Evaluating Strategies to Improve HIV Care Outcomes in Kenya

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# Abstract (300 words)

## Background:

With expanded access to antiretroviral therapy (ART) in sub-Saharan Africa, life expectancy has increased, yet life-years are still lost to AIDS. Evidence suggests that these health losses are attributable to deficiencies in pre-ART and ART care. We aimed to examine the state of a current ART-programme in Kenya and assses the potential for interventions to improve the impact of ART programmes on population health.

## Methods & Findings:

We constructed an individual-based mathematical model to describe the HIV epidemic and the experiences of care among HIV-infected adults in western Kenya. We calibrated the model to a longitudinal dataset from The Academic Model for Providing Access To Healthcare (AMPATH) describing the routes into care, losses and clinical outcomes. The model suggests that most AIDS deaths (57%) in this population are among persons that have been diagnosed with HIV but have not linked to clinical care. Other predicted drivers of death are late initiation and disengagement with care following initiation of ART. We used the model to simulate the cost and impact of alternative intervention, based on earlier trial results. We find that no single intervention to improve the cascade to care is expected to have a large outcome because any single intervention is confounded by other weaknesses up- and down-stream. However, two approaches can be recommended: a combination of interventions (including X, Y, Z) would generate a large impact (Y) cost-effectively(ICER X; < 0.5GDP?); or a shift of providing treatment to all HIV-infected persons immediately when they present for care (Y impact and X cost per DALYS av). Either approach would generate health more more cost-effectivly than than an immediate expansion of testing and treatment (universal test and treat) without strengthening the care cascade.

## Conclusions:

Our results suggest that ART-programmes in Kenya can be enhanced to bring about greater health benefits by strengthening each part of the cascade or switching, as has been demonstrated to be feasible in earlier trials, and/or by shifting to treating HIV-infected persons immediately when they present to care. In contrast, a radicial expansion of treatment programmes, with the identified weakendss in linkage and retention perpetuated, would not maximize health generated with limited resources. International guideance ART should reflect these alterantives routes to program strengthening, recognize outreach as an integral part of a treatment intervention, and encourage country programs to evaluate the costs and impact of ART expansion as well as evaluating the clinical benefits of earlier initiation.

# Introduction

The major success story in the response to the HIV pandemic has been the development and provision of anti-retroviral therapy {UNAIDS:2014ta}. With timely diagnosis, treatment can increase life-expectancy such that it approaches that of an HIV-negative individual{Nakagawa:2013cv}. Consequently, adult life expectancy has increased by >11 years in South Africa as a direct result of ART becoming accessible{Bor:2013er}. However, in the worst affected countries, there are still estimated to be hundreds of thousands of AIDS death each year. In South Africa, (vital reg data)..,,XXX EXAMPLE. Further, a prospective cohort study in Uganda has revealed that the life expectancy of men and women initiating ART aged 20-24 years still falls below that of the general population (19.1 and 30.6 years vs. 41.6 years, respectively){Mills:2011gx}; therefore indicating, life-years are still being lost to AIDS{Collaboration:2008ed}. In the era of wide-scale ART availability, why are such large health losses continuing and what can be done to improve the population health that is generated by ART programs?

The reasons for continued health losses to HIV have not been well understood but attention has been focussed on the ‘care cascade’. This the series of events and appointments through which HIV-infected individuals must pass in order to benefit fully from ART, beginning with HIV testing and ending with patients in a state of sustained viral suppression with regular monitoring. In 2011, Fox and Rosen highlighted how fewer patients reach each successive stage. And since then, there have been many detailed reports for different countries detailing the care cascade as it appears to operate in particular countries.NOTE pervasiveness – All Africa region, plus UK, USA as well. However, these studies have been limited by not having had the opportunity to follow the same patients through all stages of the cascade as they would typically be focussed on that subset of the population that presents to a clinic, and would be blind to outcomes of patients that disengage from care.

During the last few years there has also been a massive proliferation in innovative approaches to improving the care cascade. These variously aim to improve testing, linkage to care, retention in pre-ART care, rates of viral suppression or retention in post-ART care. Many of these have been subject to a trial and there have been some remarkable successes – e.g. ; as well as some showing less success than had been hoped, e.g. However, these trials seldom measured the gains accrued in population health (e.g. longer-term effects, and knock-on effects to persons not directly reached with an intervention) and have had to largely focus on examining the impact of new intervention at a time, and have not been able to measure the combined impact of interventions as different part of the cascade.

At the same, there has been a push to continue the rapid expansion of treatment, including expanding the eligibility criteria for treatment (to potentially all HIV-infected persons) and to increase active out-reach to populations for testing (i.e. ‘Universal Test and Treat’). This can be thought of as an alternative, transformational, intervention in the care cascade. In hypothetical idealised programs, there are persuasive arguments in favour of such an approach (cite wiliams and eaton LGH) but the extent to which that is the right approach given the apparent fragility of some current systems has been unclear and source of concern with respect to the equality of health benefits to patients.

As a result, program managers facing the question of understanding the drivers of AIDS mortality in the populations they serve, and having to decide which of the potential ‘care cascade’ interventions should be prioritised in order to generate the greatest gains in population health for the available resources have had little data to guide them.

However, mathematical models combined with longitudinal data from real programs can offer a way to come to conclusions about the way in which programs should develop. The AMPATH program furnishes unique data of the care cascade in Western Kenya including information on persons out of care, prior to testing, through an integrated household-based testing survey and intervention. We have used these data to calibrate an individual-based mathematical model that represents the HIV epidemic in western Kenya and the experiences of care for the HIV-infected patients. With this, we produce the first estimates of the drivers of AIDS mortality in a population benefitting from a mature ART program. We are then able to use the model to estimate the cost and and impact of possible intervention, in isolation and in combination, examining impact on patient health and downstream benefits simultaneously. In this way, we are able to come to broad recommendations about how program managers can modify their programs to maximise the health generated.

~~Firstly, the on-time identification of infected individuals in many resource-limited settings is scarce{Drain:2013iv,Sabin:2004uy}. Timely diagnosis is defined as alerting an individual to their serostatus prior to that individual becoming eligible for treatment; yet, data from Uganda indicate that almost half of all infected individuals newly diagnosed were already eligible for treatment, and therefore detected late{Wanyenze:2011gz}. Secondly, late diagnosis is followed by late initiation of treatment; with many studies reporting patients initiating ART with CD4 counts far lower than treatment guidelines recommend{Boulle:2014uj,Lahuerta:2012hi, Lahuerta:2013tk,Nash:2011ki}. The major consequence of late ART initiation, is an observed increase in HIV-related mortality, negatively correlating with CD4 count at the time of initiation{Johnson:2013co}. Thus, from the viewpoint of the clinic, late treatment initiation is the major driver behind HIV-related mortality in ART programmes. Current data now indicates that the hazard ratio of mortality for patients initiating ART with CD4 counts ≥200 vs. <25 cells per μl is 0.21 (95% CI, 0.17 – 0.27){May:2010ee}. However, mortality is likely to be underestimated due to significant unreported deaths among patients lost to follow up{Brinkhof:2010gr}. Additionally late treatment initiation likely results in onward transmission until viral suppression can be achieved{Lahuerta:2013tk,Cohen:2011kr}.~~

~~This discrepancy between treatment access and eventual patient outcomes allude to inefficiencies within HIV care systems{Gardner:2011de}. Moreover, accumulating evidence suggests that HIV care is suboptimal not at one particular point, but across the entire spectrum of care, as “cascading losses” have been reported throughout ART programmes{Rosen:2011ii,Fox:2014ch}. A review by Rosen and Fox in 2011 highlighted the scale of the issue in sub-Saharan Africa; illustrating that on average only 18% of patients are retained from HIV testing until ART initiation{Rosen:2011ii}. Results indicated that, 59% of patients were retained from HIV testing to receipt of CD4 test results, whereupon 46% of remaining individuals were retained until ART and finally 68% of the remainder were retained up to treatment initiation{Rosen:2011ii}. While among those patients initiating ART, recent estimates from South Africa indicate that 81% were retained in care two years after starting treatment{Fox:2014ch}.~~

~~The milestones that must be achieved to realise optimal care outcomes begin with diagnosis. Positive HIV-testing to confirm infection is followed by a blood draw for CD4 count measurement to assess the state of disease progression and eligibility for treatment. Once deemed eligible for treatment, ART is initiated and must be adhered to thereafter. However, the operational steps required to deliver these milestones are complex. Initially, once diagnosed individuals need to be linked to pre-ART care, meaning they must attend a clinic to be bled for a CD4 test. Consequently, there is a risk they may not attend. Kranzer~~ *~~et al.~~* ~~have shown that in South Africa, 37.4% of individuals tested failed to link to care within six months of diagnosis{Kranzer:2010hp}. Furthermore, after linking to care and receiving a CD4 test, the patient is advised to return at a later date to receive the results and learn of their eligibility for treatment. The time delay is due to CD4 tests being predominantly lab-based requiring central processing{Larson:2012dq}. A utility cost is often incurred when travelling to the HIV clinic as patients travel long distances from remote areas to attend and often receive no immediate therapeutic benefit{Geng:2010fh, Yu:2007wh, Ware:2009id}. This represents another opportunity for patients to be lost from care, as demonstrated by a study in South Africa where 65% of patients failed to return to receive CD4 test results within 12 weeks of the test{Larson:2010dz}. When receiving CD4 test results, if the patient is not immediately eligible for treatment, they are asked to return after a period of time for a follow-up test. Patients may endure multiple rounds of CD4 tests and clinic visits prior to ART initiation. This can result in loss from care, as shown by findings from Kenya, in which a CD4 count of >200 cells/μl at pre-ART enrolment resulted in a 3.49 fold increase in the odds of being lost from care{Geng:2010du}. Confirmatory CD4 test results indicating ART eligibility are followed by counselling and treatment initiation. ART initiation marks the start of lifelong ART care, where a successful treatment outcome can be achieved through retention in care and adherence to ART. However, long-term retention in ART care is also suboptimal as was illustrated by a review of over 200 thousand individuals across sub-Saharan Africa, demonstrating average retention three years after treatment initiation to be just over 70%{Fox:2010gt}. Additionally, a meta-analysis of 12 sub-Saharan countries has estimated that only 77% of patients are achieving adequate adherence to ART, increasing the risk of mortality and resistance development among those failing to adhere{Gardner:2009fb,Nachega:2006bx,Mills:2006gf}.~~

~~With poor patient outcomes being linked to structural weaknesses in ART programmes, providers have begun to intervene and improve care. For example, interventions aimed at improving the uptake of HIV-testing have targeted individuals through setting up voluntary counselling and testing (VCT) clinics in accessible sites and by establishing provider-initiated counselling and testing (PICT) by incorporating HIV counselling and testing into healthcare services{Obure:2012fb, Thielman:2006fm}. Home-based counselling and testing (HBCT) interventions also aim to improve testing uptake{Menzies:2009fs}. This type of intervention involves home-visits by care workers who administer counselling and rapid HIV-tests to consenting participants{vanRooyen:2013gy}. Infected individuals learn of their status immediately and are then encouraged to attend a clinic for CD4 testing{Kimaiyo:2010tq}. HBCT has been shown to be a powerful diagnostic tool as individuals are sought out rather than seek care themselves; although, the impact of HBCT on linkage to care remains limited{vanRooyen:2013gy, Genberg:2015cd}. A method for increasing linkage to care is to provide individuals with point-of-care (POC) CD4 testing at the site of HIV-testing. While this doesn’t remove the linkage step, informing patients of how advanced their infection is has been shown to indirectly improve linkage to care{Larson:2012dy}. Once engaged in pre-ART care, interventions such as decentralising care involving patients switching from hospital-based clinics to primary care centres have been proposed for improving retention{Geng:2010du}. Additionally, POC CD4 testing has also been shown to reduce loss to follow up while patients are engaged in CD4 staging{Jani:2011eb}. Many interventions have additionally targeted retention in ART care, with decentralisation interventions improving care accessibility and reducing loss to follow up{Long:2011cx}. The use of peer health workers to conduct recurrent home-visits, provide counseling and administer a pill count has been shown to reduce the risk of loss to follow up from ART by almost half{Chang:2013ke}. Several reviews have identified multiple interventions to improve ART adherence{Barnighausen:2011cb, Scanlon:2013ko}; including, peer or nurse-delivered directly-observed-therapy (DOT){Pearson:2007fw, Sarna:2008tb}, the use of electronic drug monitoring{Sabin:2010ce}, SMS text message reminders{Lester:2010jp, Mbuagbaw:2014jg}, adherence counseling and education{Chung:2011jm}, together with food incentives{Cantrell:2008ii, Mamlin:2009gf}.~~

~~With a variety of interventions aimed at strengthening various points of care, programme providers need to calculate where best to implement interventions to maximise patient outcomes. The concept of the “Cascade of Care” is a means of visualising the events and pathways through care taken by individuals, and allows us to link outcomes to earlier care experience{Kilmarx:2013iy, Hallett:2013ig}. As evidence now highlights deficiencies across the spectrum of care, the traditional concept of linear flow is challenged by trends in the data indicating patients often become lost from care, before subsequently re-engaging, or potentially engage for the first time later than indicated{Hallett:2013ig, Gardner:2011de, Rosen:2011ii}. However, the drivers behind patients’ disengagement and reengagement are still ambiguous; although it has been hypothesised that the development of symptomatic HIV is likely to be key in driving individuals to seek care, data around those lost from care is scarce. To reconcile these trends and to further distinguish the routes into care, we termed the routes by which patients re-engage with care or engage late as “side doors”, to supplement the conventional “front door” route by which care naïve individuals enter{Hallett:2013ig}. Stratifying routes into care in this way allows ART programmes to be properly characterised, enabling insight to be gained from the dynamics of care, which is crucial to understanding where best to intervene and how to prioritise interventions.~~

~~To fully characterise care, linked longitudinal data is required at the individual-level to capture the experience of all HIV-infected individuals. Yet the majority of available data is not linked and only describes individuals who have had contact with the clinic. This clinic-level data is biased, as individuals who have never come into contact with the clinic are not accounted for. Additionally, outcomes of patients lost to follow up are also needed to exhaustively characterise care. In summary, these data limitations restrict the ability to which ART programmes can assess themselves and identify where to take action.~~

~~However, select facilities in sub-Saharan Africa are beginning to distribute such data, thereby allowing comprehensive insight into the dynamics of care. In this paper, through the use of mathematical modelling, we evaluate an ART-programme in Kenya to demonstrate how to prioritise interventions to improve health outcomes for patients.~~

# Methods

*Overview*

We constructed an individual-based micro-simulation model representing the HIV epidemic in western Kenya and capturing the care experience of individuals as they progress through an ART programme. We reviewed literature on interventions can be used to improve elements of the care cascade and simulated their effects in the model.

The model is briefly described below in three sections: (i) Epidemic and natural history assumption; (ii) Representation of the care cascade at baseline; and (iii) Interventions on the care cascade. Further details are presented in Text S1.

1. Epidemic and natural history assumption;

The microsimulaton model represents births, ageing and death among the population of western Kenya, using data from XXX. The risk of HIV incidence, for persons of a particular age and sex at a particular time, is equal to the estimates published by UNAIDS (?) for the years 1980-2005. For the years following 2005, the incidence rate in the model is re-calculated to reflect the growing number of persons on ART and to enable there to be the feedback between a successful ART program reducing the number of new HIV infections.

Upon infection, diseaseis modelled by an individual falling to states of lower CD4 cell count category (<200, 200-350, 350-500 and 500+ cells per microlitre) and states of greater disease severity (WHO stages I, II, III and IV). An individual’s CD4 cell count and disease state are both tracked as they have independent predictive effects on the risk of mortality, and the latter is assumed to also predict the propensity to seek care. Rates of transitioning through these stages were inferred through fitting the model to all available data on HIV/AIDS natural history.

When an individual has a suppressed viral load on ART, they can transition to states of higher CD4 cell count category and lower disease severity. The rates of transitioning are informed through fitting the model to X, Y, Z. If an individual ceases ART, following a period of successful viral suppression, they will again progress to lower CD4 cell counts and higher disease states, but at a greater rate than ART-naïve patients.

SOMETHING HERE ABOUT COMPARING MODEL OUTPUT PROJECTS ON PRVALENCE AND MORTALIUTY WITH THOSE OF UNAIDS AND OR AMPATH ITSELF.

(ii) Representation of the care cascade at baseline

The model describes the pathway through for each HIV-infected person (figure 1). EXPLAIN THE AIN PHASES THAT ARE IN THE DIAGRAM.

## 



Figure 1. Flow diagram representing the operational steps involved in navigating an ART-programme.

The model was parameterised using data from AMPATH. The AMPATH Medical Record System (AMRS) has been collecting individual-level data on the AMPATH AIDS-control system since 2006{Einterz:2007js, Tierney:2007th}. Service delivery occurs through public sector hospitals and health centres run by the Ministry of Health{Einterz:2007js}. Building on well established VCT and PICT programmes, the use of HBCT was trialled in 2007 before becoming a permanent intervention in 2010{Wachira:2013dc}.

In this setting, VTC has been available since 2004 with PICT becoming more widely available from 2008. (IS THIS RIGHT? I AM JUST WRITING!). In the area of Bunyala, there have additionally been multiple rounds of household-based testing campaigns in X, Y, Z, which have achieved a coverage of, x,y,z, respectively.. We used these data to fully charactersize the care cascade and then used these as input parameters to the model, or otherwise adjusted a paramnetes in the model that was not directly observed in order to induce an agreement between the model and data. The baseline scenario of the analysis represents the program just prior the implementation of the household-based testing that has been implemented already in this population. (Table 1)

The cost of the ART program at baseline is estimated from the perspective of a health care provider, based on the recent CHAI MATCH study of ART facilities, and assumed to be comprised of cost of ART care, the cost of pre-ART clinic visits and CD4 lab-based tests{Tagar:GTMxY-pi}.



1. iiInterventions on the care cascade

Interventions in the care cascade can be divided into those that ai to increase testing, linkage, retention in pre-ART care or retention and suppression for patients on ART. We reviewed the literature to identify realistic assumptions for the efficact and cost of representative interventions in each of these categories (Table) . As the effect size measured in different trials, and that which would arguably be attainable, two assumptions for the effect size (a ‘maximum’ and a ‘realistic’) are used.

. The impact of the program is quantified in terms of DALYS averted and deaths averted, both with respect to a baseline in which a program similar to AMPATH before the launch housrold testing program, is maintained indefinitely

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| --- | --- |
| Key Assumptions | Data Sources |
| For a given health state, the mortality rate on ART is less than the mortality rate off ART. | Natural history calibrated from clinical surveillance data. |
| Declining health drives care-seeking behaviour. | Calibration of events that make up HIV care from longitudinal dataset from AMPATH. |
| Individuals are exposed to a background rate of testing through VCT in addition to a rate of testing through PICT (dependant upon previous health care experience and health). | Disability weights sourced from the Global Burden of Disease Study 2010{Salomon:2012ib}. |
| Patients have the propensity to be lost from care at any stage. | Majority of costing data derived from the CHAI MATCH Study{Tagar:GTMxY-pi}. |
| If lost from pre-ART care, patients can re-engage at a later date. |  |
| If lost from ART care, patients will not re-engage with care (unless identified through an ART Outreach but patients can only re-initiate ART once). |  |

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Table 1. Key model assumptions and data sources.

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| --- | --- | --- | --- | --- | --- |
| **Aspect of care to be addressed** | **Intervention type** | **Intervention** | **Maximum Impact** | **Realistic Impact** | **Cost**  **(2013 USD)** |
| Individuals are initially unaware of their HIV infection. At baseline, the mean time for an individual to test through VCT is 7.2 years. Additionally individuals may test through PICT, and the time to test varies depending on prior health care experience and symptoms: Asymptomatic and no previous care experience = 15.6 years. Asymptomatic and diagnosed = 11 years. Asymptomatic and aware of CD4 count = 5 years. Symptomatic = 1.5 years. | *Testing* | ***HBCT*** | Every four years, 90% coverage of population. 100% linked to care. | Every four years, 90% coverage. 5% linked if had not previously been diagnosed, else 25%. | $18 per HBCT person tested ($8 home-visit [*Barnabas unpublished*] + $10 rapid HIV-test{Wright:2004jd}). |
| ***Enhanced VCT*** | The rate of HIV testing is twice that of baseline. | The rate of HIV testing is 125% that of baseline. | $50 per person tested ($28 clinic visit{Tagar:GTMxY-pi} + $10 rapid HIV-test {Wright:2004jd} + $12 CD4 lab test{Tagar:GTMxY-pi}). |
| *Testing & Linkage* | ***HBCT (with POC)*** | Ever four years, 90% coverage of population. POC CD4 reduces risk of not linked to 0%. | Every four years, 90% coverage of population. POC CD4 reduces risk of not linked by 50%. | $60 per HBCT person tested ($8 home-visit [*Barnabas unpublished*] + $10 rapid HIV-test{Wright:2004jd} + $42 POC-CD4 test{Larson:2012dq}). |
| In some cases, individuals are not connecting to care following diagnosis in timely manner. At baseline, 60% of patients tested through VCT or PICT successfully link to care. | *Linkage* | ***Facilitated Linkage*** | The risk of failure-to-link is reduced to 0% | The risk of failure-to-link is reduced by 50%. | No additional costs applied. |
| ***VCT POC*** | At VCT testing, a POC CD4 test is given to patients reducing the risk of not linking to 0%. | | $80 per POC CD4 test ($28 clinic visit{Tagar:GTMxY-pi} + $10 rapid HIV-test {Wright:2004jd} + $42 POC-CD4 test{Larson:2012dq}). |
| Individuals that have linked to care can sometimes subsequently disengage prior to starting treatment. On average at baseline, for every CD4 test 56% of patients disengage from care before receiving their results. On the day of a CD4 test result appointment, 20% of patients do not attend and are also lost from care. After receiving the results of a CD4 test, on average 35% of patients fail to return for a subsequent CD4 test in a years time. | *Pre-ART Retention* | ***Pre-ART Outreach*** | In the middle of each year, 100% of tested individuals lost from care are returned. | In the middle of each year, 20% of tested individuals lost from care are returned. | $19.55 per patient sought{Rosen:2010ca}. |
| ***Improved Care*** | The risk of a patient missing an appointment is reduced to 0%. | The risk of a patient missing an appointment is reduced by 50%. | No additional costs applied. |
| ***POC*** | A POC CD4 test reduces loss from care between CD4 test and result by 100%, as results are available instantaneously. (The risk of loss to follow-up between appointments is unchanged). | | $70 per POC CD4 test ($28 clinic visit{Tagar:GTMxY-pi} + $42 POC-CD4 test{Larson:2012dq}). |
| Individuals initiate ART but subsequently disengage from care. At baseline, 8% dropout in the first year of ART and 5% thereafter. | *On-ART Retention* | ***On-ART Outreach*** | In the middle of each year, 100% of patients who have initiated ART and been lost from care are returned. | In the middle of each year, 40% of patients who have initiated ART and been lost from care are returned. | $19.55 per patient sought{Rosen:2010ca}. |
| Some individuals on ART do not adhere sufficiently to fully benefit from effects of ART. | ***Adherence*** | At ART initiation, all individuals adhere to ART and become virally suppressed. | At ART initiation, 87.5% of individuals adhere to ART and become virally suppressed. | $33.54 per person per year{Sarna:2008tb}. |
| Pre-ART care as a whole. | *Sweeping Changes* | ***Immediate ART*** | No pre-ART care, all individuals who enter care are treated immediately. | | Only additional costs due to increased usage of ART. |
| ***Universal Test & Treat*** | Immediate ART & HBCT (every four years, 90% coverage. 5% linked if had not previously been diagnosed, else 25%). | Immediate ART & HBCT (every four years, 90% coverage. 5% linked if had not previously been diagnosed, else 25%), but 20% do not link and a further 20% link to care but defer ART until their CD4 cell count reaches 350 cells/microlitre | $18 per HBCT person tested ($8 home-visit [*Barnabas unpublished*] + $10 rapid HIV-test{Wright:2004jd}). |

Table 2. Summary of individual interventions designed to target various aspects of care.

# Results

## Current Sources of Health Losses

We first projected the ‘status quo’ model to 2030 and analysed the drivers of AIDS deaths in the period 2010-2030 (Figure 2). The model finds that among all HIV-related deaths, the majority (57%) occur in individuals who were diagnosed with HIV but who did not ever start treatment (Figure 2(a)). A further 19% of AIDS deaths are among persons who never engaged with care prior to death. The remainder of AIDS deaths were among those who started ART.

Most data systems, however, do not benefit from such a holistic view of the population are instead based upon only those who attend a clinic at least once. In that case, those persons that never connect to a clinic to care following testing, which accounts for 76% of all AIDS deaths, who not be apparent. It is therefore crucial that better systems of surveillance are developed that can include outcomes of patients who do not link to care at all.

Figure 2. Care experience of patients suffering HIV-related deaths between 2010 and 2030.



## The Impact of Cascade Interventions

We applied each of the 12 potential interventions in turn and assessed the impact on DALYs averted, compared to baseline, and the additional cost of care, compared to baseline, between 2010 and 2030 (figure 3 and table 3).

Broadly, the impact of most single interventions cluster together with relatively low impact and low cost. This is because there are weakness throughout the care cascade, so interventions at one point only cannot have a large impact as they are confounded by remaining weakness elsewhere.

The exceptions to this are HBCT, which attracts a high cost given its projected benefit. This is due to the assumption here that only a small proportion of persons being diagnosed for the first time at HBCT will link to care without further intervention. HBCT with POC CD4, by increasing linkage, accrues nearly twice as many DALYS averted for a small increse in costs.

The two interventions that simulate large changes to the delivery of ART – Immedidtae ART and Universal Test and Treat – both have much greater impact. The intervention to provide treatment to those presenting for care immidiately is highly impactful because the model assumes that a large number of people would naturally present for care without additional outreach costs, and benefit is accrued by eliminating the potential for losses from pre-ART care. The UTT intervention is much more costly and somewhat more impactful because the outreach costs are estimated to be very large but the population coverage of ART can reach higher levels with outreach intervention such as HBCT.

*// Then a very quick canter through the results for the others. I had noted before that I thought the sensitivity analysis thing we did woud be a useful thing. We said we could have one model parameterisation with strong “health care seeking” and another “weaker”. (If possible to construct both in way that is consistent the data). And then to show how that strongly modulate the impact of each.*

~~Among the testing interventions, the maximum impact scenario of HBCT was much more impactful than the VCT intervention (1.88m and 0.62m DALYs averted, 17% and 5% MAI, respectively); however, the HBCT intervention with imperfect linkage to care (realistic scenario), highlights the importance of linkage after HBCT as this was less impactful than the maximum impact VCT intervention (0.43m and 0.62m DALYs averted, 4% and 5% of MAI, respectively). Yet, both scenarios of the HBCT intervention were more than twice as expensive to implement than the VCT intervention ($2.62b, $2.06b and $898.44m (2013 USD), respectively).~~

~~Among the linkage interventions, HBCT POC CD4 was the most impactful as it combines HBCT with a POC CD4 test to alert HIV-positive individuals of their eligibility for treatment (3.53m DALYs averted, 31% MAI). This was the second most expensive intervention due to the cost of POC CD4 test kits and the cost of actively seeking individuals at home ($3.13m between 2010 and 2030). Interestingly, the VCT POC CD4 intervention averted more DALYs in the twenty-year period than the Linkage intervention (1.43m vs. 0.82m DALYs averted, 13% vs. 7% of MAI). This is due to the VCT POC CD4 intervention providing perfect linkage to care with the addition of a POC CD4 test; and also explains the difference in cost between the two interventions ($527.20m vs. $294.73m).~~

~~Each of the pre-ART retention interventions had a considerable impact on care. Of these interventions, the maximum impact scenario of Improved Care, the intervention preventing any loss from pre-ART care was most impactful (1.95m DALYs averted, 17% MAI), followed closely by the maximum impact scenario of the Pre-ART Outreach intervention that re-engages anyone lost from pre-ART care (1.83m DALYs averted, 16% MAI). Interestingly, the maximum impact Improved Care intervention was only slightly more expensive than the maximum impact Pre-ART Outreach intervention; this was due to the cost of additional testing that retaining individuals in pre-ART care incurs ($983.26m vs. $689.03m). Comparing the POC CD4 intervention against the VCT POC CD4 intervention, the former was less impactful and also cheaper than the latter (1.35m DALYs averted, 12% MAI, at a cost of $498.27m vs. 1.43m DALYs averted, 13% MAI, at a cost of $527.20m). The reasoning behind this is that the VCT POC CD4 intervention immediately links all individuals testing through VCT and provides them with a POC CD4 test; whereas, the POC CD4 intervention applies only to individuals who have entered pre-ART care. That is, patients that have successfully linked to care. Thus, without perfect linkage POC CD4 involves testing fewer individuals. Furthermore, the ART retention interventions were constrained by the limited number of individuals whom initiated ART. Nonetheless, both scenarios of the ART Outreach intervention had a larger impact and were more expensive (by increasing the total life-years spent on ART) than the adherence interventions.~~

## The Impact of Bundles of Interventions

An optimal combination of cascade interventions was found by simulating all possible combinations and selecting those that, at each budget level, provide the greatest increase in health. We did this for all the ‘realistic’ interventions and imposed the additional constraint that, once an intervention had been included in the combination at one budget level it cannot be removed at higher budget levels. (table 3).

This finds that a combination of six interventions would be prioritised in this setting (Table 3). The interventions are pre-ART Outreach, POC CD4, VCT POC CD4, Linkage, Pre-ART Outreach and Adherence (table 3). Importantly, this combination of intervention includes elements that act on each part of the cascade. As the major driver of AIDS death in this population was found to be persons diagnosed but no linked to care, interventions that increase linkage and retention in pre-ART attract most investment.

Collectively this combination interventions has the same impact on reducing deaths and averting DALYs (give the numbers) as Universal Test and treat intervention but is estimated to cost only approximayely 44% as much. The combination intervention of cascade intervention is a similar cost as the Immediate ART intervention and is estimated to have a slightly greater impact.

The comparatively low cost and higher impact of the combination cascade interventions is a result of the collection of intervention operating synergistically, whereas the UTT and Immediate ART intervention operate with inefficiencies due to the remaining weakness of some part of the cascade.

The alternative approaches for strengthening the care cascade exact their impact in different ways. The combination approach does not substantially reduce deaths among those who do not naturally present for HIV testing, but does reduce deaths among those who have tested, linked and those on ART. The immediate initiation approach…. In comparison, the UTT approach dramatically reduces the number of persons that die from AIDS that were not diagnosed, due to the large outreach component of that intervention, but impact is moderated by the persisting large number of deaths among those that have started ART but who have since disengage from care.

~~combination of interventions, the majority of HIV-related deaths occurred among individuals who had not initiated ART, with 24% of individuals never tested and 33% of individuals diagnosed~~ ~~but never initiated ART. Yet, this is a reduction from the baseline scenario where 57% of HIV-related deaths were among individuals who were tested but never initiated ART. In contrast, HIV-related deaths when the Universal Test and Treat intervention was applied were predominantly among patients who had initiated ART (87%), and in particular those who initiated ART but were then lost from care (51%).~~

Figure 3. DALYs averted and additional cost of care for individual interventions between 2010 and 2030.



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|  |  |  |  |
| --- | --- | --- | --- |
| Intervention | Scenario | DALYs Averted between 2010 and 2030 (millions) | Additional Cost between 2010 and 2030 (millions) (2013 USD) |
| HBCT | **Maximum** | 1.88 | $2,622.22 |
| **Realistic** | 0.43 | $2,060.71 |
| Enhanced VCT | **Maximum** | 0.62 | $898.44 |
| **Realistic** | 0.14 | $232.11 |
| HBCT (with POC) | **Maximum** | 3.53 | $3,127.03 |
| **Realistic** | 3.47 | $3,067.88 |
| Facilitated Linkage | **Maximum** | 0.82 | $294.73 |
| **Realistic** | 0.45 | $160.15 |
| VCT POC | | 1.43 | $527.20 |
| Pre-ART Outreach | **Maximum** | 1.83 | $689.03 |
| **Realistic** | 0.72 | $365.12 |
| Improved Care | **Maximum** | 1.95 | $983.26 |
| **Realistic** | 0.89 | $333.31 |
| POC | | 1.35 | $498.27 |
| On-ART Outreach | **Maximum** | 0.74 | $251.06 |
| **Realistic** | 0.63 | $194.92 |
| Adherence | **Maximum** | 0.70 | $183.54 |
| **Realistic** | 0.31 | $131.90 |
| Immediate ART | | 3.62 | $1,639.93 |
| Universal Test & Treat | **Maximum** | 5.59 | $4,267.86 |
| **Realistic** | 5.08 | $4,077.49 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Intervention Combination | DALYs averted (millions) | Additional Cost (millions)  (2013 USD) | Cost per DALY averted compared to previous increment (ICER) | Cost per DALY averted compared to baseline (ACER) | Percentage of maximum attainable impact achieved |
| ART Outreach | 0.63 | $194.92 | $309.59 | $309.59 | 6% |
| ART Outreach +  POC CD4 | 2.22 | $769.43 | $360.55 | $346.11 | 20% |
| ART Outreach +  POC CD4 +  VCT POC CD4 | 2.91 | $1,012.53 | $352.49 | $347.62 | 26% |
| ART Outreach +  POC CD4 +  VCT POC CD4 +  Linkage | 3.18 | $1,104.69 | $348.90 | $347.73 | 28% |
| ART Outreach +  POC CD4 +  VCT POC CD4 +  Linkage +  Pre-ART Outreach | 3.59 | $1,261.61 | $379.93 | $351.43 | 32% |
| ART Outreach +  POC CD4 +  VCT POC CD4 +  Linkage +  Pre-ART Outreach +  Adherence | 4.45 | $1,571.24 | $359.85 | $353.06 | 39% |

Table 3. DALYs averted and additional cost of care for individual interventions between 2010 and 2030.

Table 4. DALYs averted and additional cost of implementing a combination of interventions between 2010 and 2030.

# Discussion

Figure 4. Care experience of deceased individuals who suffered an HIV-related death between 2010 and 2030.



Our results suggest that ART-programmes can be materially enhanced to bring about greater health benefits by strengthening each part of the cascade , as has been demonstrated to be feasible in earlier trials, and/or by shifting to treating HIV-infected persons immediately when they present to care. In contrast, a radicial expansion of treatment programmes, with the identified weakendss in linkage and retention perpetuated, would not maximize health generated with limited resources.

* Improvements in the care cascade have long been hoped to be small, feasible, likely inexpensive changes to the operations of a clinic that would yield a large benefit, and leverage the enormous impact already made in ART to generate greater health outcomes.
* Whilst we find that to be true to some extent, the multifaceted nature of the current cascade means that no single cascade intervention has a very large impact.
* Trials and other studies that have examined the impact of intervention on the cascde have focussed on single interventons as those experiemental designs are not very ameanable to measuring the impact of combinations of changes simultanesouly.
* However, by doing the modelling we can see how attractive that a combination set of intervention potentially is.
* Everything intervention modelled is based on a real study (appedix) meaning that the impact projected may be realistic. However, studies looking at complete combinations would be needed to confirm these findings – it may be that greater synergies accure giving higher benefits and lower costs, or, instead that the increased complexity of the operations leads to higher cost and less benfits that expected.
* Further interventions are in the pipeline too. In particular, there has been discussion about making pre-ART more attractive to patients, which may also be expected to bring benefits.
* Immidiate ART has been talked about --- there has been debate about the benefits clinically and on transmission. But, ultimatelyt, what we are finding here is that the pragmatic benefits of not loosing someone who presents to care is powerful. This is consistent with the story from {New sydeny rosen trial about same day treat}. This represents a very different approach to the strengthen the pre-ART route. Under current assumption, these two options have about the same impact and cost and both can be recommended on this basis.
* However, population perspective reveals loci of deaths and clinic-focussed interventions, though cheap and do-able and good, will not bring the largest impacts. Large number of deaths exist outside the clinic among persons never diagnosed.
* Data from ALPHA Network (CITe ; hoW?) confirms that picture.
* M&E of cascade, as well as treatment guideliens should consider this point carefully. The effectiveness of a treatment program is only as good as the HIV testing program!
* Neither of the above approaches would reduce this. For the largest impact, massive outreach is required – no free lunch - and this will attract massive cost. There is also an EQUITY dimension – should programs continue to improve care for those (wealthier? More urban? More educated? DATA on this?) population that can more readily link to care, or seek to bring the whole population to a standard of care?
* The exact size of that cost is unknown and seem quite variable among studies. Ultimately, the cost depends on how much demand creation is required and how convenient testing and linkage can become. It will be useful to improve how these costs are understood and approaches developed to keep costs low.
* For instance, other exampels of HBCT (e.g Ruanne Linkage pilot and in Lancet HIV and Jenny’s paper) find high rates of linkages and lower cost than assumed here, which in South Africa arguably makes such an intervention cost-effective under the WHO criteria (AND HOW DOES IT FAIR AGAINST THE 0.5GDP THRESHOLD??).
* The wider point is that its hard to compare one intervention done in a trial to others (as no two interventions are quite the same) and hard to extrapolate to other settings (as the underlying causes of impact and cost – balance between program and underlyng population behaviorus etc) is unknown. So, this is all a rough guide.
* The issue of patient health care seeking behaviour also confounds our estimated impact of interventions. We have previously highlighted this as an issue and we have been able to make some inferences on that through confrongint the model with the AMPATH data – e..g we find ??? proportions of person starting ART that are connecting for first time.. However, little is known on this still (-- and is another driver of uncerainity here) and undersanding this remains a major priority for work to strengthen the impact of health systems, more generally.
* Extrapolation to other places.--- perhaps possible in general terms. We have benefit from the detailed AMPATH data but the general picture of a mature program with relatielt frequency care seeking and drop-out from ART is common. However the balance will be expected to change over time, and the relativr impact and costs of itnerventions will be modulated by health care seeking behaiorund and local conditions, will probably dominate the analysis.
* Findings of other moelling work, which relied on routinely available data on national programs at aggregated level, have been in broad agreement – although these have not been able to examine the same range of itnerventions options that we have nor be grounded in the data from the operations of a single program, nor benefit from the linkage of longitudiianl data from community outreach and clinical data.
* Many Contries moving ahead (e.g. Brazil – UTT: Rwanda; Imm ART) and it will be import to evaluate.
* UNAIDS 90-90-90 thing – urgent aim for everything all at once. WHO treatment guidelines have been focussed on threshold for initation and paient monitoring and with recommendations focussed on clinical evidence. WHO tretmet guidelines not include testing. But our results suggest that, in fact, programs need to either strengthen thieir cascade, especially on the pre-ART side; or, radically simplify care and provide treatment to all presenting; and then to achieve the greatest impact to include large outreach programs. Expandiing outreach whilst weaknesses remains risks faling to get maximum impact from invesmtnet.

~~These results indicate that within an ART programme in Kenya and under our baseline conditions, care is suboptimal. When assessing HIV-related deaths at the community-level, among all individuals, the majority of deaths were attributable to patients who never initiated ART and in particular to patients who were aware of their HIV-status but due to failings of pre-ART care, did not initiate treatment (figure 2, left). However, when the same scenario was considered from the clinic-level, among all individuals who had contact with the clinic yet suffered an HIV-related death (figure 2, right), the 19% of individuals who never engaged with care (from the left-hand figure) was absent. Additionally, the clinic-level view indicates that 35% of deceased patients had initiated ART; however, stepping back to the community-level view, only 24% initiated ART prior to death. These results highlight the major limitation of clinic-level data: only patients who contact the clinic are accounted for. Consequently, masking a major deficiency in care and cause of mortality.~~

~~Intervening at various points in care with individual interventions illustrates that HIV-testing and pre-ART retention are suboptimal, as interventions targeting those areas, such as HBCT or Improved Care, were highly impactful (figure 3). In contrast, removing pre-ART care all together (Immediate ART) and additionally actively seeking individuals (Universal Test & Treat) averted the most DALYs between 2010 and 2030(3.62m and 5.59m DALYs averted, 32% and 50% of MAI, respectively); however, these interventions were the most expensive to implement($1.64b and $4.27b, respectively). From analysis of these individual strategies, no single large-impact low-cost intervention was identified, with high impact interventions having a high cost per DALY averted and low cost interventions having a low cost per DALY averted. Additionally, we identified a combination of six interventions that when applied simultaneously improved patient outcomes at a cost of $353 per DALY averted compared to baseline. This combination strengthened care at multiple points and is potentially as impactful as the Universal Test and Treat strategy but with a lower average cost-effectiveness ratio.~~

~~This work indicates that it is imperative for ART programmes to evaluate patient outcomes from the population perspective. The clinic-level view is biased, as only individuals who have had contact with the clinic are accounted for. Thus, to fully understand where deficiencies in care are leading to lives being lost to HIV, the entire community must be fully represented. This poses significant challenges for HIV care providers, as assessing community-level outcomes, particularly among individuals with no prior engagement in care, is both financially and logistically testing. Additionally, as ART programmes consider intervening to improve care, many currently available interventions only target one aspect of care{Kilmarx:2013iy, Barnighausen:2011cb,Govindasamy:2014fa}. Our results deduce that a single intervention strategy provides limited benefit, as any individual interventions enacted will be attenuated by downstream deficiencies in care, and also limited by any upstream constraints. For instance, interventions targeting linkage to care will be constrained by the number of individuals who attempt to link and further capped by downstream losses from pre-ART and ART care. Thus as our results corroborate, care must be strengthened by intervening at multiple points with a combination of interventions to fully realise the benefits afforded by ART. Although interventions utilising an immediate ART strategy provide the largest improvement in patient outcomes, these gains are brought about through circumnavigating the operational challenges of pre-ART care by removing it, potentially depriving patients of its ancillary benefits{Burtle:2012kw,Govindasamy:2014fa}.~~

~~This model was predominantly calibrated using a longitudinal dataset provided by AMPATH of western Kenya. However, only the clinical elements of HIV care were calibrated to AMPATH data. National estimates of incidence were used to drive and replicate the epidemic before model results were then validated against further national estimates of prevalence, AIDS-related deaths and ART coverage{Spectrum:tl, KAIS:2014ux, NASCOP:2012tp}. Additionally, our baseline scenario does not include a HBCT component unlike the current programme at AMPATH. Consequently, this model deviates from directly describing the state of care at AMPATH to more broadly capturing the probable state of care in Kenya. Thus, the generalisability of these results to other ART programmes and elsewhere in sub-Saharan Africa remains open to debate. With limited data of this type currently available, insight into the state of care in other sub-Saharan countries is restricted. A similar modelling study recently found that improving the re-initiation of ART in a treatment programme in South Africa was a highly cost-effective intervention{Klein:2014ho}. This leads us to speculate that a larger proportion of individuals are initiating ART in South Africa as our model results indicate that a similar intervention was not particularly impactful. However, this type of intervention becomes nearly 5-fold more powerful if upstream care is flawless[~~*~~results not shown (in Leaks.docx)~~*~~]. In another mathematical model investigating HIV testing strategies in South Africa, Bendavid~~ *~~et al~~*~~. demonstrate that implementing a universal test and treat strategy with enhanced linkage and retention in care would nearly double the survival benefits of a strategy with current linkage and retention rates{Bendavid:2010gu}. Status quo linkage rates were 67% compared to 60% in our results, further illustrating the importance of successfully linking patients to care{Bendavid:2010gu}.~~

~~While this work discusses individual interventions targeting specific aspects of care, there are often substantial differences between two interventions of the same, or similar, name{Barnighausen:2011cb}. For example, in regard to HBCT, two such interventions have been trialled in different locations in sub-Saharan Africa with contrasting results. An intense HBCT intervention was tested in Kwazulu-Natal involving home-based HIV-testing followed by immediate POC CD4 testing and follow-up visits to facilitate linkage and adherence to care{vanRooyen:2013gy}. This intervention achieved 91% coverage of the community and within six months, 96% of newly diagnosed individuals had been linked to care{vanRooyen:2013gy}. In contrast, an HBCT intervention trialled at another AMPATH site in Kenya, achieved coverage of 88% of the population, but among newly diagnosed individuals only 15% had been linked to care over a median of 3.4 years since diagnosis{Genberg:2015cd}. The difference in linkage rates between the two interventions is likely a result of the former involving a combination of POC CD4 testing and follow-up visits to motivate individuals to link. Together with our results, demonstrating the limited impact of HBCT in the absence of POC CD4 or perfect linkage, this provides evidence to suggest that HBCT alone is not capable of generating the impact that it was designed to achieve.~~

~~Overall, the results of these analyses resonate with the health losses reported in many ART-programmes and thus reaffirm the link between patient outcomes and suboptimal care. When considering the distribution of care experience among HIV-related deaths in the entire population(figure 2, left), 19% of individuals were never diagnosed and 57% failed to initiate ART before death. These results are in agreement with data from ALPHA sites in Rakai, Uganda, which indicate that around ~20% of deaths in 2011 were among undiagnosed individuals and ~50% were among individuals tested but who never initiated ART[~~*~~Slaymaker (only going off the Paris slides here – can’t find the relevant paper)~~*~~]. This reinforces our results, indicating that mortality is chiefly occurring outside the clinic.~~

~~Additionally, we illustrated that no single intervention provided large gains in patient outcomes without incurring significant costs. The most impactful intervention, Universal Test & Treat, averted 5.59m DALYS at a cost of $4.27b ($763.86 per DALY averted). However, when compared to the maximum attainable impact scenario, in which all infected individuals are placed onto ART from 2010 onwards with perfect adherence and retention in care, the Universal Test & Treat intervention averted 50% of the MAI. This scenario illustrates the lowest number of DALYs that will accrue given baseline care prior to 2010, as averting 100% of DALYs accrued between 2010 and 2030 at baseline is an impossibility. Obtaining an MAI value higher than 50% would require the combination of a Universal Test & Treat strategy with ART adherence and outreach interventions to prevent long-term losses from ART care. However, through the use of a combination of interventions targeting both pre-ART and ART care, 88% of the DALYs averted by the Universal Test and Treat intervention can be achieved at 44% of the cost per DALY averted (table 3). Yet, this combination of interventions was only able to avert 39% of the maximum attainable impact; due to the lack of any interventions targeting HIV-testing, as these have a high cost per DALY averted (table 3). Consequently, this indicates that intervening at multiple points to strengthen care is almost as effective as removing pre-ART care in its entirety, such as in the Immediate ART or Universal Test & Treat strategies, but without depriving patients of the ancillary benefits provided by pre-ART care. However, little is known about the long-term impacts of immediate ART on patient retention and adherence; but the recently published early results of the RapIT trial in South Africa evaluating the effect of immediate ART initiation on ART uptake illustrate that 88% of enrolled patients were virally suppressed six months after treatment initiation[~~*~~Rosen et al. (2015). Confidential. Unpublished~~*~~].~~

~~Interestingly, the distribution of care experience among deceased individuals when the combination of interventions was compared to a Universal Test & Treat strategy highlights, how both strategies significantly reduced HIV mortality in comparison to baseline, but through different mechanisms(figure 4). We see that the combination of interventions was able to reduce the proportion of HIV-related deaths among individuals who were diagnosed but never initiated ART, but as none of the interventions enhance HIV-testing a similar proportion of individuals decease, without being diagnosed, to the baseline scenario. In contrast, in the Universal Test & Treat intervention only 13% of individuals who suffered an HIV-related death never initiated ART; with the vast majority (51%) lost from ART care before death. Therefore, the total person-time spent on ART by individuals in the Universal Test & Treat intervention exceeded that of individuals in the combination intervention scenario, this is reflected by the increased cost of Universal Test & Treat and the larger proportion of cost that is attributable to ART care. Consequently, the combination of interventions results in fewer person-years on ART, reducing the likelihood of resistance through failure to adhere to treatment{Oyugi:2007fs}. An alternative category of interventions recently hypothesised to improve patient outcomes and reduce costs, is that of tiered care, using patient strata to determine the provision of care services. For example, Babigumira~~ *~~et al.~~* ~~(2011), implementing a task-shifting intervention for eligible patients at an HIV clinic in Kampala, Uganda{Babigumira:2011gg}. Eligibility criteria selected adherent, healthy randomised patients on ART to switch from monthly physician visits to seeing a physician every six months and picking up medication from a pharmacy on a monthly basis. No significant difference in clinical outcomes was observed and the annual cost of care decreased by 20% for patients attending physician visits every six months{Babigumira:2011gg}. This type of tiered intervention, selecting adherent patients to be monitored more infrequently, illustrates how care can be stratified between patients.~~

~~The motivating stimuli driving HIV-infected individuals to seek care are not yet fully understood. With progress being made in other fields{Buregyeya:2011fi, Salaniponi:2000tc, Pronyk:2001uk}, it is hoped that new insights into HIV health-care seeking behaviour will follow{Burns:2014jz}. Furthermore, the generalisability of these results to other settings remains undetermined; but for progress to be made in assessing the current state of care along with strategies to resolve deficiencies, individual-level longitudinal data similar to data provided by AMPATH will be required. While a mathematical model can demonstrate the impact of a combination of interventions, it remains to be seen how such a strategy would be implemented by a real-world ART programme. For instance, it may be preferable to distribute intervention implementation over time as part of a graded response. Finally, the estimates of costs used in this model are predominantly based on findings from a large-scale multi-country analysis, but the true scalability of these costs and their representation of the cost of intervention execution are debatable.~~

~~Our results indicate that in Kenya, the effectiveness of current ART-programmes can be improved. While interventions targeting HIV testing and pre-ART retention were highly impactful, losses from care occurred throughout, leading to suboptimal treatment outcomes for patients. In this setting, our results show that a combination of interventions targeting multiple points of care is a cost-effective way to strengthen current ART-programmes. Consequently, we feel that this analysis will help shape the discourse around the cascade and interventions that are formulated, evaluated and rolled-out to improve the impact of ART programmes in sub-Saharan Africa.~~

# Acknowledgements

# References

# Figure Legends

***Figure 1*** *– Flow diagram representing the operational steps involved in navigating an ART-programme.*

***Figure 2*** *– Care experience of patients suffering HIV-related deaths between 2010 and 2030.*

***Figure 3*** *– DALYs averted and additional cost of care for individual interventions between 2010 and 2030.*

***Figure 4*** *– Care experience of deceased individuals who suffered an HIV-related death between 2010 and 2030.*

***Table 1*** *– Key model assumptions and data sources.*

***Table 2*** *– Summary of individual interventions designed to target various aspects of care.*

***Table 3*** *– DALYs averted and additional cost of care for individuals interventions between 2010 and 2030.*

***Table 4*** *– DALYs averted and additional cost of implementing a combination of interventions between 2010 and 2030.*

# Supporting Information

See appendix.