# SYSTEMATIC REVIEW AND META-ANALYSIS OF MORTALITY RISK AND ASSOCIATED FACTORS IN HIV-EXPOSED, UNINFECTED CHILDREN

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**Abstract**

**Objective**

Although with increasing maternal ART, the number of children newly infected with HIV has declined, possible increased mortality in the large number of HEU children may be of concern. We quantified mortality risks among HEU children and reviewed associated factors.

**Methods**

Systematic search of electronic databases (PubMed, Scopus). We included all studies reporting mortality of HEU children to age 60 months and associated factors. Relative risk of mortality between HEU and HUU children was extracted where relevant. Inverse variance methods were used to adjust for study size. Random-effects models were fitted to obtain pooled estimates.

**Results**

Fourteen studies were included in the meta-analysis and thirteen in the review of associated factors. The pooled cumulative mortality in HEU children was 5.5% (95% CI: 4.0-7.2; I2 = 94%) at 12 months (11 studies) and 11.0% (95% CI: 7.6-15.0; I2 = 93%) at 24 months (4 studies). The pooled risk ratios for the mortality in HEU children compared to HUU children in the same setting were 1.9 (95% CI: 0.9-3.8; I2 = 93%) at 12 months (4 studies) and 2.4 (95% CI: 1.1-5.1; I2 = 93%) at 24 months (3 studies).

**Conclusion**

Compared to HUU children, mortality risk in HEU children was about double at both age points, although the association was not statistically significant at 12 months. Interpretation of the pooled estimates is confounded by considerable heterogeneity between studies. Further research is needed to inform the impact of maternal death and breastfeeding on the survival of HEU infants in the context of maternal ART, where current evidence is limited.

# INTRODUCTION

With increasing availability of lifelong antiretroviral treatment (ART) globally, the landscape surrounding mother-to-child transmission (MTCT) of HIV has dramatically changed over the past decades. When antiretroviral drugs are available as prophylaxis, overall HIV transmission can be reduced to less than 5% at cessation of breastfeeding ([1](#_ENREF_1)). UNAIDS reported that many low- and middle-income countries had achieved at least 80% coverage of services to prevent HIV transmission to children by December 2009, with global coverage reaching 53% ([1](#_ENREF_1)). In this context, the number of children newly infected with HIV was reported to be 220,000 [190,000-260,000] in 2014, a 48% reduction from 2002 in the highest-burden countries([2](#_ENREF_2)). The risk of MTCT has been reduced to virtually zero in high-income countries. While serious challenges remain in resource-limited countries to ensure better access to and coverage of ART, elimination of MTCT is now on the global agenda ([3](#_ENREF_3)). With fewer infants and children becoming infected with HIV each year, additional attention has been given to the health and survival of children born to HIV-infected mothers who are themselves not HIV-infected (HIV exposed uninfected children, hereafter HEU children).

Studies have suggested increased mortality risks in this group, mostly based on data when antiretroviral drugs (ARVs) were not available ([4-6](#_ENREF_4)). Mortality estimates are scarce in settings where maternal ARV or lifetime ART is available. Different factors were found to be associated with vulnerability of HEU children: i) altered caregiving practices when the mother was unwell or died ([4](#_ENREF_4)), ii) infant feeding practices aimed at preventing HIV transmission through breastfeeding including early weaning and inappropriate use of breast milk substitutes ([6-8](#_ENREF_6)), iii) increased exposure to co-morbidities secondary to living in HIV-affected households([9](#_ENREF_9)), and iv) socio-demographic and geographic factors related to the HIV status of the mother ([4](#_ENREF_4)). In addition to such external and potentially modifiable risk factors, inherent vulnerability of HEU children has also been reported. Studies have found that exposure to HIV was associated with immunological alterations among HEU children, that may put them at higher risk of certain infections, especially in the absence of, or with reduced duration of, breastfeeding ([10](#_ENREF_10), [11](#_ENREF_11)).(10) Poor weight gain and linear growth as well as high incidence of invasive group B streptococcal infections among HEU children have been reported in Europe and the United States, suggesting adverse impacts of HIV exposure and altered immunological response in this group ([12](#_ENREF_12), [13](#_ENREF_13)). A study from South Africa demonstrated that HEU infants at birth had lower antibody responses to certain pathogens compared to children born to HIV uninfected women (HIV-unexposed, uninfected children, hereafter HUU children) ([14](#_ENREF_14)).

Building on available literature, the present study aims to analyze the risk of increased mortality among HEU children. Given limited availability of data reporting mortality in HEU children compared to HUU children living in the same communities with similar access to health services, we firstly aim to generate the pooled mortality rates of HEU children specifically. Where data is available, the pooled relative risk of mortality of HEU children compared to HUU children is estimated. Finally, we aim to systematically compile and describe factors which might influence the risk of death among HEU children in order to better understand the drivers of mortality risk in this population.

# METHOD

**Search methods for identification of studies**

Electronic searches were conducted in two databases, namely PubMed and Scopus, between 2004 and 2015 with the following keywords: “HIV”; “Mortality”; and “Child” OR “Infant”. The search strategy used in the databases is shown in Web appendix 1. There were no restrictions on the type of studies. Published data from all regions were eligible. Language was limited to English or French. Given a pooled analysis undertaken in 2004 which reported mortality in HEU infants in sub-Saharan Africa, we started our search from the year 2004 ([15](#_ENREF_15)). Relevance of studies was firstly assessed by screening their title and abstract. Retained articles were subject of full texts reviews. References of selected articles were also screened manually for identification of additional studies.

**Inclusion and exclusion criteria**

Studies were included if they reported mortality of infants and/or children born to mothers tested HIV positive but who themselves tested HIV negative without seroconversion during follow-up. Primary outcome was all-cause mortality in HEU children at any time points between birth and 60 months of age. Relative risk of mortality between HEU and HUU children were also sought as primary outcome when studies included HIV-unexposed children as a control group. Studies reporting case-specific mortality estimates were excluded. Studies not reporting raw data were also excluded from the analysis as they did not allow calculation of mortality estimates or relative risk with 95% confidence interval. In certain cases, authors of studies were contacted to obtain necessary data. For qualitative analysis, studies were included if they reported factors associated with mortality risks of HEU children.

**Statistical analysis**

Primary data regarding the sample size, the number of death and the total number of time at risk observed (where incidence density is reported) were extracted as raw numbers. Inverse variance methods were used to adjust for study size and random-effects models were fitted ([16](#_ENREF_16)). Pooled mortality rates of HEU children at different time points, calculated as the number of deaths observed divided by the number of live births, as well as risk ratios of mortality between HEU and HUU children, where available, were presented using a forest plot along with the weight of each study in the pooled effect size. The degree of between-study heterogeneity was assessed using I2 statistics ([17](#_ENREF_17)). When high heterogeneity was observed (I2>75%), the source of heterogeneity was explored narratively by assessing exposure to factors that can influence the risk of mortality. Sensitivity analyses were performed to explore the effect of studies with high risk of classification bias on the pooled estimates. The analyses were performed with Review Manager version 5.3 and MetaXL version 2.2. We also undertook a narrative qualitative analysis on factors possibly associated with mortality of HEU children. The quality of the studies included in the meta-analysis was assessed using the GRADEpro GDT (<http://www.guidelinedevelopment.org/>).

The present study was conducted in accordance with PRISMA guidelines.

**Ethics statement**

The study was based on published articles and did not require further ethical review.

# RESULTS

Characteristics of included studies

As shown in Figure 1, 1,867 articles were identified through electronic searches, of which 59 articles were retained for full text review. A total of 35 studies were excluded for different reasons but mainly due to absence of disaggregated data on children’s HIV status. Hand searches of the reference lists of the remaining 24 articles identified seven additional studies. Among 31 articles deemed relevant at this stage, we finally retained 14 articles for meta-analysis purpose by excluding six articles which did not report mortality estimates in HEU infants and further 11 articles for different reasons; one study reporting a case fatality rate for invasive pneumococcal disease, one pooled analysis, four studies as their mortality rates were generated with particular inclusion criteria (e.g. conditional on survival to 9 months), one study for the study samples being too old, and four studies because they reported the mortality at 4, 9 and 18 months from birth. We were unable to make use of all the data retrieved from individual studies as different studies estimated mortality risks at diverse time points. In the present study, we chose the mortality estimates at 3, 6, 12 and 24 months from birth as these time points were used by most studies. The lists of 14 included and 11 excluded articles are shown in Web appendix 2. For qualitative analysis, we retained 13 articles with information on associated factors.

Thirteen of the 14 studies included in the meta-analysis were undertaken in sub-Saharan Africa, and one was conducted in India. All the included studies were observational in nature: eight were nested within clinical trials ([18-25](#_ENREF_18)) and six were based on cohort data ([4-6](#_ENREF_4), [26-28](#_ENREF_26)). The majority were undertaken before the widespread use of maternal ART. Table 1 summarizes the characteristics of the studies included in the meta-analysis.

(Table 1 here)

**Quality of evidence of the included studies**

As shown in Table 2, we assessed the quality of evidence in the included studies according to different outcomes. Since all the studies were observational, the quality of evidence was assessed low to start with ([29](#_ENREF_29)). As for the cumulative mortality in HEU infants at 3 months, overall quality of six studies was further downgraded to very low due to high inconsistency in study results and variability in study population in terms of access to maternal ART, breastfeeding and infant cotrimoxazole. For the same reasons, overall quality of the studies included at 6, 12 and 24 months estimates were assessed as very low. For these three estimates, downgrading was also related to the risk of classification bias in the studies of Marinda et al. and Wei et al.([4](#_ENREF_4), [30](#_ENREF_30)).

For the relative risk of mortality between HEU and HUU infants at both 12 and 24 months, quality of evidence was also downgraded to very low because of high inconsistency in study results, the risk of classification bias in Marinda’s study and the small number of studies included in the generation of pooled estimates.

(Table 2 here)

### Mortality estimates of HEU infants (Meta-analysis)

Figure 2 (2a, 2b, 2c, 2d) shows the results of the meta-analysis with pooled estimates of cumulative mortality at different time points.

As Figure 2a shows, pooled mortality in HEU infants at 3 months of age was 2.0% [95% confidence interval (CI): 1.5-2.7], based on 131 deaths among 5,967 HEU infants from six studies ([18](#_ENREF_18), [21](#_ENREF_21), [25](#_ENREF_25), [26](#_ENREF_26)). The studies of Becquet et al. and Kafulafula et al. show estimates from two independent studies conducted in the same setting with no overlaps in the study populations (Ditrame & Ditrame Plus for Becquet et al. and PEPI trial & NVAZ trial for Kafulafula et al.). The reported mortality varied from 1.0 % ([25](#_ENREF_25)) to 2.6 %.([21](#_ENREF_21)) A substantial difference was observed in the duration of breastfeeding; about half the infants in Ditrame Plus in Cote d’Ivoire had short-term breastfeeding (a median of 4 months) whereas most infants in NVAZ in Malawi were breastfed for longer than 12 months. All six studies were conducted before the availability of life-long maternal ART. In Bork’s study (Kesho Bora), a randomized control trial in Burkina Faso, Kenya and South Africa, half of the women received triple ARVs until breastfeeding cessation at six months of age. As indicated by the value of I2, 60% of variability between studies cannot be explained by chance. Duration of breastfeeding might explain to a certain extent the inconsistency in reported mortality rates; however we were unable to undertake sub-group analyses because the information on the median duration of breastfeeding was not available in all the studies.

There were a total of seven studies reporting the mortality in HEU infants at six months of age ([4](#_ENREF_4), [6](#_ENREF_6), [18](#_ENREF_18), [21](#_ENREF_21), [26](#_ENREF_26)). The reported mortality differed significantly across studies: from 2.4% in the study of Bork et al. to 6.0% in that of Marinda et al.. There was no coverage of life-long maternal ART when these studies were undertaken, except for Shapiro’s study in Botswana where a small number of women had started maternal ART. Half the women in Bork’s study also received three ARVs until cessation of breastfeeding at six months postpartum. It is noteworthy that the HEU infants in included studies had different exposures to breastfeeding both in terms of duration and modality due to changing recommendations on infant feeding by HIV-infected women over time. The estimated pooled 6-month cumulative mortality was 3.6% (95% CI: 2.6-4.7), based on the data on 8,940 infants with 385 deaths (Figure 2b) with substantial heterogeneity (I2=84%). The study of Marinda et al. seems to be the likely source of heterogeneity, pulling the overall estimate to a higher end. A possible explanation could be that 16% of infants classified as “uninfected” in Marinda’s study included those who had tested negative shortly after birth but who died subsequently without further testing, and thus problems associated with misclassification of HIV-infected infants might explain this higher mortality rates reported ([4](#_ENREF_4)). In a separate meta-analysis excluding Marinda’s study, the pooled estimate was slightly attenuated to 3.4% (95% CI: 2.9-3.9) with significant reduction in heterogeneity (I2=11%) (data not shown).

A total of 11 studies contributed to the summary estimate of 12-month cumulative mortality (based on 14,507 HEU infants and 891 deaths observed by 12 months of age) ([4](#_ENREF_4), [20-24](#_ENREF_20), [26](#_ENREF_26), [28](#_ENREF_28), [30](#_ENREF_30)). The reported mortality rates varied considerably: the lowest estimate was 2.2% in India ([24](#_ENREF_24)) and the highest mortality of 10.5% was reported in Tanzania ([30](#_ENREF_30)). Figure 2c shows the pooled mortality estimated at 5.5% (95% CI: 4.0-7.2) with extremely high heterogeneity (I2=94%). The high mortality rate reported by the study of Wei et al. in Tanzania should be understood in the context that the HEU and HIV-indeterminate infants were grouped together for analysis, which might have caused overestimation of mortality rates. We attempted to address this classification bias by excluding the study of Wei et al. and Marinda et al. in a separate meta-analysis, which generated a pooled estimate of 4.8% (95%CI: 3.2-6.7), but still with high heterogeneity (I2= 94%) (data not shown). Other potential sources of heterogeneity could be background infant mortality, duration of breastfeeding, exposure to infant cotrimoxazole, and access to maternal ART (8% of women in Singh’s study in India)([24](#_ENREF_24)) and use of short-term ART by one-third of women included in Kourtis’s study in Malawi ([22](#_ENREF_22)). We were unable to account for these factors in subgroup analyses as necessary information was not available.

Finally, we identified four studies reporting the cumulative mortality in HEU infants at 24 months of age ([4](#_ENREF_4), [6](#_ENREF_6), [19](#_ENREF_19), [23](#_ENREF_23)). Again, the reported mortality were subject to significant variability: 6.7% in a PMTCT trial in Botswana ([6](#_ENREF_6)), 9.2% in Zimbabwe ([4](#_ENREF_4)), 13.6% in Zambia and 16.0% in Tanzania. As shown in Figure 2d, the pooled cumulative mortality at 24 months was estimated at 11.0% (95% CI: 7.6-15.0). As in the case of previous estimates, heterogeneity among the study results was significantly high (I2= 93%). This high heterogeneity remained (I2=93%) even after removing the Marinda’s study for the risk of bias with no significant modification in the mortality estimate (11.6%, 95%CI: 6.8-17.6) (data not shown).

### Relative Risk of Mortality of HEU children compared to HUU children (Meta-analysis)

As stated earlier, there are a limited number of studies comparing mortality outcome between HEU and HUU children in the same setting. We identified four studies for the meta-analysis of the overall mortality risk ratio (RR) in these two groups at 12 months of age ([4](#_ENREF_4), [5](#_ENREF_5), [20](#_ENREF_20), [28](#_ENREF_28)). A total of 5,995 HEU and 13,906 HUU infants were included in the pooled analysis. These studies were undertaken in sub-Saharan Africa before ART was readily available for mothers. All the HEU infants in Chilongozi’s study were given cotrimoxazole. Information on infant feeding modalities was available only in Rollins’s study in which the majority of the infants received some type of breastfeeding with the median duration of 7 months for HEU and 9 months for HUU infants ([28](#_ENREF_28)). As shown in Figure 3a, the difference in pooled mortality of HEU and HUU infants at 12 months did not reach statistical significance (RR: 1.9, 95% CI: 0.9-3.8) possibly due to lack of statistical power and high underlying mortality for all children. The pooled estimate is again difficult to interpret in the presence of extremely high heterogeneity (I2 = 93%). The study by Marinda et al. provides outlying results, and given the risk of classification bias in this study, we ran a separate analysis excluding this study. The pooled RR estimate from the three remaining studies was 1.4 (95%CI: 1.0-1.8), indicating that HEU infants were likely to be at increased risk. There was no heterogeneity of study results (I2 = 14%) in this additional analysis (Figure 3b).

Figure 3c shows the result of the pooled analysis on comparative mortality risk at 24 months in HEU and HUU children. We included three cohort studies, comprising a total of 3,938 HEU and 12,530 HUU children ([4-6](#_ENREF_4)). In the study of Brahmbatt et al. and Marinda et al., there were no mothers benefitting from maternal ART whereas Shapiro’s study included some women on ART. Also noteworthy was that all HEU children in Shapiro’s study were breastfed with a median of 6 months while information on feeding modality was not available in the other two papers. The pooled estimate indicated that the mortality of HEU children was more than double that of HUU children at 24 months of age (RR: 2.4, 95% CI: 1.1-5.1). The level of heterogeneity was extremely high (I2 = 93%). As previously, we ran a separate analysis in order to address the risk of classification bias in Marinda’s study. In this additional analysis, the difference between the groups did not reach statistical significance (RR: 2.0, 95% CI: 0.6-6.5) (Figure 3d). However, the removal of Marinda’s study caused a substantial reduction of sample size, leading to a very large uncertainty interval. The residual heterogeneity still remained relatively high (I2 = 66%).

### Factors associated with increased mortality risk of HEU infants

Given the diversity of definitions of variables and heterogeneity across studies, a narrative summary was considered appropriate. The following synthesis focused on direction of the association between different factors and the mortality outcome in HEU infants. We identified 13 articles reporting the factors associated with the risk of mortality among HEU infants.

**Maternal death and ill health**

Maternal death significantly affects survival of uninfected infants. However, available data are limited to the time when maternal ART was not available. In a large observational cohort in Zimbabwe, Marinda et al. reported that HEU infants whose mother had died were 2.7 times more likely to die (95% CI: 1.9-3.9) than those whose mothers survived ([4](#_ENREF_4)). The pooled analysis of seven randomized trials in sub-Saharan Africa also identified a strong effect of maternal death (adjusted odds ratio: 3.7, 95% CI: 1.9-7.0) on child mortality ([15](#_ENREF_15)). Significant association was also found in Zambia where hazard of death of HEU infants through 4 months of age was 16.2 times higher when mother died within 4 months after delivery, after allowing for maternal CD4 counts, hemoglobin level and infant birth weight ([31](#_ENREF_31)). There is some evidence to suggest that timing of death of mother impacts on the risk of death of her uninfected infant: Zaba et al. reported that the mortality risk was tripled in the two years centering around mother’s death, irrespective of the mother’s HIV status ([32](#_ENREF_32)).

Studies suggested that the overall health status of mothers also plays a major role in the survival of uninfected infants. Reduced care or breastfeeding cessation as a result of maternal ill health or increased exposure to infectious pathogens in the households could explain increased risk of death of their uninfected infants ([4](#_ENREF_4), [9](#_ENREF_9)). The definition of poor health and the indicators used however varied between studies. Taha et al. used maternal HIV clinical stage as an indicator to predict the risk of death in HEU infants and found 1.8 fold increase in the hazard of death [adjusted hazard ratio (aHR): 1.8, 95%CI: 1.2-2.7] in children aged 6-15 months with mothers in advanced disease stage (3 or 4) ([7](#_ENREF_7)). A study in Tanzania has also shown the association of a borderline statistical significance (HR: 1.5, 95% CI: 1.0-2.3) between the mortality through 24 months and advanced maternal HIV stage (defined as WHO disease stage two or more) ([19](#_ENREF_19)). In this study, higher maternal viral load at delivery (≥50,000 copies/mL) was associated with sevenfold (95% CI: 2.4-23.7) increase of mortality hazard through 24 months of age in HEU children. Several studies have shown the association between low maternal hemoglobin level and increased child mortality risk: Kuhn et al. reported that maternal hemoglobin level of below 10g/dL was significantly associated with HEU infant mortality through 4 months of age (aHR: 2.4, 95% CI: 1.1-5.4) ([31](#_ENREF_31)). Marinda et al. also found that HEU infants with mothers with hemoglobin <70g/L were at 3.8 times higher risk of dying than those of mothers with hemoglobin above the threshold (95% CI: 2.1-7.0) ([4](#_ENREF_4)). Such association was however not found in HEU children aged up to 24 months in Tanzania when the risk of death was compared between those with maternal hemoglobin below and above 8.5g/dL ([19](#_ENREF_19)).

Studies have shown mixed results with regard to the impacts of maternal CD4 counts. Kuhn et al. found in Zambia that HEU infants born to mothers with CD4 cell counts less than 350 cells/µL were significantly more likely to die during the first 4 months, after adjusting for maternal death and low birth weight (HR: 2.9 with 95% CI: 1.0-8.0) ([31](#_ENREF_31)). Further analysis on the same population confirmed this association through 18 months of life: the mortality hazard in children with mothers having low CD counts (<200 cells/µL) was 3.2 times higher (95% CI: 1.3–8.1) than in those with higher maternal CD4 counts (>500 cells/µL) ([33](#_ENREF_33)). Similar results were put forward by a study in Zimbabwe that HEU children born to mothers with CD4<200/µL were at 2.6 higher risk of dying than those born to mothers with CD4≥400/µL (95% CI: 1.8-3.8), allowing for infant’s birth weight, sex, mother’s marital status and household income ([4](#_ENREF_4)). A pooled analysis of seven randomized trials in sub-Saharan Africa showed that risk of death among HEU infants was 1.7 times higher when maternal CD4 counts were below 200/µL compared to when they were above 500/µL although the result did not reach statistical significance ([15](#_ENREF_15)). Similarly, no significant effects of maternal CD4 counts during pregnancy on the mortality of HEU infants through 48 weeks were observed in the Antiretrovirals and Nutrition (BAN) clinical trial in Malawi ([22](#_ENREF_22)).

**Infant feeding practices**

Our literature review revealed complexity of the issues related to infant feeding, with inconsistent results between studies suggesting that findings may be context-specific. Some studies showed that type and duration of infant feeding was associated with the risk of death among HEU infants. Data from the Kesho Bora trial showed that non-breastfed (never breastfed) or short-breastfed (early weaning) infants had a seven-fold increased likelihood of dying within 6 months after birth compared to those still being breastfed, after controlling for confounders including infant’s HIV infections status (95% CI: 2·5-17·9) ([8](#_ENREF_8)). Similar findings were put forward in a study conducted in Malawi: looking at cumulative mortality at 6-15 months of age, Taha et al. found that the mortality rate at 15 months was nearly double in non- or short-breastfed HEU infants than in those being breastfed for long durations (p=0·04) ([7](#_ENREF_7)). The study has suggested long-term adverse impacts of early weaning given that this difference became significant only after 12 months of age ([7](#_ENREF_7)). Kourtis et al. further highlighted that the mortality of HEU infants increased after 28 weeks of age, the timing of which corresponds with weaning from breastmilk for the majority of infants in the cohort ([22](#_ENREF_22)).

However, a comparative study of two trials in Uganda showed that overall all-cause infant mortality did not statistically significantly differ in the trial in which HEU infants were weaned earlier (median 4 months) and the trial with later weaning (median 9 months) ([34](#_ENREF_34)). A study in urban South Africa reported that infant feeding modality was not associated with increased risk of mortality at three months of age among HEU infant; mothers in this study had fairly good access to safe replacement feeding including clean water and infant formula ([25](#_ENREF_25)). An absence of significant associations between infant feeding modality and mortality risk was also reported by the pooled analysis of seven PMTCT trials in sub-Saharan Africa ([15](#_ENREF_15)). Early cessation of breastfeeding (i.e. before 4 months) was not significantly associated with the hazard of death among HEU infants in an observational cohort in Malawi after adjusting for other covariates including maternal CD4 counts and vital status ([31](#_ENREF_31)).

**Low birth weight**

Data from a randomized trial in Tanzania showed that low birth weight was significantly associated with neonatal and post-neonatal mortality among HEU infants ([27](#_ENREF_27)), which confirms the findings of the multi-site pooled analysis in sub-Saharan Africa ([15](#_ENREF_15)) and those of observational cohort in Zambia ([31](#_ENREF_31)). Retrospective analysis of cohort study in Kenya further revealed that low birth weight was associated with 3.3-fold increased hazard of dying among HEU infants after adjusting for maternal viral load (95% CI: 1.1-10.0) ([35](#_ENREF_35)). However, it may be difficult to distinguish low birth weight from preterm appropriate for gestational age and to assess its effects from other factors including breastfeeding.

# DISCUSSION

Our results show that HEU infants and children are at increased risk of mortality, although the differences between HEU and HUU were statistically significant only for the estimate at 24 months. Our pooled estimates on cumulative mortality of HEU at 3, 6, 12 and 24 months of age ranged from 2.0%, 3.6%, 5.5% to 11.0%. Our estimates are comparable with previous results of a pooled analysis of seven PMTCT trials conducted in sub-Saharan Africa in the pre-ART era in which the mortality estimates in HEU children were 4.9% and 7.6% at 12 and 24 months respectively ([15](#_ENREF_15)). Compared to the WHO estimates of infant mortality in the sub-Saharan region in 2013 (61/1,000 live births)([36](#_ENREF_36)), our estimate at 12 months is similar, suggesting that HEU infants may not be at increased risk compared to the general population. Compared to HUU, estimated relative mortality in HEU children at 12 months of age was nearly doubled, although the difference did not reach statistical significance; at 24 months of age, there was a statistically significant doubling in risk between the two groups but statistical significance was lost once the study with bias concerns was removed ([4](#_ENREF_4)). All the four studies contributing to the pooled estimate of relative risk at 12 months were from the pre-ART era ([4](#_ENREF_4), [5](#_ENREF_5), [20](#_ENREF_20), [28](#_ENREF_28)). For 24 months of age, only one ([6](#_ENREF_6)) out of three studies ([4](#_ENREF_4), [5](#_ENREF_5)) had data on mothers on ART.

The strength of our study lie in the systematic identification and analysis of studies, with no restrictions on study design and geographical locations; this enabled us to analyze a total of 14 articles, mostly from the pre-ART era, with mortality data on HEU infants and 13 articles reporting on associated factors. The quality and potential bias of included studies were adequately addressed, which gave important consideration to the interpretation of pooled estimates.

The major limitation is the heterogeneity of study results. The pooled estimates are useful as they provide a summary of what is published so far on the mortality risk of HEU infants at different ages. Nevertheless, meaningful interpretation of our results is limited due to substantial heterogeneity, with the value of I2 statistics ranging from 60 to 95%. Our effort to remove the studies with outlying results made little difference and residual heterogeneity persisted. Factors that may explain such high heterogeneity include inconsistency in the coverage of maternal ART and PMTCT prophylaxis in the studied populations. While our meta-analyses used data mostly from studies conducted before the widespread use of ART, two studies included some women already benefiting from ART([6](#_ENREF_6), [24](#_ENREF_24)) and another two had women randomized to receive ART until cessation of breastfeeding at six months postpartum ([18](#_ENREF_18), [22](#_ENREF_22)). As highlighted in our qualitative review, maternal survival and health significantly improves survival probability of their uninfected infants. The association between mortality and duration of breastfeeding is also reported by the reviewed literature. Maternal ART, whether for mother’s own health or for ensuring appropriate nutritional or immunological benefits for infants through breastfeeding, is very likely to impact on mortality of HEU infants. Two studies demonstrate either a direct association between ART and improved under-5 mortality of all infants ([37](#_ENREF_37)) or the importance of ART availability with ecological association between maternal survival and reduced mortality of infants aged less than two years ([38](#_ENREF_38)). Due to lack of information, we were unable to assess the contribution of maternal exposure to ART to overall heterogeneity in the pooled estimates. The evidence regarding maternal survival and infant feeding in relation to the mortality of HEU children needs to be substantiated in the post-ART era. Another possible source of heterogeneity is children’s different exposure to cotrimoxazole prophylaxis, which may have survival benefits ([4](#_ENREF_4), [22](#_ENREF_22), [39](#_ENREF_39)). The mortality risks in the study of Chilongozi might have been underestimated as the children were routinely given cotrimoxazole. Children in other three studies ([21-23](#_ENREF_21)) also had exposure to cotrimoxazole, but details of coverage were unknown, limiting sub-group analyses by cotrimoxazole exposure. Finally, heterogeneity related to context-specific factors such as background mortality and access to health care in different study settings may have been important.

# CONCLUSION

As the use of maternal ART expands, the number of HEU infants continues to increase globally. In this context, there is need for better understanding of the risks faced by this vulnerable group of infants. Our results suggest that early mortality of HEU infants might not be significantly different from that of general population or HUU infants living in the same community but may become significant when considering the overall period to two years of age. However, heterogeneity between studies and lack of high quality data of comparing the mortality of HEU infants to that of HUU infants limits interpretation of the pooled estimates. We recognize the needs for more data from post-ART era in order to understand the impact of maternal health on breast feeding and survival of HEU infants. Further research is needed to inform more precise estimates of HEU infant mortality and to identify strategic interventions to reduce mortality risks in this vulnerable population.

Table 1: Characteristics of the studies included in the meta-analysis

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Author / Study** | **Country** | **Study  enrolment year** | **Study design** | **No. of participants** | | **Breastfeeding duration (month), median (IQR3)** | **Breastfeeding pattern** | **Support for replacement  feeding** | **Maternal ARVs/ART4** | **Child cotrimo-xazole** |
| **HEU1** | **HUU2** |
| [Becquet et al. 2007/  Ditrame Plus](file:///C:\Users\SHINO\Dropbox\HEU%20meta-analysis\Revised%20table.xlsx#RANGE!_ENREF_26) ([26](#_ENREF_26)) | Côte d'Ivoire | 2001-2003 | Secondary analysis of a prospective cohort study | 507 | 0 | 4 (3-5) | 50% short-term breast-fed | Yes | No | N/A5 |
| [Becquet et al. 2007 / Ditrame](file:///C:\Users\SHINO\Dropbox\HEU%20meta-analysis\Revised%20table.xlsx#RANGE!_ENREF_26) ([26](#_ENREF_26)) | Côte d'Ivoire, Burkina Faso | 1995-1998 | Secondary analysis of randomized controlled trial data | 168 | 0 | 8 (6-10) | Predominantly long-term breastfeeding | N/A | No | N/A |
| Bork et al. 2014 /  Kesho Bora ([18](#_ENREF_18)) | Burkina-Faso, Kenya,  South Africa | 2005-2008 | Secondary analysis of randomized controlled trial data | 751 | 0 | N/A | Majority of women ever breastfed | N/A | One arm of mothers treated by ART from 28-36 weeks of pregnancy to 6.5 months postpartum | N/A |
| Brahmbhatt et al. 2006 / Rakai ([5](#_ENREF_5)) | Uganda | 1994-1998 | Secondary analysis of a prospective cohort study | 269 | 3183 | N/A | N/A | N/A | No | N/A |
| [Chatterjee et al. 2007](file:///C:\Users\SHINO\Dropbox\HEU%20meta-analysis\Revised%20table.xlsx#RANGE!_ENREF_19)([19](#_ENREF_19)) | Tanzania | 1995-1997 | Prospective cohort nested in clinical trial | 682 | 0 | N/A | N/A | N/A | No | N/A |
| Chilongozi et al. 2008 / HIVNET 024 ([20](#_ENREF_20)) | Malawi, Tanzania, Zambia | 2001-2003 | Observational cohort analysis of multisite trial data | 1648 | 331 | N/A | N/A | N/A | No | Yes |
| Kafulafula et al. 2010 / NVAZ ([21](#_ENREF_21)) | Malawi | 2000-2003 | Secondary analysis of randomized trial data | 1810 | 0 | N/A | Prolonged breastfeeding (> 12 months) | N/A | No | N/A |
| Kafulafula et al. 2010 / PEPI ([21](#_ENREF_21)) | Malawi | 2004-2007 | Secondary analysis of randomized trial data | 2035 | 0 | N/A | Breastfeeding cessation by 6 months | Yes | No | Yes |
| Kourtis et al. 2013 / BAN trial ([22](#_ENREF_22)) | Malawi | 2004-2010 | Secondary analysis of randomized clinical trial data | 2250 | 0 | N/A | N/A | N/A | Maternal regimen group received triple ARVs until cessation of breastfeeding | Yes |
| Kuhn et al. 2010 / ZEBS trial ([23](#_ENREF_23)) | Zambia | 2001-2004 | Secondary analysis of randomized trial data | 749 | 0 | N/A | All women breastfeeding with a half weaning at 4 months | Yes | No | Yes |
| Marinda et al. 2007 / ZVITAMBO ([4](#_ENREF_4)) | Zimbabwe | 1997-2000 | Secondary analysis of retrospective cohort study data | 3135 | 9210 | N/A | N/A | N/A | No | N/A |
| [Rollins et al. 2013 / Vertical Transmission Study](file:///C:\Users\SHINO\Dropbox\HEU%20meta-analysis\Revised%20table.xlsx#RANGE!_ENREF_28) ([28](#_ENREF_28)) | South Africa | 2001-2005 | Intervention cohort study | 943 | 1182 | 7 (6-9) for HEU and 9 (8-15) for HUU | All women breastfeeding; exclusive breastfeeding for the first 6 months encouraged | N/A | No | N/A |
| Shapiro et al. 2007 / Mashi ([6](#_ENREF_6)) | Botswana | 2003 | Prospective cohort study | 534 | 137 | 6 for HEU and 9 for HUU  (IQR: N/A) | All women breastfeeding; exclusive breastfeeding encouraged | Yes for HEU | ART became available from Oct 2002 to women with CD4 counts <200 or AIDS | No |
| Singh et al. 2011 / SWEN ([24](#_ENREF_24)) | India | 2002-2007 | Secondary analysis of trial data | 644 | 0 | N/A | N/A | N/A | Not available in public facilities   Women who could afford to pay for ART received it (8%) | N/A |
| [Venkatesh et al. 2011](file:///C:\Users\SHINO\Dropbox\HEU%20meta-analysis\Revised%20table.xlsx#RANGE!_ENREF_25) ([25](#_ENREF_25)) | South Africa | 2000-2002 | Secondary analysis of randomized controlled trial data | 696 | 0 | N/A | N/A | Yes | No | N/A |
| [Wei et al. 2004](file:///C:\Users\SHINO\Dropbox\HEU%20meta-analysis\Revised%20table.xlsx#RANGE!_ENREF_27) ([27](#_ENREF_27)) | Tanzania | N/A | Prospective cohort | 618 | 0 | N/A | N/A | N/A | No | N/A |

1: HEU – HIV exposed uninfected (children)

2: HUU – HIV-unexposed uninfected (children)

3: IQR – Interquartile range

4: ARVs/ART – Antiretroviral drugs/Antiretroviral treatment

5: N/A – Not available

Table 2: Grade assessment

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Quality assessment** | | | | | | | **№ of patients** | | **Relative risk**  **(95% CI)** | **Quality** |
| **№ of studies** | **Study design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **HEU** | **HUU** |
| Cumulative mortality at 3 months | | | | | | | | | | |
| 6 | observational studies | not serious | serious | serious 1 | not serious | N/A | 131/5967 (2.2%) | N/A | not estimable | Very Low |
| Cumulative mortality at 6 months | | | | | | | | | | |
| 7 | observational studies | serious 2 | very serious 3 | serious 1 | not serious | N/A | 385/8940 (4.3%) | N/A | not estimable | Very Low |
| Cumulative mortality at 12 months | | | | | | | | | | |
| 11 | observational studies | serious 4 | very serious 3 | serious 1 | not serious | N/A | 891/14507 (6.1%) | N/A | not estimable | Very Low |
| Cumulative mortality at 24 months | | | | | | | | | | |
| 4 | observational studies | serious 2 | very serious 3 | serious | not serious | N/A | 535/5100 (10.5%) | N/A | not estimable | Very Low |
| Relative mortality risk at 12 months | | | | | | | | | | |
| 4 | observational studies | serious 2 | very serious 3 | not serious | serious 5 | N/A | 413/5995 (6.9%) | 506/13906 (3.6%) | RR 1·9 | Very Low |
| (0.9 to 3.8) |
| Relative mortality risk at 24 months | | | | | | | | | | |
| 3 | observational studies | serious 2 | very serious 3 | not serious | serious 5 | N/A | 369/3938 (9.4%) | 677/12530 (5.4%) | RR 2·4 | Very Low |
| (1.1 to 5.1) |

RR – relative risk

1. Studied population had different exposures to breast feeding, infant cotrimoxazole and maternal ARVs/ART.
2. Risk of classification bias in Marinda's study
3. High heterogeneity in between-study results
4. Risk of classification bias in Marida's and Wei's studies
5. Small number of studies included

**Records identified through database searching (N = 1867)**

PubMed (n =222) / Scopus (n = 1645)

)

Duplicates removed (n = 188)

Titles and abstracts screened (n = 1679)

**Records excluded (N=1620)**

* No information on authors (n = 25)
* Language not English/French (n=1)
* Articles not related to the mortality in HEU children (n = 1594)

Full-text articles assessed for eligibility (n = 59)

**Full-text articles excluded with reasons (N= 35)**

* Reviews (n =2) / Correspondence (n=2)
* Full text not available (n=1)
* Immunologic or hematologic analysis of HEU infants (n=3)
* Focus on morbidity of HEU infants (n=3)
* Mortality data not disaggregated by HIV status of infant/child (n=22)
* Endpoint defined as combination of infant HIV infection and death (n=1)
* Time point of mortality estimate not clear (n=1)

Full-text articles identified as relevant (n =24)

Articles identified from reference lists   
(n = 15)

Studies excluded upon full-text review (n=8)

**Studies not included in meta-analysis (N =17)**

* No mortality estimates (n=6)
* Case fatality rate of specific disease (n=1)
* Pooled analysis (n=1)
* Mortality estimates with specific conditions (n=4)
* Study samples aged up to 13 years old (n=1)
* Mortality estimated at time points different from those used in the present study (n= 4)

Studies identified as relevant (N= 31)

No qualitative information on associated factors

(n=18)

**Studies included in meta-analysis (n = 14)**

**Studies included in qualitative analysis (n = 13)**

Figure 1: Flow diagram of study selection



Note: (a) 50% short-term breast-fed group (median of 4 months), with support for replacement feeding.

(b) Predominantly long-term breastfeeding (median of 8 months).

(c) Breastfeeding cessation by 6 months, with support for replacement feeding. Infant cotrimoxazole.

(d) Prolonged breastfeeding (> 12 months).

(e) Infants receiving ARV post-exposure prophylaxis. Mortality at 100 days. Subsidized formula.

(f) Majority of women ever breastfed. ART arm receiving 3 ARVs from 28-36 weeks of pregnancy up to 6.5 months postpartum or breastfeeding cessation whichever first occurs.

**Figure 2a: Pooled 3-month cumulative mortality in HEU infants**



Note: (a) 50% short-term breast-fed group (median of 4 months), with support for replacement feeding.

(b) Predominantly long-term breastfeeding (median of 8 months).

(c) All infants were breastfed (median of 6 months). Maternal ART introduced during study.

(d) Breastfeeding cessation by 6 months, with support for replacement feeding. Infant cotrimoxazole.

(e) Prolonged breastfeeding (> 12 months).

(f) Majority of women ever breastfed. ART arm receiving 3 ARVs from 28-36 weeks of pregnancy up to 6.5 months postpartum or breastfeeding cessation whichever first occurs.

**Figure 2b: Pooled 6-month cumulative mortality in HEU infants**



Note: (a) 50% short-term breast-fed group (median of 4 months), with support for replacement feeding.

(b) Predominantly long-term breastfeeding (median of 8 months).

(c) Cotrimoxazole given to all infants.

(d) Breastfeeding cessation by 6 months, with support for replacement feeding. Infant cotrimoxazole.

(e) Prolonged breastfeeding (> 12 months)

(f) All women breastfeeding with a half weaning at 4 months. Infants received weaning supplement and cotrimoxazole.

(g) 8% of mothers with maternal ART.

(h) Women randomized to receive triple ARVs until cessation of breastfeeding. Majority weaned at 6 months. Cotrimoxazole given to all infants.

(i) Majority of infants received some type of breastfeeding (median of 7 months)

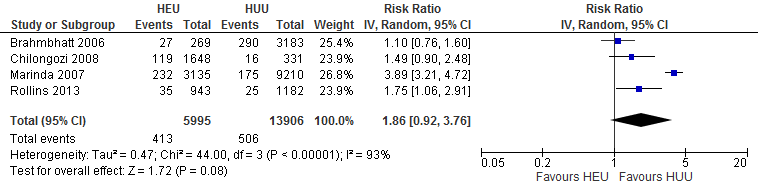
**Figure 2c: Pooled 12-month cumulative mortality in HEU infants**



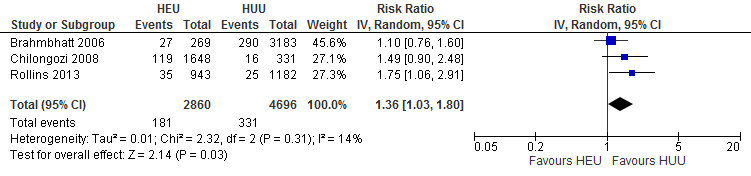
Note: (a) All infants were breastfed (median of 6 months). Maternal ART introduced during study.

(b) All women breastfeeding with a half weaning at 4 months. Children received cotrimoxazole.

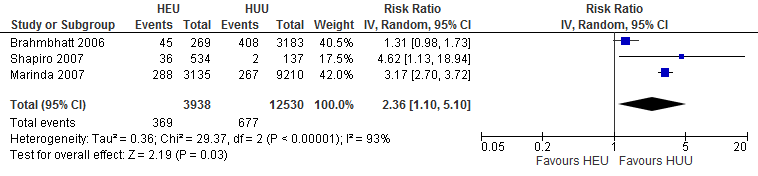
**Figure 2d: Pooled 24-month cumulative mortality in HEU children**

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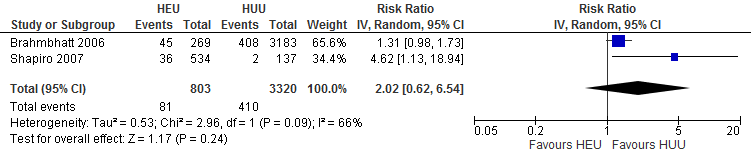
**Figure 3a: Mortality risk ratio at 12 months between HEU and HUU infants**



**Figure 3b: Mortality risk ratio at 12 months between HEU and HUU infants (excluding Marinda 2007)**



**Figure 3c: Mortality risk ratio at 24 months between HEU and HUU children**

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**Figure 3d: Mortality risk ratio at 24 months between HEU and HUU children (excluding Marinda 2007)**

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