparing results of Petersen *et al* [19] and our data analyses

Table 3

Cohort viral load (CVL) and new infections in one thousand patients receiving ART over 5 years with either CD4 or routine viral load (rVL) monitoring, under different assumptions.

	CD4 monitoring		rVL monitoring		Reduction (rVL compared to CD4)	
	CVL, 10^6 copies/mL (95% CI)	Infections (95% CI)	CVL, 10^6 copies/mL (95% CI)	Infections (95% CI)	CVL (95% CI)	Infections (95% CI)
Main scenario *)	2.57 (2.05–3.09)	6.25 (5.60–6.91)	1.72 (1.38–2.05)	4.33 (4.07–4.59)	30.6% (11.3–49.9)	30.6% (22.2–39.0)
Sensitivity analyses						
1) Level of undetectable viral load						
100 copies/mL	2.81 (2.29–3.33)	9.70 (9.06–10.35)	1.97 (1.65–2.30)	7.98 (7.71–8.26)	29.9% (11.8–46.6)	17.7% (11.6–23.7)
2) Mean viral load after failure						
1,000 copies/mL	1.52 (1.26–1.78)	4.59 (4.31–4.88)	1.43 (1.17–1.69)	3.86 (3.73–4.00)	5.4% (−17.9–28.6)	15.8% (10.0–21.6)
Equal to baseline (100,000 copies/mL)	10.85 (7.11–14.58)	9.53 (8.11–10.96)	3.64 (2.43–4.84)	5.17 (4.70–5.64)	65.4% (49.0–81.9)	45.4% (35.8–55.1)
3) Mean time from undetectable viral load to reaching failure threshold (in patients experiencing virological failure)						
1 month	2.60 (2.08–3.13)	6.27 (5.63–6.90)	1.73 (1.43–2.03)	4.33 (4.09–4.57)	32.8% (15.4–50.3)	30.7% (22.7–38.7)
4) Mortality						
Reduced	2.68 (2.16–3.20)	6.71 (6.04–7.39)	1.73 (1.43–2.03)	4.59 (4.36–4.83)	34.8% (18.0–51.5)	31.4% (23.4–39.2)
5) Virological failure						
Reduced	1.98 (1.59–2.37)	4.92 (4.45–5.39)	1.53 (1.24–1.82)	3.90 (3.73–4.07)	21.9% (0.4–43.4)	20.6% (12.4–28.7)
CD4 monitoring equal – rVL monitoring reduced	2.57 (2.05–3.09)	6.25 (5.60–6.91)	1.53 (1.24–1.82)	3.90 (3.73–4.07)	39.6% (23.1–56.1)	37.4% (30.4–44.4)

CI, confidence interval; CVL, cohort viral load; rVL, routine viral load

*) Level of undetectable viral load: 10 copies/mL; mean viral load after failure: 10,000 copies/mL; mean time from undetectable viral load to reaching failure threshold: 3 months; risk of mortality: according to data; hazard of virological failure: according to data