Cascade of HIV care and population viral suppression in a high-burden region of Kenya

David Maman[a], Clement Zeh[b], Irene Mukui[c], Beatrice Kirubi[d], Sophie Masson[a], Valarie Opolo[e], Elisabeth Szumilin[f], Benjamin Riche[g] and Jean-François Etard[a,h]

Introduction: Direct measurement of antiretroviral treatment (ART) program indicators essential for evidence-based planning and evaluation – especially HIV incidence, population viral load, and ART eligibility – is rare in sub-Saharan Africa.

Design/methods: To measure key indicators in rural western Kenya, an area with high HIV burden, we conducted a population survey in September to November 2012 via multistage cluster sampling, recruiting everyone aged 15–59 years living in 3330 randomly selected households. Consenting individuals were interviewed and tested for HIV at home. Participants testing positive were assessed for CD4$^+$ cell count and viral load, and their infections classified as either recent or long term based on Limiting Antigen Avidity assays. HIV-negative participants were tested by nucleic acid amplification to detect acute infections.

Results: Of 6833 household members eligible for the study, 6076 (94.7% of all women and 81.0% of men) agreed to participate. HIV prevalence and incidence were 24.1% [95% confidence interval [CI] 23.0–25.2] and 1.9 new cases/100 person-years (95% CI 1.1–2.7), respectively. Among HIV-positive participants, 59.4% (95% CI 56.8–61.9) were previously diagnosed, 53.1% (95% CI 50.5–55.7) were receiving care, and 39.7% (95% CI 37.1–42.4) had viral load less than 1000 copies/ml. Applying 2013 WHO recommendations for ART initiation increased the proportion of ART-eligible people from 60.0% (based on national guidelines in place during the survey; 95% CI 57.3–62.7) to 82.0% (95% CI 79.5–84.5). Among HIV-positive people not receiving ART, viral load increased with decreasing CD4$^+$ cell count (500–749 vs. ≥750 cells/μl, adjusted mean difference, 0.40 log$_{10}$ copies/ml, 95% CI 0.20–0.60, $P < 0.01$).

Conclusion: This study demonstrates how population-level data can help optimize HIV programs. Based on these results, new regional programs are prioritizing diagnosis and expanding ART eligibility, key steps to reach undetectable viral load.

[a]Epicentre, Paris, France, [b]Centers for Disease Control and Prevention, Kisumu, [c]National AIDS & STI Control Programme, [d]Médecins Sans Frontières, Nairobi, [e]Center for Global Health Research, Kenya Medical Research Institute, Kisumu, Kenya, [f]Médecins sans Frontières, Paris, [g]Service de biostatistique, Hospices Civils de Lyon, Lyon, and [h]UMI 233 TransVIHMI, Institut de Recherche pour le Développement, Montpellier 1 University, Montpellier, France.

Correspondence to David Maman, MD, MSc, Epicentre, 8 rue Saint Sabin, 75011 Paris, France.

E-mail: david.maman@epicentre.msf.org

Introduction

In 2012, more than 10 million people living with HIV in sub-Saharan Africa were receiving antiretroviral therapy (ART) [1], which dramatically reduces both morbidity and mortality [2−4]. In 2011, the HPTN 052 study showed that early initiation of ART prevents sexual transmission at the individual level [5], confirming earlier observational findings [6,7]. However, the hypothesis that increasing the proportion of HIV-positive individuals with an undetectable viral load will gradually reduce HIV incidence in the population has yet to be conclusively demonstrated. This is partially because evaluating the impact of ART programs on incidence is a complex undertaking, requiring repeated measurements of inci-dence and viral suppression in a population over time, and has therefore rarely been done. The resulting 'data gap' has been identified by the WHO and other leading international organizations and advocacy groups as a major hurdle not only to assessing the population-level impact of ART but also to monitoring the effectiveness of HIV treatment programs [8,9].

To help plug the data gap, WHO recently published a framework of metrics for evaluating 'treatment as prevention' programs [10]. Beyond the usual monitoring of treatment cohorts, it recommends conducting periodic population surveys in the community to measure HIV incidence, prevalence, and retention of patients along the continuum of care (often called the 'cascade of care') from initial diagnosis through linkage to care, ART initiation and finally, viral suppression. Such studies are aimed at identifying weak points in the cascade when patients are lost from treatment, preventing them from achieving undetectable viral load [11]. Indeed, reaching a high level of viral suppression at the population level (a good proxy for both transmission risk and ART effectiveness [9,12]) requires good outcomes at every step along the care continuum [10,13]. Carefully monitoring loss along the cascade is critical for ART programs so they can prioritize interventions likely to have the most impact.

Despite their complexity, such population surveys are increasingly feasible because HIV incidence can be estimated directly using serologic assays that distinguish recent from established HIV infections [14−16]. These assays are also simpler, cheaper, and easier to implement than traditional approaches for measuring incidence by monitoring an incident cohort over a defined period [14].

Equally important, population surveys can directly measure ART eligibility in a population. To monitor the quality of ART coverage and to prepare for implementing new ART guidelines, it is essential to assess the numbers of people needing ART. While many studies have quantified patient losses at key steps along the cascade [17], few measured each step in a sub-Saharan African population.

Ndhiwa is a subcounty within the County of Homa-Bay in Kenya and has a population of 172 000 inhabitants. It is located in the Nyanza region, the area of Kenya most affected by HIV, with an estimated prevalence of 15.1% in 2011 [18]. To directly evaluate key HIV indicators and the current national response, and thereby to inform planning, budgeting and setting priorities for regional programming, Kenya's Ministry of Health (MoH) and Médecins Sans Frontières conducted a population survey in September to November 2012 to simultaneously measure HIV incidence, prevalence and all steps in the cascade of care.

Material and methods

Study design

The Ndhiwa HIV Impact in Population Study was a representative population-based survey conducted from September to November 2012 in Ndhiwa, Kenya. It used a two-stage sampling design to randomly select 3300 households. In the first stage, 165 clusters were selected from a list of Ndhiwa's 402 enumeration areas (admin-istrative units defined by the Kenyan National Bureau of Statistics for the purpose of census-taking) obtained from the 2002 national census. Each cluster was one enumeration area. At the second stage, 20 households were randomly selected from each cluster. All residents aged 15−59 years were considered eligible and, after being informed about the study as described below, invited to participate.

Ethical approvals

Ethical approval was obtained in Kenya from the Kenya Medical Research Institute Ethical Review Committee (KEMRI, ref 347) and in France, from the 'Comité de Protection des Personnes d'Ile de France' (CPP, ref 12056). Written consent for participating in the study and undergoing HIV testing was obtained from each participant prior to the survey interview.

Community participation and questionnaire

Community mobilization was done prior to the survey in two steps. First, the study team met with all local leaders; then they visited each selected enumeration unit to directly mobilize the community, which involved distributing information leaflets about the survey and each person's right to refuse to participate. Community members were told that the survey was about HIV and that they would be tested for HIV if they agreed to participate.

The questionnaire was based on the MACRO ques-tionnaire framework used for the Demographic and Health Survey, a design meant to ensure maximal comparability of results with Demographic and Health Survey findings [19,20]. The questionnaire was translated into Luo, the main language spoken in the county, and

then back-translated as a quality check. It was pretested in the community in early September 2012.

Questionnaires collected socioeconomic, behavioral, and medical information about each participant. Men self-reported their circumcision status using graphics tools, whereas women reported their history of births, antenatal care and, if HIV-positive, PMTCT care. Participants were also asked about previous HIV testing and the result of their most recent test.

Cascade of care steps and definitions

The first four stages were all self-reported by participants. Stage 1, HIV awareness, was defined as a history of at least one positive HIV test prior to the survey. Linkage to care (stage 2) was defined as at least one medical contact for HIV care after a positive test, whereas retention in care (stage 3) was defined as an HIV-related medical consultation within the prior 6 months. ART use (stage 4) was also self-reported. The last stage, viral load suppression, was defined as a viral load below 1000 copies/ml as measured from the sample collected during the survey visit and tested as described below. ART eligibility was assessed according to the Kenyan 2010 ART guidelines [21], which considered an HIV-positive individual eligible for ART if he or she had ever started ART (except for PMTCT) or had a $CD4^+$ cell count 350 cells/μl or less. We also assessed eligibility based on the 2013 WHO ART guidelines, which recommend initiating ART at $CD4^+$ cell count 500 cells/μl or less and for all pregnant and breastfeeding women regardless of $CD4^+$ cell count [22].

Laboratory procedures

Participants were tested for HIV at home using a serial rapid testing algorithm according to Kenyan national guidelines, using Determine Rapid HIV1/2 Antibody (Abbott Laboratories, Abbott Park, Illinois, USA) followed by Unigold Rapid HIV Test (Trinity Biotech, PLC, Bray, Co Wicklow, Ireland). Participants with discordant or equivocal results were tested by ELISA to confirm their status.

For all participants who tested positive, a venous blood sample was collected at home for $CD4^+$ cell count, performed using the PIMA $CD4^+$ cell counter (Alere, PIMA, Jena, Germany), and for both viral load (COBAS Amplirep/Cobas Taqman platform; Roche Diagnostic System, Branchburg, New Jersey, USA) and recent infection using the Limiting Antigen Avidity (LAg) EIA test (Sedia Biosciences Corp., Portland, Oregon, USA). LAg is a serological assay that detects increasing avidity antibody maturation following seroconversion and can detect recent HIV-1 infections (those for which seroconversion occurred during the past 130 days; 95% CI 118−142) [23]. To be classified as recently infected, a participant must have a normalized optical density threshold of 1.5 or below, report not being on ART,

and have a detectable viral load (>300 copies/ml). Therefore, the overall mean duration of recent infection in our algorithm was 158 days (95% CI 146−170) as it included the 130 days of the LAg and 28 days window period of the Nucleic Acid Amplification Testing (NAAT). The false recent rate of the recent infection testing algorithm, which is the proportion of the nonrecent HIV population incorrectly classified as recent, was estimated at 0.5% (95% CI 0.01−1.0) [24].

To identify infections prior to seroconversion (i.e., acute infection), samples from all individuals testing negative for HIV by serological tests underwent NAAT on a COBAS Amplirep/Cobas Taqman platform (Roche Diagnostic System) from a finger prick of whole blood preserved on a dried blood spot. The number of newly acquired infections was obtained by adding the number of NAAT-detected acute infections to LAg-identified recent infections.

Data management and analysis

Data were entered and checked using Epidata version 3.1 and analyzed using Stata 13 (Stata Corp., College Station, Texas, USA). All data were anonymized. Descriptive analyses were weighted to account for sampling design and are presented here with 95% CIs. We estimated HIV incidence rate per 100 person–years with 95% CIs using the McWalter and Welte formula [25]. To calculate the mean population viral load we log-transformed individual viral load. The proportion of the population classified as virologically suppressed was defined as the ratio of the number of suppressed individuals to the number of individuals tested positive. Two-sample t test and Pearson chi-square statistics were used to compare continuous and categorical descriptive outcomes, respectively. To identify risk factors associated with viral load among those not receiving ART, we used a weighted multivariate linear regression model and considered people not on ART.

Results

Inclusion and characteristics of the study population

The study was conducted between September and November 2012 and collected information on 3300 households (Fig. 1). A total of 3966 women and 2867 men were eligible for the study. Of this group, 3755 women (94.7%) and 2321 men (81.0%) agreed to participate and were tested for/underwent HIV. Among participating individuals, 3154 (51.9%) were 18−34 years old.

HIV prevalence and incidence

HIV prevalence and incidence results are presented in Table 1. Of the 6076 participants tested for HIV, 1457 were HIV-positive. Overall HIV prevalence was 24.1%
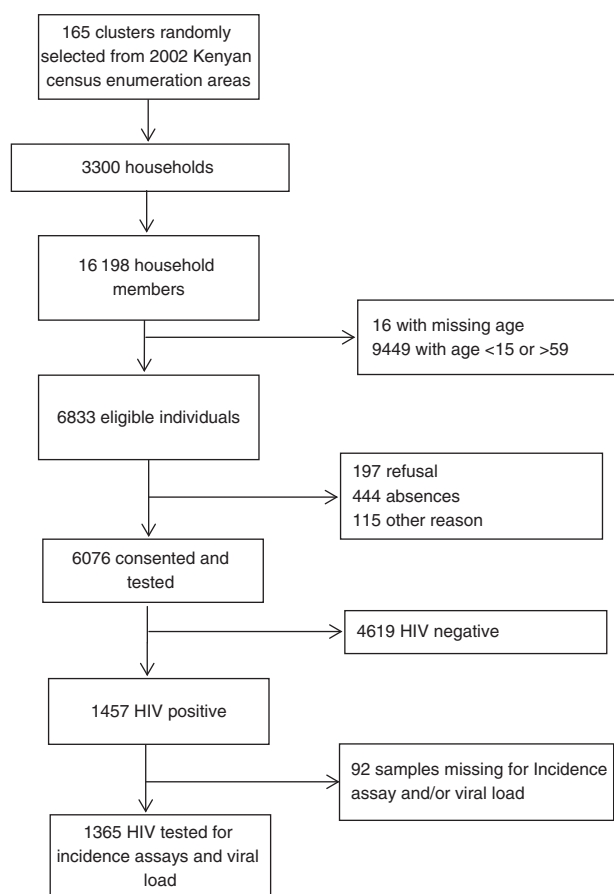
Fig. 1. HIV Cascade of care, Ndhiwa, Kenya, 2012.

(95% CI 23.0−25.2) and was higher for women (26.7%, 95% CI 25.3−28.3) than for men (19.8%, 95% CI 18.2−21.6, $P < 0.01$), and more than double in those 30−44 years old compared with those aged 15−29 (34.7%; 95% CI 32.4−30.8 vs. 16.8%, 15.4−18.1, $P < 0.01$). Concerning marital status, prevalence was 4.0% (95% CI 3.0−5.3) among those never married and 55.6% (95% CI 51.0−60.0) among widowed participants. Prevalence was significantly lower among pregnant or breastfeeding women than among women who were neither (21.7 vs. 29.8%, $P < 0.01$), and among medically circumcised compared with uncircumcised men (14.9 vs. 21.5%, $P < 0.01$).

Of the HIV-positive participants, 11 were NAAT-positive (and rapid diagnostic test negative), that is, had acute infections, while 31 patients were classified as recently infected using the LAg test algorithm. Overall HIV incidence was estimated at 1.90 new cases/100 person-years (95% CI 1.11−2.70). Incidence in women was more than twice that in men (2.47 new cases/100 person-years, 95% CI 1.36−3.58 vs. 1.06 new cases/100 person-years, 95% CI 0.18−1.94) and nearly doubled in people aged 15−29 compared with 45−59 year olds (1.98 new cases/100 person-years [95% CI 1.12−2.85] vs. 1.03 new cases/100 person-years [95% CI 0−2.39]). Among men, HIV

incidence among uncircumcised men was over four-fold more in uncircumcised compared with medically circumcised men (1.20 [95% CI 0.08−2.33] vs. 0.24 new cases/100 person-years [95% CI 0.00−1.28]).

Cascade of care and ART eligibility

The proportions of HIV-positive people retained at each key step in the cascade of care are shown in Fig. 2. Of 1457 HIV-positive individuals identified in our survey, complete information regarding $CD4^+$ cell count and viral load was recorded for 1365 (93.7%). Of this latter group, 59.4% (95% CI 56.8−61.9) reported in the survey interview that they had previously been diagnosed as HIV-positive; this proportion was higher in women than in men (61.6 vs. 54.6%, $P = 0.02$), as was the proportion of HIV-positive women reporting retention in care (55.3 vs. 48.3% for men, $P = 0.02$). However, there was no significant sex difference in the proportions of HIV-positive participants on ART (39.0% [95% CI 35.9−42.2] for women vs. 40.9% [95% CI 36.3−45.7] for men, $P = 0.51$) or among HIV-positive participants showing viral suppression (39.3% [95% CI 36.1−42.6] for women vs. 40.6% [95% CI 35.8−45.6] for men, $P = 0.67$; overall 39.7% [95% CI 37.1−42.4]).

The proportion of HIV-positive individuals in need of ART based on the guidelines in effect in Kenya at the time of the study (2010 national guidelines: $CD4^+$ cell count less than 350 cells/μl and PMTCT option A), and those eligible under the 2013 WHO guidelines ($CD4^+$ cell count < 500 cells/μl and PMTCT option B+), are shown in Table 2. Overall, 60.0% (95% CI 57.3−62.7) of the HIV-positive population was eligible using the 2010 Kenyan guidelines. A higher proportion of men than women was in need of treatment (65.0%, 95% CI 60.1−69.6 vs. 57.8%, 95% CI 54.4−61.0, $P = 0.02$). Under the 2013 WHO guidelines, 83.0% (95% CI 80.2−85.4) of HIV-positive women and 79% (95% CI 74.9−82.7) of HIV-positive men would be eligible for treatment. Calculating the ART coverage rate (proportion of those receiving ART divided by those eligible) based on the newer WHO guidelines, coverage dropped from 69.1% (95% CI 65.8−72.2) to 50.7% (95% CI 47.8−50.7). Among participants not initiated on ART, the median $CD4^+$ cell count was high, at 519 [IQR 341−714] for women and 436 [IQR 279−635] for men.

Population viral load

Distribution of the population viral load stratified by ART use and awareness of HIV status is shown in electronic supplementary Fig. 1. Of the 1365 HIV-positive individuals with viral load data, the proportion showing viral suppression (<1000 copies/ml) was 39.7% (95% CI 37.1−42.4). If the total population tested for HIV is considered regardless of HIV status, 889 of 6076 individuals (13.7%, 95% CI 12.8−14.6) had a viral load more than 1000 copies/ml. Among those on ART (578 individuals, median time on ART 22.9 months), the

Table 1. HIV incidence and prevalence, Ndhiwa, Kenya, 2012.

|	Total tested	Number of HIV-infected patients	Weighted HIV prevalence (95% CI)	HIV incidence rate (new cases per 100 PY(95% CI)
Sex				
Male	2321	457	19.8 (18.2–21.6)	1.06 (0.18–1.94)
Female	3755	1000	26.7 (25.3–28.3)	2.47 (1.36–3.58)
Age (years)				
15–29	3154	533	16.7 (15.4–18.1)	1.98 (1.12–2.85)
30–44	1786	614	34.7 (32.4–30.8)	1.51(0.06–2.96)
45–59	1136	310	27.9 (25.3–30.8)	1.03 (0.00–2.39)
Marital status (missing: 36)				
Never married	1291	49	4.0 (3.0–5.3)	1.62 (0.44–2.80)
Married/living together	4133	1095	26.4 (25.1–27.8)	2.30 (1.26–3.33)
Divorced/separated	105	28	28.6 (20.3–38.6)	NA
Widowed	511	279	55.6 (51.0–60.0)	NA
Education (missing: 4)				
Primary or less	5046	1283	25.6 (24.4–26.9)	1.91 (1.04–2.79)
Secondary or higher	1026	174	16.8 (14.6–19.4)	1.86 (0.28–3.45)
History of HIV testing (missing: 19)				
Never tested	1224	191	26.2 (24.9–27.5)	1.03 (0.00–2.15)
Ever tested	4833	1266	16.3 (14.2–18.7)	2.16 (1.22–3.11)
Residence Ndhiwa (missing: 3)				
<10 years	1422	333	23.3 (21.1–25.7)	3.79 (1.80–5.79)
≥10 years	4651	1089	24.3 (23.1–25.6)	1.27 (0.52–2.02)
Mobility (nights outside/month) (missing: 19)				
0	2009	367	18.5 (16.8–20.3)	2.15 (0.93–3.38)
1–5	3177	840	26.8 (25.2–28.5)	1.72 (0.68–2.75)
6+	871	245	24.1 (23.0–25.2)	1.56 (0.00–3.38)
Pregnant or breastfeeding[a]				
Yes	1411	312	21.7 (19.6–24.1)	2.70 (1.00–4.40)
No	2344	688	29.8 (27.8–31.7)	2.34 (0.97–3.71)
Medical circumcision[b] (missing: 15)				
Yes	563	84	14.9 (12.1–18.3)	0.24 (0.00–1.28)
No	1743	372	21.5 (19.5–23.6)	1.20 (0.08–2.33)
Total	6076	1457	24.1 (23.0–25. 2)	1.90 (1.11–2.70)

CI, confidence interval; PY, person-years.
[a]Only women.
[b]Only men.

proportion showing suppression rose to 83.6% (95% CI 80.0−86.1). No significant difference in viral load distribution was found between those aware of their status but not on ART and those undiagnosed at the time of the study ($P = 0.24$).

Overall mean and median population viral load measurements were 2.87 $\log_{10}$ copies/ml (95% CI 2.75−3.00) and 7272 copies/ml [IQR 0−75200], respectively (Table 3). To identify associations between viral load and selected covariates among those not on
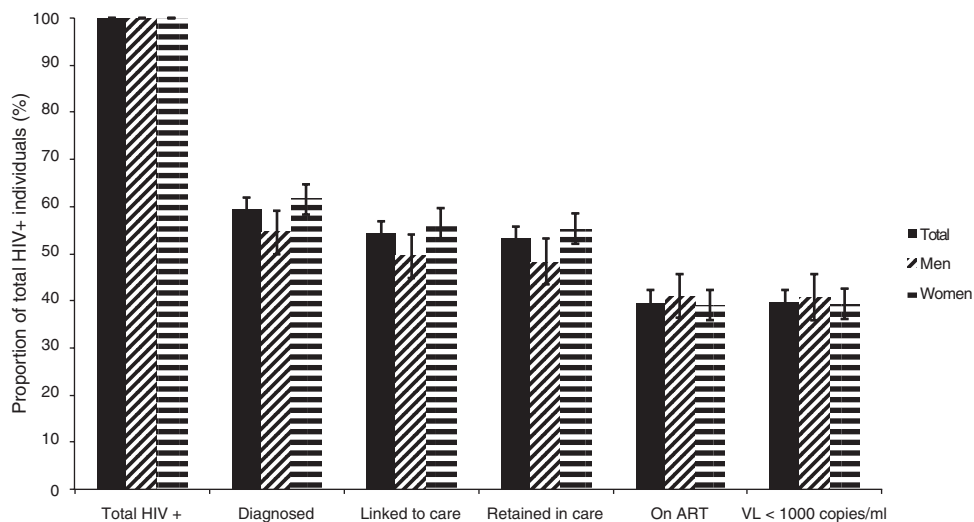
Fig. 2. HIV Cascade of care, Ndhiwa, Kenya, 2012.

Table 2. Art eligibility and coverage, Ndhiwa, Kenya, 2012.

	Kenya 2010 guidelines	WHO 2013 guidelines
ART eligibility (% +95% CI)		
Women	57.8 (54.4–61.0)	83.0 (80.2–85.4)
Men	65.0 (60.1–69.6)	79.0 (74.9–82.7)
Total	60.0 (53.3–62.7)	81.7 (74.5–83.8)
ART coverage (% +95% CI)		
Women	70.3 (66.2–74.2)	49.0 (45.4–52.6)
Men	66.6 (60.7–72.1)	54.8 (49.3–60.3)
Total	69.1 (65.8–72.2)	50.7 (47.8–50.7)

ART, antiretroviral treatment; CI, confidence interval.

ART, we performed a multivariate analysis using a weighted linear model. Men had higher viral load than women (adjusted mean difference 0.27 $\log_{10}$ copies/ml; 95% CI 0.12–0.42) after accounting for all variables included in the model. Viral load was also strongly associated with $CD4^+$ cell counts, increasing as $CD4^+$ cell count decreased. For example, individuals with $CD4^+$ cell count between 500 and 749 $CD4^+$ cells/μl had a mean viral load that was 0.40 $\log_{10}$ copies/ml (95% CI 0.20–0.60, $P < 0.01$) higher than those with $CD4^+$ cell count 750 cells/μl at least. The difference is highest for individuals with $CD4^+$ cell count less than 200 cells/μl at 0.91 $\log_{10}$ copies/ml (vs. $CD4^+$ cell count ≥ 750 cells/μl; 95% CI 0.65–1.18, $P < 0.01$). Age was not associated with viral load in the multivariate model (30–44 vs. 15–29 years old, 0.05 $\log_{10}$ copies/ml; 95% CI −0.09–0.20; $P = 0.46$).

Discussion

This study reports the direct measurement of HIV incidence and key steps along the cascade of care in a rural district in Nyanza province, Kenya. To our knowledge, it is among the first reports from sub-Saharan Africa to directly evaluate incidence and cascade of care, from diagnosis to ART eligibility and viral suppression, in a single population-based study.

Most HIV programs in sub-Saharan Africa are based on relatively limited data, often extrapolated from selected populations and/or sites, or from modeling studies. WHO and other stakeholders have been urgently calling for better evidence to support program planning and assessment of populations and how many people need which services, and how many are receiving them. These data are essential for evaluating the impact of treatment-as-prevention strategies on reducing the rate of new infections, and ultimately curbing the epidemic. Several countries in the region, including Kenya, Uganda, and Swaziland, have begun implementing population studies to measure these indicators [26,27].

Our findings clarified some prevailing notions about the HIV epidemic in the region and brought a far more detailed picture of the cascade, while also offering several surprises.

HIV incidence in the adult population of the Ndhiwa subcounty, which we estimated at 1.9 new cases per 100 person-years, was four times higher than the national estimate derived from the 2012 Kenya AIDS Indicator survey, highlighting (among other factors) the hetero-geneous distribution of the HIV epidemic in Kenya [18]. This figure is relatively similar to the estimate of 2.4 new cases/100 person-years for Homa-Bay county, where Ndhiwa is situated, produced in late 2011 using spectrum mathematical modeling [28]. Incidence was higher for women and young adults − a trend also seen in the Swaziland and Uganda surveys, where the high incidence was also driven mainly by the incidence in young women [29,30].

One key finding was that 60.3% of the HIV-positive population, representing 13.8% of the overall adult Ndhiwa population, had a viral load above 1000 copies/ml. Only the Swaziland HIV measurement survey used similar methodology, and it found similar results [31]. Compared with previous efforts in other settings to measure community viral load from routinely available data − that is, data only from people in care − our estimate is based on viral load measurements across the entire HIV-positive population, regardless of linkage to care and ART status [12,32]. Measuring the proportion of individuals with high viral load in an entire community was recently described as a strategy for overcoming bias inherent to routinely available data [9]. Our study also includes people with acute infection, which is associated with much higher viral load levels [33,34].

By studying risk factors associated with viral load among people not receiving ART, this study also provides new information to help identify individuals most at risk of transmitting HIV. One such group is people with $CD4^+$ cell count levels in the 500−749 $CD4^+$ cells/μl range, who are not eligible for ART under either Kenyan (2010) or WHO (2013) guidelines but who we found to have higher viral load levels proportional to their decreased $CD4^+$ cell count. Although this relationship between $CD4^+$ cell count levels and viral load is well characterized in Western settings [35,36] and in a sub-Saharan African population [37], this finding suggests that individuals with $CD4^+$ cell count between 500 and 749 cells/μl could be at higher risk for transmitting HIV and progressing to AIDS than those with higher $CD4^+$ cell counts. Men in general could also be at higher risk for transmitting (relative to women), with overall viral load more than twice that of women, even when $CD4^+$ cell count and age were accounted for − again, findings previously reported in Western cohorts [38,39]. In sub-Saharan Africa, at population level, two studies found no gender differences in viral load [37,40] whereas one did [17]. These data provide valuable support for a focused

Table 3. Population viral load and associated risk factors among HIV-positive individuals not on art in Ndhiwa, Kenya, weighted multivariate linear model.

	No HIV-positive	Median VL (copies/ml) [+IQR]	Mean log (VL) (copies/ml) (+95% CI)	Unadjusted difference in mean viral load in $\log_{10}$ (copies/ml) (+95% CI)	P	Adjusted difference in mean viral load in $\log_{10}$ (copies/ml) (+95% CI)	P
Sex							
Female	547	36 788 [6446–109 000]	4.38 (4.30–4.46)	Ref		Ref	
Male	240	86 165 [24 612–202 856]	4.76 (4.64–4.88)	0.37 (0.22–0.52)	<0.01	0.27(0.12–0.42)	<0.01
Age (years)							
15–29	369	39 852 [7220–109 000]	4.41 (4.31–4.51)	Ref		Ref	
30–44	305	49 400 [13 852–167 662]	4.58 (4.47–4.68)	0.18 (0.03–0.33)	0.02	0.05 (−0.09–0.20)	0.46
45–59	113	61 152 [9962–173 586]	4.58 (4.38–4.77)	0.12 (−0.11–0.37)	0.29	−0.03 (−0.27–0.19)	0.74
CD$^+$ cell count (cells/μl)							
≥750	136	11 377 [2029–55 631]	3.95 (3.79–4.11)	Ref		Ref	
500–749	232	33 026 [6589–101 993]	4.37 (4.26–4.48)	0.43 (0.23–0.64)	<0.01	0.40 (0.20–0.60)	<0.01
350–499	172	52 509 [17 001–134 006]	4.57 (4.45–4.70)	0.60 (0.38–0.81)	<0.01	0.55 (0.34–0.76)	<0.01
200–349	129	78 248 [29 978–188 678]	4.72 (4.56–4.89)	0.72 (0.49–0.96)	<0.01	0.68 (0.44–0.90)	<0.01
0/199	105	149 356 [52 138–339 712]	5.01 (4.86–5.18)	0.99 (0.73–1.25)	<0.01	0.91 (0.65–1.18)	<0.01
HIV status awareness							
Not aware	524	51 154 [9508–151 106]	4.52 (4.44–4.60)	Ref			
Aware	263	40 572 [9576–114 684]	4.45 (4.34–4.56)	−0.07 (−0.22–0.07)	0.32		
Marital status (missing: 6)							
Never married	31	56 220 [16 028–239 374]	4.70 (4.37–5.04)	Ref			
Married/living together	617	46 838 [10 388–135 942]–	4.51 (4.43–4.58)	−0.16 (−0.45–0.13)	0.29		
Divorced/Separated	13	46 196 [4574–105 816]	4.26 (3.74–4.77)	−0.46 (−1.04–0.11)	0.12		
Widowed	120	52 574 [6625–136 161]	4.43 (4.25–4.61)	−0.28 (−0.63–0.07)	0.11		
Education							
Primary or less	715	49 400 [10 580–144 708]	4.51 (4.45–4.59)	Ref			
Secondary or less	72	31 337 [4171–94 153]	4.31 (4.06–4.55)	−0.20 (−0.47–0.07)	0.15		
Total	787	47 312 [9576–140 066]	4.50 (4.43–5.56)				

CI, confidence internal; VL, viral load.

programmatic approach targeting individuals most at risk for transmitting HIV.

Our data on the cascade of care found that patients were lost mostly at two points: HIV testing and ART initiation. First, 40% of all HIV-positive individuals were unaware of their status, a similar figure to those from the most recent Kenya AIDS Indicator survey and from Swaziland [18,27]. This represents the biggest loss along the cascade and indicates the urgent need to expand testing in Ndhiwa, where 10% of all adults have undiagnosed HIV. Second, although 56.2% of the HIV-positive population reported being in care, only 42.2% were on ART. This discrepancy can be explained by the district's ART eligibility requirements (initiation at 350 CD4$^+$ cells/μl and PMTCT option A), which exclude many HIV-positive people. If the WHO 2013 guidelines (initiation at 500 cells/μl and PMTCT option B+) were implemented in Ndhiwa, the proportion of HIV-positive individuals eligible for ART would rise from 60 to 82%.

Our estimate that 60% of the total HIV-positive population was in need of ART is higher than that derived from the mathematical model (42%) used in program planning by Kenya's Ministry of Health, in Homa-Bay, the county where Ndhiwa is situated [28]. We believe that certain indicators measured in population studies, including ART eligibility and population distribution of viral load and CD4$^+$ cell count should be regularly used to strengthen assumptions used in mathematical models for predicting the potential impact of different interventions. It was already done with the Spectrum model that used the CD4$^+$ cell count distribution of the 2007 Kenya Incidence Survey to strengthen its assumptions [41].

This study presents some limitations. Because of the cross-sectional observational design, no causal inference can be made between HIV incidence and population viral load. Furthermore, other than the laboratory data, the information we collected was self-reported by participants, which can lead to recall bias and misclassifications. This was seen, for example, during the clinical trial HPTN 052, where approximately 3% of the participants who did not self-report using ART nevertheless had detectable blood levels of ART [42]. Finally, incidence was calculated based on recent infection assays which can have with poorer outcomes with HIV sub-type D, known to be common in this part of Kenya [43].

Based on the unexpectedly high incidence and prevalence rates found in this survey, Kenya's MoH, together with Médecins Sans Frontières, launched several new initiatives in Ndhiwa in early 2014 to strengthen the two weakest points in the cascade of care − that is, improving HIV diagnosis and expanding ART eligibility by implementing the 2013 WHO guidelines. The survey will be repeated four years after the initial one presented here, to assess whether these initiatives have led to improved programmatic outcomes and to decreasing HIV incidence. Similarly, population-based studies that measure these same indicators in other high prevalence settings should provide useful information for identifying the weakest points in the cascade of care and prioritizing programs to address them, thereby increasing impact on patient outcomes and on realizing the promise of treatment as prevention strategies.

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Conflicts of interest
The authors declare they have no conflict of interest with respect to this article.

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