RESEARCH ARTICLE

Mortality rates in a cohort of infants attending immunization clinics in Uganda (2017–2019)

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Abstract

Background

Uganda reported a significant reduction in the mortality rate of children under 5 years of age, from 146/1,000 live births in 2000–42/1,000 live births in 2021. With the roll-out of Option B+, the vertical transmission rate of HIV decreased from 13.0% (2012) to 6.0% (2019). However, its impact on the mortality rate among children is not well documented. We determined the mortality rate and associated risk factors among infants exposed and not exposed to HIV attending immunization clinics in Uganda.

Methods

We conducted an observational prospective cohort study of mother–infant pairs (MIPs) with infants exposed or unexposed to HIV. We enrolled infants aged 4–12 weeks. The inclusion criteria were biological mothers attending health facilities that provide routine immunization for children and/or postnatal care visits who were able to provide signed written informed consent; mothers or infants who were not severely ill; and those who consented to have their infants tested for HIV antibodies at baseline and follow-up visits every 3 months until the children were aged 18 months. Child-HIV infection and death were censored events. Children lost to follow-up or withdrawn from the study were censored from analyses at the last documented study visit. The outcome of interest was child mortality, and the independent variables were mother's age; infant HIV exposure status; infant sex; family socioeconomic status; marital status; education level; malaria during pregnancy; birth attendee; mother's ART initiation; mode of transport to health facilities; breastfeeding pattern; 4 or more

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ANC visits; and mother's baseline viral load nonsuppression and place of delivery. We used Kaplan–Meier survival curves to estimate cumulative mortality probability and the Wilcoxon log-rank test to compare differences in cumulative survival functions. We used multivariate Weibull proportional hazards and Weibull accelerated failure time (AFT) regression models with 95% confidence intervals (CIs) to identify factors associated with child death.

Results

Among the 16,718 MIPs identified, 11,519 (68.9%) mothers consented to study follow-up. At the 18-month follow-up, 0.7% (79/11,519) of the infants had died, 40.5% (32/79) of whom were exposed to HIV. The overall child mortality rate per 1,000 person-years was 5.0 (95% CI: 4.0--6.2) and was significantly greater among the infants exposed to HIV (14.2; 95% CI: 10.0--20.0) than among the infants not exposed to HIV (3.5; 95% CI: 2.6--4.6). In the adjusted model, the mortality risk factors were HIV exposure status (aHR5.6 95% CI: 3.5--9.4), maternal age < 25 years (aHR1.8; 95% CI: 1.1--2.9), living without a partner (aHR1.8; 95% CI: 1.1--2.9), and delivery at home (aHR2.2; 95% CI: 1.3--4.0).

Conclusion

Single young mothers living with HIV delivering at home increased the risk of child mortality. Identifying mothers with risk factors early for support could reduce the risk of child mortality.

Introduction

In 2021, 5.0 million children died before they reached the age of 5 years, and 56% (2.8 million) were in sub–Saharan Africa, despite the region accounting for 29% of the global live births [1]. There has been a 59% reduction in the child underfive mortality rate (U5MR) globally in previous decades, from 93 to 38 deaths per 1,000 live births between 1990 and 2021. However, the reduction in the U5MR in sub-Saharan Africa (SSA) was slower than that in other regions, with 74 deaths per 1,000 live births in 2021 [1]. The implementation of the United Nations' Sustainable Development Goals (SDGs) started in 2016 with a target U5MR of no more than 25 deaths per 1,000 live births in every country of the world by 2030 [2]. Uganda has yet to achieve this target, with a current U5MR of 42 deaths per 1,000 live births in 2021 [1].

Globally, communicable and infectious diseases such as pneumonia, diarrhea, HIV/AIDS, and malaria continue to be the leading causes of preventable underfive deaths [3]. Other factors, such as death of the mother, child vaccination status, breastfeeding status and low birth weight, have also been shown in several studies to be associated with morbidity and mortality among infants and are more pronounced among infants exposed than those not exposed to HIV [4–6]. Mosley et al.'s analytical approach to the study of the determinants of child survival in low- and

middle-income countries highlights the premise that all socioeconomic determinants, such as income/wealth, the political economy and the health system of child mortality, operate through a common set of biological mechanisms or proximate determinants, such as maternal factors, nutrition, and personal illness control, to affect mortality [7].

Exposure to HIV has been widely documented to be a risk factor for infant mortality in the ZVITAMBO trial, which reported a 2-year mortality rate of 9.2% in infants exposed but not infected compared with 2.9% in those not exposed to HIV [8,9]. However, maternal antiretroviral therapy (ART) use during pregnancy and breastfeeding has been shown to reduce mortality in children under 5 years of age to levels observed in children of mothers not infected with HIV in South Africa [10]. Young mother, illiteracy and income inequality have been documented to predict the infant mortality rate (IMR) in low- and middle-income countries [11]. In 2013, in accordance with the WHO guidelines, Uganda was among the first countries in sub-Saharan Africa to incorporate Option B+ (life-long universal maternal antiretroviral therapy (ART)) into its national prevention of vertical transmission of HIV strategy [12]; since then, the percentage of pregnant and breastfeeding women living with HIV receiving lifelong ART has increased from <1% to >95%, and transmission rates have decreased from 24% to 6% from 2010–2019 [12–17]. Uganda is a country with a mature generalized HIV epidemic, with an HIV prevalence of 5.8% among adults aged 15 years plus approximately 1.5 million people living with HIV [18]. Over time, the HIV epidemic has had a negative impact on overall child mortality rates in the country; thus, with increased access to ART for pregnant women living with HIV, the rate of HIV-related child mortality has been declining in Uganda. To determine child mortality rates and associated risk factors among infants exposed and not exposed to HIV, we analyzed data from the evaluation of the Impact of the national program for prevention of vertical transmission of HIV in Uganda, a nationally representative cohort of infants exposed and not exposed to HIV in Uganda up to 18 months postdelivery.

Methods

We analyzed data collected as part of the Uganda prevention of vertical transmission of HIV impact evaluation study, a prospective observational cohort study of vertical transmission of HIV. The study included a nationally representative sample of mother–infant pairs (MIPs), including infants exposed and those not exposed to HIV, recruited from immunization clinics within health facilities from 20th September 2017–26th February 2018. The health facility sampling frame included all private and public facilities that offered infant first DPT vaccination in 2015, of which 206 health facilities were randomly selected without replacement. Infants aged 4–12 weeks and their biological mothers receiving routine health care at the selected facilities were screened. Trained research assistants obtained written consent and enrolled mother–infant pairs. Mother-infant pairs were excluded if the infant or mother was severely ill or if the mother did not consent to infant HIV testing. The infants were followed until incident HIV infection, death, or 18 months of age. MIPs had follow-up visits at 6, 9, 12, 15, and 18 months postpartum, with a ±6-week allowance for follow-up visits. All infants exposed to HIV were assessed for HIV infection at follow-up visits with infants aged <18 months via HIV DNA PCR via dried blood spots and those aged ≥18 months through onsite rapid antibody testing. For mothers living without HIV, at every visit, they were screened for new HIV infection via onsite rapid antibody testing. In addition, mothers living with HIV underwent maternal viral load testing at the 6- and 12-month follow-up visits. Data were obtained through maternal and infant questionnaires and abstraction of selected clinical variables from the child's Child Health Card (CHC).

Child characteristics collected at baseline included age, sex, birth weight (low, defined as < 2.5 kg), feeding practices from birth to enrollment (exclusive breastfeeding or not), and HIV exposure status. Maternal characteristics collected at baseline included age, marital status, education, HIV viral load suppression (<1000 copies/ml), type of birth attendee, malaria during pregnancy, gestational age at antenatal care (ANC) enrollment, place of infant delivery, mode of transport to nearest health facility, and maternal ART status (the timing of maternal ART initiation). Socioeconomic status (SES) index by quintiles was a composite measure derived from household income and assets.

Child mortality was defined as any child death that was verbally reported by the mother or caretaker (not a biological mother) during the follow-up period. We defined a child as an infant exposed to HIV, if it was born to a mother who had an

HIV-positive status confirmed by data from either the CHC, ANC card, maternal outpatient card, or rapid HIV test result during any study visit. Children were defined as an infant not exposed, if they were born to a mother who had an HIV-negative status and did not seroconvert during the study.

Statistical analysis

Our outcome of interest was all-cause child mortality within the follow-up period to child age 18 months. Children who experienced the primary endpoint of the parent study (HIV infection via vertical transmission of HIV) at the baseline visit were excluded from analysis. Children who were lost to follow-up (i.e., unable to contact or locate participants for three consecutive missed appointment visits) or withdrew from the study for other reasons (i.e., refusal to continue or relocate out of the study area) and children who seroconverted during the follow-up period were censored from mortality analyses on the date recorded on the study suspension form or the last recorded study visit; their time at risk was age at their last visit. The time at risk for children who died was age at death. We calculated percentages, median values, and mortality rates per 1,000 person-years for maternal and child characteristics. We estimated the cumulative mortality probability via Kaplan–Meier curves and the log-rank test to compare differences in cumulative survival functions among infants exposed and those not exposed to HIV. We used plots of the log-log of survival functions to assess for Cox proportional hazards assumptions that were violated for most of the independent variables. For multivariate analysis, we therefore used Weibull proportional hazards and Weibull accelerated failure time (AFT) regression models with 95% confidence intervals (CIs) to identify factors associated with hazard of child death. To identify independent factors associated with child death, stepwise regression with the minimum Akaike information criterion (AIC) between the full model and the reduced model was used to identify variables to include in the final model. The strength of the association was expressed as adjusted hazard ratios and associated 95% CIs as well as failure time ratios with a 5% level of statistical significance. We used multiple imputation by chained equation (MICE) to impute missing values for variables with less than 10% missing values to avoid bias when more than 10% of the data were missing [19]. Variables with more than 10% missing data were dropped from the model. The imputed variables were infant sex, feeding practice, maternal age, marital status, socioeconomic status, malaria during pregnancy, mode of transport to health facilities, place of delivery and number of ANC visits. We conducted 20 imputations to create a set of conditional distributions for each imputed variable, which replaced the missing value with a set of plausible values that represent the uncertainty about the value to impute.

The analyses were not weighted for the complex survey design of the parent study. All the statistical analyses were conducted in Stata 16.0 (StataCorp, Lakeway Drive, Texas, USA).

Ethical considerations

This study was reviewed and approved by the Uganda Virus Research Institute (UVRI) IRB with reference number GC/127/17/03/579 and registered with the Uganda National Council for Science and Technology (See 45 C.F.R. part 46.114; 21 C.F.R. part 56.114). All the participating mothers or caregivers provided written consent at the baseline and follow-up enrollment visits.

Results

A total of 11,519 (68.9%) of the 16,718 infants identified were enrolled in the study, with a median age of 56 days (IQR 46–64); 50.0% were male, and 87.1% were exclusively breastfed in the first 6 months. More than half of the mothers (63.4%) were aged 15–24 years. A total of 1,723 (15.0%) children were HIV-exposed by the end of the study; of these, 63.1% of the mothers were on ART before conception, and 88.2% of the mothers with a baseline HIV viral load had a suppressed viral load. In total, 79 (0.7%) children died, 32/79 (40.5%) of whom were infants exposed to HIV (Table 1).

Table 1. Baseline characteristics of mother–infant pairs by child mortality status (N = 11,519).

Characteristics	Dead, N = 79 n (%)	Alive, N = 11440 n (%)	All, N = 11519 n (%)	*P value*
Infants				
Age at baseline *(days), median (IQR)*	56 (45–65)	56 (46–64)	56 (46–64)	
Sex				
Male	37 (43.0)	5698 (49.9)	5735 (50.0)	
Female	42 (57.0)	5687 (50.1)	5729 (50.0)	0.5695
Birth weight				
Low (<2.5 kgs)	1 (2.1)	540 (7.2)	541 (7.2)	
Not Low (>=2.5 kgs)	46 (97.9)	6949 (92.8)	6995 (92.8)	0.1784
Feeding practice (first 6 months)				
Exclusively breastfed first 6 months	67 (85.2)	9926 (87.1)	9993 (87.1)	
Mixed/replacement feeding first 6 months	9 (14.8)	1378 (12.9)	1387 (12.9)	0.7035
HIV Exposure Status				
Unexposed	47 (59.5)	9750 (85.2)	9797 (85.0)	
Exposed	32 (40.5)	1691 (14.8)	1723 (15.0)	<.0001
Maternal				
Age				
15-24 years	52 (69.1)	7263 (63.4)	7315 (63.4)	
25 years and older	27 (30.9)	4125 (36.6)	4152 (36.6)	0.7063
Marital Status				
Living without a Partner	26(33.8)	2289(20.6)	2315 (20.7)	
Living with a Partner	51 (66.2)	8829(79.4)	8880(79.3)	0.4220
Education				
Above primary	42 (33.5)	3532 (32.1)	3557 (32.1)	
Primary and below	54 (66.5)	7908 (67.9)	7962 (67.9)	0.8816
Social Economic Status				
High (4th or 5th quintile)	22 (27.4)	4093 (36.3)	4115 (36.3)	
Low (1st or 2nd quintile)	38 (53.1)	4914 (43.6)	4952 (43.6)	0.1762
Middle (3rd quintile)	17 (19.5)	2268 (20.1)	2285 (20.1)	0.3051
Birth attendee				
Skilled	38 (77.8)	6904 (85.6)	6942 (85.6)	
Traditional birth attendants(TBA)/Others	11 (22.2)	1179 (14.4)	1190 (14.4)	0.1248
Malaria in Preganacy				
Yes	59 (77.4)	8478 (74.4)	8537 (74.4)	0.8309
No	19 (22.6)	2889 (25.6)	2908 (25.6)	
Gestation Age at start of ANC				
0-3 months	22 (31.4)	3099 (30.4)	3121 (30.4)	
4-6 months	43 (61.4)	6334 (62.1)	6377 (62.1)	0.8651
7-9 months	5 (7.2)	765 (7.5)	770 (7.5)	0.8680
Mode of transport to health facility				
Walking	51 (71.2)	6631 (58.4)	6682 (58.1)	0.2421
Motorized	28 (28.8)	4798 (41.6)	4826 (41.9)	
ART Status (HIV infected only)*				
Initiated preconception	14 (51.9)	924 (63.0)	938 (62.8)	
Initated during pregnancy/Identified during pregnancy	10 (37.0)	417 (28.4)	427 (28.6)	0.2723
Initiated post delivery/Identified Positive during study	3 (11.1)	117 (8.0)	120 (8.0)	0.4138
Don't know	0 (0)	8 (0.6)	8 (0.6)	0.9911

(Continued)

Table 1. (Continued)

Characteristics	Dead, N = 79 n (%)	Alive, N = 11440 n (%)	All, N = 11519 n (%)	*P value*
Suppressed HIV Virally Load (<1000 copies/ml) at baseline(mothers living with HIV only)				
Suppressed	26 (81.7)	1283 (88.3)	1309 (88.2)	
Not suppressed	4 (18.3)	165 (11.7)	169 (11.8)	0.7415
Place of delivery				
Public Facility	40 (53.7)	6905(61.4)	6945 (61.3)	
Home	17 (20.1)	1542(13.7)	1559 (13.8)	0.0270
Private Facility	20 (26.2)	2797(24.9)	2817 (24.9)	0.4437

[a]Missing: Infant Sex: n = 55(0.5%); Birth weight: n = 4450 (38.6%);Feeding practice: n = 139(1.2%); Maternal age: n = 52(0.5%); Marital status: n = 320 (2.8%); Social Economic Status: n = 167 (1.5%); Viral load suppression: n = 244(2.1%); Birth attendee: n = 3387 (29.4)%; Malaria in Pregnancy: n = 74 (0.6%); Gestation Age at start of ANC: n = 1251 (10.9%); Mode of transport to health facility: n = 11 (0.1%); ART status: n = 229 (2.0%); Place of delivery: n = 194 (1.7%).

*The timing of maternal ART initiation for mothers living with HIV.

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The overall child mortality rate was 5.0 per 1,000 person-years (95% CI: 4.0–6.2). HIV-exposed children and those born at home had significantly greater risks of death ($p \leq 0.0000$ and $p = 0.03$, respectively). Mortality rates were significantly higher for infants exposed (14.2, 95% CI: 10.0–20.0) compared to those not exposed to HIV (3.5, 95% CI: 2.6–4.6); mothers not living with their partners (8.5, 95% CI: 5.8–12.4) compared to those living with a partner (4.1, 95% CI: 3.1–5.4) and infants born at home compared (7.8, 95% CI: 4.8–12.6) to those born at a public facility (4.2, 95% CI: 3.1–5.7) (Table 2).

On comparison of cumulative survival functions, survival experiences were significantly different between infants exposed and not exposed to HIV (log rank $p < 0.0001$) (Fig 1).

Compared with that of infants not exposed to HIV, the adjusted hazard ratio (aHR) of child mortality was significantly greater for infants exposed to HIV (aHR: 5.6, 95% CI: 3.4–9.2), with a median survival time reduced by 70% (Table 3). Children born to mothers aged 15--24 years had a significantly greater hazard (aHR: 1.8, 95% CI: 1.1--2.9) than those born to mothers aged ≥25 years, with the median survival time reduced by 30%. There was a significantly greater hazard ratio (aHR: 1.8, 95% CI: 1.1--2.9) for mothers living without a partner than those living with a partner, with the median survival time ratio reduced by 30%. Home-delivered babies had a significantly greater hazard rate (aHR: 2.3; 95% CI: 1.3–4.0) than did those delivered in a public facility, with a reduced median survival time of 20%.

The overall Weibull model shape parameter of $p = 1.37$ suggested that the hazard of child mortality generally increased with time.

Discussion

The overall mortality rate of 5.0 deaths per 1,000 person-years observed in the study cohort (with follow-up to 18 months) was six times lower than the 32.9 deaths per 1,000 person-years reported in a 2009–2011 cohort of children from rural Uganda over a median follow-up of 2 years [20]. Of note,in 2011 13.8% of children under five years of age were under weight with increased vulnerability to diesases; the infant and under-five mortality rates were 54/1000 and 90/1000 live births respectively with HIV prevalence at 7.3% [21,22]. The lower observed rate in this analysis could reflect that all infants in the study were engaged in health care regularly for study visits at the clinics where they could receive health education, vaccinations and child nutrition monitoring, which improved the quality of child health services and thus reduced the number of preventable child deaths [23]. Furthermore, infants exposed to HIV and their mothers had access to prevention of vertical transmission of HIV interventions, including maternal ART; the use of cotrimoxazole prophylaxis to prevent opportunistic infections, malaria, and upper respiratory infections; and the promotion of breastfeeding following the guidance of the World Health Organization (WHO) and Ministry of Health (MOH), which recommends a longer duration of breastfeeding instead of replacement feeding for infants exposed to HIV [24–26].

Table 2. Child mortality rate per 1,000 person-years during the 18-month follow-up period.

Characteristic	Deaths	Number of Infants	Person years of infant age	MR per 1000 person years	*95%CI*	*p values*
Infants						
Overall	79	11519	15870.5	5	[4.0–6.2]	
Sex						
Male	37	5735	7894.6	4.7	[3.4–6.5]	
Female	42	5730	7905.4	5.3	[3.9–7.2]	0.5781
Feeding practice (first 6 months)						
Mixed/replacement feeding first 6 months	9	1387	1921.7	4.7	[2.4–9.0]	
Exclusively breastfed first 6 months	67	9993	13760.2	4.9	[3.8–6.1]	0.7110
HIV exposure status						
Unexposed	47	9797	13613.2	3.5	[2.6–4.6]	
Exposed	32	1723	2257.3	14.2	[10.0–20.0]	<.0001
Maternal						
Age						
15-24 years	52	7316	10068.2	5.2	[3.9–6.8]	
25 years and older	27	4152	5732.1	4.7	[3.2–6.9]	0.6978
Marital Status						
Living without a partner	26	2315	3068.4	8.5	[5.8–12.4]	
Living with a partner	51	8880	12380.2	4.1	[3.1–5.4]	0.0028
Education						
Above Primary Level	25	3552	4919.3	5.1	[3.4–7.5]	
None/Primary/Don't Know	54	7741	10951.3	4.9	[3.8–6.4]	0.9007
Social Economic Status						
High (4th or 5th quintile)	22	4115	5646.7	3.9	[2.6–5.9]	
Low (1st or 2nd quintile)	38	4952	6832.5	5.6	[4.0–7.6]	0.1840
Middle (3rd quintile)	17	2285	3162.7	5.4	[3.3–8.6]	0.3190
Birth attendee						
Skilled	38	6942	9526.0	4.0	[2.9–5.5]	
Traditional birth attendant (TBA)/Other	11	1190	1645.3	6.7	[3.7–12.1]	0.1315
Malaria in preganacy						
No	59	8537	11769.9	5.0	[3.9–6.5]	
Yes	19	2908	4001.6	4.7	[3.0–7.4]	0.8370
Gestation Age at start of ANC						
0-3 months	22	3121	4263.8	5.2	[3.4–7.8]	
4-6 months	43	6377	8813.7	4.9	[3.6–6.6]	0.8309
7-9 months	5	770	1058.7	4.7	[1.9–11.3]	0.8582
Mode of transport to Health Facility						
Motorize	28	4826	6640.7	4.2	[2.9–6.1]	
Walking	51	6682	9214.5	5.5	[4.2–7.3]	0.2474
ART Status (HIV infected only)						
Initiated preconception	14	938	1256.2	11.1	[6.6–18.8]	
Initated during pregnancy/Identified during pregnancy	10	427	549.8	18.2	[9.7–33.8]	0.2368
Initiated post delivery/Identified Positive during study	3	120	143.1	21	[6.7–65.0]	0.3205
Suppressed HIV Viral Load (<1000 copies/ml) at baseline(mothers living with HIV only)						
Suppressed	26	1310	1737.4	15.0	[10.2–22.0]	
Not suppressed	4	169	214.2	18.7	[7.0–49.8]	0.6808

(Continued)

Table 2. (Continued)

Characteristic	Deaths	Number of Infants	Person years of infant age	MR per 1000 person years	*95%CI*	*p values*
Place of delivery						
Public Facility	40	6945	9557.3	4.2	[3.1–5.7]	
Home	17	1559	2164.1	7.8	[4.8–12.6]	0.0296
Private Facility	20	2817	3885.8	5.1	[3.3–7.9]	0.4501

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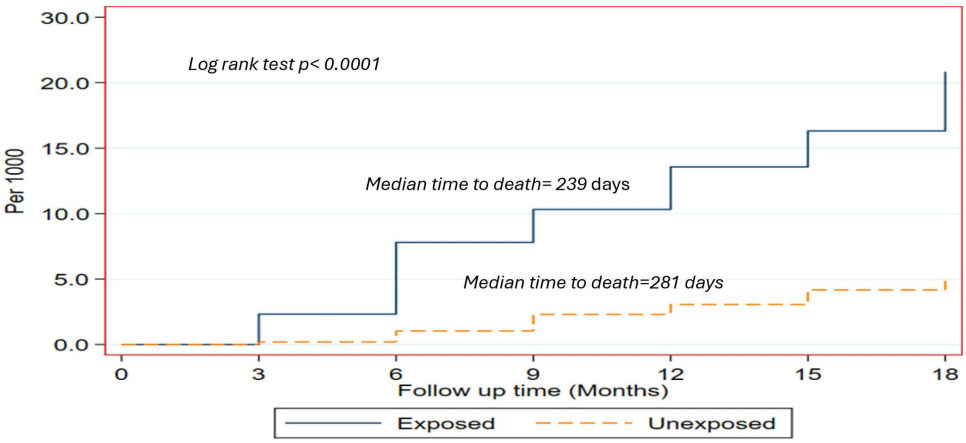

y -axis scaled to out of 1000 infants.

	Exposed		Unexposed		Total	
Interval (Months)	Deaths	Cum. Failure	Deaths	Cum. Failure	Deaths	Cum. Failure
1	0	0.0000	0	0.0000	0	0.0000
3	4	0.0023	2	0.0002	6	0.0005
6	9	0.0078	8	0.0010	17	0.0020
9	4	0.0103	12	0.0023	16	0.0035
12	5	0.0136	7	0.0031	12	0.0046
15	4	0.0163	10	0.0042	14	0.0059
18	6	0.0208	8	0.0051	14	0.0074

Fig 1. Kaplan–Meier cumulative survival curve for infants exposed and not exposed to HIV.

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In this study, an approximately fourfold greater child mortality rate was observed among infants exposed than among those not exposed to HIV. These findings are consistent with the available literature showing that infants exposed to HIV have higher mortality rates than those not exposed to HIV do, ranging from 4.0–13.6% [8,27,28]. This could be due to the infant feeding options available, such as exclusive breastfeeding or no breastfeeding, which poses different dilemmas. For example, longer breastfeeding may increase the vertical transmission of HIV and thus HIV-associated mortality, whereas shorter or no breastfeeding may expose the uninfected child to common illnesses such as pneumonia that lead to mortality [29,30]. Notably, there was no significant difference in mortality rates between exclusively breastfed infants and those receiving mixed or replacement feeding in the first 6 months, although studies have documented greater mortality rates among infants exposed than those not exposed to HIV with similar feeding patterns [8,31,32]. Other studies have shown that even after the introduction of prevention of vertical transmission of HIV policies and programs, infants exposed are at increased risk of severe bacterial infections, impaired cognitive function and death compared with those not exposed

Table 3. Crude and adjusted times and hazard ratios for child mortality.

	Crude Time Ratio [95%CI]	Adj. Time Ratio [95%CI]	Crude Weibull HR [95%CI]	Adj.Weibull HR [95%CI]
Cohort				
HIV Unexposed	**1**		**1**	
HIV Exposed	**0.4 [0.2–0.5]**	**0.3 [0.2–0.4]**	**4.1 [2.6–6.6]**	**5.6 [3.4–9.2]**
Mother's Age				
25 + years	1		1	
15-24 years	0.9 [0.7–1.3]]	**0.7 [0.5–0.9]**	1.1 [0.7–1.7]	**1.8 [1.1–2.9]**
Infant Sex				
Male	1		1	
Female	0.9 [0.7–1.3]	0.9 [0.7–1.2]	1.1 [0.7–1.7]	1.2 [0.7–1.8]
Family Social Economic Status				
High (4th or 5th quintile)	1		1	
Low (1st or 2nd quintile)	0.8 [0.5–1.2]	0.7 [0.4–1.0]	1.4 [0.8–2.4]	1.7 [1.0–3.0]
Middle (3rd quintile)	0.8 [0.5–1.3]	0.7 [0.4–1.1]	1.4 [0.7–2.5]	1.6 [0.8–3.0]
Mother's Marital Status				
Living with a partner	1		1	
Living without a partner	**0.6 [0.4–0.9]**	**0.7 [0.5–0.9]**	**2.0 [1.2–3.4]**	**1.8 [1.1–2.9]**
Mother's Education				
Above Primary level	1		1	
None/Primary	1.0 [0.7–1.4]		1.0 [0.6–1.6]	
Malaria in Pregnancy				
No	1		1	
Yes	1.0 [0.7–1.5]		0.9 [0.6–1.6]	
Birth attendee				
Skilled	1		1	
Traditional birth attendants (TBA)/Other	0.7 [0.4–1.1]		1.9 [1.1–3.4]	
Mode of transport to health facility				
Motorized	1		1	
Walking	0.8 [0.6–1.2]	0.8 [0.5–1.1]	1.3 [0.7–2.2]	1.5 [0.9–2.3]
Breastfeeding pattern				
Exclusive 1st 6 months	1		1	
Mixed/Replacement	1.0 [0.7–1.8]	1.0 [0.6–1.7]	1.0 [0.4–2.0]	1.0 [0.5–1.9]
Attended 4 or more ANC visits				
No	1		1	
Yes	1.1 [0.7–1.8]		1.1 [0.4–3.0]	
ART Status (HIV infected only)				
Preconception	1		1	
During pregnancy	0.7 [0.4–1.3]		1.6 [0.7–3.5]	
Post delivery	0.6 [0.2–1.7]		1.7 [0.5–5.7]	

(Continued)

Table 3. (Continued)

	Crude Time Ratio [95%CI]	Adj. Time Ratio [95%CI]	Crude Weibull HR [95%CI]	Adj.Weibull HR [95%CI]
Mother baseline Viral load non suppression(only Exposed)				
No	1		1	
Yes	0.8 [0.3–2.0]		1.4 [0.4–3.6]	
Place of Delivery				
Public Facility	1		1	
Private Facility	0.9 [0.6–1.3]	0.8 [0.5–1.1]	1.2 [0.7–2.1]	1.4 [0.8–2.5]
Home	**0.6 [0.4–0.9]**	**0.8 [0.4–0.8]**	**1.9 [1.1–3.5]**	**2.3 [1.3–4.0]**

The effective sample size was 11,514 and the bolded figures represent the significant variables.

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to HIV. While the causes of these poor outcomes are multifactorial, studies suggest that this could be attributed to the impaired innate and adaptive immune responses observed in infants exposed to HIV, secondary to ART exposure and maternal HIV infection [33,34].

A mother's age of less than 25 years was a significant risk factor for child mortality, which is consistent with several studies that have shown associations between young maternal age and poor child survival [20,35–39]. This is especially relevant for Uganda, with a teenage pregnancy rate of 25% and a high percentage of women under the age of 25 [40]. Young maternal age is associated with child mortality risk factors such as low birth weights, preterm deliveries, limited exposure to reproductive health and low maternal health-seeking behaviors, especially postnatal care [40–43]. Low birth weight is a known risk factor for infant mortality and influences the health outcomes of newborns [44,45]. In this analysis, the absence of infant birthweight data precluded its inclusion in the analytical models. With the estimated unmet need for family planning at 30.4% among women aged 15--19 years in Uganda, strategies such as additional socioeconomic and educational support and meeting the family planning needs of young mothers may further reduce child mortality rates [35,40,46–48].

In this analysis, both mothers living without a partner and those delivering an infant at home significantly increased the risk of child mortality. Nabongo et al., in their cohort study of children in rural Uganda, reported that the child's birthplace, which was not a health facility, was associated with child mortality [20]. These factors could be markers of a lower socioeconomic status of the household [49]. Studies have revealed that low economic status is associated with infant mortality because it affects access to healthcare, nutrition, and social services [11,50,51]. The quality of health care received by the infant and mother is often determined by the place of delivery, with infants delivered at home not receiving the full package of postnatal care. Sarmistha provides new evidence that institutional delivery can significantly lower child mortality risk because it ensures effective and timely access to modern diagnostics and medical treatments to save lives [52]. While public health and treatment programs are in place to address the availability of healthcare services, interventions that enhance the economic well-being of the lower socioeconomic group might also have positive downstream impacts on child mortality. There were at least five limitations in this study. First, the total number of infant deaths identified was small, limiting the ability to perform regression analyses. Second, MIPs were recruited from child immunization clinics, creating selection bias in the sample. While immunization rates in Uganda are high, MIPs not engaging in early childhood care or engaging outside the enrollment age would not have been screened for participation in the study. The selection approach likely excluded children who were not immunized and were at high risk of mortality from vaccine-preventable diseases [53]. Therefore, the study population might have represented a

healthier subset of the broader community, which potentially underestimated the true burden of mortality in the general population. Third, the study was not able to actively follow-up MIPs that were transferred to areas outside of the 152 study sites. As a result, transient MIPs may have been lost to follow-up. Fourth, selection bias could also have been introduced because of the study eligibility criteria, which excluded MIP due to severe illness of either the infant or the mother, mothers who were unable to give informed consent and those who refused the infant's HIV antibody test at baseline. Finally, there were significant missing data for some of the critical variables, such as birth weight, due to a lack of source documents.

Mortality among infants exposed to HIV was significantly greater than that among those not exposed to HIV. Several factors, including HIV exposure, younger maternal age, the absence of a male partner, and home delivery of the child, increase the risk of mortality. Efforts to reduce child mortality could consider screening for these factors to be able to provide interventions during pregnancy and through the postpartum period for mothers whose children are at increased risk. Future studies are needed to explore how these factors drive mortality in this age group.

Supporting information

S1 Dataset. Mortality dataset used in analysis.
(XLS)

S2 Data. Dictionary. Varible descriptions within the mortality dataset.
(DOCX)

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References

1. UNICEF. Levels & Trends in Child Mortality: Report 2022, Estimates developed by the United Nations Inter-agency Group for Child Mortality Estimation. New York: United Nations Children's Fund; 2023.
2. UN. Sustainable Development Goals New York: United Nations. 2015. Available from: https://www.un.org/sustainabledevelopment/health/.
3. Perin J, Mulick A, Yeung D, Villavicencio F, Lopez G, Strong KL, et al. Global, regional, and national causes of under-5 mortality in 2000-19: an updated systematic analysis with implications for the sustainable development goals. Lancet Child Adolesc Health. 2022;6(2):106–15. https://doi.org/10.1016/S2352-4642(21)00311-4 PMID: 34800370
4. Chikhungu LC, Newell M-L, Rollins N. Under-five mortality according to maternal survival: a systematic review and meta-analysis. Bull World Health Organ. 2017;95(4):281–7. https://doi.org/10.2471/BLT.15.157149 PMID: 28479623
5. Adetokunboh OO, Uthman OA, Wiysonge CS. Morbidity benefit conferred by childhood immunisation in relation to maternal HIV status: a meta-analysis of demographic and health surveys. Hum Vaccin Immunother. 2018;14(10):2414–26. https://doi.org/10.1080/21645515.2018.1515453 PMID: 30183488
6. Arikawa S, Rollins N, Jourdain G, Humphrey J, Kounis A, Hoffman I. Contribution of maternal antiretroviral therapy and breastfeeding to 24-month survival in human immunodeficiency virus-exposed uninfected children: an individual pooled analysis of African and Asian studies. PLOS ONE. 2018;13(5):e0197060. https://doi.org/10.1371/journal.pone.0197060
7. Mosley WH, Chen LC. An analytical framework for the study of child survival in developing countries. Popul Dev Rev. 1984;10:25. https://doi.org/10.2307/2807954
8. Marinda E, Humphrey JH, Iliff PJ, Mutasa K, Nathoo KJ, Piwoz EG, et al. Child mortality according to maternal and infant HIV status in Zimbabwe. Pediatr Infect Dis J. 2007;26(6):519–26. https://doi.org/10.1097/01.inf.0000264527.69954.4c PMID: 17529870
9. Evans C, Chasekwa B, Ntozini R, Majo F, Mutasa K, Tavengwa N. Mortality, human immunodeficiency virus (HIV) transmission, and growth in children exposed to HIV in rural Zimbabwe. Clin Infect Dis. 2021;72(4):586–94.
10. Ndirangu J, Newell M-L, Thorne C, Bland R. Treating HIV-infected mothers reduces under 5 years of age mortality rates to levels seen in children of HIV-uninfected mothers in rural South Africa. Antivir Ther. 2012;17(1):81–90. https://doi.org/10.3851/IMP1991 PMID: 22267472
11. Schell CO, Reilly M, Rosling H, Peterson S, Ekström AM. Socioeconomic determinants of infant mortality: a worldwide study of 152 low-, middle-, and high-income countries. Scand J Public Health. 2007;35(3):288–97. https://doi.org/10.1080/14034940600979171 PMID: 17530551
12. MOH. Addendum to the National Antiretroviral Treatment Guidelines: Ministry of Health. 2013. Available from: http://preventcrypto.org/wp-content/uploads/2012/07/Uganda-National-ART-Guidelines_2014.pdf
13. UNAIDS. HIV Estimates. 2021. Available from: https://data.unicef.org/topic/hivaids/emtct/
14. WHO. Consolidated guidelines on the use of antiretroviral drugs for treating and preventing HIV infection WHO. 2013. Available from: http://apps.who.int/iris/bitstream/10665/85321/1/9789241505727_eng.pdf
15. WHO. Global guidance on criteria and processes for validation: elimination of mother-tochild transmission of HIV, syphilis and hepatitis B virus. Geneva: WHO. 2021 [cited 2025 Mar 18]. Available from: https://www.who.int/publications/i/item/9789240039360
16. Baryamutuma R, Kansiime E, Nuwagaba CK, Nabitaka L, Muhumuza S, Akello E, et al. An early assessment of Uganda's roll-out of Option B+: service capacity and infant outcomes. East Afr J Appl Health Monitor Eval. 2017;2017(1):16–21. PMID: 30264036
17. Dirlikov E, Kamoga J, Talisuna SA, Namusobya J, Kasozi DE, Akao J, et al. Scale-up of HIV antiretroviral therapy and estimation of averted infections and HIV-related deaths - Uganda, 2004-2022. Morb Mortal Wkly Rep. 2023;72(4):90–4. https://doi.org/10.15585/mmwr.mm7204a2 PMID: 36701255
18. Health Mo. Uganda Population Based HIV Impact Assessment 2020-2021, Final Report Kampala: Ministry of Health; 2020 April. 2024.
19. Bennett DA. How can I deal with missing data in my study? Aust N Z J Public Health. 2001;25(5):464–9. https://doi.org/10.1111/j.1467-842x.2001.tb00294.x PMID: 11688629
20. Nabongo P, Verver S, Nangobi E, Mutunzi R, Wajja A, Mayanja-Kizza H, et al. Two year mortality and associated factors in a cohort of children from rural Uganda. BMC Public Health. 2014;14:314. https://doi.org/10.1186/1471-2458-14-314 PMID: 24708689
21. Uganda Bureau of Statistics - UBOS, ICF International. Uganda Demographic and Health Survey 2011. Kampala, Uganda: UBOS and ICF International; 2012.
22. Ministry of Health/Uganda, ICF International. Uganda AIDS Indicator Survey (UAIS) 2011. Calverton, Maryland, USA: Ministry of Health/Uganda and ICF International; 2012.
23. Simmons RA, Anthopolos R, O'Meara WP. Effect of health systems context on infant and child mortality in sub-Saharan Africa from 1995 to 2015, a longitudinal cohort analysis. Sci Rep. 2021;11(1):16263. https://doi.org/10.1038/s41598-021-95886-8 PMID: 34381150
24. Homsy J, Dorsey G, Arinaitwe E, Wanzira H, Kakuru A, Bigira V, et al. Protective efficacy of prolonged co-trimoxazole prophylaxis in HIV-exposed children up to age 4 years for the prevention of malaria in Uganda: a randomised controlled open-label trial. Lancet Glob Health. 2014;2(12):e727-36. https://doi.org/10.1016/S2214-109X(14)70329-8 PMID: 25433628
25. Chintu C, Bhat GJ, Walker AS, Mulenga V, Sinyinza F, Lishimpi K, et al. Co-trimoxazole as prophylaxis against opportunistic infections in HIV-infected Zambian children (CHAP): a double-blind randomised placebo-controlled trial. Lancet. 2004;364(9448):1865–71. https://doi.org/10.1016/S0140-6736(04)17442-4 PMID: 15555666

26. Nakiyingi JS, Bracher M, Whitworth JA, Ruberantwari A, Busingye J, Mbulaiteye SM, et al. Child survival in relation to mother's HIV infection and survival: evidence from a Ugandan cohort study. AIDS. 2003;17(12):1827–34. https://doi.org/10.1097/00002030-200308150-00012 PMID: 12891069
27. Sewankambo N, Gray R, Ahmad S, Serwadda D, Wabwire-Mangen F, Nalugoda F. Mortality associated with HIV infection in rural Rakai district, Uganda. AIDS. 2000;14(15).
28. Thorne C, Idele P, Chamla D, Romano S, Luo C, Newell M-L. Morbidity and mortality in HIV-exposed uninfected children. Future Virol. 2015;10(9):1077–100. https://doi.org/10.2217/fvl.15.70
29. Kuhn L, Sinkala M, Semrau K, Kankasa C, Kasonde P, Mwiya M, et al. Elevations in mortality associated with weaning persist into the second year of life among uninfected children born to HIV-infected mothers. Clin Infect Dis. 2010;50(3):437–44. https://doi.org/10.1086/649886 PMID: 20047479
30. Thior I, Lockman S, Smeaton LM, Shapiro RL, Wester C, Heymann SJ, et al. Breastfeeding plus infant zidovudine prophylaxis for 6 months vs formula feeding plus infant zidovudine for 1 month to reduce mother-to-child HIV transmission in Botswana: a randomized trial: the Mashi Study. JAMA. 2006;296(7):794–805. https://doi.org/10.1001/jama.296.7.794 PMID: 16905785
31. Brahmbhatt H, Kigozi G, Wabwire-Mangen F, Serwadda D, Lutalo T, Nalugoda F, et al. Mortality in HIV-infected and uninfected children of HIV-infected and uninfected mothers in rural Uganda. J Acquir Immune Defic Syndr. 2006;41(4):504–8. https://doi.org/10.1097/01.qai.0000188122.15493.0a PMID: 16652060
32. Shapiro RL, Lockman S, Kim S, Smeaton L, Rahkola JT, Thior I, et al. Infant morbidity, mortality, and breast milk immunologic profiles among breast-feeding HIV-infected and HIV-uninfected women in Botswana. J Infect Dis. 2007;196(4):562–9. https://doi.org/10.1086/519847 PMID: 17624842
33. du Toit LDV, Prinsloo A, Steel HC, Feucht U, Louw R, Rossouw TM. Immune and metabolic alterations in children with perinatal HIV exposure. Viruses. 2023;15(2):279. https://doi.org/10.3390/v15020279 PMID: 36851493
34. Afran L, Jambo KC, Nedi W, Miles DJC, Kiran A, Banda DH, et al. Defective monocyte enzymatic function and an inhibitory immune phenotype in human immunodeficiency virus-exposed uninfected African Infants in the era of antiretroviral therapy. J Infect Dis. 2022;226(7):1243–55. https://doi.org/10.1093/infdis/jiac133 PMID: 35403683
35. Selemani M, Mwanyangala MA, Mrema S, Shamte A, Kajungu D, Mkopi A, et al. The effect of mother's age and other related factors on neonatal survival associated with first and second birth in rural, Tanzania: evidence from Ifakara health and demographic surveillance system in rural Tanzania. BMC Pregnancy Childbirth. 2014;14:240. https://doi.org/10.1186/1471-2393-14-240 PMID: 25048353
36. Neal S, Channon AA, Chintsanya J. The impact of young maternal age at birth on neonatal mortality: evidence from 45 low and middle income countries. PLoS One. 2018;13(5):e0195731. https://doi.org/10.1371/journal.pone.0195731 PMID: 29791441
37. Chen X-K, Wen SW, Fleming N, Demissie K, Rhoads GG, Walker M. Teenage pregnancy and adverse birth outcomes: a large population based retrospective cohort study. Int J Epidemiol. 2007;36(2):368–73. https://doi.org/10.1093/ije/dyl284 PMID: 17213208
38. Finlay JE, Özaltin E, Canning D. The association of maternal age with infant mortality, child anthropometric failure, diarrhoea and anaemia for first births: evidence from 55 low- and middle-income countries. BMJ Open. 2011;1(2):e000226. https://doi.org/10.1136/bmjopen-2011-000226 PMID: 22021886
39. Finlay JE, Norton MK, Guevara IM. Adolescent fertility and child health: the interaction of maternal age, parity and birth intervals in determining child health outcomes. Int J Child Health Nutr. 2017;6(1):16–33. https://doi.org/10.6000/1929-4247.2017.06.01.2
40. ICF UBoSUa. Uganda Demographic and Health Survey 2016: Key Indicators Report. Kampala, Uganda: UBOS, and Rockville, Maryland, USA: UBOS and ICF; 2017.
41. Chemutai V, Musaba MW, Amongin D, Wandabwa JN. Prevalence and factors associated with teenage pregnancy among parturients in Mbale Regional Referral Hospital: a cross sectional study. Afr Health Sci. 2022;22(2):451–8. https://doi.org/10.4314/ahs.v22i2.52 PMID: 36407378
42. Noori N, Proctor JL, Efevbera Y, Oron AP. Effect of adolescent pregnancy on child mortality in 46 countries. BMJ Glob Health. 2022;7(5):e007681. https://doi.org/10.1136/bmjgh-2021-007681 PMID: 35504693
43. DeMarco N, Twynstra J, Ospina MB, Darrington M, Whippey C, Seabrook JA. Prevalence of low birth weight, premature birth, and stillbirth among pregnant adolescents in Canada: a systematic review and meta-analysis. J Pediatr Adolesc Gynecol. 2021;34(4):530–7. https://doi.org/10.1016/j.jpag.2021.03.003 PMID: 33727190
44. Friede A, Baldwin W, Rhodes PH, Buehler JW, Strauss LT, Smith JC, et al. Young maternal age and infant mortality: the role of low birth weight. Public Health Rep. 1987;102(2):192–9. PMID: 3104976
45. Vilanova CS, Hirakata VN, de Souza Buriol VC, Nunes M, Goldani MZ, da Silva CH. The relationship between the different low birth weight strata of newborns with infant mortality and the influence of the main health determinants in the extreme south of Brazil. Popul Health Metr. 2019;17(1):15. https://doi.org/10.1186/s12963-019-0195-7 PMID: 31775758
46. Ochen AM, Chi PC, Lawoko S. Predictors of teenage pregnancy among girls aged 13-19 years in Uganda: a community based case-control study. BMC Pregnancy Childbirth. 2019;19(1):211. https://doi.org/10.1186/s12884-019-2347-y PMID: 31234816
47. Sully E, Biddlecom A, Darroch J, Riley T, Ashford L, Lince-Deroche N. Adding it up: investing in sexual and reproductive health 2019. 2020.
48. Speizer IS, Calhoun LM. Her, his, and their fertility desires and contraceptive behaviours: a focus on young couples in six countries. Glob Public Health. 2022;17(7):1282–98. https://doi.org/10.1080/17441692.2021.1922732 PMID: 33939936

49. Sacre H, Haddad C, Hajj A, Zeenny RM, Akel M, Salameh P. Development and validation of the socioeconomic status composite scale (SES-C). BMC Public Health. 2023;23(1):1619. https://doi.org/10.1186/s12889-023-16531-9 PMID: 37620893

50. Mohamoud YA, Kirby RS, Ehrenthal DB. Poverty, urban-rural classification and term infant mortality: a population-based multilevel analysis. BMC Pregnancy Childbirth. 2019;19(1):40. https://doi.org/10.1186/s12884-019-2190-1 PMID: 30669972

51. Stockwell EG, Goza FW, Balistreri KS. Infant mortality and socioeconomic status: new bottle, same old wine. Popul Res Policy Rev. 2005;24(4):387–99. https://doi.org/10.1007/s11113-005-0088-2

52. Pal S. Impact of hospital delivery on child mortality: an analysis of adolescent mothers in Bangladesh. Soc Sci Med. 2015;143:194–203. https://doi.org/10.1016/j.socscimed.2015.08.003 PMID: 26363451

53. McGovern ME, Canning D. Vaccination and all-cause child mortality from 1985 to 2011: global evidence from the demographic and health surveys. Am J Epidemiol. 2015;182(9):791–8. https://doi.org/10.1093/aje/kwv125 PMID: 26453618