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Incidence of postnatal HIV transmission after an initial negative HEID PCR among HIV-exposed infants in Tanzania: a cohort study

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Abstract

Background

Postnatal HIV transmission through breastfeeding remains poorly characterized within Tanzania's Prevention of Mother-to-Child Transmission (PMTCT) programme. Early infant diagnosis (EID) identifies most infections within the first 8 weeks of life; however, inadequate post-diagnosis follow-up has left population-level postnatal incidence largely unmeasured.

Methods

We conducted a retrospective cohort analysis linking Tanzania's national HIV Early Infant Diagnosis (HEID) records with maternal viral load (VL) data obtained from centralized laboratory information systems between December 2018 and February 2026. HIV-exposed infants with a negative (HEID) polymerase chain reaction (PCR) result at or before 8 weeks of age were eligible for inclusion (N = 98,456). The analytic cohort comprised those who had at least one subsequent (HEID) PCR test (n = 1,583; 1.6%). Baseline characteristics were compared against non-retained infants (n = 96,873) using chi-squared tests. Postnatal incidence and cumulative risk were estimated using exact Poisson 95% confidence intervals and Kaplan–Meier analysis, with loss to follow-up modelled as a competing risk to generate a lower-bound sensitivity estimate.

Results

The analytic cohort differed significantly from non-retained infants ($p < 0.001$), showing lower maternal viral suppression (43.6% vs. 60.0% with target not detected) and a higher proportion of missing VL data. Overall, 79.8% of maternal VL evaluations occurred after 6 weeks postpartum. Twenty infections occurred over 894.8 person-years, yielding an incidence of 2.24 per 100 person-years (95% CI: 1.37–3.45). Incidence increased from 1.25 per 100 person-years (95% CI: 0.40–2.91) among mothers with undetectable VL to 7.15 per 100 person-years (95% CI: 0.87–25.85) among those with VL ≥ 1,000 copies/mL. Cumulative incidence at 40 weeks reached 2.03% (95% CI: 1.13–3.62%), with a competing-risk lower bound of 1.2%.

Conclusions

This study provides the first longitudinal estimate of postnatal HIV transmission derived from a Tanzanian HEID cohort. The high proportion of eligible infants lacking follow-up (HEID) PCR test likely reflects both unintegrated point-of-care testing data and true clinical attrition. Given the highly selected analytic subpopulation, selection bias may limit population-level inference. While biomedical interventions remain central to PMTCT, achieving and sustaining the elimination of vertical transmission

in Tanzania will require systemic monitoring enhancements—specifically, a unified, longitudinal mother–infant tracking system that integrates centralized and decentralized (point-of-care) HIV VL and HEID platforms with ePMTCT and CTC-2. Supported by optimized VL monitoring schedules and expanded testing coverage during pregnancy and breastfeeding, this system would close structural gaps in care retention and strengthen tracking of viral suppression and incident infections.

Background

Sub-Saharan Africa bears the overwhelming burden of mother-to-child HIV transmission (MTCT), accounting for approximately 86% of children living with HIV globally **(UNAIDS, 2024)**. Within this region, Tanzania remains a high-burden country, with an estimated 68,000 children aged 0–14 years living with HIV in 2023 **(UNAIDS, 2024)**. This high burden is driven by ongoing MTCT, which remained at 6.9% in 2025 **(Tanzania spectrum file, 2026)**, and the resulting large cohort of HIV-exposed infants requiring long-term follow-up. With an estimated 746,000–841,000 women of reproductive age living with HIV nationally, Tanzania has a substantial annual birth cohort requiring early infant diagnosis (EID) and ongoing PMTCT follow-up.

Substantial reductions in intrauterine and intrapartum transmission followed the scale-up of Option B+ antiretroviral therapy (ART) under the WHO 2016 PMTCT framework **(WHO, 2016)** and the subsequent universal Test and Treat strategy **(NASHCOP, 2024)**. However, despite these gains, postnatal HIV transmission through breastfeeding now accounts for an increasing proportion of residual paediatric infections, as its decline has been slower than that of peripartum transmission **(**Van de Perre et al., 2021; Landes et al., 2019). Evidence from Uganda, Tanzania, and Zambia suggests that breastfeeding-related transmission now contributes a growing share of residual MTCT in high-burden settings **(UNAIDS, 2024)**, underscoring persistent postnatal vulnerability. Key programmatic drivers include postpartum maternal HIV acquisition, untreated maternal HIV, suboptimal maternal ART adherence, and inadequate provision of or adherence to infant **prophylaxis (**Van de Perre et al., 2021; Lwilla et al., 2025). These drivers influence maternal plasma viral load, the strongest biological predictor of transmission risk, with measurable risk even at low-level viraemia (50–199 copies/mL) and a steep increase above 1,000 copies/mL (Dugdale et al., 2025). Even with high fidelity implementation, existing prevention strategies are considered insufficient to eliminate postnatal transmission without complementary biomedical interventions, including pre-exposure prophylaxis for breastfeeding women at risk of HIV acquisition, postnatal maternal care reinforcement, extended infant prophylaxis, and broadly neutralizing antibody immunoprophylaxis **(**Van de Perre et al., 2021).

National programme data show that the proportion of HIV-exposed infants testing positive at the first HIV Early Infant Diagnosis (HEID) PCR (approximately 2 months of age) declined from 1.7% in 2021 to 0.9% in 2024 **(Ministry of Health, Tanzania, 2025)**. However, this reduction largely reflects prevention of intrauterine and intrapartum transmission rather than elimination of postnatal risk. The reported decline in Tanzania's overall MTCT rate from 11.1% to 7.6% over the same period derives from UNAIDS Spectrum modelling rather than observed longitudinal data **(Ministry of Health, Tanzania, 2025)**. Tanzania's HEID

programme recommends a baseline DNA/PCR HIV test at birth, followed by the first PCR at ~ 6 weeks, with repeat testing at 9 months, 12 weeks after complete cessation of breastfeeding, and confirmatory testing at 18 months (**NASHCOP, 2024).** However, implementation gaps remain substantial, with low uptake of repeat PCR testing and fewer than half of HIV-exposed infants completing the final 18-month antibody test **(**Samson et al., 2018; Morris et al., 2023). A critical evidence gap remains in population-level estimates of postnatal HIV incidence following an initial negative HIV Early Infant Diagnosis (HEID) PCR in Tanzania. While national PMTCT programmes routinely report first PCR positivity, far less is known about HIV acquisition after an initial negative result.

While national PMTCT programs routinely report positivity at first infant PCR testing, far less is known about HIV acquisition occurring after an initial negative result. Consequently, most national estimates of residual MTCT rely on mathematical modelling rather than direct longitudinal observation. In Tanzania, no previous national analysis has quantified postnatal HIV acquisition among infants with documented negative early PCR results while simultaneously examining the influence of maternal viral load on transmission risk. This study analyzed data from Tanzania's national HIV Early Infant Diagnosis (HEID) centralized laboratory information systems (December 2018–February 2026) to estimate postnatal HIV incidence and its variation by maternal viral load. The analysis included HIV-exposed infants with a documented negative early PCR result and at least one follow-up PCR record.

Methods

Study design and data source

We conducted a retrospective cohort study using national HIV VL and HEID laboratory records from December 2018 to February 2026. Data were extracted from conventional centralized laboratory information systems, which capture VL and HEID records from centralized laboratories in Tanzania. At the time of this study, conventional centralized laboratories were not linked to point-of-care (POCT) platforms; therefore, POCT PCR HEID records were not captured.

Study population and cohort definition

Eligible infants had a negative (HEID) PCR at or before 8 weeks of age (N = 98,456). Of these, 1,583 (1.6%) had at least one subsequent HEID test (analytic cohort); 96,873 (98.4%) had no subsequent test (non-retained). Infants with a positive HEID PCR at or before 8 weeks were excluded (n = 856), as these represent intrauterine or intrapartum infections preceding the postnatal risk window. Cohort derivation is shown in Fig. 1. Follow-up time was defined as up to 40 weeks after the baseline negative HEID PCR at or before 8 weeks. Infants' records were linked to maternal records using unique maternal identifiers.

Maternal Viral Load Exposure

The primary exposure was maternal plasma HIV RNA, measured by PCR and categorized into five strata: TND (reference), detected < 50 copies/mL, 50–199, 200–999, and ≥ 1,000 copies/mL. The detected < 50 copies/mL category was separated from TND and broader suppressed categories because Tanzania's PMTCT programme defines virological suppression as < 50 copies/mL, allowing assessment of transmission risk at very low-level viraemia.

For each infant, we assigned the maternal VL measurement obtained closest to, but preceding, the infant's HIV test date. Eligible maternal records were restricted to timeframes falling within the respective pregnancy's antenatal, peripartum, or breastfeeding windows (up to 40 weeks postpartum) relative to the infant's date of birth. Because maternal VL was not measured continuously, this exposure represents a time-fixed proxy of maternal viraemia before infant outcome ascertainment rather than contemporaneous exposure at infection. This may introduce non-differential exposure misclassification, likely biasing effect estimates toward the null. We could not fully capture variation in VL during pregnancy and breastfeeding.

Cohort comparison analysis

To assess selection bias, we compared analytic versus non-retained groups on maternal VL category (TND, detected < 50, 50–199, 200–999, ≥ 1,000 copies/mL, or missing), maternal age group (≤ 19, 20–34, ≥ 35, or missing), and parity (1, 2, 3, ≥ 4) using Pearson chi-squared tests, treating missing as an explicit category. Because differential missingness in VL (37.3% in the analytic cohort vs. 13.2% in the non-retained group) may inflate the chi-squared statistic, the significant result for VL partly reflects differences in data completeness rather than covariate distributions alone. Therefore, we interpret VL results primarily descriptively.

Survival analysis and incidence estimation

The index date was the date of the baseline negative (HEID) PCR result. Follow-up time was recorded in weeks and converted to years for incidence rate estimation. Each infant contributed person-time from the index date until the earliest of: (i) a confirmed positive HIV result, (ii) the date of the last negative test in the HEID record, or (iii) the end of the study period (19 February 2026). The primary outcome was incident HIV infection, defined as a confirmed positive (HEID) PCR at any point after the baseline negative result. Twenty such events were identified. Incidence rates were estimated using Poisson methods (stptime, Stata 17; StataCorp LLC, College Station, TX) and expressed as events per 100 person-years with exact 95% confidence intervals. Cumulative incidence was estimated using the Kaplan-Meier failure function (sts list). We performed exploratory subgroup analyses by maternal VL category, maternal age group, and parity. Crude rate ratios were computed with TND as the reference category for VL comparisons. Multivariable Cox or Poisson regression models were not pursued due to limited event numbers, which would violate recommended events-per-parameter assumptions and produce unstable estimates. Accordingly, inference was restricted to unadjusted estimates and

descriptive stratification. The survival analysis assumed non-informative censoring, whereby loss to follow-up was assumed independent of the risk of postnatal HIV infection. This assumption may be violated if loss to follow-up is related to maternal engagement in care or unmeasured infant risk factors. Therefore, we performed a sensitivity analysis treating loss to follow-up (non-retention) as a competing event to determine the lower bound risk estimate.

Strengths and Limitations of the Analytic Cohort

Because only infants with at least one repeat HEID PCR test contributed outcome data, the analytic cohort represents a retained subpopulation rather than the entire national cohort of HIV-exposed infants. Consequently, incidence estimates should be interpreted with caution. We compared retained and non-retained infants specifically to assess the direction and magnitude of potential selection bias.

Ethical considerations

The study was approved by the Tanzania Ministry of Health as part of routine data review (reference number: MA/155/174/01/973). Ethical approval was waived due to the retrospective use of anonymized surveillance data collected during routine care. All analyses were conducted on de-identified datasets with no access to personal identifiers. Authorization for publication was obtained from the Ministry of Health (reference number: HA.173/218/01/61). The study complied with national data protection regulations governing secondary use of health surveillance data.

Results

Maternal and infant characteristics

Of 99,312 infants tested for HIV by 8 weeks of age, 856 (0.86%) tested positive and were excluded. The eligible source population comprised 98,456 HIV-negative infants. Median maternal age was 30 years (IQR 25–35), with 56.8% of mothers aged 20–34 years and 37.7% having parity ≥ 4. Infant sex was balanced (51.5% female). Most mothers had undetectable viral load (TND, 59.8%), while 4.0% had VL ≥ 1,000 copies/mL **(**Table 1**).** Regarding timing of the last VL test relative to delivery, 18.2% were performed before conception, 19.0% during pregnancy, and 58.4% later than 6 weeks postpartum.

From the eligible source population, 1,583 mother–infant pairs (1.6%) had at least one subsequent HEID follow-up test and were included in the primary analysis. Among these mothers, median age was 30 years (IQR 25–35), with 697 (44.0%) aged 20–34 years and 474 (29.9%) having parity ≥ 4. Most mothers had undetectable VL (TND, n = 690, 43.6%). Regarding timing of the last maternal VL test relative to delivery: 41 (2.6%) were performed before conception, 204 (12.9%) during pregnancy, 22 (1.4%) at delivery (0–7 days postpartum), 53 (3.3%) in the early postpartum period (≤ 6 weeks), and 1,263 (79.8%) later than 6 weeks postpartum.

Flowchart depicting the selection and longitudinal follow-up of HIV-exposed infants. From 98,456 eligible infants with a negative baseline (HEID) PCR at (≤ 8 weeks), 1.6% (n = 1,583) had subsequent testing and formed the analytic cohort. Within this cohort, 20 incident HIV infections were identified during follow-up

Table 1
Baseline characteristics of the eligible source population (infants HIV-negative by 8 weeks of age)

Characteristic	N = 98,456 (%)
Maternal age (years)	
≤19	3,081 (3.13)
20–34	55,923 (56.80)
≥35	27,894 (28.33)
Missing	11,558 (11.74)
Parity	
1	18,771 (19.07)
2	21,269 (21.60)
3	21,285 (21.62)
≥4	37,131 (37.71)
Infant sex	
Female	50,725 (51.52)
Male	47,731 (48.48)
Maternal viral load (copies/mL)	
TND (target not detected)	58,836 (59.76)
<50	15,916 (16.17)
50–199	4,532 (4.60)
200–999	1,792 (1.82)
≥1,000	3,973 (4.04)
Missing VL (documented missing)	2,360 (2.40)
No VL record (no date/result)	11,047 (11.22)
Timing of last VL test relative to delivery	
Before conception	17,921 (18.20)
During pregnancy	18,685 (18.98)
At delivery (0–7 days)	832 (0.85)
Early postpartum (≤ 6 weeks)	3,523 (3.58)

Characteristic	N = 98,456 (%)
Maternal age (years)	
Later postpartum (> 6 weeks)	57,495 (58.40)

Notes:

Percentages are column percentages of the total eligible source population (N = 98,456).

"Missing VL" indicates a documented maternal viral load result that was missing (category 5 in the original data).

"No VL record" indicates infants whose mother had no documented viral load test date or result.

Timing of the last VL test is based on the available VL test date; infants with no VL record are excluded from timing rows.

VL, viral load; TND, target not detected.

Comparison of the analytic cohort with non-retained eligible infants

The analytic cohort was not representative of the eligible source population. Compared with non-retained infants, retained infants were less likely to have mothers with fully suppressed VL and substantially more likely to have missing VL information. These differences indicate selection mechanisms that may influence observed incidence estimates and limit generalizability. The source population had higher proportions of mothers aged 20–34 (57.0% vs. 44.0%) and ≥ 35 (28.5% vs. 16.1%), while missing maternal age was more common in the analytic cohort (35.5% vs. 11.3%). A higher proportion of mothers in the source population had undetectable VL (60.0% vs. 43.6%), whereas missing VL was more common in the analytic cohort (37.3% vs. 13.2%). Mothers in the source population also had higher grand multiparity (≥ 4: 37.8% vs. 29.9%) **(**Table 2; Fig. 1**).**

Table 2
Comparison of the analytic cohort and non-retained eligible infants by baseline characteristics, national HEID Data repository, Tanzania 2018–2026

Characteristic	Analytic cohort (n = 1,583)	Non retained eligible infants (n = 96,873) (%)	p†
Maternal viral load category			
TND	690 (43.6%)	58,159 (60.0)	< 0.001
<40 copies/mL	177 (11.2%)	15,701 (16.2)	
50–199 copies/mL	51 (3.2%)	4,499 (4.6)	
200–999 copies/mL	24 (1.5%)	1,751 (1.8)	
≥1,000 copies/mL	51 (3.2%)	3,938 (4.1)	
Missing VL‡	590 (37.3%)	12,825 (13.2)	
Maternal age group (years)			
≤19	70 (4.4%)	3,008 (3.1)	< 0.001
20–34	697 (44.0%)	55,242 (57.0)	
≥35	254 (16.0%)	27,642 (28.5)	
Missing	562 (35.5%)	10,981 (11.3)	
Parity			
1	397 (25.1%)	18,374 (19.0)	< 0.001
2	393 (24.8%)	20,876 (21.5)	
3	319 (20.2%)	20,966 (21.6)	
≥4	474 (29.9%)	36,657 (37.8)	

†Pearson chi-squared test, including missing as a category. ‡Missing VL combines labelled ‘Missing VL’ records and system-missing entries. Percentages are column percentages within each group. TND = target not detected.

Overall postnatal HIV incidence

The Kaplan–Meier cumulative incidence of postnatal HIV infection by 40 weeks of follow-up, following an early negative HEID PCR test (within the first 8 weeks of life), was 2.03% (95% CI: 1.13–3.62%). Twenty infections occurred over 894.8 person-years; the incidence rate was 2.24 per 100 person-years

(95% CI: 1.37–3.45) with a median follow-up time of 34.6 weeks (IQR: 33.0–36.6). In a sensitivity analysis treating loss to follow-up as a competing event, the cumulative incidence was 1.2%, representing the lower bound of the risk estimate.

Table 3
Kaplan–Meier cumulative incidence of postnatal HIV infection, analytic cohort, Tanzania 2018–2026

Time (weeks)	At risk (n)	New failures (n)	Cumulative incidence % (95% CI)
4	1522	2	0.13% (0.03–0.52%)
8	1413	1	0.20% (0.06–0.61%)
12	1263	1	0.27% (0.10–0.73%)
16	1214	3	0.52% (0.25–1.08%)
20	1197	2	0.68% (0.35–1.31%)
24	1184	2	0.85% (0.47–1.53%)
36	447	6	1.58% (0.96–2.59%)
40	178	1	2.03% (1.13–3.62%)

Kaplan–Meier failure function calculated over the full dataset and evaluated at indicated time points. The marked decline in infants at risk between week 24 (n = 1,184) and week 36 (n = 447) reflects censoring as follow-up records ended.

Incidence by maternal viral load

Incidence rose with increasing viraemia: low-level viraemia (50–199 copies/mL): 3.77/100 PY (crude RR 3.03 vs. TND); unsuppressed (≥ 1,000 copies/mL): 7.15/100 PY (crude RR 5.74 vs. TND). No events occurred in the 200–999 stratum (11.9 person-years). These VL subgroup estimates are based on very small numbers (1–2 events each) and are exploratory and hypothesis-generating **(**Tables 4 and 5**)**.

Table 4
Postnatal HIV incidence rates by subgroup, analytic cohort, Tanzania 2018–2026 (n = 1,583; 20 events; 894.8 person-years)

Characteristic	n	Person-years	IR* /100 PY	95% CI
Overall cohort	20	894.8	2.24	1.37–3.45
Maternal viral load category				
TND (reference)	5	401.1	1.25	0.40–2.91
<40 copies/mL	1	99.2	1.01	0.03–5.62
50–199 copies/mL (LLV)	1	26.5	3.77	0.10–21.03
200–999 copies/mL	0	11.9	0.00	—
≥1,000 copies/mL (unsuppressed)	2	28.0	7.15	0.87–25.85
Maternal age group (years)				
≤19	0	46.3	0.00	0.00–7.96
20–34	6	388.0	1.55	0.57–3.37
≥35	3	144.0	2.08	0.43–6.09
Parity				
1 (primiparous)	4	222.6	1.80	0.49–4.60
2	7	223.4	3.13	1.26–6.46
3	3	179.3	1.67	0.35–4.89
≥4 (grand multiparous)	6	269.5	2.23	0.82–4.85

*IR = incidence rate per 100 person-years; exact Poisson 95% confidence intervals. Given the small number of events, subgroup-specific estimates should be interpreted descriptively. VL subgroup totals include 993 infants with available VL data (9 events; 566.7 person-years). Age subgroup totals include 1,021 infants with available maternal age data (9 events; 578.3 person-years); the remaining 11 events occurred among the 562 infants (35.5%) with missing maternal age. Parity data complete. PY = person-years; LLV = low-level viraemia.

Table 5
Crude rate ratios for postnatal HIV transmission by maternal viral load category, analytic cohort, Tanzania 2018–2026

Maternal VL Category	N	Person-years	IR*	Rate Ratio (vs TND)	% of VL-documented infants
TND (reference)	5	401.1	1.25 (0.40–2.91)	1.00 (ref.)	43.6%
< 40 copies/mL	1	99.2	1.01 (0.03–5.62)	0.81 (0.02–7.23)	11.2%
50–199 copies/mL (LLV)	1	26.5	3.77 (0.10–21.03)	3.03(0.06–27.05)	3.2%
200–999 copies/mL	0	11.9	0.00	—	1.5%
≥ 1,000 copies/mL (unsuppressed)	2	28.0	7.15 (0.87–25.85)	5.74(0.55–35.00)	3.2%

*IR = incidence rate per 100 person-years. Rate ratios are unadjusted with TND as the reference category. Rate ratio for 200–999 copies/mL not presented due to zero events. The final column shows the percentage distribution within the 993 infants with available VL data. LLV = low-level viraemia; TND = target not detected.

Incidence by maternal age and parity

Nine of 20 total events occurred among infants with available maternal age data; incidence was 1.55/100 PY (20–34 years) and 2.08/100 PY (≥ 35 years). No infections occurred among adolescent mothers (≤ 19 years; 46.3 PY). Parity 2 showed the highest incidence (3.13/100 PY; 7 events), but all parity estimates have wide confidence intervals (Table 4).

Discussion

This study yields three principal findings regarding postnatal HIV transmission among HIV-exposed infants in Tanzania. First, using national HEID data from centralized laboratory records, we estimated a postnatal HIV cumulative incidence of 2.03% (95% CI: 1.13–3.62%) by 40 weeks of age among infants with an initial negative (HEID) PCR within the first 8 weeks of life. Second, we demonstrated a clear, biologically plausible dose–response relationship between maternal viraemia and postnatal transmission risk, with infections concentrated during the extended breastfeeding period (24–40 weeks). Third, we identified a critical gap in longitudinal surveillance within conventional centralized laboratory records: only 1.6% of infants with a negative HEID PCR within the first 8 weeks had a follow-up HEID PCR test. While the lack of POCT integration into centralized systems may artificially depress these figures due to the increasing shift toward decentralized diagnostics, historically high attrition rates for the final antibody test in Tanzania suggest that a substantial proportion of these infants were likely lost to follow-up rather than simply tested via unrecorded POCT. This observation is consistent with prior

evidence from sub-Saharan Africa showing persistent gaps in postnatal HIV surveillance despite ART scale-up (Carlucci et al., 2018; Ndarukwa et al., 2025).

According to programmatic data from the national Tanzania PMTCT report, the reported retesting rate among HIV-exposed infants was 52.1% at 9 months, while the reported 18-month retesting rate rose from 47.7% in 2023 to 54.4% in 2024. Furthermore, the report indicates that the national retesting rate at 3 months post-breastfeeding cessation stood at 31.4% in 2024. During this period, 66.4% of diagnostic samples were reportedly processed via conventional, centralized laboratory platforms, while 33.6% were handled using POCT networks as part of decentralization efforts. Because the conventional centralized laboratory records miss unintegrated POCT data, the stark discrepancy between these reported national programmatic indicators (52%) and our observed repository follow-up rate (1.6%) may be partially driven by this diagnostic platform divergence, alongside unmeasured clinical attrition.

This study achieved its primary objective by providing a critical longitudinal characterization of postnatal HIV transmission in Tanzania, demonstrating a clear biological link between maternal viraemia and infant infection risk. However, the stark operational divergence between follow-up rate of conventional centralized laboratories information systems records and official programmatic indicator (~ 52%) underscores the need for integrating HEID PCR POCT platforms with conventional centralized laboratories information systems to strengthen integrated surveillance tools.

Postnatal HIV transmission in the retained analytical cohort

The cumulative incidence of 2.03% at 40 weeks should be interpreted alongside the competing-risk estimate of 1.2%, which accounts for loss to follow-up in the retained analytical cohort as a competing event and provides a conservative lower-bound risk under the assumption of non-informative censoring. Among the retained cohort, the overall incidence was 2.24 per 100 person-years (95% CI: 1.37–3.45); notably, this rate increased from 1.25 per 100 person-years (95% CI: 0.40–2.91) among infants born to mothers with an undetectable viral load to 7.15 per 100 person-years (95% CI: 0.87–25.85) for those whose mothers had VL ≥ 1,000 copies/mL. Although stratum-specific estimates are imprecise, the monotonic gradient is biologically coherent and consistent with established evidence that maternal plasma HIV VL is the dominant determinant of postnatal transmission risk (Van de Perre et al., 2021; Dugdale et al., 2025). Incident infections accumulated mainly between 24 and 40 weeks, during which cumulative incidence more than doubled (0.85% to 2.03%), consistent with sustained breastfeeding exposure.

Crucially, our data also highlight a temporal mismatch in risk monitoring: nearly 80% (79.8%) of maternal VL evaluations were conducted later than 6 weeks postpartum. This delay indicates that routine maternal monitoring frequently misses the critical peripartum and early breastfeeding windows, limiting the health system's ability to identify and address viraemia during periods of highest postnatal vulnerability.

These findings underscore three intersecting programmatic gaps: (1) suboptimal post-6-week follow-up, with limited subsequent infant testing despite national guideline recommendations **(NASHCOP, 2024);** (2) inopportune maternal monitoring windows, with VL testing skewed toward late postpartum periods rather than peri-delivery windows; and (3) persistent residual risk during breastfeeding despite widespread ART scale-up under Option B + and Test-and-Treat policies **(WHO, 2016; NASHCOP, 2024).**

Regional and mechanistic context

Our estimates are broadly consistent with regional and modelling-based evidence. Dugdale et al. (2025) reported monthly postnatal transmission risks of ~ 0.1% with viral suppression and up to 0.5% with detectable viraemia. While direct comparison is limited by differing designs, our findings align directionally given the cohort's viraemia distribution. Furthermore, regional studies and WHO analyses have consistently shown that breastfeeding-associated transmission now constitutes an increasing proportion of residual MTCT in settings where peripartum transmission has declined substantially following ART implementation **(**Ka'e et al., 2023; **WHO, 2023)**.

The observed dose–response pattern is consistent with pooled evidence identifying maternal viraemia as the primary driver of postnatal transmission **(**Van de Perre et al., 2021; Dugdale et al., 2025). Crude rate ratios were lower than pooled estimates (3.03 vs. 6.3 for low-level viraemia; 5.74 vs. 22.5 for ≥ 1,000 copies/mL), likely reflecting sparse events, exposure misclassification, and narrower viraemia categories. Despite this, the monotonic increase across strata supports a biologically plausible gradient, including elevated risk at low-level viraemia (< 200 copies/mL), consistent with emerging evidence that transmission risk persists below conventional failure thresholds **(**Van de Perre et al., 2021; Ndarukwa et al., 2025). However, these findings do not support revision of treatment thresholds or evaluation of U = U in breastfeeding contexts.

Exploratory subgroup findings

Age and parity analyses were exploratory and underpowered. The higher incidence in parity two and absence of infections among adolescents are most plausibly explained by differential follow-up and limited person-time rather than biological effects. Given substantial missingness and imbalance **(**Table 2**)**, these findings are hypothesis-generating only and consistent with known surveillance biases in routine PMTCT datasets **(**Carlucci et al., 2018).

Limitations

This study has several limitations. First, only 1.6% of eligible infants had a subsequent (HEID) PCR test, restricting analysis to a small, non-random retained subgroup. Despite our comparative assessment, residual selection bias cannot be excluded, and incidence estimates may not generalize to the full HIV-exposed birth cohort. Second, conventional centralized laboratory records capture only centralized testing, so true retesting coverage is likely underestimated and could not be reliably distinguished from genuine loss to follow-up. Third, limited event numbers precluded multivariable adjustment; reported associations are unadjusted and may be confounded by unmeasured factors, and age and parity

subgroup findings are exploratory. Fourth, maternal VL was frequently measured late postpartum and was missing for many infants, limiting precision in exposure classification around the period of highest transmission risk. Fifth, survival estimates assumed non-informative censoring; because loss to follow-up may not meet this assumption, we conducted a competing-risk sensitivity analysis to bound the potential impact. Finally, as an analysis of routine programmatic data, findings reflect the completeness of the surveillance system data and may have limited generalizability beyond Tanzania's PMTCT and HEID infrastructure.

Programme implications

Three priorities emerge. First, integrating conventional centralized and decentralized (POCT) HIV VL and HEID diagnostic platforms information systems, ePMTCT, and CTC-2 into a unified, longitudinal mother-infant tracking system—complemented by optimized VL monitoring schedules and expanded coverage during pregnancy and breastfeeding—should be prioritized to enable continuous monitoring of the mother–infant pair throughout care. Second, follow-up strategies and biomedical interventions including novel biomedical interventions should prioritize infants exposed to any detectable maternal viraemia. More broadly, elimination of vertical HIV transmission cannot be achieved and verified without longitudinal follow-up. Strengthening surveillance systems is therefore essential for both accurate program evaluation and operational improvement.

Conclusion

Despite extensive missing laboratory follow-up—defined as eligible infants lacking subsequent HEID PCR records—this study demonstrates that postnatal HIV transmission remains measurable and increases substantially with maternal viraemia among infants who tested HIV-negative within the first 8 weeks of life. Equally important, this study identifies a profound lack of longitudinal follow-up within conventional centralized laboratory records as a major programmatic finding in its own right. This gap likely reflects both the absence of integrated POCT data and genuinely suboptimal programmatic retesting, consistent with historical evidence. Because the analytic cohort represents a highly selected subpopulation, selection bias may further limit direct population-level inference. Together, these limitations preclude definitive population-level estimates of postnatal HIV transmission using conventional centralized laboratories information systems records alone, but the available data nevertheless provide an important baseline characterization of the burden and distribution of postnatal transmission. Achieving and validating pediatric HIV elimination will depend not only on current and emerging PMTCT biomedical interventions, but equally on closing this surveillance gap through integrated mother–infant tracking across centralized and decentralized testing platforms, ePMTCT, and CTC-2.

Declarations

Competing interests

The authors declare no competing interests.

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Authors' contributions

RB, RN, RBU, and RYM conceptualized this study. RB conducted the analysis and wrote the first draft of the manuscript. The first draft underwent critical review by MIM, RN, PRT,MN,AK, and MM, who contributed substantial improvements. Further writing, critical review, and editorial revisions were carried out by RB, RN, RBU, AKH, PRT, RYM, AK, HM, EM, RM, EK, VS, AM, ASM, MM, and MIM. All authors approved the final manuscript.

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Availability of data and materials

The data supporting the findings of this study are held by the Tanzania Ministry of Health. Access to national HEID laboratory data is restricted under national data governance and data protection policies. Requests for access should be directed to the relevant ministry department in accordance with national data governance policies. De-identified aggregate data may be made available upon reasonable request, subject to ethical and regulatory approval.

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Figures

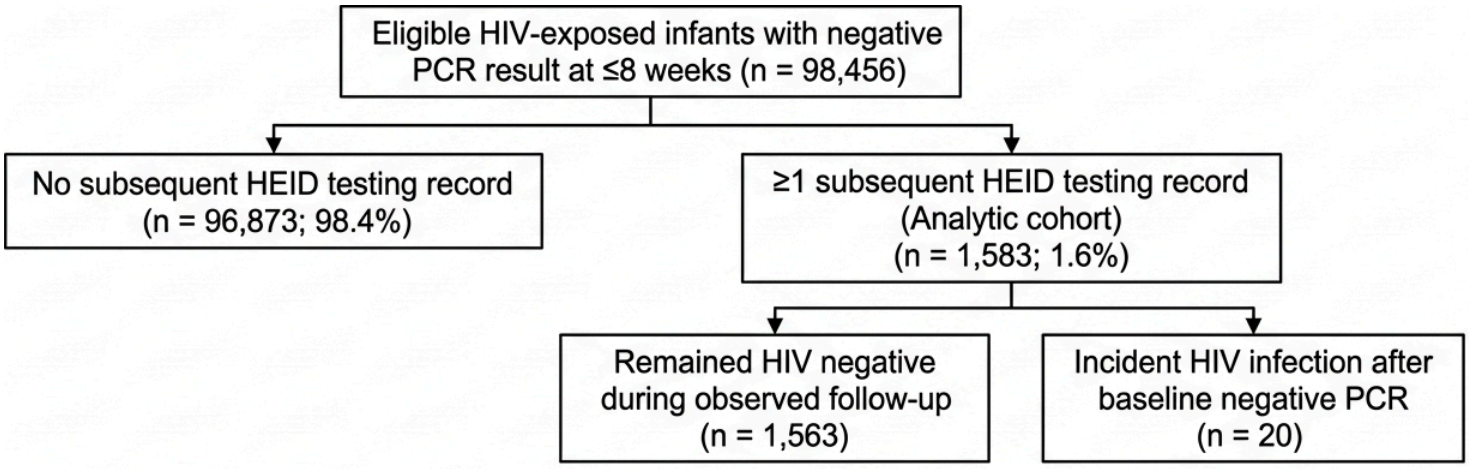


Figure 1

Cohort derivation and follow-up flow, national HEID Laboratory data repository, Tanzania 2018–2026.

Flowchart depicting the selection and longitudinal follow-up of HIV-exposed infants. From 98,456 eligible infants with a negative baseline (HEID) PCR at (≤8 weeks), 1.6% (n = 1,583) had subsequent testing and formed the analytic cohort. Within this cohort, 20 incident HIV infections were identified during follow-up