Assessing the cost-effectiveness of national Kenyan repeat maternal HIV testing guidelines

Shiza Farid

A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Public Health

University of Washington
2018

Committee:

Alison Drake, Co-Chair
Anna Bershteyn, Co-Chair

Program Authorized to Offer Degree:

Global Health

University of Washington

Abstract

Assessing the cost-effectiveness of national Kenyan repeat maternal HIV testing guidelines

Shiza Farid

Chair of Supervisory Committee:

Alison Drake, Assistant Professor

Department of Global Health

Kenya has aims to achieve the 95-95-95 goals for prevention of mother-to-child HIV transmission (PMTCT) by 2030; yet, each year there are 13,000 new infant HIV infections. Repeat testing in the third trimester and in the postpartum period, when risk of HIV acquisition is high, can help detect and treat incident maternal infections and reduce mother-to-child HIV transmission. Current data on the timing, frequency, and utility of repeat testing are lacking. We assessed the cost-effectiveness of repeat HIV testing during pregnancy and the postpartum period, comparing various repeat testing scenarios to inform more targeted policies on PMTCT programs, and maximize HIV prevention resources in Kenya. We assessed the cost-effectiveness of 5 repeat testing scenarios, varying the number and timing of repeat testing, in averting infant HIV infections. We constructed a separate decision analytic model for each scenario to estimate the number of infant infections averted, the incremental cost-effectiveness ratio in terms of infections averted (ICER-IA), and the total cost to the Kenyan health care system. As a conservative estimate, repeat testing scenarios were considered to be cost-effective if the ICER-IA was less than 3 times Kenya's gross domestic product (GDP) per capita ($4365 USD in 2016) and highly cost-effective if less than Kenya's GDP per capita ($1455 USD in 2016). All repeat testing strategies are cost-effective

in averting infant infections. Repeat testing at delivery; at 6 weeks postpartum; at both 6 weeks postpartum and 6 months postpartum; and in the third trimester/at delivery, at 6 weeks postpartum, and at 6 months postpartum (complete repeat testing) are all also considered highly-cost-effective. The most cost-effective strategy is conducting complete repeat maternal HIV testing, which averts a 12,023 infant infections with an ICER-IA of $1,189. The second most cost-effective scenario is repeat testing at 6 weeks postpartum and 6 months postpartum, which averts 8,403 infections at the ICER-IA of $1,249. Repeat testing at 6 weeks postpartum averts 5,160 infections at the ICER-IA of $1,426. Among all the repeat testing scenarios, complete retesting averts the most infant infections and is highly cost-effective. Data on implementation of repeat testing guidelines will be useful to measure health and economic impact of scaling up repeat maternal testing in Kenya.

Background

Worldwide, over 90% of HIV infections among children are transmitted during pregnancy, childbirth, and through breastfeeding.[1] Women with incident HIV infections in pregnancy and the postpartum period have a 2-fold higher risk of mother-to-child HIV transmission (MTCT) compared to women with chronic infections.[2,3] Each year, there are 13,000 new infant HIV infections in Kenya.[4] While Kenya pledged to reduce MTCT to less than 5% in 2011, only 15% of counties have achieved this goal, and 32% have MTCT rates exceeding 15%.[3,4] In order to move towards elimination of MTCT (eMTCT), Kenya must achieve 95-95-95 goals by 2030.[4]

Studies suggest risk of HIV acquisition remains high in pregnancy and the postpartum period in Kenya, with a pooled risk of 3.8 per 100 person-years during pregnancy and the postpartum period.[2,5] Moreover, maternal HIV infections acquired after initial HIV testing during antenatal care will go undetected if women are not offered repeat testing in the third trimester or the postpartum period. In South Africa, over one-third of MTCT was attributed to incident maternal HIV infections that were undetected after the initial antenatal care (ANC) HIV test.[6] Thus, repeat testing in the third trimester and in the postpartum period can help detect and treat incident maternal infections, and subsequently reduce MTCT.

The World Health Organization (WHO) recommends conducting repeat testing during pregnancy, labor and delivery, and/or in the postpartum period; but lack of guidance on operationalizing guidelines in prevention of mother-to-child transmission (PMTCT) programs has led countries to develop separate national recommendations.[7,8] In Kenya, current guidelines recommend repeat testing during the third trimester or at the time of delivery, at 6 weeks postpartum, and at 6 months postpartum.[9,10] However, guidelines may not be uniformly implemented.[11] In a recent study conducted in Kenya, only 27% of the women eligible to retest were retested by delivery.[11] Furthermore, the frequency of repeat testing in the postpartum period has not been well characterized. Both timing and frequency of repeat maternal HIV testing are expected to affect utility of subsequent maternal HIV testing, and likelihood of detecting new maternal HIV infections. Data that demonstrate the public health impact of retesting at specific time points during pregnancy and postpartum, alone at one time point or in combination at multiple time points, would be useful in determining utility of specific repeat testing strategies.

Cost-effectiveness analyses of repeat maternal testing can aid in guiding policies and PMTCT programs, and maximize HIV prevention resources. To assess the cost-effectiveness of repeat HIV testing during pregnancy and the postpartum period, we constructed decision analytic models comparing various repeat testing scenarios based on current Kenyan guidelines.

Methods

Base-case and comparator repeat testing scenarios

We developed 5 repeat maternal HIV testing scenarios to compare with the base-case scenario (no repeat maternal HIV testing) (Table 1). In the base-case scenario, we assume all women test negative for HIV during their first ANC visit by 28 weeks gestation and do not receive a repeat test. There are 3 scenarios that model only 1 repeat test, including repeat testing in the third trimester (scenario 1), at delivery (scenario 2), and at 6 weeks postpartum (scenario 3). We modeled 2 scenarios where women receive multiple repeat tests, including repeat testing at 6 weeks postpartum and 6 months postpartum (scenario 4), and complete repeat testing in the third trimester or delivery, at 6 weeks postpartum, and 6 months postpartum (scenario 5).

Decision analytic models

While dynamic epidemiological S-I-R and Markov models have been used widely in HIV research to guide decision-making on HIV prevention and treatment programs and estimate the cost-effectiveness of interventions, we utilized a decision analytic model design as they are comparatively easier to interpret and

adapt for a single individual or cohorts. Five separate decision analytic models were constructed, one for each repeat testing scenario. The schematic in Figure 1 illustrates the decision analytic model for scenario 1 (repeat testing in the third trimester). In this model, pregnant women with initial HIV negative results in ANC are followed through 9 months postpartum; infants are followed from birth through 9 months postpartum.

Input parameters

Probabilities in the model are shown in Table 2. Probabilities included maternal HIV acquisition, infant HIV acquisition, attendance at the MCH clinic for ANC and postnatal care visits, facility delivery, breastfeeding, antiretroviral therapy (ART) use, and reduction in HIV transmission due to infant prophylaxis and/or ART. Model parameters were derived from published literature unless otherwise indicated in Table 2. Wherever available, we used data for the Kenya-specific country context. According to the World Bank, the population of Kenya is 48 million with a crude birth rate of 3.9.[12] Therefore, we modeled a cohort of 1.7 million pregnant women.

We assumed all pregnancies were singleton births, repeat HIV test acceptability was 100%, and women deliver at 40 weeks gestational age. We assumed incident infections would only be detected 12 weeks after HIV acquisition, and incident maternal infections are in the acute stage for 12 weeks. We assumed the probability of testing was the same at all time points with the exception of delivery; we assumed that at delivery it was 25% lower than testing in the third trimester (100% for women offered a repeat test). Among women who had HIV detected through repeat testing, we assumed 100% started and adhered to ART through 9 months postpartum. Similarly, we assumed that women that were detected through repeat testing provided their infants with infant prophylaxis for the duration of breastfeeding. Our treatment parameters follow Kenya's ART guidelines, which implement the PMTCT strategy, Option B+. Under Option B+, HIV-infected pregnant (or postpartum) women initiate ART at diagnosis and continue for life; infants born to HIV-infected women initiate infant prophylaxis and continue for the duration of breastfeeding.[9,10] We assumed no differential HIV acquisition risk based on age or sexual behavior, such as having multiple sexual partners. We also do not incorporate maternal mortality or neonatal mortality.

Costs

The cost of the initial test was abstracted from a WHO meta-analysis on the cost of HIV testing in low and high resource settings. The average cost of provider initiated HIV test at the sub-district, district, health center levels in Kenya was $5.18 in 2013 U.S. Dollars (USD), adjusted for inflation, $5.54 in 2018 USD.[29] Repeat cost data were collected between June and November 2017 in Kenya from the provider perspective. We conducted time and motion studies that micro-costed the cost of personnel, and abstracted costs of 3rd generation HIV test kits and other supplies (e.g. gloves) from clinic registers at Ahero County and Bondo sub-County Hospitals in western Kenya. All costing analysis was conducted in the context of an on-going study implementing repeat testing during pregnancy and postpartum using a 4th generation HIV test; all research-related costs were removed from our cost estimates (Table 3). All costs were converted to 2018 USD and no discount rates were applied as the time horizon was less than a year.

Cost-effectiveness analysis

While cost-effectiveness analysis is more typically expressed as the cost per life-year saved, quality-adjusted life-year (QALY) gained, or disability-adjusted life-year (DALY) averted, in this case the future health impact of an infant HIV infection is difficult to assess in a data-driven way, because the future quality of HIV care for an individual now born with infection will depend greatly upon options for HIV treatment or cure in coming decades. We therefore assessed the cost per infant infection averted (ICER-IA) rather than per unit of health gained. This form of incremental cost-effectiveness cannot be compared to standard cost-effectiveness thresholds such as gross domestic product, nor can it be compared to investments in other disease areas. However, it can be used to compare internally across testing strategies to identify the most cost-effective

strategy to avert infant infections. For reference, the gross domestic product (GDP) of Kenya is $1,455[13] and a typical threshold for cost-effectiveness is 3 times the per-capita GDP, or $4,365, per life-year saved, QALY gained, or DALY averted. Averting an infant infection is likely to gain at least a QALY or avert a single DALY (as lifelong HIV treatment is still challenging and a cure does not yet exist), and thus, comparing the cost per infant infection averted to GDP would give a conservative estimate for cost-effectiveness.

Model estimates were used to calculate the incremental cost-effectiveness ratios per infant infection averted (ICER-IA) of adding repeat maternal HIV testing to the base-case scenario (no repeat maternal HIV testing) per infant HIV infection averted. As a conservative estimate, repeat testing scenarios were considered to be cost-effective if the ICER-IA was less than 3 times Kenya's gross domestic product (GDP) per capita ($4,365 USD in 2016) and highly cost-effective if less than Kenya's GDP per capita ($1,455 USD in 2016).

One-Way Sensitivity Analyses

We conducted several one-way sensitivity analyses for repeat testing scenario 1 (repeat testing in the third trimester) to evaluate the impact of varying specific input parameters on the ICER-IA for scenario 1. We a priori set to modify the input parameters by 25-50%. The full set of parameters we conducted sensitivity analyses on are in Table 5.

Results

All repeat testing strategies are cost-effective in averting infant infections (Table 4) even with the conservative comparison of GDP to cost per infant infection averted. Repeat testing at delivery (scenario 2), at 6 weeks postpartum (scenario 3), at 6 weeks postpartum and 6 months postpartum (scenario 4), and complete repeat testing (scenario 5) are all also considered highly-cost-effective. The most cost-effective strategy is conducting complete repeat maternal HIV testing (scenario 5), as outlined in the 2016 Kenyan guidelines, which averts a total of 12,023 infant infections at the ICER-IA of $1,189.[9] Implementation of the complete repeat testing averts more infant infections than any other scenario, and more than twice the number of infections as repeat testing at only 6 weeks postpartum (5,160 infections; ICER-IA= $1,426). Scenario 4 was the second most cost-effective scenario; repeat testing at 6 weeks postpartum and 6 months postpartum averts 8,403 infections at the ICER-IA of $1,249. We modeled repeat testing in the third trimester and at delivery separately, and found 1,123 more infant infections were averted through repeat testing at delivery. The total cost to the Kenyan health care system ranges from around $5 million to $14 million dollars depending on which repeat testing scenario is implemented.

Sensitivity Analyses

The parameters that the models are most sensitive are the maternal and infant HIV transmission. For the parameter for infant transmission during the acute stage, both a 50% increase and decrease in transmission results in higher ICER-IAs. Additionally, our models are also sensitive to infant transmission during the chronic stage of the infection, where a 50% decrease results in over a $1000 increase in the ICER-IA. The probability of transmission of HIV to mother is also another parameter our model is highly sensitive to—a 50% decrease increases the ICER-IA by over $1,000, while an increase by 50% result in more modest savings under $500.

Our models was robust with respect to infant ART costs and repeat testing costs. However, the models were sensitive to the maternal ART costs where the ICER-IA decreases by over $250 with a 50% reduction in price of ARTs.

Discussion

We found that repeat maternal HIV testing was cost-effective under all repeat testing scenarios evaluated in decision analytic models; 4 of 5 repeat testing scenarios were highly cost-effective. Complete implementation of current repeat testing guidelines averted the highest number of infant infections by 9 months postpartum, but was also the more costly to implement. The total cost to the Kenyan health care system to uniformly implement the complete repeat testing guidelines would be $14.3 million over 9 months, whereas costs incurred by the government would decrease to below $7.3 million if only one repeat test is implemented. These costs are significantly lower than the $34 million the Kenyan government currently spends on HIV testing and counseling and the additional $10 million it spends on PMTCT services (including delivery services, ART, and infant prophylaxis costs).[14] Furthermore, Kenya's economy in 2016 was worth $75b USD, and the country currently spends roughly 7% of its GDP on health care with plans to further increase.[15] Repeat testing implementation should be considered as Kenya's health spending continues to expand.

Our results are similar to another study that showed repeat HIV testing at the time of delivery in pregnancy was cost-effective in Uganda, and averted over 400,000 disability adjusted life-years (DALYs).[27] However, to our knowledge, no studies have assessed the public health or economic impact of conducting repeat maternal HIV testing in both pregnancy and during the postpartum period. Our model assessed the impact of conducting repeat maternal HIV testing across the pregnancy-postpartum continuum, both at individual time points and at combinations of time points, to show the utility of each approach. This analysis is novel in that it estimates infant HIV infections averted if current Kenyan guidelines were completely or partially implemented. Additionally, in multiple sensitivity analyses, we found that even with varying levels of uncertainty around the input parameters, repeat testing remained cost-effective.

Our analysis was subject to several limitations. Current Kenyan guidelines suggest that only women who did not receive a repeat test in pregnancy should have repeat test at the time of labor or delivery. However, due to the limitations of our model structure, infections averted by repeat testing in the third trimester and at delivery were modeled separately. Furthermore, since we did not vary estimates of maternal HIV transmission risk by age, our estimates of infant infections averted may be attenuated since transmission rates are known to be higher women who are younger women or have multiple partners.[16] Furthermore, HIV transmission acquisition risk varies by whether women use pre-exposure prophylaxis (PrEP), or have male partners who have sex with men or are circumcised—these parameters were also not included in our model. Additionally, we assumed 100% acceptability if repeat testing was offered, and studies on PMTCT interventions have shown testing rates are high (above 90%), but are not universal.[17] We also assumed 100% ART adherence which likely inflates the number infections averted; however, in the 2016 Kenya AIDS Response Progress (KAIS) Report adherence was found to be above 80%.[3] Moreover, we did not model all costs incurred for women on treatment and costs saved from infant infections averted past 9 months. Finally, our modeled estimates are not generalizable against other health interventions since we did not conduct a cost-utility analysis using quality adjusted life years (QALYs) or DALYs. Therefore, we cannot compare the cost-effectiveness of repeat testing to other health interventions. However, we can compare all the repeat testing scenarios as they have the same base-case.

We found that the current Kenyan guidelines for repeat maternal HIV testing are optimal in averting the most infant infections by 9 months postpartum, and are highly cost-effective, but are more costly to implement. Data from these results can help inform utility and cost of implementing current guidelines. However, future modeling studies should consider incorporating costs saved from averting infant infections, including the lifetime costs incurred by identifying additional infant infections, and QALYs or DALYs, to better ascertain the spectrum of costs incurred and averted.

Table 1: Repeat testing scenarios[1]	
Base case	HIV test at first antenatal care visit
1: Third trimester	HIV retest in the third trimester
2: Delivery	HIV test at first antenatal care visit Repeat test at delivery (40 weeks)
3: 6 weeks postpartum	Repeat test at 6 weeks postpartum
4: 6 weeks and 6 months postpartum	Repeat tests at 6 weeks postpartum and at 6 months postpartum
5: Third trimester/ delivery, 6 weeks postpartum, and 6 months postpartum *(Complete repeat testing guidelines)*	Repeat tests in the third trimester/delivery, at 6 weeks postpartum, and 6 months postpartum

[1]All test case scenarios assume repeat testing in addition to the base case scenario HIV test at first antenatal care visit

Table 2: Parameters

	Value	Source
Probability of first ANC and before 28 gestational weeks.	0.932	Kenya DHS 2014[17]
Probability of testing HIV negative at first ANC	0.946	Nedge 2016[18]
Probability of second ANC visit	0.924	Kenya DHS 2014[17]
Probability of facility delivery	0.612	Kenya DHS 2014[17]
Probability of attending 6 weeks visit	0.98	Kenya DHS 2014[17]
Probability of attending 6 months visit	0.364	Kenya DHS 2014[17]
Probability of HIV test acceptability	1	Assumed
Weekly probability of maternal HIV acquisition	Kinuthia et al. 2015[19]	
	28 weeks- up to 36 weeks (in pregnancy)	0.0053
	Delivery- up to 40 weeks	0.0080
	6 weeks postpartum	0.0119
	6 months postpartum	0.0135
Sensitivity of HIV test	0.99	Abbott[20]
Probability of breastfeeding at 9 months	0.75	Oiye 2016[21]
Probability of maternal ART initiation after diagnosis	0.75	KAIS 2016[3]
Probability of maternal ART adherence	1	Assumed
Probability of transmission to infant while on ART from delivery to 9 months postpartum	0.067	Ashiono et al. 2017[22]
Weekly probability of MTCT among women with chronic infection-	0.039	Liang 2009[23]
Weekly probability of MTCT among women with acute infection	0.059	Marinda 2011[24]
Probability of transmission to infant during delivery, in the absence of maternal/infant ART	.15	Assumed based on WHO estimates[25]
Probability MTCT while on ART by 9 months postpartum	.18	Morrison 2015[26]
Probability MTCT while on infant prophylaxis by 9 months postpartum	.325	Kim 2013[27] and Connor 1994[28]

Table 3: Costs for repeat maternal HIV test

Total cost for initial HIV Test		
$5.54[1]		
	Repeat test (HIV negative)	**Confirmatory test (if HIV positive on repeat test)**
Personnel (nurse salary)	$1.51[2]	$2.27[3]
HIV test kit (3rd generation)	$0.52[4]	$0.60[5]
Other supplies		
Gloves (1 pair)	$0.14	$0.14
Cotton wool (per use)	$0.01	$0.01
Rubbing alcohol (per use)	$0.05	$0.05
TOTAL COST	$2.23	$3.07

[1] The average cost of provider initiated HIV test at the sub-district, district, health center levels in Kenya was $5.18 in 2013 U.S. Dollars, adjusted for inflation, $5.54 in 2018 U.S. Dollars.[29]

[2] 30 minutes for repeat test

[3] 45 minutes for confirmatory test for woman that tested positive on the repeat test- includes 15 minutes wastage time

[4] Using Alere Determine™ HIV-1/2

[5] First Response® HIV 1-2-0 Card Test

Table 4: Repeat maternal HIV testing scenarios modeled

Time point(s) of repeat testing	Total number of infant infections averted	ICER-IA	Total cost for health system to avert all infections
Scenario 1: *At third trimester*	2,785	$2,014	$5,608,565
Scenario 2: *At delivery*	3,908	$1,303	$5,093,292
Scenario 3: *At 6 weeks*	5,160	$1,426	$7,356,412
Scenario 4: *At 6 weeks and 6 months postpartum*	8,403	$1,249	$10,499,004
Scenario 5: *At third trimester /delivery; at 6 weeks postpartum; and 6 months postpartum**	12,023	$1,189	$14,299,225

**Complete repeat testing guidelines in Kenya*

Table 5: One-Way Sensitivity Analyses of Parameters in Model 1

Parameter	Low-High Values for Parameters	ICER-IA	Percent Change in Parameter
Probabilities			
Weekly maternal HIV acquisition during pregnancy	0.003-0.008	$3,375- $1,560*	50%
MTCT at delivery	0.075- 0.225	$2,236- $1,832*	50%
MTCT to infant post-delivery (acute)	0.025-0.076	$3,877-$3,020*	50%
MTCT to infant post-delivery (chronic)	0.020-0.060	$3,317-$1,445*	50%
MTCT while on ART by 9 months postpartum	0.506-0.844	$2,100-$1,932*	25%
Maternal ART initiation after diagnosis	0.188-0.938	$2,022-$2,011*	25%
Cost parameters			
Cost of 3rd generation per HIV Test	$1.12- $3.35	$2,011-$2,017*	50%
Cost of maternal ART per?	$3.13-$9.39	$1,767-$2,260*	50%
Cost of infant ART per?	$2.75-$8.25	$1,933-$2,094*	50%
***Denotes ICER-IA cost-effective			

Figure 1: Schematic for Scenario 1-Repeat testing in third trimester

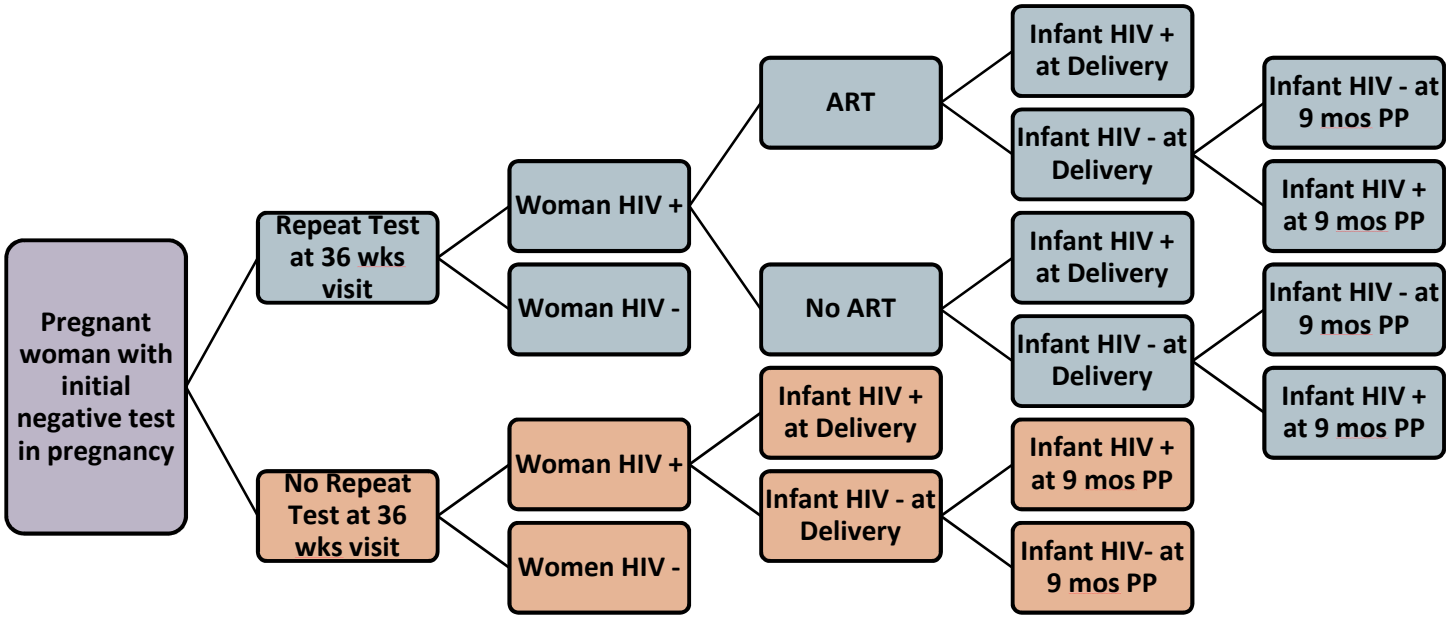
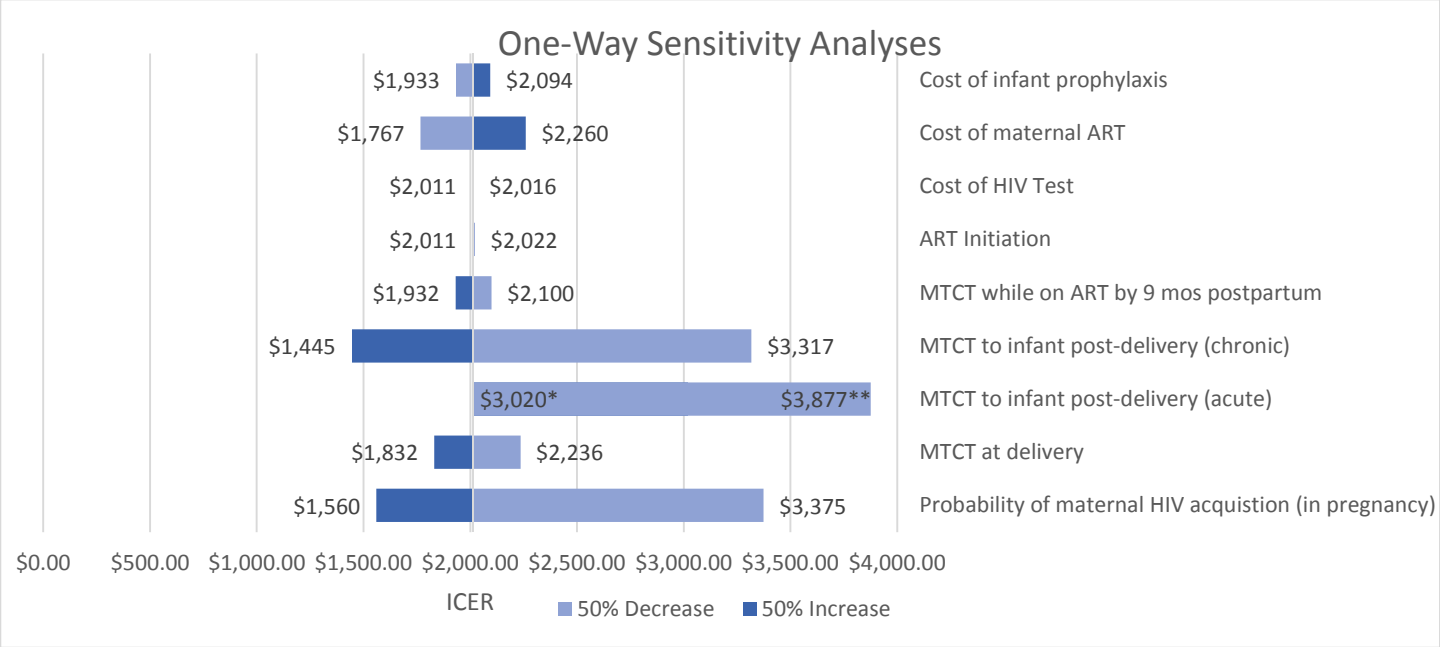


Figure 2



*ICER-IA increased with a 50% increase in maternal to child transmission in acute stage

**ICER-IA increased with a 50% decreased in maternal to child transmission in acute stage

References

[1] Joint United Nations Programme on HIV/AIDS (UNAIDS) Sub-Saharan Africa Fact Sheet December 2006.

Geneva, Switzerland: UNAIDS; 2006. Retrieved 15 February, 2018 from: http://data.unaids.org/pub/GlobalReport/2006/200605-fs_subsaharanafrica_en.pdf.

[2] Drake A, Wagner A, Richardson B, John-Stewart G. Incident HIV during pregnancy and postpartum: a systematic literature review and meta-analysis [2014]. Retrieved from PLoS medicine, Retrieved 21 April 2018 from: http://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1001608

[3] Kenya AIDS Response Progress Report (2016). National AIDS Control Council. Retrieved 2 April 2018, from http://nacc.or.ke/wp-content/uploads/2016/11/Kenya-AIDS-Progress-Report_web.pdf

[4]Joint United Nations Programme on HIV/AIDS (UNAIDS) Global Plan Towards the Elimination of New HIV Infections Among Children by 2015 and Keeping Their Mothers Alive, 2011–2015.Vol. 2011. Geneva, Switzerland: UNAIDS; 2011. Retrieved 15 February, 2018 from: http://www.unaids.org/en/resources/documents/2015/JC2774_2015ProgressReport_GlobalPlan

[5] Kenya HIV Estimates [2015]. Ministry of Health. Retrieved 21 April 2018, from: http://nacc.or.ke/wp-content/uploads/2016/12/Kenya-HIV-Estimates-2015.pdf

[6]Johnson, Leigh F., et al. "The Contribution of Maternal HIV Seroconversion During Late Pregnancy and Breastfeeding to Mother-to-Child Transmission of HIV." JAIDS Journal of Acquired Immune Deficiency Syndromes, vol. 59, no. 4, 2012, pp. 417–425., doi:10.1097/qai.0b013e3182432f27.Retrieved 8 June 2018, from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3378499/pdf/ukmss-40367.pdf

[7] Consolidated Guidelines on HIV Testing Services. WHO, 2015, pp. 1–188. Retrieved 8 June 2018, from: http://apps.who.int/iris/bitstream/handle/10665/179870/9789241508926_eng.pdf;jsessionid=E18C95CD013F5A1435D4D9F506DF609A?sequence=1

[8] Delivering HIV test results and messages for re-testing and counselling in adults. WHO, 2010, pp.1-36 Retrieved 18 June 2018, from: http://www.who.int/hiv/pub/vct/hiv_re_testing/en/

[9] Guidelines on Use of Antiretroviral Drugs for Treating and Preventing HIV Infection in Kenya. NASCOP, 2016, pp.1-188, Retrieved 18 June, 2018 from: https://www.prepwatch.org/wp-content/uploads/2016/08/Guidelines-on-ARV-for-Treating-Preventing-HIV-Infections-in-Kenya.pdf

[10]The Kenya HIV Testing Services Guidelines. Ministry of Health and NASCOP, 2015, pp.1-78, Retrieved 18 June, 2018 from: https://aidsfree.usaid.gov/sites/default/files/hts_policy_kenya_2015.pdf

[11] Rogers, A., Akama, E., Weke, E., Blackburn, J., Owino, G., & Bukusi, E. et al. (2017). Implementation of repeat HIV testing during pregnancy in southwestern Kenya: progress and missed opportunities. Journal Of The International AIDS Society, 20(4), e25036 , Retrieved 18 June, 2018 from: http://dx.doi.org/10.1002/jia2.25036

[12] "Fertility Rate, Total (Births per Woman)." *World Bank | Data*, Retrieved 18 June, 2018 from: data.worldbank.org/indicator/SP.DYN.TFRT.IN?locations=KE.

[13] Gross Domestic Product Per Capita for Kenya." *FRED*, Federal Reserve Bank of St. Louis, 18 Jan. 2018, Retrieved 18 June, 2018 from: https://fred.stlouisfed.org/series/PCAGDPKEA646NWDB

[14] Kenya National AIDS Spending Assessment Report for the Finncial Years 2009/10-2011/12. UNAIDS, 2014, pp.1-72, Retrieved 18 June, 2018 from: http://files.unaids.org/en/media/unaids/contentassets/documents/data-and-analysis/tools/nasa/20141017/kenya_2011_en.pdf

[15]*In Kenya: Health Expenditure Up, Donor Funding Down*. Health Policy Project*, 10 June, 2015, Retrieved 18, June 2018 from:* www.healthpolicyproject.com/index.cfm?ID=KenyaNHA

[16] HIV Risk Reduction Tool. Centers for Disease Control and Prevention, Retrieved 19 June, 2018 from: https://wwwn.cdc.gov/hivrisk/increased_risk/partners/multiple_partners.html

[17] Kenya 2014 Demographic Health Survey. Kenya National Bureau of Statistics, Ministry of Health, National AIDS Control Council, Kenya Medical Research Institute, National Council for Population and Development, ICF International. Retrieved 18 June, 2018 from: https://dhsprogram.com/pubs/pdf/fr308/fr308.pdf

[18]Ndege, Samson, et al. HIV Prevalence and Antenatal Care Attendance among Pregnant Women in a Large Home-Based HIV Counseling and Testing Program in Western Kenya. *Plos One*, vol. 11, no. 1, 2016, doi:10.1371/journal.pone.0144618. Retrieved 18 June, 2018 from: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0144618

[19] Kinuthia, John, et al. "HIV Acquisition during Pregnancy and Postpartum Is Associated with Genital Infections and Partnership Characteristics." *Aids*, vol. 29, no. 15, 2015, pp. 2025–2033., doi:10.1097/qad.0000000000000793. Retrieved 18 June, 2018 from: https://journals.lww.com/aidsonline/Fulltext/2015/09240/HIV_acquisition_during_pregnancy_and_postpartum_is.15.aspx

[20] Alere Determine™ HIV-1/2 Ag/Ab Combo. *C Diff Quik Chek Complete - Alere Is Now Abbott*. Retrieved 18 June, 2018 from: www.alere.com/en/home/product-details/determine-1-2-ag-ab-combo.html.

[21] Oiye, Shadrack, et al. "Exclusive Breastfeeding Is More Common Among HIV-Infected Than HIV-Uninfected Kenyan Mothers at 6 Weeks and 6 Months Postpartum." *Breastfeeding Medicine*, vol. 12, no. 5, 2017, pp. 283–289., doi:10.1089/bfm.2016.0126.
Retrieved 18 June, 2018 from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3653987/

[22] Ashiono, Everline, et al. Vertical HIV Transmission in Perinatally-Exposed Infants in South-Rift Region of Kenya: a Retrospective Cross Sectional Study. *BMC Public Health*, vol. 17, no. 1, 2017, doi:10.1186/s12889-017-4124-z. Retrieved 18 June, 2018 from: https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-017-4124-z

[23] Liang K, Gui X, Zhang YZ, Zhuang K, Meyers K, Ho DD. A case series of 104 women infected with HIV-1 via blood transfusion postnatally: high rate of HIV-1 transmission to infants through breast-feeding. *J Infect Dis.* 2009;200(5):682-686. Retrieved 18 June, 2018 from: https://www.ncbi.nlm.nih.gov/pubmed/19627245

[24] Marinda ET, Moulton LH, Humphrey JH, et al. In utero and intra-partum HIV-1 transmission and acute HIV-1 infection during pregnancy: using the BED capture enzyme-immunoassay as a surrogate marker for acute infection. *Int J Epidemiol.* 2011;40(4):945-954. Retrieved from 18 June, 2018 from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3156369/

[25] "Mother-to-Child Transmission of HIV." *World Health Organization*, World Health Organization, 10 March 2016. Retrieved 19 June, 2018 from: www.who.int/hiv/topics/mtct/about/en/.

[26] Morrison, Susan, et al. "Rapid Antiretroviral Therapy Initiation for Women in an HIV-1 Prevention Clinical Trial Experiencing Primary HIV-1 Infection during Pregnancy or Breastfeeding." *Plos One*, vol. 10, no. 10, 2015, doi:10.1371/journal.pone.0140773.
Retrieved 19 June, 2018 from: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0140773

[27] Kim LH, Cohan DL, Sparks TN, Pilliod RA, Arinaitwe E, Caughey AB. The cost-effectiveness of repeat HIV testing during pregnancy in a resource-limited setting. *J Acquir Immune Defic Syndr.* 2013;63(2):195-200. Retrieved 8 June, 2018 from: https://www.ncbi.nlm.nih.gov/pubmed/23392461

[28] Connor EM, Sperling RS, Gelber R, et al. Reduction of maternal-infant transmission of human immunodeficiency virus type 1 with zidovudine treatment. Pediatric AIDS Clinical Trials Group Protocol 076 Study Group. *N Engl J Med.* 1994;331(18):1173-1180. Retrieved 8 June, 2018 from: https://www.nejm.org/doi/full/10.1056/nejm199411033311801

[29] Johnson C., Dalal S., Baggaley R. (2017). Annex 5. Systematic review of HIV testing costs in high and low income settings. World Health Organization. [online] Available at: http://apps.who.int/iris/bitstream/10665/180219/1/WHO_HIV_2015.24_eng.pdf / http://sti.bmj.com/content/88/7/498.long

Appendix

Table 2a: Parameters

Probability of first ANC and before 28 gestational weeks.	0.932	Kenya DHS 2014[17]	P_{anc_b28}
Probability of testing HIV negative at first ANC	0.946	Nedge 2016[29]	P_{tst_neg}

Probability of second ANC visit	0.924	Kenya DHS 2014[17]	P_{sec_vis}

Probability of facility delivery	0.612	Kenya DHS 2014[17]	P_{fal_del}
Probability of attending 6 weeks visit	0.98	Kenya DHS 2014[17]	P_{6wk_vis}
Probability of attending 6 months visit	0.364	Kenya DHS 2014[17]	P_{6m_vis}
Probability of HIV test acceptability	1	Assumed	
Weekly probability of maternal HIV acquisition	Kinuthia et al. 2015[29]		
Probability of first ANC and before 28 gestational weeks.	28 weeks- up to 36 weeks (in pregnancy)	0.0053	P_{hiv+}
	Delivery- up to 40 weeks	0.0080	P_{hiv+}
	6 weeks postpartum	0.0119	P_{hiv+}
	6 months postpartum	0.0135	P_{hiv+}
	0.932	Kenya DHS 2014[17]	P_{hiv+}
Sensitivity of HIV test	0.99	Abbott[29]	P_{tst_sen}
Probability of breastfeeding at 9 months	0.75	Oiye 2016[29]	P_{bf_6wks}
Probability of maternal ART initiation after diagnosis	0.75	KAIS 2016[3]	P_{bf_9mos}
Probability of ART initiation	0.75	Source: KAIS 2016	P_{art}
Probability of maternal ART adherence	1	Assumed	
Probability of transmission to infant while on ART from delivery to 9 months postpartum	0.067	Ashiono et al. 2017[29]	P_{trn_art}
Weekly probability of MTCT among women with chronic infection-	0.039	Liang 2009[29]	$P_{art\_hivreduc}$
Weekly probability of MTCT among women with acute infection	0.059	Marinda 2011[29]	$P_{trn\_ut\_ac}$
Probability of transmission to infant during delivery, in the absence of maternal/infant ART	.15	Assumed based on WHO estimates[29]	$P_{trn\_ut\_ch}$
Probability MTCT while on ART by 9 months postpartum	.18	Morrison 2015[29]	$P_{reduc\_inf\_art}$

Table 2b: Transition Probabilities

Scenario 1: Repeat testing in late pregnancy	
Probability of no repeat test and being positive: The probability of being positive at 36 gestational weeks and not having a repeat test are the same.	P_{hiv+}
Probability of repeat test (P_{repeat_test}): The probability of testing negative at the first visit and coming in for a second visit at 36 gestational weeks multiplied by the	$P_{repeat\_test}= [(P_{anc\_b28} * P_{tst\_neg} * P_{sec\_vis})]* [P_{whiv+} = P_{hiv+\_lp} * P_{tst\_sen}]$

probability of acquiring HIV by 36 gestational weeks

times the test sensitivity.

Probability of woman initiating ART: The probability starting ART.	P_{art}
Probability of HIV infected infant at delivery for mothers on ART ($P_{art\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to maternal and infant ARTs, and the probability of transmission while on ART.	$P_{art\_infant+}= P_{infant\_trans\_acute*\#of\_wks} *P_{reduc\_art}* P_{reduc\_\_inf\_art} * P_{inf\_trans\_risk}* P_{trn\_art}$
Probability of HIV infected infant at delivery for mothers not on ART ($P_{nart\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to infant ARTs only.	$P_{nart\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{inf\_trans\_risk} * P_{reduc\_\_inf\_art}$
Probability of HIV infected infant for mothers on ART ($P_{art\_infant+}$) at 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, probability of reduction due to maternal ARTs, the probability of transmission while on ART, and probability of breastfeeding.	$P_{art\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} *P_{reduc\_art} * P_{bf} * P_{trn\_art}* P_{inf\_trans\_risk}$
Probability of HIV infected infant for mothers not on ART ($P_{nart\_infant+}$) 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, and probability of breastfeeding.	$P_{nart\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} * P_{bf} * P_{inf\_trans\_risk}$
Scenario 2: Repeat testing in delivery	
Probability of no repeat test and being positive: The probability of being positive at delivery and not having a repeat test are the same.	P_{hiv+_del}
Probability of repeat test (P_{repeat_test}): The probability of testing negative at the first visit and probability of facility delivery multiplied by the probability of acquiring HIV by delivery times the test sensitivity.	$P_{repeat\_test}= [(P_{anc\_b28} * P_{tst\_neg} * P_{fal\_del})]* [P_{whiv+} = P_{hiv+\_del} * P_{tst\_sen}]$
Probability of woman initiating ART: The probability starting ART.	P_{art}

Probability of HIV infected infant at delivery for mothers on ART ($P_{art\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to maternal and infant ARTs, and the probability of transmission while on ART.	$P_{art\_infant+}= P_{infant\_trans\_acute*\#of\_wks} *P_{reduc\_art}* P_{reduc\_\_inf\_art} * P_{inf\_trans\_risk}* P_{trn\_art}$
Probability of HIV infected infant at delivery for mothers not on ART ($P_{nart\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to infant ARTs only.	$P_{nart\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{inf\_trans\_risk} * P_{reduc\_\_inf\_art}$
Probability of HIV infected infant for mothers on ART ($P_{art\_infant+}$) at 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, probability of reduction due to maternal ARTs, the probability of transmission while on ART, and probability of breastfeeding.	$P_{art\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} *P_{reduc\_art} * P_{bf} * P_{trn\_art}* P_{inf\_trans\_risk}$
Probability of HIV infected infant for mothers not on ART ($P_{nart\_infant+}$) 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, and probability of breastfeeding.	$P_{nart\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} * P_{bf} * P_{inf\_trans\_risk}$
Scenario 3: Repeat testing at 6 weeks postpartum	
Probability of no repeat test and being positive: The probability of being positive at 6 weeks postpartum and not having a repeat test are the same.	P_{hiv+_6wks}
Probability of repeat test (P_{repeat_test}): The probability of testing negative at the first visit and probability of coming in at 6 weeks postpartum multiplied by the probability of acquiring HIV by 6 weeks postpartum times the test sensitivity.	$P_{repeat\_test}= [(P_{anc\_b28} * P_{tst\_neg} * P_{6wks\_vis})]* [P_{whiv+} = P_{hiv+\_6wks} * P_{tst\_sen}]$
Probability of woman initiating ART: The probability starting ART.	P_{art}

Probability of HIV infected infant at delivery for mothers	$P_{art\_infant+}$=	$P_{infant\_trans\_acute}$*#of_wks	*P_{reduc_art}*	

on ART ($P_{art\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to maternal and infant ARTs, and the probability of transmission while on ART.	$P_{reduc\_\_inf\_art} * P_{inf\_trans\_risk} * P_{trn\_art}$
Probability of HIV infected infant at delivery for mothers not on ART ($P_{nart\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to infant ARTs only.	$P_{nart\_infant+} = P_{infant\_trans\_acute*\#of\_wks} * P_{inf\_trans\_risk} * P_{reduc\_\_inf\_art}$
Probability of HIV infected infant for mothers on ART ($P_{art\_infant+}$) at 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, probability of reduction due to maternal ARTs, the probability of transmission while on ART, and probability of breastfeeding.	$P_{art\_infant+} = P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} * P_{reduc\_art} * P_{bf} * P_{trn\_art} * P_{inf\_trans\_risk}$
Probability of HIV infected infant for mothers not on ART ($P_{nart\_infant+}$) 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, and probability of breastfeeding.	$P_{nart\_infant+} = P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} * P_{bf} * P_{inf\_trans\_risk}$
Scenario 4: Repeat testing at 6 weeks and 6 months postaprtum	
Probability of no repeat test (P_{repeat_test}) at 6 weeks postpartum: The probability of being positive at 6 weeks postpartum and not having a repeat test are the same.	P_{hiv+_6wks}
Probability of repeat test (P_{repeat_test}): Probability of woman having had first ANC visit and testing negative multiplied by the probability of coming in 6 weeks postpartum and testing negative multiplied by the probability of woman coming in at 6 months postpartum times the probability of acquiring HIV by 6 months postpartum times the test sensitivity.	$(P_{anc\_b28} * P_{tst\_neg}) * ((1- P_{hiv+\_6wk}) * P_{6wk\_vis}) * (P_{6m\_vis} * P_{hiv+\_6mos} * P_{tst\_sen})$
Probability of woman initiating ART: The probability starting ART.	P_{art}

Probability of HIV infected infant at delivery for mothers on ART ($P_{art\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to maternal and infant ARTs, and the probability of transmission while on ART.	$P_{art\_infant+}= P_{infant\_trans\_acute*\#of\_wks} *P_{reduc\_art}* P_{reduc\_\_inf\_art} * P_{inf\_trans\_risk}* P_{trn\_art}$
Probability of HIV infected infant at delivery for mothers not on ART ($P_{nart\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to infant ARTs only.	$P_{nart\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{inf\_trans\_risk} * P_{reduc\_\_inf\_art}$
Probability of HIV infected infant for mothers on ART ($P_{art\_infant+}$) at 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, probability of reduction due to maternal ARTs, the probability of transmission while on ART, and probability of breastfeeding.	$P_{art\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} *P_{reduc\_art} * P_{bf} * P_{trn\_art}* P_{inf\_trans\_risk}$
Probability of HIV infected infant for mothers not on ART ($P_{nart\_infant+}$) 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, and probability of breastfeeding.	$P_{nart\_infant+}= P_{infant\_trans\_acute*\#of\_wks} * P_{infant\_trans\_chronic *\#of\_wks} * P_{bf} * P_{inf\_trans\_risk}$
Scenario 5: Complete retesting	
Probability of no repeat test (P_{repeat_test}) in late pregnancy or delivery: The probability of being positive in late gestation or delivery and not having a repeat test are the same.	$P_{hiv+\_lp} \mid P_{hiv+\_del}$
Probability of repeat test (P_{repeat_test}): Probability of woman having had first ANC visit and testing negative multiplied by the probability of coming in late pregnancy or delivery and testing negative multiplied by the probability of woman coming in at 6 weeks postpartum and testing negative, multiplied by the by the probability of woman coming in at 6 months postpartum times the probability of acquiring HIV by 6 months postpartum times the test sensitivity.	$(P_{anc\_b28} * P_{tst\_neg}) * ((1- P_{hiv+\_lp} \text{ or } 1-P_{hiv+\_del})) * (1-P_{hiv+\_6wks}) * (P_{6mos\_vis}* P_{hiv+\_6mos}* P_{tst\_sen}) *$

Probability of woman initiating ART: The probability starting ART.	P_{art}
Probability of HIV infected infant at delivery for mothers on ART ($P_{art\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to maternal and infant ARTs, and the probability of transmission while on ART.	$P_{art\_infant+}= P_{infant\_trans\_acute}*\#of\_wks * P_{reduc\_art} * P_{reduc\_\_inf\_art} * P_{inf\_trans\_risk} * P_{trn\_art}$
Probability of HIV infected infant at delivery for mothers not on ART ($P_{nart\_infant+}$): The probability of infant transmission of acute infection by the number of weeks (duration as long as mothers infection), probability of infant transmission, probability of reduction due to infant ARTs only.	$P_{nart\_infant+}= P_{infant\_trans\_acute}*\#of\_wks * P_{inf\_trans\_risk} * P_{reduc\_\_inf\_art}$
Probability of HIV infected infant for mothers on ART ($P_{art\_infant+}$) at 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, probability of reduction due to maternal ARTs, the probability of transmission while on ART, and probability of breastfeeding.	$P_{art\_infant+}= P_{infant\_trans\_acute}*\#of\_wks * P_{infant\_trans\_chronic} *\#of\_wks * P_{reduc\_art} * P_{bf} * P_{trn\_art} * P_{inf\_trans\_risk}$
Probability of HIV infected infant for mothers not on ART ($P_{nart\_infant+}$) 9 months postpartum: The probability of infant transmission of acute and chronic infection by the number of weeks (duration as long as mothers infection), probability of infant transmission risk, and probability of breastfeeding.	$P_{nart\_infant+}= P_{infant\_trans\_acute}*\#of\_wks * P_{infant\_trans\_chronic} *\#of\_wks * P_{bf} * P_{inf\_trans\_risk}$