The impact of antiretroviral treatment on the age composition of the HIV epidemic in sub-Saharan Africa

Jan A.C. Hontelez[a,b,c], Sake J. de Vlas[a], Rob Baltussen[b], Marie-Louise Newell[c], Roel Bakker[a], Frank Tanser[c], Mark Lurie[d] and Till Bärnighausen[c,e]

Introduction: Antiretroviral treatment (ART) coverage is rapidly expanding in sub-Saharan Africa (SSA). Based on the effect of ART on survival of HIV-infected people and HIV transmission, the age composition of the HIV epidemic in the region is expected to change in the coming decades. We quantify the change in the age composition of HIV-infected people in all countries in SSA.

Methods: We used STDSIM, a stochastic microsimulation model, and developed an approach to represent HIV prevalence and treatment coverage in 43 countries in SSA, using publicly available data. We predict future trends in HIV prevalence and total number of HIV-infected people aged 15–49 years and 50 years or older for different ART coverage levels.

Results: We show that, if treatment coverage continues to increase at present rates, the total number of HIV-infected people aged 50 years or older will nearly triple over the coming years: from 3.1 million in 2011 to 9.1 million in 2040, dramatically changing the age composition of the HIV epidemic in SSA. In 2011, about one in seven HIV-infected people was aged 50 years or older; in 2040, this ratio will be larger than one in four.

Conclusion: The HIV epidemic in SSA is rapidly aging, implying changing needs and demands in many social sectors, including health, social care, and old-age pension systems. Health policymakers need to anticipate the impact of the changing HIV age composition in their planning for future capacity in these systems.

AIDS 2012, **26** (Suppl 1):S19–S30

Keywords: aging, antiretroviral therapy, epidemiological trends, HIV, mathematical model

Introduction

The rapid and large scale-up of antiretroviral treatment (ART) for HIV in sub-Saharan Africa (SSA) constitutes an unprecedented global public health effort, resulting in great improvements in length and quality of life of those infected. The expansion of ART coverage since the early 2000s has led to a substantial increase in the number of

[a]Department of Public Health, Erasmus MC, University Medical Center Rotterdam, Rotterdam, The Netherlands, [b]Department of Primary and Community Care, Nijmegen International Center for Health System Analysis and Education, Radboud University Nijmegen Medical Centre, The Netherlands, [c]Africa Centre for Health and Population Studies, University of KwaZulu-Natal, Somkhele, KwaZulu-Natal, South Africa, [d]Department of Epidemiology and the International Health Institute, Warren Alpert Medical School, Brown University, Providence, Rhode Island, and [e]Department of Global Health and Population, Harvard School of Public Health, Boston, Massachusetts, USA.

Correspondence to Jan A.C. Hontelez, Department of Public Health, Erasmus MC, University Medical Center Rotterdam, P.O. Box 2040, 3000 CA Rotterdam, The Netherlands.

Tel: +31 30 704 46 32; e-mail: j.hontelez@erasmusmc.nl
Received: 9 November 2011; accepted: 1 May 2012.

DOI:10.1097/QAD.0b013e3283558526

HIV-infected people on ART, with nearly 4 million people initiated in SSA as of late 2009 [1]. In June 2011, the United Nations General Assembly High Level Meeting on AIDS renewed its commitment to achieving universal ART coverage, calling for a doubling in scale-up efforts to initiate another 10 million people, to achieve universal coverage of those in need by 2015 [2]. Yet, while '[t]he UN meeting was tasked with charting the future course of the global HIV response, ... [it] failed to mention the ageing of the pandemic' [3].

Effective ART increases survival [4–6] and can decrease HIV transmission probabilities [7–10]. Mills *et al.* [5] estimated that life expectancy of HIV-infected patients in SSA can approach the life expectancy of the uninfected population if treatment is initiated early (at CD4 cell counts >250 cells/μl). The results of the HIV Prevention Trials Network (HPTN) 052 trial show that HIV transmission rates can be reduced by as much as 96% in HIV-discordant stable partnerships [8], and results from observational studies show reductions of about 90% in transmission rates [7,9]. Thus, with expanding ART coverage HIV-infected people will live into older ages and HIV incidence in the young and middle-aged population is likely to decrease, resulting in a shift of the age composition of the HIV epidemic towards older ages. Such a shift has already occurred in developed countries. About 29% of HIV-infected people in the United States were aged over 50 years in 2008, whereas this proportion was only 17% in 2001 [11]. A previous study quantified the aging of the HIV epidemic for the South African province of KwaZulu-Natal, estimating that the number of HIV-infected adults aged 50 years or older will double from 2004 to 2025 [12]. Similar projections for other parts of SSA are currently missing, and it is unlikely that the South African results can be generalized to countries with different demographic and behavioural characteristics as well as distinct HIV treatment and prevention efforts. Already, an estimated 3 million people aged 50 years or older live with HIV in SSA [13], and with a further 7 million HIV-infected people in SSA eligible for HIV treatment [14], there is a large pool of currently untreated HIV-infected adults who will be able to survive to older ages as treatment coverage expands.

Here, we predict age-specific HIV prevalence trends in 43 countries in SSA under different trajectories of ART coverage expansion. We used STDSIM, a stochastic microsimulation model that simulates individuals in a dynamic network of sexual contacts [15–17]. We developed an approach that can be applied to quantify all national HIV epidemics in 43 sub-Saharan African countries in the period 2000–2009 by using country-specific data on demographic composition [18–20], data on country-specific ART coverage [1] and country-specific circumcision prevalence rates [14,21], as well as epidemic-specific sexual behaviour profiles.

Methods

Model

In the model, HIV is represented by four consecutive stages: early infection (0.25 years); asymptomatic infection (5.5 years); symptomatic infection (4 years); and AIDS (0.7 years). Median survival of an individual with untreated HIV infection is about 10 years (95% confidence interval 5–19 years) [22]. People on ART are assumed to have a 90% reduction in infectiousness [7,9] and their life expectancy at the time of treatment initiation is four times the remaining life expectancy without treatment (Fig. S1, http://links.lww.com/QAD/A226) [6]. More details about the model structure can be found in the supplementary material and in three previous publications [15,23,24].

Model quantification

Demographics

Background mortality rates (mortality in the absence of HIV) were calculated using country-specific life tables [19] and burden of disease estimates published by the World Health Organization (WHO) [20]. For each country, we first calculated the proportion of deaths attributed to HIV through comparison of the age-specific and sex-specific burden of disease estimates [20], and the all-cause mortality rates in the WHO life tables [19]. We then used the ratio between these two mortality estimates (HIV-specific and all-cause) to compute background mortality rates for all causes except for HIV. Figure S2A and S2B, http://links.lww.com/QAD/A226, present the country-specific HIV-corrected background mortality rates for men and women, respectively. Age-specific and period-specific fertility rates for each country were obtained from the 2008 United Nations World Fertility Data [18]. We assumed that fertility rates remained constant after 2011.

Antiretroviral treatment scale-up

We fitted ART coverage until 2009 to the coverage levels reported by WHO [1], using two submodels. The first submodel represents an individual's demand for ART as a function of HIV-disease stage; the second submodel describes the capacity of the health system to meet this demand. ART coverage in our model is the ART demand met by the capacity of the health system. To fit the modelled ART coverage to the annual coverage data reported by WHO (for the period 2004–2009) [1], we used a quadratic (αx^2), linear (αx) or square-root ($\alpha x^{1/2}$) function of scale-up of ART capacity in the health system, while assuming the ART demand function to be the same as previously estimated for South Africa [15]. For each of the three scale-up functions, we calculated the annual ART coverage of those eligible (at CD4 cell counts ≤200 cells/μl) for all countries in SSA using the country-specific starting years of the ART scale-up (the scale-up started in all countries in the period 2001–2005). We chose the multiplication factors (α) in the different functions to maximize the model fit by minimizing the

mean squared error (MSE) of the model predictions compared with the country-specific ART coverage estimates reported by WHO [1].

We assumed all countries to provide ART at CD4 cell counts ≤200 cells/μl up to 2009, with three exceptions: Botswana offered ART at CD4 cell counts ≤250 cells/μl for all HIV-infected individuals since the start of its ART scale-up in 2003 [25]; Rwanda switched to ART at CD4 cell counts ≤350 cells/μl for all HIV-infected individuals in 2007 [26]; and Namibia has offered lifelong ART at CD4 cell counts ≤350 cells/μl for all pregnant women since 2007 (about 20% of all HIV-infected women aged 15–49 years and with CD4 cell counts between 200 and 350 cells/μl who seek care) [27]. We assumed a baseline annual rate of stopping treatment of 5% [28], and that people who stopped will never re-initiate treatment. As retention in care varies with the capacity of the health system to deliver ART [29], we assumed that the annual rate of stopping treatment is reduced to 2.5% when the health system's capacity to provide ART reaches 80%, and is further reduced to 1% when the capacity is 100%.

HIV epidemic and sexual behaviour profiles

To represent the different HIV epidemics in SSA, we defined five sexual behaviour profiles that differ in their age-specific and sex-specific rates of forming – and condom use during – three different types of sexual partnerships (Table S1, http://links.lww.com/QAD/A226): stable relationships (lasting on average 25 years); casual relationships (lasting on average 6 months); and commercial sex (a once-off contact) [23,24].

We named the sexual behaviour profiles according to the epidemics they have produced: *concentrated risk profile* (high risk of HIV among commercial sex workers (CSWs) and clients; low risk in the general population); *mixed risk profile* (high risk of HIV among CSWs and clients; medium risk in the general population); and *generalized risk profile* (high risk in the general population). Three of the four parameter settings of the 'four cities study' fitted these three profiles and were chosen accordingly: Cotonou, Benin (*concentrated risk profile*); Yaoundé, Cameroon (*mixed risk profile*); and Kisumu, Kenya (*generalized risk profile*) [24]. High levels of condom use among CSWs were observed in Benin and Cameroon in the early nineties and resulted in declining HIV prevalence. However, in some of the countries that fit the *concentrated risk profile* or the *mixed risk profile* (based on the prevalence level) such prevalence declines were not observed. To capture this distinction, we added two extra profiles with low condom use: *concentrated risk profile (low condom use)* and *mixed risk profile (low condom use)*, both with reduced condom use rates during commercial sex.

As in a previous study [24], sexual behaviour parameters for the population aged 15–49 years were stratified by 5-year age groups and fitted to represent the age-specific numbers of sex partners reported in the behavioural surveys of the 'four cities study' [30]. In order to derive parameter values for sexual behaviour for the people aged 50 years or older, for which measured data were not available in the study, we assumed that partner change rates and CSW visiting behaviour remained the same for all people aged 45 years or older. Within each partnership, we assumed a 25% reduction in the frequency of sexual contacts in people aged 50 years or older relative to those aged 45–49 years. This assumption fitted closely to the data from a HIV and sexual behaviour surveillance in the population aged 50 years or older in KwaZulu-Natal, South Africa [12,31].

For each country, we ran the model with all five sexual behaviour profiles and the country-specific circumcision prevalence [14,21] and ART scale-up function (see above). We then selected the profile that best described the HIV epidemic in a given county in the period 2000–2009. In order to do so, we constructed a 'fit score' that captures the development of HIV prevalence over time. The score is the sum of the MSE of HIV prevalence predictions over 2000–2009 (for fitting prevalence levels), and the squared error over the difference between prevalence in 2000–2004 and 2005–2009 (to fit the observed trend in HIV prevalence). We used UNAIDS estimates of the country-specific HIV prevalence in adults aged 15–49 years over the period 2000–2009 in order to assess fit [14].

Finally, we fine-tuned the model quantifications for each country by choosing the best-fitting combination of overall partner change rates (range ±25%; see Table S1, http://links.lww.com/QAD/A226) and year of HIV introduction that produced the lowest MSE on the HIV prevalence estimates in adults aged 15–49 years, as compared with UNAIDS estimates for the period 2000–2009. For the *concentrated risk* and *mixed risk profiles*, we allowed for a maximum of 25% reduction in CSW visit rates to further fine-tune predicted HIV epidemics, because the epidemics produced by these profiles are largely driven by commercial sex.

Simulations

We predicted trends in HIV prevalence in the populations aged 15–49 years and 50 years or older over the period 2011–2040 in 43 countries in SSA. In our baseline estimate, we assumed ART to be scaled up continuously after 2009 according to the country-specific scale-up function of the health system's capacity (see above), until capacity reaches 100%. By October 2010, seven countries in SSA had adopted the 2010 WHO treatment guidelines that recommend ART initiation at CD4 cell counts ≤350 cells/μl into their national policy (Kenya, Lesotho, Malawi, Rwanda, Tanzania, Zambia and Zimbabwe) [1], whereas South Africa adopted the guidelines in August 2011 [32]. We assumed that all other countries will have adopted the new guidelines by January 2013.

We calculated country-specific trends in HIV prevalence and total number of HIV-infected people aged 15–49 years and 50 years or older. We assumed three alternative scenarios of scale-up of health systems' capacities to provide ART: *decline* (reduction in capacity by 20% in 2012 and constant capacity levels thereafter); *no further scale up* (capacity remains constant at 2011 levels); *rapid scale up* (capacity increases to 100% for all countries by 2015).

Results

Using the five predefined sexual behaviour profiles (Fig. 1), our model was able to accurately replicate the ART coverage scale-up (Fig. 2a) and HIV epidemics (Fig. 2b and c) of all 43 sub-Saharan African countries. For only nine countries, HIV prevalence projections differed more than 10% compared with UNAIDS estimates at some point during the period 2000–2009. The absolute number of HIV-infected people aged 50 years or older (2.6 million) and the number of HIV-infected people aged 15–49 years (17.8 million) in 2007 are very similar to the estimates that Negin and Cumming [13] derived using a different methodological approach (2.9 and 17.9 million, respectively). In addition, our model predictions regarding population growth over the period 2000–2040 are very similar to those provided by the United Nations Population Prospects (Fig. S3, http://links.lww.com/QAD/A226) [33]. A detailed description of the parameters for individual countries can be found in Table S2, http://links.lww.com/QAD/A226.

Figure 3 shows the HIV prevalence in the populations aged 15–49 years and 50 years or older for the years 2011,

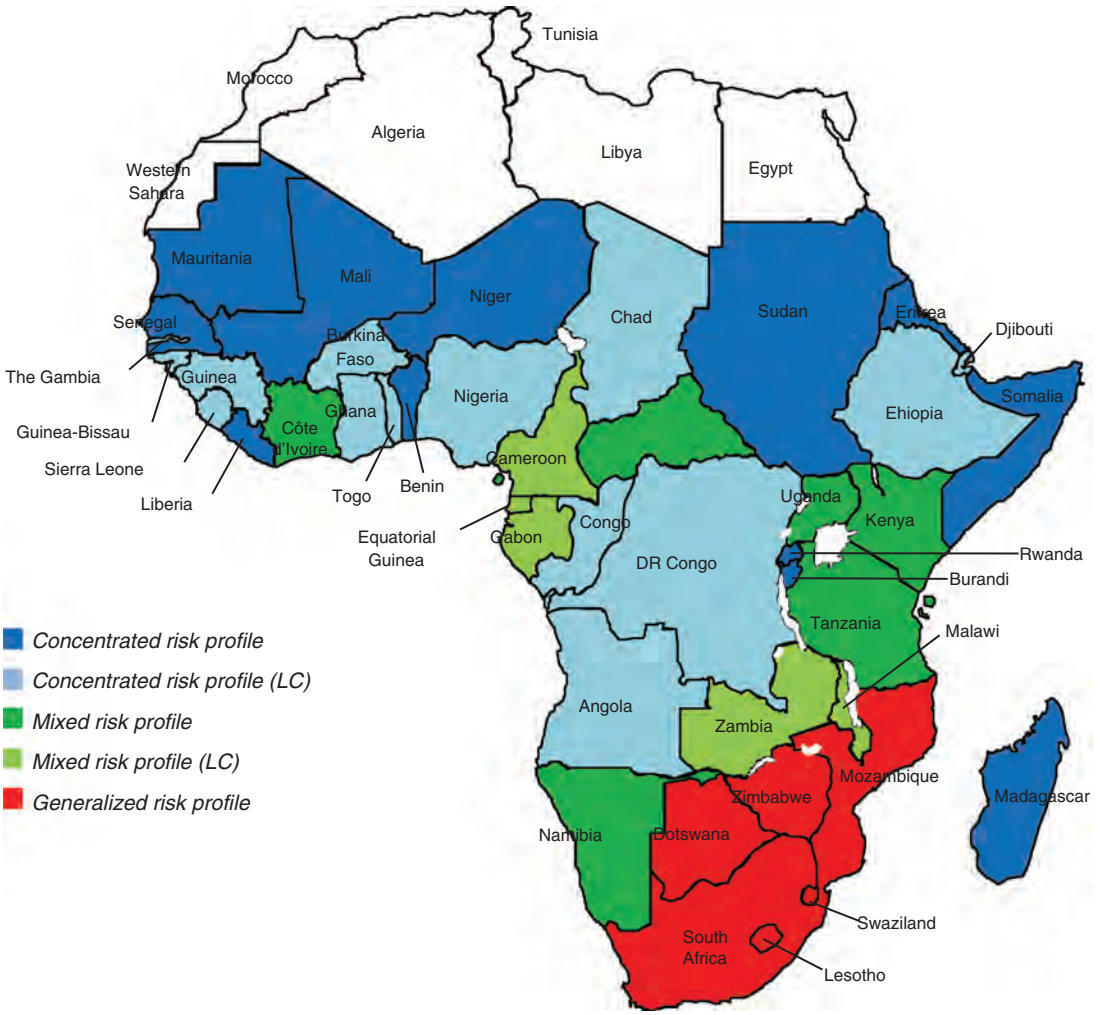

Fig. 1. Geographical distribution of sexual behaviour profiles. The colour of each country represents the best fitting sexual behaviour profile given country-specific circumcision levels (Table S2, http://links.lww.com/QAD/A226) and ART rollout (Fig. 2a). A detailed description of the profiles is given in Table S1, http://links.lww.com/QAD/A226. ART, antiretroviral treatment; LC, low condom use.

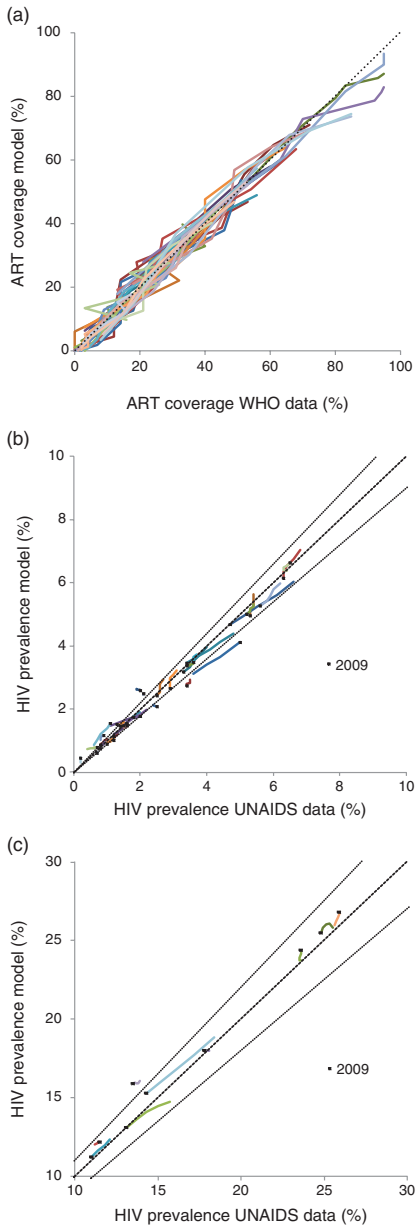

Fig. 2. Model fit compared to data. (a) Predicted ART coverage of those eligible at CD4 cell counts ≤200 cells/μl in the model compared with WHO data over the period 2004–2009. The dashed line represents a perfect fit (i.e. predicted coverage in model = WHO data). (b) Predicted HIV prevalence for low-endemic and medium-endemic countries in the model compared with UNAIDS prevalence estimates over the period 2004–2009. The dashed line represents a perfect fit (e.g. predicted prevalence in the model = UNAIDS data). The dotted line represents a 10% difference between model predictions and data. (c) Predicted HIV prevalence for high-endemic countries in the model compared with UNAIDS prevalence estimates over the period 2004–2009. The dashed line represents a perfect fit (e.g. predicted prevalence in the model = UNAIDS data). The dotted line represents a 10% difference between model predictions and data. Full country-specific parameter settings are given in Table S2, http://links.lww.com/QAD/A226. ART, antiretroviral treatment.

2025 and 2040 under the baseline scenario of continued scale-up of ART. Overall, prevalence in the population aged 15–49 years will decline from 5% in 2011 to 3% in 2040, whereas prevalence in the population aged 50 years or older will increase from 3 to 4% over the same period. The number of countries with an HIV prevalence of less than 1% in the population aged 15–49 years will increase from six in 2011 to 17 in 2040, whereas the number of countries in this prevalence category for the population aged 50 years or older will halve in the same period, from 12 to six. HIV prevalence in older adults will be 2% or higher in 22 countries in SSA in 2040, whereas this is the case for only 11 countries regarding adult HIV prevalence. In countries with currently very high HIV prevalence rates in both younger and older adults, HIV prevalence in the population aged 50 years or older will increase dramatically (Table 1). For instance, in Botswana, HIV prevalence in the population aged 50 years or older was 15% in 2011, and will increase to 24% in 2040. Similar trends are predicted for South Africa (an increase in HIV prevalence in the population aged 50 years or older from 10 to 16%), Swaziland (15 to 27%) and Lesotho (13 to 25%) (Fig. 3).

The total number of HIV-infected people aged 50 years or older in SSA will increase rapidly over the coming decades, from 3.1 million in 2011 to 9.1 million in 2040, an increase of 190% (Fig. 4 and Table 2). At the same time, the number of HIV-infected young adults (aged 15–34 years) will rapidly decline: from 12.1 million in 2011 to 9.1 million in 2030 (a 25% reduction). While prevalence levels stabilize in 2030, the total number of HIV-infected people will increase again to 10.8 million in 2040. Overall, the total number of HIV-infected people aged 15 years or older will increase over the next three decades, from 22.4 million in 2011 to 32.4 million in 2040, an increase of 44%.

As a result of the disproportionate increase in the number of HIV-infected older adults (Fig. 4), the age composition of the HIV-infected population will change (Table 2). In 2011, about 13% of all HIV-infected people were aged 50 years or older; by 2040, this proportion will have more than doubled, to 27% (Table 2). In contrast, young adults (aged 15–34 years) will contribute decreasing proportions of infections to the total number, from 52% in 2011 to 33% in 2040 (Fig. 5). Countries that have both a high ART coverage and declining HIV prevalence among the population aged 15–49 years will be faced with an especially dramatic shift in age composition of the HIV epidemic. The most extreme shift is observed in Zimbabwe, where the proportion of HIV-infected people aged 50 years or older will increase from 16% in 2011 to 62% in 2040. Countries like Kenya (13–51%), Tanzania (14–48%), Namibia (12–38%) and South Africa (14–36%) show similar trends. In contrast, countries with low and slowly expanding ART coverage show less rapid changes in age composition. In Sierra Leone, the

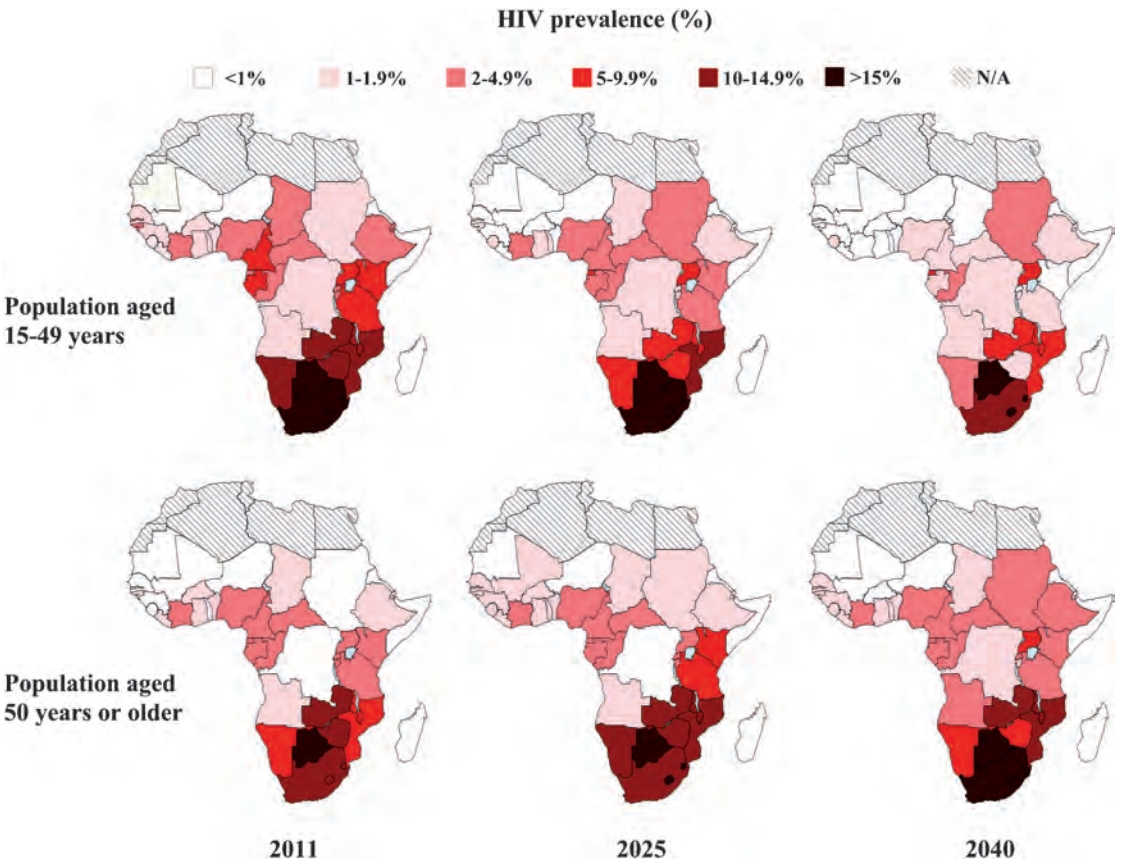

Fig. 3. HIV prevalence in the populations aged 15–49 years and 50 years or older in sub-Saharan Africa for the years 2011, 2025 and 2040, under continued scale-up of antiretroviral therapy. N/A, not applicable.

proportion of HIV-infected people aged 50 years or older increases from 11% in 2011 to 18% in 2040, and similar trends are found in Democratic Republic of Congo (13–15%), The Gambia (9–15%), Somalia (14–21%) and Burundi (16–22%) (Table 2).

In the *decline* scenario, with 20% decrease in ART capacity in 2012, we predict that the number of HIV-infected older adults will reach 6.9 million in 2040, or 22% of all HIV-infected people (Fig. 5). On the other hand, if treatment capacity remained at the level of 2011 (i.e. in the *no further scale up* scenario), the total number of HIV-infected older adults would be 7.4 million in 2040, which is 24% of all HIV-infected adults. Under the *rapid scale up* scenario, the number of HIV-infected older adults in 2040 would be 9.3 million in 2040, which is 28% of all HIV-infected people.

Discussion

We estimate that the total number of HIV-infected adults aged 50 years or older in SSA will nearly triple from about 3.1 million in 2011 to 9.1 million in 2040, assuming that ART scale-up continues at the current speed. In 2011, about one in seven HIV-infected people were aged 50 years or older in SSA, whereas in 2040, this ratio will be more than one in four. Due to an overall increase in the number of people aged 50 years or older in SSA, the increase in prevalence is relatively modest, from 3% in 2011 to 4% in 2040. In contrast, HIV prevalence among the population aged 15–49 years will decline over the coming decades, from 5% in 2011 to 3% in 2040.

This aging of the HIV epidemic is likely to have broad and important consequences for the organization of health-care services in SSA, as has been pointed out in a commentary on the results we present in this study [33]. Due to the increase in life expectancy following the scale-up of ART, populations will age, 'unmasking' the burden of noncommunicable diseases (NCDs) previously hidden due to high rates of HIV-related mortality [34]. Already, NCDs are becoming more important in low- and middle-income settings, where prevalence of risk factors is high and prevention efforts are limited [35–39]. In South Africa, 55% of all middle-aged women were found to be obese in a cross-sectional survey [40,41]. Smoking prevalence in SSA is high and increasing, and meals generally contain high levels of calories and salt [40,41]. Consequently, hypertension and diabetes are becoming more common in SSA [42,43]. Because the contribution

Table 1. HIV prevalence in the populations aged 15–49 years and 50 years or older in 2011, 2025 and 2040 for all 43 countries of sub-Saharan Africa, assuming continued scale-up of antiretroviral treatment.

	HIV prevalence (%)					
	Population aged 15–49 years			Population aged 50 years or older		
	2011	2025	2040	2011	2025	2040
Sub-Saharan Africa	5	3	2	3	4	4
Central Africa	2	2	1	2	2	2
Angola	2	2	2	1	2	2
Cameroon	5	3	1	4	4	4
Central African Rep.	5	3	1	4	4	3
Chad	3	1	1	2	2	1
Democratic Republic of Congo	1	1	1	1	1	1
The Congo	5	3	2	4	4	4
Equatorial Guinea	4	8	7	3	6	7
Gabon	3	3	2	2	4	4
Eastern Africa	4	3	2	3	3	3
Burundi	3	1	1	3	2	2
Djibouti	2	1	1	2	1	1
Eritrea	1	<0.5	<0.5	1	1	1
Ethiopia	2	2	2	2	2	2
Kenya	6	3	1	5	6	4
Madagascar	<0.5	<0.5	<0.5	<0.5	<0.5	1
Mozambique	12	11	9	8	12	14
Rwanda	3	1	1	3	3	2
Somalia	1	1	1	1	1	1
Sudan	1	2	2	1	2	2
Tanzania	5	3	1	4	5	4
Uganda	7	5	5	4	4	6
Southern Africa	16	12	9	10	13	13
Botswana	25	18	16	17	23	25
Lesotho	25	24	21	14	19	25
Malawi	11	8	8	9	10	12
Namibia	13	8	4	10	10	9
South Africa	18	15	11	11	14	16
Swaziland	25	21	20	16	23	27
Zambia	14	8	9	8	11	12
Zimbabwe	14	6	2	12	13	8
Western Africa	2	2	1	2	2	2
Benin	2	1	<0.5	1	1	1
Burkina Faso	1	1	<0.5	1	1	1
Côte D'Ivoire	4	2	1	3	3	2
The Gambia	2	2	2	1	2	2
Ghana	2	1	1	1	2	2
Guinea	2	1	1	1	1	1
Guinea-Bissau	2	1	1	1	2	2
Liberia	1	1	<0.5	1	1	1
Mali	1	1	<0.5	1	1	1
Mauritania	1	1	<0.5	<0.5	1	1
Niger	1	<0.5	<0.5	1	1	1
Nigeria	4	2	2	2	3	3
Senegal	1	1	1	1	1	1
Sierra Leone	1	1	1	1	1	1
Togo	2	1	1	1	1	2

of these risk factors to the overall risk of NCDs accumulates over age, they become particularly important as the HIV epidemic ages. In addition, HIV infections in older adults is often complicated by preexisting or developing non-AIDS-related comorbidities such as cardiovascular diseases (CVDs) and metabolic diseases, which in turn might aggravate HIV disease progression [44]. Finally, HIV infection and ART are independent risk factors of many NCDs such as non-AIDS-related malignancies, CVDs, kidney and liver failure and osteoporosis [45–47]. Therefore, quantitative estimates on the impact of the aging HIV epidemic on the overall disease burden in SSA are needed.

The predicted aging of the HIV epidemic will also affect social sectors other than the health sector, particularly in countries where HIV prevalence in older adults will substantially increase over the coming decades. Currently, many countries in SSA have no, or very limited, pension programmes [48], and support for the elderly generally

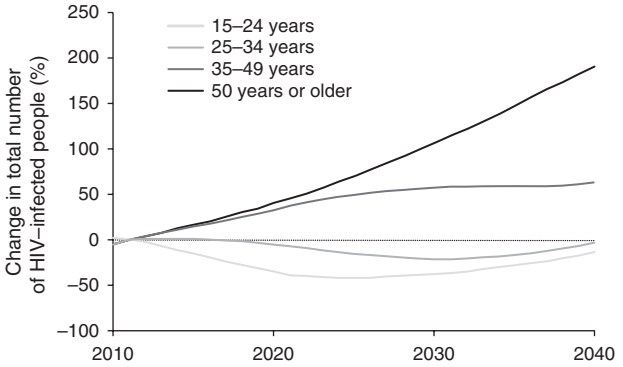

Fig. 4. Projected trends of total number of HIV-infected people in sub-Saharan Africa over the period 2010–2040 under continued scale-up of antiretroviral therapy. The change is relative to the total number of HIV-infected people in each age category in 2011.

falls under the responsibility of the family [49]. As the numbers of HIV-infected adults who live into old ages increases due to ART, the need for financial and social support of older adults will increase as well. Policymakers need to consider how this need can be met in the specific contexts of their countries' existing old-age pension and social care systems. At the same time, the increasing presence of older adults in the hyperendemic communities in SSA may bring important benefits to families and communities in the region, including improved childcare, social cohesion, and greater flexibility of middle-aged family members to temporarily migrate in search for work opportunities. Future empirical research needs to establish how the presence of older HIV-infected adults in sub-Saharan African households affects households' social and economic well being, and which interventions can strengthen positive effects and mitigate negative ones.

Our results show that the total number of HIV-infected adults aged 15 years or older will increase by 44% over the next three decades, creating a continuously growing need for financial and human resources to provide ART. Already, these resources to provide ART are stretched in SSA [50,51], emphasizing the need for continued scale-up of cost-effective prevention interventions alongside treatment in order to reduce incidence and thus future treatment needs [52–54]. In addition, it might be necessary to more closely integrate the delivery of treatment and care for different chronic diseases, in order to reduce the financial and time burdens that older ART patients bear in regularly utilizing healthcare for several conditions. Economies of scope might increase the efficiency of the healthcare delivery, and general health systems might be strengthened as vertical health system structures are integrated [55].

Our study has several limitations. We modelled countries as a homogenous mix of people, assuming country averages to apply to the entire population. However, in reality, there may be important differences in HIV epidemics within countries [56]. In addition, we assumed HIV survival and transmission probabilities to be universally applicable, whereas in reality, there may be differences in these parameters by strains of HIV virus in different parts of Africa [57]. The HIV-2 virus, which is only prevalent in some western African countries, is known to have a lower virulence and transmission potential compared with the more common HIV-1 strain [57]. Also, our model does not include mother-to-child transmission of HIV. As HIV-infected children can be treated effectively with ART [58], they may now live into young adulthood, increasing the number of HIV-infected people in this age category.

Both acquired resistance (development of resistance within an individual on treatment) and transmitted resistance (spread of drug-resistant strains) may reduce the effectiveness of treatment programs, and consequently result in a less profound effect of the ART scale-up on the population age composition. Patients who develop resistance might fail to suppress viral replication while on treatment, resulting in shorter survival times and higher infectiousness. While second-line or third-line therapies can be prescribed to treat those with resistance to first-line ART, many treatment programs in SSA are currently not well equipped to deal with drug resistance, as both monitoring for treatment resistance and providing second-line and third-line ART regimens is expensive and requires specialized expertise [59]. Therefore, if the prevalence of resistance increases, effective treatment coverage will decline. In our sensitivity analysis, we explore the effect of declining treatment coverage on the changes in age composition. We find that the changes in age composition are similar but somewhat reduced in magnitude if effective coverage is reduced substantially (e.g. by one fifth compared with the baseline case). It is currently unclear, however, in how far the fears of rapidly spreading drug resistance expressed at the start of the ART scale-up [60] are justified. The prevalence of drug resistance remains low in most countries in SSA after nearly 10 years of scaling up ART [61,62]. In addition, adherence to treatment in SSA is comparable to many high-income countries [63], and survival of patients on treatment in SSA approaches general life expectancy [5], suggesting that resistance may not become a major problem in the region in the near future.

In this study, we assumed that risk behaviour remained the same after age 45 years. Although detailed data on sexual risk taking in older age for SSA is lacking, it is plausible that the frequency of sexual activity declines to some extent in older adults [64]. On the contrary, there is evidence that older people are at increased risk for HIV through both biological mechanisms and increased riskiness in behaviour during sex. Postmenopausal women might be more susceptible to HIV because of the thinning of the vaginal wall [65], and data from the

Table 2. Impact of continued antiretroviral treatment scale-up on absolute number of HIV-infected people and the proportion of all HIV-infected people aged 50 years and older in 43 countries of sub-Saharan Africa.

	HIV-infected people aged 15–49 years			HIV-infected people aged 50 years or older					
	Absolute number (thousands)			Absolute number (thousands)			Proportion of all HIV-infected people (%)		
	2011	2025	2040	2011	2025	2040	2011	2025	2040
Sub-Saharan Africa	19 325	20 244	23 358	3 119	5 307	9 059	13	20	27
Central Africa	1 308	1 450	1 774	211	349	547	14	19	23
Angola	150	205	339	21	40	82	12	16	20
Cameroon	450	431	303	75	135	200	14	24	40
Central African Rep.	110	82	46	21	31	37	16	27	44
Chad	83	86	115	14	22	26	14	20	19
Democratic Republic of Congo	378	500	792	55	86	141	13	15	15
The Congo	54	65	97	9	16	33	14	20	25
Equatorial Guinea	21	38	51	3	6	11	11	14	18
Gabon	49	44	31	8	13	17	14	23	35
Eastern Africa	6 147	6 956	9 138	955	1 769	3 067	13	20	24
Burundi	115	95	133	22	26	38	16	22	22
Djibouti	10	8	8	2	2	3	14	22	27
Eritrea	21	19	20	3	7	11	14	26	34
Ethiopia	817	1 234	2 016	135	263	583	14	18	22
Kenya	1 101	728	341	172	319	357	13	30	51
Madagascar	26	50	78	7	18	40	20	27	34
Mozambique	1 533	1 888	2366	215	397	752	12	17	24
Rwanda	140	90	83	30	56	62	19	38	43
Somalia	31	54	80	5	11	21	14	17	21
Sudan	339	631	1 054	44	140	318	12	18	23
Tanzania	1 126	846	458	189	342	426	14	29	48
Uganda	751	1 314	2 501	84	188	456	10	13	15
Southern Africa	8 443	8 211	8 196	1 356	2 202	3 706	13	19	29
Botswana	286	310	425	43	91	175	15	23	29
Lesotho	298	375	450	34	55	105	10	13	19
Malawi	773	909	1 602	112	209	429	13	19	21
Namibia	185	132	76	26	35	47	12	21	38
South Africa	5 120	4 902	3 733	822	1 293	2 065	14	21	36
Swaziland	147	201	289	20	43	84	12	18	22
Zambia	692	763	1 326	89	185	361	11	20	21
Zimbabwe	798	618	295	158	291	440	16	32	60
Western Africa	3 428	3 626	4 249	594	987	1 739	15	21	29
Benin	47	36	35	10	16	22	17	31	38
Burkina Faso	74	61	62	14	22	27	16	26	30
Côte D'Ivoire	370	288	176	77	122	170	17	30	49
The Gambia	15	26	38	1	3	7	9	12	15
Ghana	225	256	257	38	82	153	15	24	37
Guinea	66	70	88	11	22	35	14	24	28
Guinea-Bissau	11	13	16	2	4	7	15	24	29
Liberia	24	18	17	5	7	11	16	28	39
Mali	77	57	56	13	20	27	14	26	33
Mauritania	12	12	11	2	5	8	15	28	41
Niger	48	46	53	9	20	31	17	30	37
Nigeria	2 299	2 542	3 188	373	620	1 158	14	20	27
Senegal	54	76	100	7	18	35	12	19	26
Sierra Leone	38	62	82	5	101	18	11	14	18
Togo	47	62	69	7	15	31	13	20	31

Demographic and Health Surveys show that condom use and knowledge about condoms is particularly low in older adults [13]. In the United States, condom use among older adults with known risk factors for HIV was about six times lower compared with that among adults aged 15–49 years [66]. Yet, despite the considerable and increasing burden of HIV in older adults in SSA, our understanding of sexual behaviour in this group remains limited. With increasing prevalence of HIV in older adults, HIV incidence in this age group is also likely to increase, warranting the need for age-appropriate prevention interventions.

It is important to note that our model accurately replicated the HIV epidemic in all the 43 SSA countries (Fig. 2), suggesting that the possible limitations we

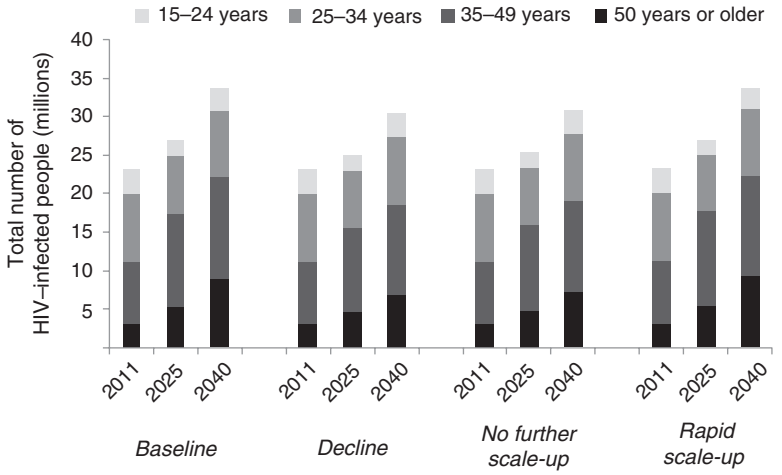

Fig. 5. Predicted age composition of the HIV-infected population by antiretroviral treatment scale-up scenario. *Baseline*, baseline scenario of continued scale-up of ART coverage; *decline*, scenario in which health system's capacity to deliver ART is reduced by 20% in 2012; *no further scale up*, scenario in which health system's capacity to deliver ART remains at the same level as in 2011; *rapid scale up*, scenario in which health system's capacity to deliver ART is scaled up to 100% for all countries by 2015. ART, antiretroviral treatment.

describe above do not substantially matter for our estimations. This claim is further supported by comparison of our estimates of a total of 2.6 million HIV-infected older adults in 2007 to the estimate published by Negin and Cumming (which is 2.9 million) [13].

In conclusion, we show that the HIV epidemic in SSA will rapidly age over the coming decades. This has important consequences for both the organization of healthcare services and the general organization of societies in the subcontinent, as older HIV-infected people require specialized treatment and care, as well as social and financial support. In addition, expanded treatment coverage is likely to increase the burdens of other diseases in SSA, in particular NCDs. Health policymakers need to anticipate the impact of the aging HIV epidemic in their planning for the future capacity of health systems to prevent and treat diseases of old age in HIV-infected individuals.

Acknowledgements

This work is supported by the National Institutes of Health (1R01MH083539-01 and R01 HD058482-01).

Conflicts of interest

There are no conflicts of interest.

References

1. WHO. *Towards universal access: scaling up priority HIV/AIDS interventions in the health sector; progress report 2010.* Geneva: World Health Organization; 2010.
2. UN. *High level meeting on AIDS.* New York: United Nations General Assembly; 2011.
3. Negin J, Mills EJ, Albone R. **Continued neglect of ageing of HIV epidemic at UN meeting.** *Lancet* 2011; **378**:768.
4. Herbst AJ, Cooke GS, Bärnighausen T, KanyKany A, Tanser F, Newell ML. **Adult mortality and antiretroviral treatment roll-out in rural KwaZulu-Natal, South Africa.** *Bull World Health Organ* 2009; **87**:754–762.
5. Mills EJ, Bakanda C, Birungi J, Mwesigwa R, Chan K, Ford N, *et al*. **Mortality by baseline CD4 cell count among HIV patients initiating antiretroviral therapy: evidence from a large cohort in Uganda.** *AIDS* 2011; **25**:851–855.
6. Mutevedzi PC, Lessells RJ, Rodger AJ, Newell ML. **Association of age with mortality and virological and immunological response to antiretroviral therapy in rural South African adults.** *PLoS One* 2011; **6**:e21795.
7. Attia S, Egger M, Muller M, Zwahlen M, Low N. **Sexual transmission of HIV according to viral load and antiretroviral therapy: systematic review and meta-analysis.** *AIDS* 2009; **23**:1397–1404.
8. Cohen MS, Chen YQ, McCauley M, Gamble T, Hosseinipour MC, Kumarasamy N, *et al*. **Prevention of HIV-1 infection with early antiretroviral therapy.** *N Engl J Med* 2011; **365**: 493–505.
9. Donnell D, Baeten JM, Kiarie J, Thomas KK, Stevens W, Cohen CR, *et al*. **Heterosexual HIV-1 transmission after initiation of antiretroviral therapy: a prospective cohort analysis.** *Lancet* 2010; **375**:2092–2098.
10. Montaner JS, Lima VD, Barrios R, Yip B, Wood E, Kerr T, *et al*. **Association of highly active antiretroviral therapy coverage, population viral load, and yearly new HIV diagnoses in British Columbia, Canada: a population-based study.** *Lancet* 2010; **376**:532–539.
11. CDC. *HIV/AIDS surveillance report 2008*. Vol. 20. Atlanta: Centers for Disease Control and Prevention; 2010.
12. Hontelez JA, Lurie MN, Newell ML, Bakker R, Tanser F, Bärnighausen T, *et al*. **Ageing with HIV in South Africa.** *AIDS* 2011; **25**:1665–1667.
13. Negin J, Cumming RG. **HIV infection in older adults in sub-Saharan Africa: extrapolating prevalence from existing data.** *Bull World Health Organ* 2010; **88**:847–853.
14. UNAIDS. *Report on the global AIDS epidemic 2010.* Geneva: UNAIDS; 2010.
15. Hontelez J, de Vlas S, Tanser F, Bakker R, Bärnighausen T, Newell M, *et al*. **The Impact of the new WHO antiretroviral treatment guidelines on HIV epidemic dynamics and cost in South Africa.** *PLoS One* 2011; **6**:e21919.

16. Korenromp EL, Bakker R, Gray R, Wawer MJ, Serwadda D, Habbema JD. **The effect of HIV, behavioural change, and STD syndromic management on STD epidemiology in sub-Saharan Africa: simulations of Uganda.** *Sex Transm Infect* 2002; **78 (Suppl 1)**:i55–i63.
17. van der Ploeg CPB, Van Vliet C, De Vlas SJ, Ndinya-Achola JO, Fransen L, van Oortmarssen GJ, *et al*. **STDSIM: a microsimulation model for decision support in STD control.** *Interfaces* 1998; **28**:84–100.
18. UN. *World fertility data 2008*. Geneva: Fertility and Family Planning Section, United Nations Population Division; 2008.
19. WHO. *Life tables for WHO member states.* Geneva: World Health Organization; 2011.
20. WHO. *The global burden of disease 2004*. Update 2008. Geneva: World Health Organization; 2011.
21. Williams BG, Lloyd-Smith JO, Gouws E, Hankins C, Getz WM, Hargrove J, *et al*. **The potential impact of male circumcision on HIV in Sub-Saharan Africa.** *PLoS Med* 2006; **3**:e262.
22. Ghys PD, Zaba B, Prins M. **Survival and mortality of people infected with HIV in low and middle income countries: results from the extended ALPHA network.** *AIDS* 2007; **21 (Suppl 6)**: S1–S4.
23. Korenromp EL, Van Vliet C, Bakker R, De Vlas SJ, Habbema JD. **HIV spread and partnership reduction for different patterns of sexual behavior: a study with the microsimulation model STDSIM.** *Math Pop Studies* 2000; **8**:135–173.
24. Orroth KK, Freeman EE, Bakker R, Buve A, Glynn JR, Boily MC, *et al*. **Understanding the differences between contrasting HIV epidemics in east and west Africa: results from a simulation model of the Four Cities Study.** *Sex Transm Infect* 2007; **83 (Suppl 1)**:i5–i16.
25. Steele KT, Steenhoff AP, Newcomb CW, Rantleru T, Nthobatsang R, Lesetedi G, *et al*. **Early mortality and AIDS progression despite high initial antiretroviral therapy adherence and virologic suppression in Botswana.** *PLoS One* 2011; **6**:e20010.
26. Musiime S, Muhairwe F, Rutagengwa A, Mutimura E, Anastos K, Hoover DR, *et al*. **Adherence to highly active antiretroviral treatment in HIV-infected Rwandan women.** *PLoS One* 2011; **6**:e27832.
27. Van der Veen F, Mugala-Mukungu F, Kangudi M, Feris A, Katjitae I, Colebunders R. **Antiretroviral treatment in the private sector in Namibia.** *Int J STD AIDS* 2011; **22**:577–580.
28. Rosen S, Fox MP, Gill CJ. **Patient retention in antiretroviral therapy programs in sub-Saharan Africa: a systematic review.** *PLoS Med* 2007; **4**:e298.
29. Mosoko JJ, Akam W, Weidle PJ, Brooks JT, Aweh AJ, Kinge TN, *et al*. **Retention in an antiretroviral therapy programme during an era of decreasing drug cost in Limbe, Cameroon.** *J Int AIDS Soc* 2011; **14**:32.
30. Buve A, Carael M, Hayes RJ, Auvert B, Ferry B, Robinson NJ, *et al*. **Multicentre study on factors determining differences in rate of spread of HIV in sub-Saharan Africa: methods and prevalence of HIV infection.** *AIDS* 2001; **15 (Suppl 4)**:S5–S14.
31. Wallrauch C, Bärnighausen T, Newell ML. **HIV prevalence and incidence in people 50 years and older in rural South Africa.** *S Afr Med J* 2010; **100**:812–814.
32. Statement on the meeting of the South African National AIDS Council (SANAC), 12 August 2011. Accessed on 10 June 2012; available at http://www.thepresidency.gov.za/pebble.asp?relid=4650.
33. UN. *World population prospects, the 2010 revision.* Geneva: United Nations Population Division; 2010.
34. Bärnighausen T, Welz T, Hosegood V, Batzing-Feigenbaum J, Tanser F, Herbst K, *et al*. **Hiding in the shadows of the HIV epidemic: obesity and hypertension in a rural population with very high HIV prevalence in South Africa.** *J Hum Hypertens* 2008; **22**:236–239.
35. Beaglehole R, Bonita R, Alleyne G, Horton R. **NCDs: celebrating success, moving forward.** *Lancet* 2011; **378**:1283–1284.
36. Beaglehole R, Bonita R, Alleyne G, Horton R, Li L, Lincoln P, *et al*. **UN high-level meeting on non-communicable diseases: addressing four questions.** *Lancet* 2011; **378**:449–455.
37. Beaglehole R, Bonita R, Horton R, Adams C, Alleyne G, Asaria P, *et al*. **Priority actions for the noncommunicable disease crisis.** *Lancet* 2011; **377**:1438–1447.
38. Mbanya JC, Squire SB, Cazap E, Puska P. **Mobilising the world for chronic NCDs.** *Lancet* 2011; **377**:536–537.
39. Dalal S, Beunza JJ, Volmink J, Adebamowo C, Bajunirwe F, Njelekela M, *et al*. **Noncommunicable diseases in sub-Saharan Africa: what we know now.** *Int J Epidemiol* 2011; **40**:885–901.
40. Thorogood M, Connor M, Tollman S, Lewando Hundt G, Fowkes G, Marsh J. **A cross-sectional study of vascular risk factors in a rural South African population: data from the Southern African Stroke Prevention Initiative (SASPI).** *BMC Public Health* 2007; **7**:326.
41. Tibazarwa K, Ntyintyane L, Sliwa K, Gerntholtz T, Carrington M, Wilkinson D, *et al*. **A time bomb of cardiovascular risk factors in South Africa: results from the Heart of Soweto Study 'Heart Awareness Days'.** *Int J Cardiol* 2009; **132**:233–239.
42. Tollman SM, Kahn K, Sartorius B, Collinson MA, Clark SJ, Garenne ML. **Implications of mortality transition for primary healthcare in rural South Africa: a population-based surveillance study.** *Lancet* 2008; **372**:893–901.
43. Hall V, Thomsen RW, Henriksen O, Lohse N. **Diabetes in Sub Saharan Africa 1999–2011: epidemiology and public health implications. A systematic review.** *BMC Public Health* 2011; **11**:564.
44. Kirk JB, Goetz MB. **Human immunodeficiency virus in an aging population, a complication of success.** *J Am Geriatr Soc* 2009; **57**:2129–2138.
45. Kearney F, Moore AR, Donegan CF, Lambert J. **The ageing of HIV: implications for geriatric medicine.** *Age Ageing* 2010; **39**:536–541.
46. Schmid GP, Williams BG, Garcia-Calleja JM, Miller C, Segar E, Southworth M, *et al*. **The unexplored story of HIV and ageing.** *Bull World Health Organ* 2009; **87**:162–1162.
47. Justice AC. **HIV and aging: time for a new paradigm.** *Curr HIV/AIDS Rep* 2010; **7**:69–76.
48. Stewart F, Yermo J. Pensions in Africa, OECD Working Papers on Insurance and Private Pensions, No. 30. Paris: OECD Publishing. 2009. doi:10.1787/227444006716.
49. Kautz T, Bendavid E, Bhattacharya J, Miller G. **AIDS and declining support for dependent elderly people in Africa: retrospective analysis using demographic and health surveys.** *Brit Med J* 2010; **340**:c2841.
50. Bärnighausen T, Bloom DE, Humair S. **Universal antiretroviral treatment: the challenge of human resources.** *Bull World Health Organ* 2010; **88**:951–952.
51. Voelker R. **HIV/AIDS funding dropped by 10% in 2010.** *JAMA* 2011; **306**:1642–1643.
52. Schwartlander B, Stover J, Hallett T, Atun R, Avila C, Gouws E, *et al*. **Towards an improved investment approach for an effective response to HIV/AIDS.** *Lancet* 2011; **377**:2031–2041.
53. Hontelez JA, Nagelkerke N, Bärnighausen T, Bakker R, Tanser F, Newell ML, *et al*. **The potential impact of RV144-like vaccines in rural South Africa: a study using the STDSIM microsimulation model.** *Vaccine* 2011; **29**:6100–6106.
54. Padian NS, McCoy SI, Balkus JE, Wasserheit JN. **Weighing the gold in the gold standard: challenges in HIV prevention research.** *AIDS* 2010; **24**:621–635.
55. Bärnighausen T, Bloom DE, Humair S. **Going horizontal: shifts in funding of global health interventions.** *N Engl J Med* 2011; **364**:2181–2183.
56. Napierala Mavedzenge S, Olson R, Doyle AM, Changalucha J, Ross DA. **The epidemiology of HIV among young people in sub-Saharan Africa: know your local epidemic and its implications for prevention.** *J Adolesc Health* 2011; **49**:559–567.
57. Tebit DM, Arts EJ. **Tracking a century of global expansion and evolution of HIV to drive understanding and to combat disease.** *Lancet Infect Dis* 2011; **11**:45–56.
58. Fatti G, Bock P, Eley B, Mothibi E, Grimwood A. **Temporal trends in baseline characteristics and treatment outcomes of children starting antiretroviral treatment: an analysis in four provinces in South Africa, 2004–2009.** *J Acquir Immune Defic Syndr* 2011; **58**:e60–e67.
59. Boyd M, Emery S, Cooper DA. **Antiretroviral roll-out: the problem of second-line therapy.** *Lancet* 2009; **374**:185–186.
60. Nagelkerke NJ, Jha P, de Vlas SJ, Korenromp EL, Moses S, Blanchard JF, *et al*. **Modelling HIV/AIDS epidemics in Botswana and India: impact of interventions to prevent transmission.** *Bull World Health Organ* 2002; **80**:89–96.

61. Hamers RL, Wallis CL, Kityo C, Siwale M, Mandaliya K, Conradie F, *et al*. **HIV-1 drug resistance in antiretroviral-naive individuals in sub-Saharan Africa after rollout of antiretroviral therapy: a multicentre observational study.** *Lancet Infect Dis* 2011; **11**:750–759.
62. Manasa J, Katzenstein D, Cassol S, Newell ML, de Oliveira T. **Primary drug resistance in South Africa: data from 10 years of surveys.** *AIDS Res Hum Retroviruses* 2012; **28**:558–565.
63. Nachega JB, Mills EJ, Schechter M. **Antiretroviral therapy adherence and retention in care in middle-income and low-income countries: current status of knowledge and research priorities.** *Curr Opin HIV AIDS* 2010; **5**:70–77.
64. Palacios-Cena D, Carrasco-Garrido P, Hernandez-Barrera V, Alonso-Blanco C, Jimenez-Garcia R, Fernandez-de-Las-Penas C. **Sexual behaviors among older adults in Spain: results from a population-based national sexual health survey.** *J Sex Med* 2012; **9**:121–129.
65. Drew O, Sherrard J. **Sexually transmitted infections in the older woman.** *Menopause Int* 2008; **14**:134–135.
66. Mack KA, Ory MG. **AIDS and older Americans at the end of the Twentieth Century.** *J Acquir Immune Defic Syndr* 2003; **33 (Suppl 2)**:S68–S75.