Supplemental appendix to:

Modelling the Health Impact and Cost Threshold of Long-Acting ART for Adolescents and Young Adults in Kenya

I. Technical specifications
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I. Technical Specifications

Model Overview:

The mathematical model simulates heterosexual HIV transmission and is parameterized to Kenya. The model reproduces population-level dynamics and stratifies the population by age, gender, and sexual risk. The model begins with an entirely HIV-negative population at time $t = 0$ with a size and distribution reflecting Kenya in 1979. In the first iteration, 0.2% of the population becomes HIV-positive, and subsequent iterations evaluate the demography, enrollment, and aging of the population. The population dynamics are governed by a system of ordinary differential equations that are approximated by 0.05-year interval iterations in R. The natural history of HIV infection is modeled in stages defined by CD4 count and viral load as shown in Figure S1. When a person becomes HIV-infected, s/he enters the acute stage characterized by a short duration and high probability of HIV transmission. The person then progresses through stages of CD4 count and viral load. New births enter the population as a function of the fertility rate.

**Figure S1. Model transition diagram.** A diagram of the natural history of HIV infection. All movement is in one direction except for enrollment in and dropout from interventions from ART.

**Model states and equations:**

The model simulates a population from ages 0 to 59 in five-year age groups, capturing vertical transmission and aging. Model states $(d_{a}, g, r, d)$ are based on age, gender, CD4 state, viral load, circumcision status, and sexual risk group. The model approximates a system of equations with the following indices:

Gender:

- $g = 0$ for females
- $g = 1$ for males

Disease state defined by CD4 cell count, treatment status, and circumcision status

- $d = 1$ for acute infection
- $d = 2$ for CD4 $> 500$ cells/µL
- $d = 3$ for CD4 350-500 cells/µL
d = 4 for CD4 200-350 cells/µL
d = 5 for CD4 < 200 cells/µL
d = 6 for HIV-negative, circumcised
d = 7 for HIV-negative, not circumcised
d = 8 for HIV positive, on ART

Viral load status:
v = 1 for acute infection
v = 2 for VL<1,000 copies/mL
v = 3 for VL 1,000-10,000 copies/mL
v = 4 for VL 10,000-50,000 copies/mL
v = 5 for VL>50,000 copies/L
v = 6 for HIV-negative
v = 7 for HIV-positive and on ART

Risk group:
r = 1 for low risk
r = 2 for medium risk
r = 3 for high risk

Age group:
a = 1 for ages 0-4
a = 2 for ages 5-9
a = 3 for ages 10-14
a = 4 for ages 15-19
a = 5 for ages 20-24
a = 6 for ages 25-29
a = 7 for ages 30-34
a = 8 for ages 35-39
a = 9 for ages 40-44
a = 10 for ages 45-49
a = 11 for ages 50-54
a = 12 for ages 55-59

The equations for the eight disease states are:

\[
\frac{dy_{a,r}^{g,1,v}(t)}{dt} = b_r^{g,1}(t) + \psi \lambda_{a,r}^{1}(t) X_{a,r}^{g,6,6}(t) + \lambda_{a,r}^{1}(t) X_{a,r}^{g,7,6}(t) + \sigma_{a}^{g} X_{a,r}^{g,8,7}(t) - (\mu_{a}^{g}(t) + \alpha_{a}^{g,1} + v_1 + \omega_v + \pi_{a}^{g}(t)) X_{a,r}^{g,1,v}(t)
\]

\[
\frac{dy_{a,r}^{g,2,v}(t)}{dt} = v_1 X_{a,r}^{g,1,v}(t) + \omega_{v-1} X_{a,r}^{g,2,v-1}(t) + \sigma_{a}^{g} X_{a,r}^{g,8,7}(t) - (\mu_{a}^{g}(t) + \alpha_{a}^{g,2} + v_2 + \omega_v + \pi_{a}^{g}(t)) X_{a,r}^{g,2,v}(t)
\]

\[
\frac{dy_{a,r}^{g,3,v}(t)}{dt} = v_1 X_{a,r}^{g,2,v}(t) + \omega_{v-1} X_{a,r}^{g,3,v-1}(t) + \sigma_{a}^{g} X_{a,r}^{g,8,7}(t) - (\mu_{a}^{g}(t) + \alpha_{a}^{g,3} + v_3 + \omega_v + \pi_{a}^{g}(t)) X_{a,r}^{g,3,v}(t)
\]

\[
\frac{dy_{a,r}^{g,4,v}(t)}{dt} = v_1 X_{a,r}^{g,3,v}(t) + \omega_{v-1} X_{a,r}^{g,4,v-1}(t) + \sigma_{a}^{g} X_{a,r}^{g,8,7}(t) - (\mu_{a}^{g}(t) + \alpha_{a}^{g,4} + v_4 + \omega_v + \pi_{a}^{g}(t)) X_{a,r}^{g,4,v}(t)
\]

\[
\frac{dy_{a,r}^{g,5,v}(t)}{dt} = v_1 X_{a,r}^{g,4,v}(t) + \omega_{v-1} X_{a,r}^{g,5,v-1}(t) + \sigma_{a}^{g} X_{a,r}^{g,8,7}(t) - (\mu_{a}^{g}(t) + \alpha_{a}^{g,5} + \omega_v + \pi_{a}^{g}(t)) X_{a,r}^{g,5,v}(t)
\]
\[
\frac{dX^{\lambda_{6}}_{ar}}{dt} = b^{\mu_{6}}_{r}(t) - (\mu^{\rho}_{a} (t) + \lambda_{a,r}^{\rho} (t) \psi) X^{\lambda_{6}}_{ar}(t)
\]
\[
\frac{dX^{\lambda_{7}}_{ar}}{dt} = b^{\mu_{7}}_{r}(t) - (\mu^{\rho}_{a} (t) + \lambda_{a,r}^{\rho} (t) X^{\lambda_{7}}_{ar}(t)
\]
\[
\frac{dv^{\lambda_{7}}_{a,r}}{dt} = \sum_{v=1}^{5} \sum_{d=1}^{5} [\pi_{a,r}^{\rho} (t) X^{\lambda_{7},\nu}_{ar}(t) - (\mu^{\rho}_{a} (t) + \sigma_{a,r}^{\rho}) X^{\lambda_{7},\nu}_{ar}(t)]
\]

The equation variables are:

- \(b^{\mu_{6}}_{r}(t)\): The number of births that are HIV-positive, not on ART (d=1), HIV-negative (d=6, 7), or HIV-positive and on ART (d=8)
- \(\lambda_{a,r}^{\rho}(t)\): The force of infection for HIV-negative persons
- \(\psi\): The reduction in HIV transmission due to circumcision
- \(\mu^{\rho}_{a}\): The background mortality
- \(\sigma_{a,r}^{\rho}\): The HIV-associated mortality
- \(v_{d}\): The rate of progressing from CD4 state \(d\) to \(d+1\)
- \(\omega_{v}\): The rate of progressing from VL state \(v\) to \(v+1\)
- \(\sigma_{a}^{\rho}\): ART dropout (not virally suppressed) rate
- \(\pi_{a}^{\rho}\): ART coverage rate

### Births:

The number of births, \(b^{\mu_{c}}_{r}(t)\), determines how many newborns enter the population of gender \(g\), disease state \(d\), sexual risk group \(r\), and circumcision status \(c\) (\(c = 0\) for uncircumcised; \(c = 1\) for circumcised males). We assume that infected births enter the acute stage, and that women age 15–49 give birth. Fertility rates are stratified by age. Each birth is multiplied by 0.5 given an assumed gender ratio at birth of 1:1. Births from uninfected mothers, \(bS(t)\), and from HIV-positive mothers, \(bI(t)\), are:

\[
bS(t) = \sum_{a=3}^{9} \sum_{r=1}^{3} \gamma_{a}^{\lambda_{6}} X^{\lambda_{6},\nu}_{ar}(t)
\]
\[
bI(t) = \sum_{a=3}^{9} \sum_{r=1}^{3} \sum_{d=1}^{5} \sum_{v=1}^{5} \gamma_{a}^{\lambda_{7},\nu} X^{\lambda_{7},\nu}_{ar}(t) + \sum_{a=3}^{9} \sum_{r=1}^{3} \gamma_{a}^{\lambda_{6},\nu} X^{\lambda_{6},\nu}_{ar}(t)
\]

HIV-negative births for uncircumcised males, \(b_{r,0}^{1,7}(t)\), are:

\[
b_{r,0}^{1,7}(t) = 0.5 \ast \phi_{0,r}^{\mu_{0}} \ast \left( bS(t) + (1 - \eta(t))bI(t) \right) \ast (1 - \pi_{0}^{\lambda_{6}}(t))
\]

HIV-negative births for circumcised males, \(b_{r,1}^{1,6}(t)\), are:

\[
b_{r,1}^{1,6}(t) = 0.5 \ast \phi_{0,r}^{\mu_{0}} \ast \left( bS(t) + (1 - \eta(t))bI(t) \right) \ast \pi_{0}^{\lambda_{6}}(t)
\]

HIV-negative births for females, \(b_{r,0}^{1,6}(t)\), are:

\[
b_{r,0}^{1,6}(t) = 0.5 \ast \phi_{0,r}^{\mu_{0}} \ast \left( bS(t) + (1 - \eta(t))bI(t) \right)
\]
HIV-positive births for males and females, $b_{r,0}^{A,t}(t)$, are:

$$b_{r,0}^{A,t}(t) = 0.5 \cdot \phi_{a,g}^{A,t} \cdot \eta(t) bl(t)$$

The equation variables are:

| Variable          | Description                                                                 |
|-------------------|------------------------------------------------------------------------------|
| $\phi_{a,g}^{A,t}$ | The proportion of individuals in age $a$, gender $g$, and treatment status $t$ ($t = 0$, no treatment; $t = 1$, ART) that is born into sexual risk group $r$ |
| $\eta(t)$         | The proportion of births from HIV-positive females that result in vertical transmission |
| $\pi_{s,0}^{g}(t)$| The proportion of HIV-negative males that is circumcised at birth             |
| $\gamma_{a}^{d}$  | The annual fertility rate for females by age and disease state                |

**Mortality:**
People leave the population due to death or aging past age 59. Mortality is represented by mortality caused by HIV, $\mu_{a}^{d}$, and all other background mortality, $\mu_{a}^{b}$. Mortality caused by HIV varies by stage of disease and age, and individuals on ART are assumed to have no disease-induced mortality.$^{1,2}$ The background mortality rate is estimated by subtracting out the mortality due to HIV from the overall mortality rate.

**Disease transmission:**
Disease transmission is governed by the force of infection, $\lambda_{a,g}^{0}(t)$, which determines the number of people who are infected at each time-step.

$$\lambda_{a,g}^{0}(t) = \frac{\sum_{a'=1}^{12} \sum_{r'=1}^{3} c_{a,a',r'}(t) \rho_{a,g,a,r}(t) \sum_{v=1}^{5} \sum_{v'=1}^{5} X_{a,a',r'}^{g,d,v,v'}(t) \beta_{g,r,v,v'}(t)}{\sum_{v=1}^{5} X_{a,a',r'}^{g,d,v,v'}(t) + X_{a,a',r'}^{g,d,\gamma',\gamma'}(t)}$$

- $c_{a,a',r'}(t)$: The number of partners from age $a'$ and sexual risk group $r'$ that an individual has per year, adjusted
- $\rho_{g,a,r}(t)$: The mixing matrix which describes the distribution of partners from each age and sexual risk group
- $\beta_{g,r,v,v'}$: The probability of HIV transmission per partnership between an HIV-positive person of stage $v'$ and HIV-negative person of risk group $r$

The overall force of infection for a specific age-group is the sum of the risk of acquiring HIV from all possible partners.

**Mixing Matrix:**
Using methods similar to other models, the mixing matrix, $\rho_{g,a,r}(t)$, describes patterns of sexual contact by calculating the proportion of one’s sexual partners that come from a specific age and sexual-risk group.

$$\rho_{g,a,r}(t) = \left[ e_a \frac{\sum_{g'=1}^{8} \sum_{a'=1}^{12} \sum_{r'=1}^{3} c_{a,a',r'}(t) \rho_{a,g,a,r}(t) \sum_{v=1}^{5} \sum_{v'=1}^{5} X_{a,a',r'}^{g,d,v,v'}(t) \beta_{g,r,v,v'}(t)}{\sum_{v=1}^{5} \sum_{v'=1}^{5} X_{a,a',r'}^{g,d,v,v'}(t) + \sum_{v=1}^{5} \sum_{v'=1}^{5} X_{a,a',r'}^{g,d,\gamma',\gamma'}(t)} + (1 - e_a) \delta_{a}^{g} \right] \beta_{r,v,v'}^{d}$$

Where

$$\delta_{r}^{r'} = 1.0 \text{ if } r = r'$$
$$\delta_{r}^{r'} = 0.0 \text{ if } r \neq r'$$

Before 2005:
$$\delta_{a}^{a'} = 0.3 \text{ if } a = a'$$
$$\delta_{a}^{a'} = 0.7 \text{ if } a = a' + 1 \text{ (for males)}$$
if \( a = a' - 1 \) (for females) \\
= 0.0 otherwise

After 2005:
\( \delta_a^{\alpha'} = 0.7 \) if \( a = a' \) \\
= 0.3 if \( a = a' + 1 \) (for males) \\
if \( a = a' - 1 \) (for females) \\
= 0.0 otherwise

Mixing patterns vary between random and assortative, as determined by the parameter \( \epsilon \). Random mixing (\( \epsilon = 1 \)) is mixing proportional to the relative sizes of all compartments and this method is consistent for both random mixing by risk and by age. However, assortative mixing (\( \epsilon = 0 \)) is among groups with similar characteristics and differs for mixing by risk and age. Assortative mixing by risk (\( \epsilon_r = 0 \)) is defined by the identity matrix \( \delta_a^{\alpha'} \), whereas assortative mixing by age (\( \epsilon_a = 0 \)) is defined by an off-diagonal matrix \( \delta_a^{\alpha'} \).

The off-diagonal pattern results in females of age \( a \) being more likely to form partnerships with males of age \( a = a' - 1 \), which is consistent with reports of such age discrepancies in sub-Saharan Africa.\(^3\)\(^4\) This off-diagonal method results in two age groups having fewer than 100% of their partnerships; therefore, males in the youngest age group and females in the oldest age group are set to \( \delta_a^{\alpha'} = 1 \) if \( a = a' \). We assume that this tendency for age-gaps diminishes in 2005. Furthermore, \( \epsilon_a \) and \( \epsilon_r \) shift from random to assortative over the course of the simulation, given the decline in risky sexual behavior.\(^5\)

**Per-Partnership Probability of Transmission:**
The per-partnership probability of transmission, \( \beta^{\alpha,r,\nu} \), depends on the sexual risk group of the HIV-negative partner and the disease state of the HIV-positive partner. The probabilities of transmission per partnership are:

\[
\begin{align*}
\beta^{0, r, \nu} &= 1 - (1 - \tau^{r'} \nu') \theta^{\nu}(t) \quad \text{for female HIV-negative partners} \\
\beta^{1, r, \nu} &= 1 - (1 - \tau^{r'} \nu') \theta^{\nu}(t) \quad \text{for male HIV-negative partners}
\end{align*}
\]

\( \tau^{r'} \nu' \) is the per-act probability of transmission for an HIV-positive partner of HIV stage \( d' \), and the exponent, \( \theta^{\nu}(t) \), is the number of coital acts based on the HIV-negative partner’s sexual risk group and gender.

**Rate of Partner Change:**
Data on sexual behavior and specifically, sexual contact rates, \( c_{a,r}^{\nu} \), are often subject to biases leading to contact rate data that, when assuming solely heterosexual contact, are inconsistent between males and females.\(^6\) We account for this variability by using an adjusted contact rate, \( c_{a,r}^{\alpha',\nu'}(t) \), which equilibrates the reported number of sexual partners by males and females.\(^7\) The adjusted contact rate can be male- or female-driven, as determined by the parameter \( \theta \), where \( \theta = 1 \) for male-driven, \( \theta = 0 \) for female-driven, and \( \theta = 0.5 \) when compromised equally. We assume \( \theta = 0.5 \) given the lack of data to assume otherwise.

For females, the adjusted contact rate is:
\[
c_{0,a,r}^{\alpha',\nu'}(t) = c_{0,a,r}^{\nu}(t) B_{a,r}^{\alpha',\nu'}(t)^{(1-\theta)}
\]

For males, the adjusted contact rate is:
\[
c_{1,a,r}^{\alpha',\nu'}(t) = c_{1,a,r}^{\nu}(t) B_{a,r}^{\alpha',\nu'}(t)\theta
\]

The discrepancy between the two populations, \( B_{a,r}^{\alpha',\nu'}(t) \), is defined as:
\[
B_{a,r}^{\alpha',\nu'}(t) = \frac{c_{0,a,r}^{\alpha',\nu'}(t) \sum_{d=1}^{8} \sum_{\nu=1}^{9} a_{a,r}^{\alpha',\nu}(t) + \sum_{d=1}^{8} \sum_{\nu=1}^{9} a_{a,r}^{\alpha',\nu}(t)}{c_{1,a,r}^{\alpha',\nu'}(t) \sum_{d=1}^{8} \sum_{\nu=1}^{9} a_{a,r}^{\alpha',\nu}(t)}
\]

**Aging:**
One-fifth of each compartment enters into the next age group with same gender and disease state. Their sexual risk is redistributed to match a set sexual-risk profile \( \phi_{a,r} \) that varies by age, gender, and treatment status. All compartments, except for the youngest and oldest age-groups, experience influx from the prior age and efflux into the next age. The 0 to 4 age-group only receives influx through births while the 55 to 59 age-group exits the population rather than entering the next age.
II. Cost Parameters

Cost of oral ART in SSA was estimated at $72.8 Costs of health care for those on treatment and those not in care were inflated to 2017 (adjusting for exchange rates).

| Costs of ART provision                                      | Kenya, 2017 (USD) |
|------------------------------------------------------------|-------------------|
| Oral antiretroviral drug cost (per person-year)             | $72               |
| Non-antiretroviral cost (per person-year)                  | $161              |
| Costs of pre-ART health-care use                           | $155              |
| Reference                                                  | CDC/Kenya MoH9    |
III. Epidemiological Parameters

Population

Table S1. Initial population size. Kenya total population in 1979 by age and sex.

| Age   | Initial Population Size | Reference          |
|-------|-------------------------|--------------------|
|       | Male                    | Female             |
| 0 – 4 | 1,422,021               | 1,421,385          |
| 5 – 9 | 1,247,091               | 1,244,749          |
| 10 – 14 | 1,050,932           | 1,023,839          |
| 15 – 19 | 854,123               | 887,722            |
| 20 – 24 | 641,401               | 686,003            |
| 25 – 29 | 514,451               | 541,261            |
| 30 – 39 | 405,385               | 412,691            |
| 35 – 39 | 290,227               | 325,367            |
| 40 – 44 | 261,480               | 273,702            |
| 45 – 49 | 218,914               | 221,965            |
| 50 – 54 | 182,908               | 191,022            |
| 55 – 59 | 140,777               | 134,534            |
| TOTAL  | 7,229,710              | 7,364,240          |

Table S2. Total population size. Kenya total population over time for model calibration

| Year | Total population size | Reference          |
|------|-----------------------|--------------------|
| 1979 | 14,593,950            | UN population data |
| 1989 | 20,398,625            | 10                 |
| 1999 | 27,154,357            | 10                 |
| 2009 | 36,662,970            |                    |

Circumcision

Reduction in force of infection due to circumcision: Several studies show that circumcised males have a 60% ($\Psi_0 = 0.6$) lower risk of acquiring HIV, but are not at a reduced risk of transmitting HIV. The proportion circumcised by 2030 was based on 2014 proportions, accounting for aging cohorts (e.g., the 35-39 proportion from 2030 is equal to the 20-24 proportion from 2014).

Table S3. Coverage of adult voluntary medical male circumcision:

| Age   | Percent Circumcised | Reference          |
|-------|---------------------|--------------------|
|       | 2003 | 2008 | 2012 | 2014 | 2030 | 2014 DHS Kenya |
| 0 – 4 | 0.039 | 0.041 | 0.045 | 0.047 | 0.047 | 14 |
| 5 – 9 | 0.148 | 0.156 | 0.172 | 0.180 | 0.180 | 14 |
| 10 – 14 | 0.353 | 0.373 | 0.411 | 0.430 | 0.430 | 14 |
| 15 – 19 | 0.715 | 0.755 | 0.832 | 0.871 | 0.871 | 14 |
| 20 – 24 | 0.890 | 0.894 | 0.941 | 0.965 | 0.965 | 14 |
| 25 – 29 | 0.883 | 0.850 | 0.914 | 0.946 | 0.965 | 14 |
| 30 – 34 | 0.893 | 0.892 | 0.920 | 0.934 | 0.965 | 14 |
| 35 – 39 | 0.893 | 0.892 | 0.920 | 0.934 | 0.965 | 14 |
| 40 – 44 | 0.837 | 0.916 | 0.918 | 0.919 | 0.946 | 14 |
### CD4 progression
Table S4. The duration of time in each CD4 stage by sex. Ying et al.15

| CD4   | Time for Males (years) | VL |
|-------|------------------------|----|
|       | Acute                  |    | Time for Females (years) |    |
|       | ≤1,000                 |    |                           |    |
|       | 1,000-10,000           |    |                           |    |
|       | 10,000-50,000          |    |                           |    |
|       | >50,000                |    |                           |    |
| Acute | 0.25                   |    | 0.25                      |    |
| >500  | 1.71                   |    | 1.94                      |    |
| 500-350 | 1.05                   |    | 1.35                      |    |
| 350-200 | 4.71                   |    | 6.71                      |    |

### Viral load progression
Table S5. The duration of time in each viral load stage by sex. Ying et al.15

| CD4   | Time for Males (years) | VL |
|-------|------------------------|----|
|       | Acute                  |    | Time for Females (years) |    |
|       | ≤1,000                 |    |                           |    |
|       | 1,000-10,000           |    |                           |    |
|       | 10,000-50,000          |    |                           |    |
|       | >50,000                |    |                           |    |
| Acute | 0.25                   |    | 0.25                      |    |
| >500  | 0.25                   |    | 0.25                      |    |
| 500-350 | 0.25                   |    | 0.25                      |    |
| 350-200 | 0.25                   |    | 0.25                      |    |
| <200  | 0.25                   |    | 0.25                      |    |

### ART coverage rate of people living with HIV
Table S6. Proportion of HIV-positive persons receiving ART. ART coverage for adults and children is assumed to reach 90-90-90 target of 81% by 2030. Adult females under age 40 are assumed to have 34% higher ART coverage based on UNAIDS estimates.16

| Year | ART coverage                          | Reference                        |
|------|---------------------------------------|----------------------------------|
|      | Adult Males | Adult Females | Adults 40+ | Children (0-14) |
| 2003 | -           | -             | -          | -              |
| 2004 | 0.02        | 0.02          | 0.02       | 0.01           |
| 2005 | 0.03        | 0.05          | 0.04       | 0.03           |
| 2006 | 0.08        | 0.10          | 0.09       | 0.07           |
| 2007 | 0.11        | 0.15          | 0.13       | 0.10           |
| 2008 | 0.15        | 0.21          | 0.19       | 0.14           |
| 2009 | 0.20        | 0.27          | 0.25       | 0.18           |
| 2010 | 0.27        | 0.37          | 0.33       | 0.24           |
| 2011 | 0.32        | 0.43          | 0.39       | 0.35           |
| 2012 | 0.36        | 0.48          | 0.43       | 0.42           |
| 2013 | 0.38        | 0.51          | 0.46       | 0.47           |
| 2014 | 0.43        | 0.58          | 0.52       | 0.53           |
| 2015 | 0.50        | 0.68          | 0.61       | 0.62           |

World Bank Development Indicators17
ART non-adherence proportion

Table S7. Pre-intervention ART non-adherence proportion. Proportions are based on a study of viral suppression of individuals on ART from routine viral load testing data in Kenya.

| Age   | Non-adherence | Reference |
|-------|---------------|-----------|
| 0 – 4 | 0.40          |           |
| 5 – 9 | 0.35          |           |
| 10 – 14 | 0.37          |           |
| 15 – 19 | 0.37          |           |
| 20 – 24 | 0.19          |           |
| 25 – 29 | 0.19          | Mwau et al.18 |
| 30 – 34 | 0.13          |           |
| 35 – 39 | 0.13          |           |
| 40 – 44 | 0.13          |           |
| 45 – 49 | 0.13          |           |
| 50 – 54 | 0.13          |           |
| 55 – 59 | 0.13          |           |

Fertility

Table S8. Fertility rate by age and HIV status. No changes in fertility rates were assumed after 2012.

| Age   | Fertility Rate (per year) | Reference |
|-------|---------------------------|-----------|
|       | 1979 | 1986 | 1991 | 1996 | 1999 | 2001 | 2007 | 2012 |               |
| 0 – 4 | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0              |
| 5 – 9 | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0              |
| 10 – 14 | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0              |
| 15 – 19 | 0.168 | 0.152 | 0.110 | 0.111 | 0.142 | 0.114 | 0.103 | 0.096 |               |
| 20 – 24 | 0.342 | 0.314 | 0.257 | 0.248 | 0.254 | 0.243 | 0.238 | 0.206 |               |
| 25 – 29 | 0.357 | 0.303 | 0.241 | 0.218 | 0.236 | 0.231 | 0.216 | 0.183 |               |
| 30 – 34 | 0.293 | 0.255 | 0.197 | 0.188 | 0.185 | 0.196 | 0.175 | 0.148 |               |
| 35 – 39 | 0.239 | 0.183 | 0.154 | 0.109 | 0.127 | 0.123 | 0.118 | 0.100 |               |
| 40 – 44 | 0.145 | 0.099 | 0.070 | 0.051 | 0.056 | 0.055 | 0.050 | 0.038 |               |
| 45 – 49 | 0.059 | 0.035 | 0.050 | 0.016 | 0.007 | 0.015 | 0.012 | 0.009 |               |
| 50 – 54 | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0              |
| 55 – 59 | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0              |

2014 DHS Kenya14

Table S9. Fertility rate multipliers for HIV-positive women. HIV-positive women are assumed to have lower fertility rates than uninfected women, except for the 15-19 age group. Those on ART or in the acute stage are assumed to have equal fertility to HIV-negative women. Fertility for HIV-negative women is adjusted so that the overall fertility rate is equal to Table S8.

| Age   | Fertility Multiplier | Reference |
|-------|----------------------|-----------|
| 15 – 19 | 1.454                | Marston et al.19 |
| 20 – 24 | 0.720                |           |
Background mortality
Table S10. Background mortality. The background mortality rate is estimated by adjusting the overall Kenyan mortality rate estimated by WHO for the mortality due to HIV in Kenya estimated by IHME. Mortality rates were estimated for 1990 and each year from 2000-2015. After 2015, age 0-4 mortality rate is assumed to decrease by 2% per year. Table S10 shows 2015 annual rates.

| Age   | 2015 Background Mortality |
|-------|---------------------------|
|       | Male          | Female        |
| 0–4   | 0.0106        | 0.0088        |
| 5–9   | 0.0024        | 0.0017        |
| 10–14 | 0.0013        | 0.0010        |
| 15–19 | 0.0018        | 0.0011        |
| 20–24 | 0.0030        | 0.0015        |
| 25–29 | 0.0026        | 0.0014        |
| 30–34 | 0.0026        | 0.0015        |
| 35–39 | 0.0034        | 0.0022        |
| 40–44 | 0.0043        | 0.0031        |
| 45–49 | 0.0057        | 0.0040        |
| 50–54 | 0.0084        | 0.0061        |
| 55–59 | 0.0121        | 0.0093        |

HIV-associated mortality
Table S11. HIV-associated mortality. Values are annual estimates from observational studies of untreated HIV-positive persons.

| Age   | HIV Mortality | Reference |
|-------|---------------|-----------|
|       | Male          | Female    |           |
|       | Acute | CD4 >350 | CD4 200-350 | CD4 <200 | Acute | CD4 >350 | CD4 200-350 | CD4 <200 |
| 0–4   | 0.05  | 0.12    | 0.20       | 0.66     | 0.04  | 0.09    | 0.15       | 0.50     | Chaudhury et al. | 22 |
| 5–9   | 0.02  | 0.06    | 0.10       | 0.32     | 0.05  | 0.12    | 0.19       | 0.65     | Chaudhury et al. | 22 |
| 10–14 | 0.03  | 0.08    | 0.13       | 0.43     | 0.03  | 0.07    | 0.11       | 0.36     | Chaudhury et al. | 22 |
| 15–19 | 0.04  | 0.11    | 0.18       | 0.60     | 0.01  | 0.03    | 0.05       | 0.18     | Chaudhury et al. | 22 |
| 20–29 | 0.02  | 0.05    | 0.08       | 0.27     | 0.02  | 0.05    | 0.08       | 0.27     | Badri et al. | 23 |
| 30–34 | 0.02  | 0.05    | 0.09       | 0.29     | 0.02  | 0.05    | 0.09       | 0.29     | Balslev et al. | 24 |
| 35–39 | 0.02  | 0.05    | 0.09       | 0.29     | 0.02  | 0.05    | 0.09       | 0.29     | Balslev et al. | 24 |
| 40–44 | 0.03  | 0.07    | 0.10       | 0.35     | 0.03  | 0.07    | 0.10       | 0.35     | Balslev et al. | 24 |
| 45–49 | 0.03  | 0.07    | 0.10       | 0.35     | 0.03  | 0.07    | 0.10       | 0.35     | Balslev et al. | 24 |
| 50–54 | 0.03  | 0.09    | 0.14       | 0.47     | 0.03  | 0.09    | 0.14       | 0.47     | Balslev et al. | 24 |
| 55–59 | 0.03  | 0.09    | 0.14       | 0.47     | 0.03  | 0.09    | 0.14       | 0.47     | Balslev et al. | 24 |

Force of infection
**Mixing matrix**

**Table S12. Sexual mixing by age and sexual risk group.** The mixing parameter varies from random ($\epsilon_a = 1$) to assortative ($\epsilon_a = 0$), calibrated to fit age-specific HIV incidence and prevalence data.

| Year         | Force of Infection Mixing | Reference         |
|--------------|---------------------------|-------------------|
|              | $\epsilon_a$ (age) | $\epsilon_r$ (sexual risk) |
| Before 1994  | 0.7                      | 0.7               | Calibrated to fit data |
| After 1998   | 0.1                      | 0.1               |                         |

**Number of coital acts**

**Table S13. The number of coital acts per partnership by gender and sexual risk group.** Values are calibrated to fit age-specific HIV incidence and prevalence data.

| Gender   | Coital Acts per Partnership | Reference       |
|----------|-----------------------------|-----------------|
|          | Low-Risk | Moderate-Risk | High-Risk |       |
| Male     | 95        | 30           | 3.2       | Calibrated to fit data |
| Female   | 80        | 24           | 2.2       |                         |

**Probability of transmission and acquisition**

**Table S14. Probability of HIV transmission by viral load.**

| Baseline Transmission Probability | Increase in transmission probability by HIV stage | Reference |
|-----------------------------------|-----------------------------------------------|-----------|
|                                   | VL Acute $\leq$1,000 | VL 1,000-10,000 | VL 10,000-50,000 | VL $>$50,000 | ART |
| 0.00049$^a$                      | 0$^b$ | 1$^c$ | 5.8$^c$ | 6.9$^c$ | 11.9$^c$ | 0.04$^d$ |
|                                   | $^a$Powers et al., Boily et al.$^{25,26}$ |        |        |        |        |
|                                   | $^b$Hollingsworth et al.$^{27}$ |        |        |        |        |
|                                   | $^c$Quinn et al.$^{28}$ |        |        |        |        |
|                                   | $^d$Attia et al., Cohen et al., Donnell et al.$^{29-31}$ |        |        |        |        |

**Table S15. Proportion of births from HIV-positive females not on ART that result in mother-to-child transmission.** No transmissions are assumed from HIV-positive females on ART.

| Year | MTCT rate | Reference |
|------|-----------|-----------|
| 1993 | 0.255     | Connor et al.$^{32}$ |
| 2009 | 0.24      | UNAIDS$^{33}$ |
| 2014 | 0.17      | UNAIDS$^{33}$ |

**Table S16. Pregnancy HIV acquisition risk factor.** Pregnant women are assumed to have a 2.76 times greater risk of acquiring HIV.$^{34}$ This factor is combined with fertility rates to create acquisition multipliers applied to all women in a year and age group.

| Pregnancy acquisition | Reference |
|-----------------------|-----------|
| 2.76                  | Thomson et al.$^{34}$ |

**Table S17. Age-specific STI prevalence.** Coinfections representing HSV2 and other STIs are assumed to increase HIV acquisition by a factor of 3.4 for women and 2.8 for men$^{35}$ and transmission by a factor of
STIs are distributed by age and sex according to the observed HSV2 prevalence in sub-Saharan Africa.

| Age   | Prevalence (%) | Reference |
|-------|----------------|-----------|
|       | Men            | Women     |
| 15-19 | 0.055          | 0.126     |
| 20-24 | 0.102          | 0.277     |
| 25-29 | 0.207          | 0.409     |
| 30-34 | 0.291          | 0.514     |
| 35-39 | 0.371          | 0.559     |
| 40-44 | 0.473          | 0.594     |
| 45-49 | 0.450          | 0.556     |
| 50-54 | 0.424          | 0.543     |
| 55+   | 0.396          | 0.573     |

**Risk behavior**

**Table S18. Risk behavior parameter by year.** Risk behavior includes the number of partners and risk group distribution. The change in risk behavior as a result of the HIV epidemic is measured as a value between 0 and 1, with 0 being the least risky (lowest number of partners and lower proportion of people in the higher risk groups). Values up to the year 2000 are calibrated to the HIV incidence and prevalence in Kenya by year; values after 2000 are derived by fitting an exponential curve to historical prevalence from 2001-2017.

| Year | Behavior | Year | Behavior |
|------|----------|------|----------|
| 1990 | 0.95     | 2010 | 0.26     |
| 1991 | 0.80     | 2011 | 0.28     |
| 1992 | 0.70     | 2012 | 0.28     |
| 1993 | 0.60     | 2013 | 0.31     |
| 1994 | 0.50     | 2014 | 0.37     |
| 1995 | 0.35     | 2015 | 0.41     |
| 1996 | 0.25     | 2016 | 0.44     |
| 1997 | 0.15     | 2017 | 0.53     |
| 1998 | 0.10     | 2018 | 0.54     |
| 1999 | 0.05     | 2019 | 0.55     |
| 2000 | 0.01     | 2020 | 0.57     |
| 2001 | 0.01     | 2021 | 0.58     |
| 2002 | 0.02     | 2022 | 0.59     |
| 2003 | 0.04     | 2023 | 0.60     |
| 2004 | 0.06     | 2024 | 0.62     |
| 2005 | 0.09     | 2025 | 0.63     |
| 2006 | 0.12     | 2026 | 0.64     |
| 2007 | 0.14     | 2027 | 0.65     |
| 2008 | 0.17     | 2028 | 0.67     |
| 2009 | 0.18     | 2029 | 0.68     |
2030 0.70

Number of sexual partners

Table S19. Annual number of sexual partnerships by age, gender, and sexual risk. Values are based on a previous study and calibrated to fit age-specific HIV incidence and prevalence data. The number of partnerships is interpolated between S19a and S19b based on the risk behavior parameter in that year. For example, the number of partnerships for low-risk 20-24 year-old males in 2000, when the risk behavior parameter is 0.01, is $0.99 \times 0.2 + 0.01 \times 0.8 = 0.21$.

### S19a: Sexual partnerships when risk behavior parameter = 0

| Age     | Male Partnerships per Year | Female Partnerships per Year | Reference |
|---------|----------------------------|-----------------------------|-----------|
|         | Low Risk                   | Moderate Risk               | High Risk | Low Risk | Moderate Risk | High Risk |
| 0 – 4   | 0.00006                    | 0.00006                     | 0.00006   | 0.00006  | 0.00012      | 0.00012   |
| 5 – 9   | 0.00006                    | 0.006                       | 0.06      | 0.00007  | 0.007        | 0.12      |
| 10 – 14 | 0.0                        | 0.1                         | 0.6       | 0.01     | 0.06         | 0.4       |
| 15 – 19 | 0.2                        | 1.2                         | 32.0      | 0.23     | 0.06         | 27.9      |
| 20 – 24 | 0.2                        | 1.5                         | 32.0      | 0.28     | 1.2          | 25.3      |
| 25 – 29 | 0.3                        | 1.9                         | 20.0      | 0.18     | 0.81         | 15.4      |
| 30 – 34 | 0.2                        | 1.1                         | 18.0      | 0.09     | 0.57         | 10.4      |
| 35 – 39 | 0.2                        | 0.8                         | 18.0      | 0.09     | 0.49         | 9.5       |
| 40 – 44 | 0.2                        | 0.6                         | 10.5      | 0.09     | 0.41         | 8.7       |
| 45 – 49 | 0.2                        | 0.6                         | 10.5      | 0.09     | 0.41         | 8.1       |
| 50 – 54 | 0.2                        | 0.6                         | 10.5      | 0.09     | 0.41         | 6.1       |
| 55 – 59 | 0.1                        | 0.4                         | 8.5       | 0.07     | 0.41         | 1.6       |

Adapted from Barnabas\textsuperscript{38}

### S19b: Sexual partnerships when risk behavior parameter = 1

| Age     | Male Partnerships per Year | Female Partnerships per Year | Reference |
|---------|----------------------------|-----------------------------|-----------|
|         | Low Risk                   | Moderate Risk               | High Risk | Low Risk | Moderate Risk | High Risk |
| 0 – 4   | 0.00006                    | 0.00006                     | 0.00006   | 0.00006  | 0.00012      | 0.00012   |
| 5 – 9   | 0.00006                    | 0.006                       | 0.06      | 0.00007  | 0.007        | 0.12      |
| 10 – 14 | 0.02                       | 0.2                         | 2         | 0.09     | 0.18         | 1.8       |
| 15 – 19 | 0.8                        | 3.6                         | 82        | 0.72     | 2.16         | 72        |
| 20 – 24 | 0.8                        | 6                           | 82        | 0.68     | 6            | 68        |
| 25 – 29 | 1.2                        | 9.4                         | 68        | 0.56     | 4.06         | 44.8      |
| 30 – 34 | 0.6                        | 5.3                         | 52.7      | 0.28     | 2.87         | 41.8      |
| 35 – 39 | 0.5                        | 4.1                         | 52.7      | 0.28     | 2.45         | 38.1      |
| 40 – 44 | 0.5                        | 2.9                         | 46.8      | 0.21     | 2.03         | 34.8      |
| 45 – 49 | 0.5                        | 2.9                         | 46.8      | 0.21     | 2.03         | 32.2      |
| 50 – 54 | 0.5                        | 2.9                         | 46.8      | 0.21     | 1.61         | 24.5      |
| 55 – 59 | 0.4                        | 1.8                         | 35.1      | 0.07     | 0.63         | 6.3       |

Adapted from Barnabas\textsuperscript{38}

Risk distribution
Table S20. Sexual risk distribution by age and sex. Values are calibrated to fit age-specific HIV incidence and prevalence data. The sexual risk distribution is interpolated between S20a and S20b based on the risk behavior parameter in that year. For example, the percentage of low-risk 20-24 year-old males in 2000, when the risk behavior parameter is 0.01, is 0.99*0.71 + 0.01*0.60 = 0.709.

| Age  | Male Risk Distribution | Female Risk Distribution | Reference |
|------|------------------------|--------------------------|-----------|
|      | Low-Risk               | Moderate-Risk            | High-Risk |
|      | Low-Risk               | Moderate-Risk            | High-Risk |
| 0 – 4| 0.999                  | 0.0005                   | 0.0005    | 0.998  | 0.001  | 0.001  |
| 5 – 9| 0.999                  | 0.0005                   | 0.0005    | 0.998  | 0.001  | 0.001  |
| 10 – 14| 0.98                  | 0.015                    | 0.005     | 0.975  | 0.015  | 0.01   |
| 15 – 19| 0.72                  | 0.25                     | 0.03      | 0.68   | 0.26   | 0.06   |
| 20 – 24| 0.71                  | 0.25                     | 0.04      | 0.64   | 0.33   | 0.03   |
| 25 – 29| 0.75                  | 0.22                     | 0.03      | 0.75   | 0.22   | 0.03   |
| 30 – 34| 0.75                  | 0.22                     | 0.03      | 0.75   | 0.22   | 0.03   |
| 35 – 39| 0.79                  | 0.18                     | 0.03      | 0.82   | 0.15   | 0.03   |
| 40 – 44| 0.85                  | 0.12                     | 0.03      | 0.86   | 0.11   | 0.03   |
| 45 – 49| 0.86                  | 0.11                     | 0.03      | 0.87   | 0.1    | 0.03   |
| 50 – 54| 0.92                  | 0.05                     | 0.03      | 0.91   | 0.07   | 0.02   |
| 55 – 59| 0.96                  | 0.015                    | 0.025     | 0.975  | 0.015  | 0.01   |

S20b: Sexual risk distribution when risk behavior parameter = 1

| Age  | Male Risk Distribution | Female Risk Distribution | Reference |
|------|------------------------|--------------------------|-----------|
|      | Low-Risk               | Moderate-Risk            | High-Risk |
|      | Low-Risk               | Moderate-Risk            | High-Risk |
| 0 – 4| 0.999                  | 0.0005                   | 0.0005    | 0.998  | 0.001  | 0.001  |
| 5 – 9| 0.999                  | 0.0005                   | 0.0005    | 0.998  | 0.001  | 0.001  |
| 10 – 14| 0.98                  | 0.015                    | 0.005     | 0.975  | 0.015  | 0.01   |
| 15 – 19| 0.7                  | 0.26                     | 0.04      | 0.68   | 0.26   | 0.06   |
| 20 – 24| 0.6                  | 0.28                     | 0.12      | 0.52   | 0.36   | 0.12   |
| 25 – 29| 0.55                  | 0.38                     | 0.07      | 0.55   | 0.38   | 0.07   |
| 30 – 34| 0.65                  | 0.28                     | 0.07      | 0.64   | 0.3    | 0.06   |
| 35 – 39| 0.67                  | 0.27                     | 0.06      | 0.7    | 0.24   | 0.06   |
| 40 – 44| 0.74                  | 0.2                      | 0.06      | 0.77   | 0.17   | 0.06   |
| 45 – 49| 0.77                  | 0.17                     | 0.06      | 0.79   | 0.16   | 0.05   |
| 50 – 54| 0.87                  | 0.08                     | 0.05      | 0.84   | 0.13   | 0.03   |
| 55 – 59| 0.96                  | 0.035                    | 0.005     | 0.94   | 0.045  | 0.015  |

Calibrated to fit data

HIV prevalence for model calibration

Table S21. HIV prevalence for model calibration (age 15-49)

| Year | Prevalence | Reference       |
|------|------------|-----------------|
| 1995 | 0.105      | UNDP, Kenya     |
| 2003 | 0.067      | AIDS Indicator  |
| 2007 | 0.076      | Survey, DHS Kenya |
| 2008 | 0.063      | 39–41           |
| 2012 | 0.056      |                 |

Table S22. Age-specific HIV prevalence

| Age  | 2012 HIV prevalence | Reference       |
|------|---------------------|-----------------|
|      |                     |                 |

Calibrated to fit data
|   | Male  | Female |
|---|-------|--------|
| 0 – 4 | 0.9% | 2.3% |
| 5 – 9 | 0.6% | 0.9% |
| 10 – 14 | 0.6% | 0.5% |
| 15 – 19 | 0.9% | 1.1% |
| 20 – 24 | 1.3% | 4.6% |
| 25 – 29 | 4.3% | 7.9% |
| 30 – 34 | 6.6% | 6.6% |
| 35 – 39 | 5.0% | 12.3% |
| 40 – 44 | 8.1% | 10.6% |
| 45 – 49 | 8.9% | 10.7% |
| 50 – 54 | 6.7% | 10.2% |
| 55 – 59 | 3.7% | 5.1% |

Kenya AIDS Indicator Survey\(^{40}\)

Utility rates for DALYs
Table S23. Utility weights for estimating disability-adjusted life-years averted

| Health State                  | DALY Weight | Reference       |
|-------------------------------|-------------|-----------------|
| HIV-negative                  | 0           |                 |
| HIV-positive CD4>350          | 0.078       |                 |
| HIV-positive CD4 200-350      | 0.274       | Salomon et al.\(^{42}\) |
| HIV-positive CD4<200          | 0.582       |                 |
| HIV-positive on ART           | 0.078       |                 |
| Dead                          | 1           |                 |
IV. Calibration results

The following figures display model outputs and primary data from Kenya listed in the tables in the previous section of this supplemental appendix.

Population size

HIV prevalence (15-49) over time
Age-specific HIV prevalence (2012)

CD4 Distribution among HIV-positive over time
ART Coverage (proportion of all HIV-positive on ART and virally suppressed)
V. References

1. Adler WH, Baskar PV, Chrest FJ, Dorsey-Cooper B, Winchurch RA, Nagel JE. HIV infection and aging: Mechanisms to explain the accelerated rate of progression in the older patient. *Mech Ageing Dev*. 1997;96(1-3):137-155. doi:10.1016/S0047-6374(97)01888-5

2. Mills EJ, Bakanda C, Birungi J, et al. Mortality by baseline CD4 cell count among HIV patients initiating antiretroviral therapy: evidence from a large cohort in Uganda. *AIDS*. 2011;25(6):851-855. doi:10.1097/QAD.0b013e32834564e9

3. Anderson RM, May RM, Ng TW, Rowley JT. Age-dependent choice of sexual partners and the transmission dynamics of HIV in sub-Saharan Africa. *Philos Trans - R Soc London, B*. 1992;336(1277):135-155. doi:10.1098/rstb.1992.0052

4. Ott MQ, Bärnighausen T, Tanser F, Lurie MN, Newell M-L. Age-gaps in sexual partnerships: seeing beyond ‘sugar daddies.’ *AIDS*. 2011;25(6):861-863. doi:10.1097/QAD.0b013e32834344c9

5. Cheluget B, Baltazar G, Orege P, Ibrahim M, Marum LH, Stover J. Evidence for population level declines in adult HIV prevalence in Kenya. *Sex Transm Infect*. 2006;82(SUPPL. 1):i21-6. doi:10.1136/sti.2005.015990

6. Burington B, Hughes JP, Whittington WLH, et al. Estimating duration in partnership studies: issues, methods and examples. *Sex Transm Infect*. 2010;86(2):84-89. doi:10.1136/sti.2009.037960

7. Garnett GP, Gregson S. Monitoring the course of the HIV-1 epidemic: The influence of patterns of fertility on HIV-1 prevalence estimates. *Math Popul Stud*. 2000;8(3):251-277. doi:10.1080/08898480009525485

8. Clinton Health Access Initiative. *HIV Market Report*.; 2018. https://clintonhealthaccess.org/content/uploads/2018/09/2018-HIV-Market-Report_FINAL.pdf. Accessed December 11, 2018.

9. U.S. Centers for Diseases Control and Kenya Ministry of Health. *The Cost of Comprehensive HIV Treatment in Kenya: Report of a Cost Study of HIV Treatment Programs in Kenya*. Atlanta, GA (USA) and Nairobi, Kenya; 2013.

10. UNdata | Population by age, sex and urban/rural residence. http://data.un.org/Data.aspx?id=POP&f=tableCode%3A22. Accessed December 4, 2017.

11. Auvert B, Taljaard D, Lagarde E, Sobngwi-Tambekou J, Sitta R, Puren A. Randomized, Controlled Intervention Trial of Male Circumcision for Reduction of HIV Infection Risk: The ANRS 1265 Trial. Deeks S, ed. *PLoS Med*. 2005;2(11):e298. doi:10.1371/journal.pmed.0020298

12. Gray RH, Kigozi G, Serwadda D, et al. Male circumcision for HIV prevention in men in Rakai, Uganda: a randomised trial. *Lancet (London, England)*. 2007;369(9562):657-666. doi:10.1016/S0140-6736(07)60313-4

13. Weiss HA, Quigley MA, Hayes RJ. Male circumcision and risk of HIV infection in sub-Saharan Africa: a systematic review and meta-analysis. *AIDS*. 2000;14(7):2361-2370. doi:10.1016/S1473-3099(00)70235-X

14. Kenya 2014 Demographic and Health Survey. https://dhsprogram.com/pubs/pdf/fr308/fr308.pdf. Accessed December 6, 2017.

15. Ying R, Sharma M, Celum C, et al. Home testing and counselling to reduce HIV incidence in a generalized epidemic setting: a mathematical modelling analysis. *Lancet HIV*. 2016;3(6):e275-e282. doi:10.1016/S2352-3018(16)30009-1

16. UNAIDS. http://aidsinfo.unaids.org. Accessed December 10, 2018.

17. World Bank Development Indicators. https://data.worldbank.org/country/kenya. Accessed December 16, 2017.
18. Mwau M, Syeunda CA, Adhiambo M, et al. Scale-up of Kenya’s national HIV viral load program: Findings and lessons learned. *PLoS One.* 2018;13(1):e0190659. doi:10.1371/journal.pone.0190659

19. Marston M, Nakiyingi-Miro J, Kusemererwa S, et al. The effects of HIV on fertility by infection duration: Evidence from African population cohorts before antiretroviral treatment availability. *Aids.* 2017;31:S69-S76. doi:10.1097/QAD.0000000000001305

20. Life Tables for WHO Member States: Kenya. http://www.who.int/gho/countries/ken/en/. Accessed December 16, 2017.

21. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2016 (GBD 2016) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2017. http://ghdx.healthdata.org/gbd-results-tool. Accessed December 16, 2017.

22. Chaudhury S, Hertzmark E, Muya A, et al. Equity of child and adolescent treatment, continuity of care and mortality, according to age and gender among enrollees in a large HIV programme in Tanzania. 2018. doi:10.1002/jia2.25070/full

23. Badri M, Lawn SD, Wood R. Short-term risk of AIDS or death in people infected with HIV-1 before antiretroviral therapy in South Africa: a longitudinal study. *Lancet.* 2006;368(9543):1254-1259. doi:10.1016/S0140-6736(06)69117-4

24. Balslev U, Monforte AD, Stergiou G, et al. Influence of Age on Rates of New AIDS-defining Diseases and Survival in 6546 AIDS Patients. *Scand J Infect Dis.* 1997;29(4):337-343. doi:10.3109/00365549709011827

25. Powers KA, Poole C, Pettifor AE, Cohen MS. Rethinking the heterosexual infectivity of HIV-1: a systematic review and meta-analysis. 2008:553. doi:10.1016/S1473

26. Boily MC, Baggaley RF, Wang L, et al. Heterosexual risk of HIV-1 infection per sexual act: systematic review and meta-analysis of observational studies. *Lancet Infect Dis.* 2009;9(2):118-129. doi:10.1016/S1473-3099(09)70021-0

27. Hollingsworth TD, Anderson RM, Fraser C. HIV-1 Transmission, by Stage of Infection. 2008. doi:10.1086/590501

28. Quinn TC, Wawer MJ, Sewankambo N, et al. Viral Load and Heterosexual Transmission of Human Immunodeficiency Virus Type 1. *N Engl J Med.* 2000;342(13):921-929. doi:10.1056/NEJM200003303421303

29. Attia S, Egger M, Müller M, Zwahlen M, Low N. Sexual transmission of HIV according to viral load and antiretroviral therapy: Systematic review and meta-analysis. *AIDS.* 2009;23(11):1397-1404. doi:10.1097/QAD.0b013e32832b7dca

30. Cohen MS, Chen YQ, McCauley M, et al. Prevention of HIV-1 Infection with Early Antiretroviral Therapy. *N Engl J Med.* 2011;365(6):493-505. doi:10.1056/NEJMoa1105243

31. Donnell D, Baeten JM, Kiarie MBChB J, et al. Heterosexual HIV-1 transmission after initiation of antiretroviral therapy: a prospective cohort analysis. *Lancet.* 2010;375:2092-2098. doi:10.1016/S0140-6736(10)60705-2

32. Connor EM, Sperling RS, Gelber R, et al. Reduction of Maternal-Infant Transmission of Human Immunodeficiency Virus Type 1 with Zidovudine Treatment. *N Engl J Med.* 1994;331(18):1173-1180. doi:10.1056/NEJM199411033311801

33. 2015 Progress Report on the Global Plan. 2009. http://www.unaids.org/sites/default/files/media_asset/JC2774_2015ProgressReport_GlobalPlan_en.pdf. Accessed February 24, 2018.

34. Thomson KA, Hughes J, Baeten JM, et al. Increased Risk of HIV Acquisition Among Women Throughout Pregnancy and During the Postpartum Period: A Prospective Per-Coital-Act Analysis Among Women With HIV-Infected Partners. *J Infect Dis.* March 2018. doi:10.1093/infdis/jiy113
35. Glynn JR, Biraro S, Weiss HA. Herpes simplex virus type 2: A key role in HIV incidence. *Aids*. 2009;23(12):1595-1598. doi:10.1097/QAD.0b013e32832e15e8

36. Hughes JP, Baeten JM, Lingappa JR, et al. Determinants of per-coital-act HIV-1 infectivity among African HIV-1-serodiscordant couples. *J Infect Dis*. 2012;205(3):358-365. doi:10.1093/infdis/jir747

37. Kenya AIDS indicator Survey 2007. https://stacks.cdc.gov/view/cdc/12122. Accessed June 12, 2017.

38. Barnabas R. Mathematical Modelling of the Natural History of Human Papillomavirus Infection and Cervical Carcinoma: The Impact of Intervention Strategies on Disease Incidence. *Univ Oxford*. 2005.

39. Kenya AIDS Strategic Framework. http://www.undp.org/content/dam/kenya/docs/Democratic Governance/KENYA AIDS STRATEGIC FRAMEWORK.pdf. Accessed June 12, 2017.

40. Kenya AIDS indicator Survey 2012. http://nacc.or.ke/wp-content/uploads/2015/10/KAIS-2012.pdf. Accessed June 12, 2017.

41. 2008 Kenya Demographic and Health Survey. http://statistics.knbs.or.ke/nada/index.php/catalog/23. Accessed December 6, 2017.

42. Salomon JA, Haagsma JA, Davis A, et al. Disability weights for the Global Burden of Disease 2013 study. *Artic Lancet Glob Heal*. 2015;3:712-735. www.thelancet.com/lancetgh. Accessed July 10, 2018.