BMC Pregnancy and Childbirth

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Associations between nighttime or weekend deliveries and adverse maternal, birth, and neonatal outcomes: secondary analysis of the MANGO study in western Kenya

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Abstract

Background Maternal and neonatal morbidity and mortality remain high in low-income and middle- income countries (LMICs), and staffing schedules may contribute to adverse pregnancy outcomes. Particularly, during the nighttime and on weekends, provider staffing is often limited, which may make it difficult for pregnant persons to receive quality care. We leveraged existing data collected in a pharmacovigilance pregnancy project, named Measuring Adverse Pregnancy and Newborn Congenital Outcomes (MANGO) study, to determine any associations between nighttime/weekend deliveries and adverse (1) maternal, (2) birth, or (3) neonatal outcomes.

Methods We conducted a secondary analysis of prospective data from the MANGO study, which documents delivery outcomes for pregnant persons at the Moi Teaching and Referral Hospital in western Kenya, from September 2020-November 2023. We utilized multivariable Poisson regression models, with log link, robust standard errors, and adjusted for several covariates, to assess the association between nighttime/weekend deliveries and adverse composite maternal, birth, or neonatal outcomes.

Results A total of 25,911 neonates born to 25,247 pregnant persons were included. More than half of deliveries occurred during nighttime (6pm to 7am)/weekends (62.6%). In multivariate modeling, nighttime/weekend delivery was associated with a reduced risk of adverse composite maternal outcomes (adjusted risk ratio [aRR] 0.92, 95% confidence interval [CI]: 0.88, 0.96) and composite birth outcomes (aRR 0.92, 95% CI: 0.88, 0.96). No association was found between nighttime/weekend delivery and neonatal death. In post-hoc analyses, weekend deliveries were associated with reduced risk of emergency Caesarean deliveries, preterm birth, and low birth weight. Having

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advanced maternal age, obstetric complications, and transferring to the hospital for delivery were associated with adverse maternal and birth outcomes. Poor APGAR score was strongly associated with neonatal death.

Conclusions Nighttime/weekend deliveries were associated with better maternal and birth outcomes, perhaps due to decreased emergency Caesarean deliveries for high-risk pregnancies or other factors. Greater attention to individual-level factors, such as obstetric complications, may be considered to improve outcomes for pregnant persons and their neonates. Future research may focus on under-resourced, non-tertiary hospitals to offer a more generalizable view of this exposure-outcome relationship in LMICs.

Keywords Nighttime/weekend deliveries, Hospital staffing, Adverse pregnancy outcomes, Emergency caesarean delivery, Preterm birth, Neonatal death, Kenya

Background

Maternal and neonatal morbidity and mortality remain high in low-and middle-income countries (LMICs) [1–3]. Global trends show that the burden of poor pregnancy outcomes continues to be significant. For example, hypertensive disorders of pregnancy increased by nearly 11% from 1990 to 2019 [4]. Globally, 13.4 million neonates were born preterm in 2020 with no significant improvements over the last decade [5]. Given these persistent adverse outcomes, there is a global push to promote in-facility deliveries as skilled birth attendance has been associated with significant reductions in adverse pregnancy outcomes [6–10]. Thus, it is important to ensure that health systems, including delivery facilities, are robust. Other health system factors, such as travel time to a hospital, racial bias, and health insurance barriers, have been associated with various adverse pregnancy outcomes [11–17].

Of the various health system factors associated with poor maternal and neonatal outcomes, staffing schedules, including among nursing staff may be a key determinant of these outcomes [18–21]. One study assessing staffing needs for perinatal care in Tanzania discussed the potential link of shortage of essential staffing, paired with the high workload of these limited staff, with poor quality of care and outcomes [22]. Even in a high income country (HIC), such as Austria, lower maternal unit volume was associated with lower risk for adverse neonatal outcomes, having senior staff and midwives involved in deliveries was associated with a reduced risk of adverse neonatal outcomes [23]. During the nighttime and on weekends, formal provider staffing (e.g., specialized physicians, nurses, and other trained hospital staff) is often limited, which may make it difficult for pregnant persons to receive the quality care they need. Pregnancy and delivery complications are often time-sensitive and require skilled healthcare professionals to be present in order to minimize further complications. With limited staff present, signs of perinatal complications may be missed or attended to with a poorer quality than they would when sufficient staffing is available [24, 25]. A lack of sufficient staffing creates a potential for poor outcomes, thus a focus on staffing schedules, particularly those at nighttime and during weekends, is important to study.

Given the potential influence staffing schedules may have on adverse birth outcomes, the primary objective of our study was to determine the associations between nighttime/weekend deliveries and adverse composite: (1) maternal outcomes (e.g., maternal death, prolonged labor, postpartum hemorrhage, emergency Caesarean delivery); (2) birth outcomes (e.g., stillbirth, miscarriage/spontaneous abortion, preterm birth, small for gestational age, low birth weight, low APGAR scores); and (3) neonatal outcomes (e.g., neonatal death) in a LMIC setting. We leveraged existing data collected in the Measuring Adverse Pregnancy and Newborn Congenital Outcomes (MANGO) study, which aims to support a surveillance program for adverse maternal, birth, and neonatal outcomes in order to examine the effects of HIV and antiretroviral treatment (ART) exposure among pregnant persons living with and without HIV in western Kenya, where the burden of adverse pregnancy outcomes remains high. In particular, the five year average in 2022 for neonatal deaths was 21 deaths per 1,000 live births and births delivered via caesarean sections have almost doubled in the last eight years, from 9% in 2014 to 17% in 2022 [26]. We hypothesized that nighttime and weekend deliveries would be associated with an increased risk of adverse maternal, birth, and neonatal outcomes compared to daytime and weekday deliveries.

Methods

Study setting

The MANGO study occurs at the Moi Teaching and Referral Hospital (MTRH), located in Eldoret, Kenya, which is the second largest national referral hospital in Kenya serving a catchment population of 4 million people. In 2017, the antenatal clinic (ANC) and maternity ward at MTRH served approximately 7,200 pregnant persons and performed 12,300 deliveries, respectively. Given a county-level HIV prevalence among women of childbearing age (15–49 years) of 5.5%, we estimate 677 deliveries among pregnant persons living with HIV annually. MTRH hosts a robust service, education, and research

infrastructure through the Academic Model for Providing Access to Healthcare (AMPATH), a collaboration between MTRH, Moi University, and a consortium of North American and European universities. MANGO is a sub-study within the East Africa International Epidemiology Databases to Evaluate AIDS (EA-IeDEA) consortia [27, 28].

MANGO study design

The MANGO study was designed to bolster an existing Kenya Ministry of Health (MOH) surveillance system for adverse pregnancy outcomes in order to investigate the effects of HIV infection and ART exposure (at conception and during pregnancy). The Kenya MOH surveillance approach uses passively collected case reporting forms. The MANGO study, which began in 2020 and is ongoing, uses both prospective and retrospective data collection. For this analysis, we utilized data collected from September 2020 through November 2023.

Prospective data in the MANGO study were collected on two cohorts. Cohort 1 (C1), includes a pregnant person living with HIV and an age-matched (+/- two years) pregnant person not living with HIV engaging in care at the MTRH ANC. These individuals were then followed by the study staff during their pregnancy through delivery. If the individuals in C1 did not deliver at MTRH, telephone and field follow-up were conducted to ascertain pregnancy outcomes. Cohort 2 (C2) consists of predominantly pregnant persons who delivered at MTRH during the study period. Individuals transferring to MTRH for postpartum care, delivering en route to MTRH, or delivering < 24 weeks of gestational age (as these persons are admitted to the gynecology ward and not the delivery hospital) were excluded from study. For the C2 cohort, pregnancy outcomes were ascertained in real-time during the delivery visit. However, exposures that occurred during the ANC period were extracted by study personnel, as close to real time as possible, after delivery and prior to maternal/neonatal discharge from the postnatal ward, from medical record sources, including the MOH Mother-Baby booklet (which contains information about the pregnancy including antenatal medications, laboratory results, and appointment dates and is carried by the pregnant person both prior to and after delivery), maternal medical record file, maternity register, antenatal care register, and AMPATH electronic medical record. The research assistants, who staffed the delivery units weekday work hours, occasionally clarified any inconsistencies in data, missing information, etc. with the pregnant person while they were still at the delivery unit.

This is a secondary analysis that utilizes the prospective data of pregnant persons from both the C1 and C2 cohorts (Fig. 1). Those from C1 who delivered outside of MTRH were excluded. C1 and C2 pregnant persons with missing data on day/time of delivery or pregnancy outcomes were also excluded.

Definitions of exposure variables

We defined nighttime deliveries as deliveries occurring from 6:00 PM to 6:59 AM, daytime deliveries as deliveries occurring from 7:00 AM to 5:59 PM, regardless of the day, and weekend deliveries as deliveries occurring on Saturdays and Sundays (defined as beginning at 12:00 AM on Saturday and ending at 11:59 PM on Sunday). Thus, we defined nighttime/weekend deliveries (exposed group) as those occurring from 6:00 PM to 6:59 AM Monday through Thursday nights and from 6:00 PM on Friday evening to 6:59 AM on Monday morning; any deliveries outside of these times are considered daytime weekday deliveries (unexposed group). The timing of nighttime deliveries were anchored to the times of staff (i.e. nurses, medical officers, and physicians) shift changes as there is growing evidence indicating a potential association between improved patient outcomes (e.g., lower mortality rates) and improved hospital staff levels, such as nurses [18–20], with nurses playing a critical role in deliveries [21]; actual staffing numbers were not recorded in this study.

Definitions of outcome variables

Our study outcomes are categorized into three groups of adverse composite outcomes: (1) maternal, (2) birth, and (3) neonatal outcomes, based on recent WHO recommendations [29]. Missingness is likely not at random for the variables included in these composite outcomes, so we inferred missing as lack of evidence of that outcome in our models; thus, we interpret the lack of any of the relevant variables as lack of any of the above adverse outcomes.

The adverse composite maternal outcomes of interest include maternal death (defined as pregnant person dead at discharge); prolonged labor (defined as labor lasting ≥ 20 h); postpartum hemorrhage (≥ 500 ml blood loss for vaginal or ≥ 1000 ml for Caesarean delivery); and emergency Caesarean delivery.

The adverse composite birth outcomes of interest were stillbirth (defined as non-live birth with gestational age ≥ 28 weeks) or miscarriage/spontaneous abortion (defined as non-live birth with gestational age < 28 weeks); preterm birth (defined as live birth with a gestational age < 37 weeks and included very preterm birth (live birth with a gestational age < 32 weeks); small for gestational age (SGA, birth weight < 10th percentile for gestational age); low birth weight (LBW; defined as < 2500 g, for both live and stillbirths); and APGAR score < 7 at 5 minutes only.

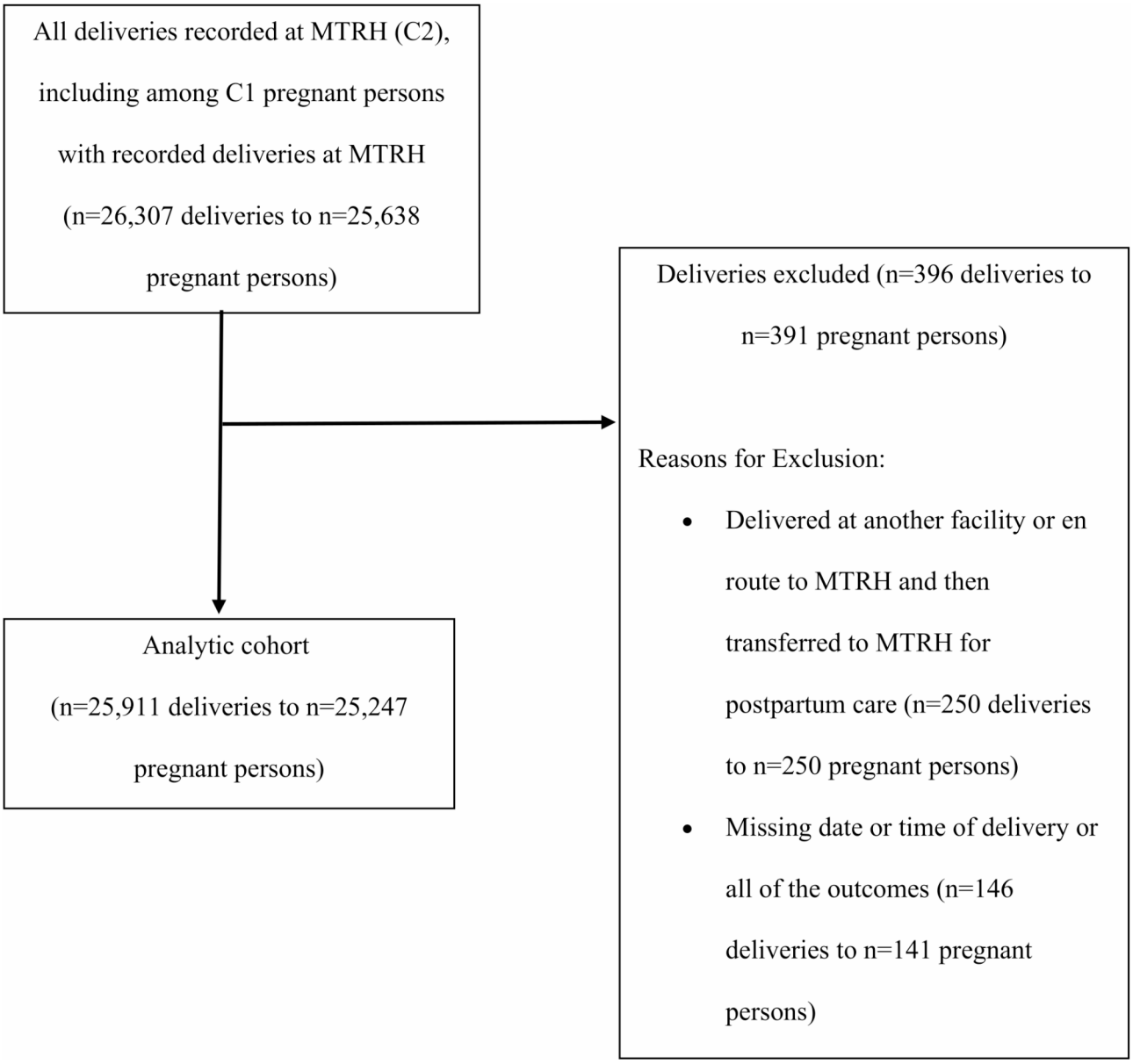

Fig. 1 Cohort flow diagram of Kenyan pregnant persons delivering at Moi Teaching and Referral University, MANGO study, September 2020-November 2023 ($n=25,911$ deliveries to $n=25,247$ pregnant persons)

The neonatal outcome of interest was neonatal death (defined as death prior to discharge from the hospital among live births).

Definitions of covariates possibly associated with study outcomes

Predictors potentially associated with study endpoints were determined a priori based on existing literature, team knowledge, and data availability and included: maternal age [30–33], parity [33, 34], gravidity [35], maternal or newborn ICU admission [36], APGAR (an acronym that stands for evaluation of newborn activity, pulse, grimace, appearance, and respiration) score [37, 38], maternal HIV status [39], alcohol use during pregnancy [40, 41], tobacco use during pregnancy [42], maternal medical conditions and medical complications of pregnancy [36], hereafter termed "maternal complications" (e.g., hypertensive complications of pregnancy, diabetes, asthma, etc.) [43, 44], obstetric complications (e.g., prior history of Caesarean delivery or stillbirth), fetal complications (e.g., congenital abnormality of infant noted during antenatal care), and transfer in from another facility to MTRH for delivery [45]. Greater details describing the covariates and inclusion in each model can be found in Supplementary Materials, Additional File 1.

Statistical analysis

We compared descriptive statistics of characteristics at delivery using frequency and percentage for the total cohort included in analysis as well as by groups of those who do vs. do not have adverse outcomes. We utilized multivariable Poisson regression models, with log link and robust standard errors, to assess the association between nighttime/weekend deliveries and the risk of adverse composite maternal, birth, and neonatal outcomes. In the multivariate models, we included covariates with p-value < 0.20 in the univariate models to assess their joint effects, alongside nighttime/weekend delivery, on the adverse outcomes. We report adjusted risk ratios (aRR) with 95% confidence intervals (95% CI). Of note, we used each pregnant person as the unit of analysis for the models for maternal outcomes while we used each neonate as the unit of analysis for the models for birth and neonatal outcomes. The birth and neonatal outcomes models clustered for multiple gestations (e.g., twins) to allow for correlations between births for the same women when multiple gestations were present. Post-hoc we conducted sensitivity analyses varying our exposure (time of delivery, i.e. either nighttime or weekend deliveries) for the composite outcomes models for maternal and birth outcomes, where the combined nighttime/weekend deliveries variable had a slightly protective association with adverse composite maternal and birth outcomes. We also conducted sensitivity analyses contrasting weekday vs. weekend time of delivery as predictors of individual maternal or birth outcomes, where there were differences between the distribution of that outcome among the nighttime/weekend and daytime/weekday deliveries. The data were managed and analyzed in R version 4.2.2 and SAS version 9.4 was used to prepare the analysis datasets. Since this is a secondary analysis of the MANGO Kenya cohort data, we had not calculated *a priori* sample size when designing this study.

Results

Baseline characteristics

A total of 25,911 neonates born to 25,247 pregnant persons were included in this study (Fig. 1). More than half of the deliveries occurred during the nighttime or on the weekend (62.6%; Table 1). The median gestational age was 39 weeks (interquartile range [IQR]: 37, 40) and the median maternal age was 27 years (IQR: 23, 31) at delivery. The median parity was 1 (IQR: 0, 2) and gravidity was 2 (IQR: 1, 3). Most of the pregnant persons were not living with HIV (96.1%) and few were transferred in for delivery (7.1%).

Description of adverse maternal, birth, and neonatal outcomes

About three out of every four (n = 19,501, 75.3%) deliveries were classified as spontaneous vaginal delivery, 384 (1.5%) were elective Caesarean delivery, and 5,581 (21.5%) were emergency Caesarean delivery (Table 1). Most pregnant persons (n = 22,159, 99.9%) and most neonates (n = 23,743, 99.3%) were discharged alive from the hospital. The median birth weight of live birth neonates was 3.0 kg (IQR: 2.7, 3.4). The median APGAR score at 1 minute was 9 (IQR: 8, 9) and at 5 minutes was 10 (IQR: 9, 10).

Associations with adverse maternal outcomes

In multivariate modeling, pregnant persons who had nighttime or weekend delivery times had lower risk of adverse composite maternal outcomes (aRR 0.92, 95% CI: 0.88, 0.96; Table 2). Additionally, the following factors were associated with adverse composite maternal outcomes: maternal age, maternal complications, obstetric complications, and maternal transfer-in status. Pregnant persons aged < 24 years had lower risk of adverse composite maternal outcomes (aRR 0.86; 95% CI: 0.81, 0.91) and pregnant persons aged > 35 years had higher risk of adverse composite maternal outcomes (aRR 1.13; 95% CI: 1.06, 1.21) compared to pregnant persons aged 25–35 years. Pregnant persons with maternal complications had an increased risk of adverse composite maternal outcomes (aRR 1.25; 95% CI: 1.19, 1.32) compared to pregnant persons with no maternal complications. Pregnant persons with obstetric complications had an increased risk of adverse composite maternal outcomes (aRR 2.16; 95% CI: 2.02, 2.31) compared to pregnant persons with no obstetric complications. Pregnant persons transferred in for delivery were at an increased risk of adverse maternal outcomes (aRR 1.42; 95% CI: 1.32, 1.52) compared to non-transferred pregnant persons.

Associations with adverse birth outcomes

In multivariate modeling, infants with nighttime or weekend delivery time had lower risk of adverse composite birth outcomes (aRR 0.92, 95% CI: 0.88, 0.96; Table 3). Additionally, the following factors were associated with adverse composite birth outcomes: higher maternal age, maternal intensive care unit (ICU) admission, maternal complications, obstetric complications and maternal transfer-in status. Pregnant persons aged < 24 years had lower risk of adverse composite birth outcomes (aRR 0.85; 95% CI: 0.81, 0.91) and pregnant persons aged > 35 years had higher risk of adverse composite birth outcomes (aRR 1.13; 95% CI: 1.05, 1.21) compared to pregnant persons aged 25–35 years. Pregnant persons with maternal complications had an increased risk of adverse composite maternal outcomes (aRR 1.23; 95% CI: 1.17,

Table 1 Distribution of characteristics at delivery among Kenyan pregnant persons delivering at Moi Teaching and Referral Hospital, MANGO study, September 2020-November 2023

Characteristics	Total neonates delivered, N (%) or median (IQR) (n = 25,911)[1]	Neonates delivered during weekday daytimes, N (%) or median (IQR) (n = 9697)	Neonates delivered during weekends/nighttimes, N (%) or median (IQR) (n = 16214)
Maternal characteristics			
Maternal age at delivery (median, IQR)	26.5 (22.9, 31.3)	26.8 (22.9, 31.5)	26.4 (22.8, 31.1)
Missing	54 (0.2)	15 (0.1)	39 (0.2)
Gestational age at delivery, weeks (median, IQR)	39.0 (37.0, 40.0)	39.0 (37.0, 40.0)	39 (37.0, 40.0)
Missing	821 (3.2)	296 (3.1)	525 (3.2)
Parity (median, IQR)	1.0 (0, 2.0)	1.0 (0, 2.0)	1.0 (0, 2.0)
0	10352 (39.9)	3686 (38.0)	6666 (41.1)
1	7324 (28.3)	2807 (28.9)	4517 (27.8)
2	4425 (17.1)	1736 (17.9)	2689 (16.6)
3 or more	3795 (14.6)	1464 (15.1)	2331 (14.4)
Missing	15 (0.1)	4 (0.04)	11 (0.1)
Gravidity (median, IQR)	2.0 (1.0, 3.0)	2.0 (1.0, 3.0)	2.0 (1.0, 3.0)
1	9796 (37.8)	3504 (36.1)	6292 (38.8)
2	7234 (27.9)	2727 (28.1)	4507 (27.8)
3	4459 (17.2)	1755 (18.1)	2704 (16.7)
4 or more	4403 (16.9)	1705 (17.6)	2698 (16.6)
Missing	19 (0.1)	6 (0.1)	13 (0.1)
Maternal medical conditions & medical complications of pregnancy[2]			
Yes	3530 (13.6)	1363 (14.1)	2167 (13.4)
No	22381 (86.4)	8334 (85.9)	14047 (86.6)
Obstetric complications[3]			
Yes	1247 (4.8)	442 (4.5)	805 (4.9)
No	24664 (95.2)	9255 (95.4)	15409 (95.0)
Fetal complications[4]			
Yes	22 (0.08)	13 (0.13)	9 (0.05)
No	25889 (99.9)	9684 (99.9)	16205 (99.9)
Alcohol use during pregnancy			
Yes	29 (0.10)	9 (0.10)	20 (0.12)
No	25882 (99.9)	9688 (99.9)	16194 (99.9)
Tobacco use during pregnancy			
Yes	2 (0.01)	2 (0.02)	-
No	25909 (99.9)	9695 (99.9)	16214 (100)
Maternal HIV status			
Positive	1011 (3.9)	367 (3.8)	644 (4.0)
Negative	24900 (96.1)	9330 (96.2)	15570 (96.0)
Maternal transferred-in to study facility status			
Yes	1828 (7.0)	657 (6.8)	1171 (7.2)
No	23981 (92.5)	8997 (92.8)	14984 (92.4)
Missing	102 (0.4)	43 (0.4)	59 (0.4)
Neonatal characteristics			
Sex of child			
Male	13359 (51.5)	5018 (51.7)	8341 (51.4)
Female	12518 (48.3)	4661 (48.1)	7857 (48.5)
Ambiguous	13 (0.05)	6 (0.06)	7 (0.04)
Missing	21 (0.1)	12 (0.12)	9 (0.05)
Number of neonates born to each pregnant person (pregnant persons = 25247)			
One	24601 (97.4)	9143 (97.1)	15458 (97.7)
Two	630 (2.5)	269 (2.9)	361 (2.3)
Three	14 (0.05)	4 (0.04)	10 (0.1)

Table 1 (continued)

Characteristics	Total neonates delivered, N (%) or median (IQR) (n = 25,911)[1]	Neonates delivered during weekday daytimes, N (%) or median (IQR) (n = 9697)	Neonates delivered during weekends/nighttimes, N (%) or median (IQR) (n = 16214)
Four	2 (0.01)	1 (0.01)	1 (0.01)
NICU admission			
Yes	1754 (6.7)	662 (6.8)	1092 (6.7)
No	23234 (89.7)	8652 (89.2)	14582 (89.9)
Missing	923 (3.6)	383 (3.9)	540 (3.3)
Delivery timings (primary exposure)			
Nighttime (6:00 PM to 6:59 AM) delivery			
Yes	12605 (48.6)	–	12605 (77.7)
No	13306 (51.3)	9697 (100)	3609 (22.3)
Weekend (Saturday or Sunday) delivery			
Yes	7190 (27.7)	–	7190 (44.3)
No	18721 (72.2)	9697 (100)	9024 (55.6)
Maternal outcomes			
Mode of delivery			
Spontaneous vaginal delivery	19501 (75.3)	7069 (72.9)	12432 (76.7)
Spontaneous breech delivery	162 (0.6)	63 (0.6)	99 (0.6)
Elective Cesarean delivery	384 (1.5)	296 (3.05)	88 (0.5)
Emergency Cesarean delivery	5581 (21.5)	2155 (22.2)	3426 (21.1)
Assisted vaginal delivery	277 (1.1)	111 (1.1)	166 (1.0)
Missing	6 (0.02)	3 (0.03)	3 (0.02)
Prolonged labor (labor > = 20 hours)			
Yes	149 (0.6)	68 (0.7)	81 (0.5)
No	2567 (9.9)	1194 (12.3)	1373 (8.5)
Missing	23195 (89.6)	8435 (86.9)	14760 (91.0)
Postpartum hemorrhage[5]			
Yes	1233 (4.8)	454 (4.7)	779 (4.8)
No	23770 (91.7)	8906 (91.8)	14864 (91.7)
Missing	908 (3.5)	337 (3.5)	571 (3.5)
Maternal death at discharge			
No	22159 (85.5)	8031 (82.8)	14128 (87.1)
Yes	20 (0.1)	1 (0.01)	19 (0.1)
Missing	3732 (14.4)	1665 (17.2)	2067 (12.7)
Birth outcomes			
Birth outcome			
Live birth	25230 (97.4)	9455 (97.5)	15775 (97.3)
Stillbirth[6]	619 (2.4)	228 (2.3)	391 (2.4)
Miscarriage/spontaneous abortion[7]	62 (0.2)	14 (0.1)	48 (0.3)
Preterm birth[8]			
Yes	4355 (17.2)	1696 (17.9)	2659 (16.8)
No	20870 (82.7)	7757 (82.0)	13113 (83.1)
Missing	5 (0.02)	2 (0.02)	3 (0.02)
Very preterm birth[9]			
Yes	764 (3.0)	310 (3.3)	454 (2.9)
No	24461 (96.9)	9143 (96.7)	15318 (97.1)
Missing	5 (0.02)	2 (0.02)	3 (0.02)
Small for gestational age[10]			
Yes	3851 (15.3)	1470 (15.5)	2381 (15.1)
No	19953 (79.1)	7452 (78.8)	12501 (79.2)
Missing	1426 (5.6)	533 (5.6)	839 (5.7)
Very small for gestational age[11]			
Yes	1959 (7.8)	725 (7.7)	1234 (7.8)

Table 1 (continued)

Characteristics	Total neonates delivered, N (%) or median (IQR) (n = 25,911)[1]	Neonates delivered during weekday daytimes, N (%) or median (IQR) (n = 9697)	Neonates delivered during weekends/nighttimes, N (%) or median (IQR) (n = 16214)
No	21845 (86.6)	8197 (86.7)	13648 (86.5)
Missing	1426 (5.6)	533 (5.6)	893 (5.6)
Infant birth weight, kg (median, IQR)[12]	3 (2.7, 3.4)	3 (2.7, 3.4)	3 (2.7, 3,4)
Missing	59 (0.2)	27 (0.3)	32 (0.2)
Low birth weight [13]			
Yes	3490 (13.8)	1340 (14.2)	2150 (13.6)
No	21681 (85.9)	8088 (85.5)	13593 (86.2)
Missing	59 (0.2)	27 (0.3)	32 (0.2)
Very low birth weight[14]			
Yes	507 (2.0)	228 (2.4)	279 (1.7)
No	24664 (97.7)	9200 (97.3)	15464 (98.0)
Missing	59 (0.2)	27 (0.3)	32 (0.2)
APGAR score at 1 minute (median, IQR)	9.0 (8.0, 9.0)	9.0 (8.0, 9.0)	9.0 (8.0, 9.0)
Missing	336 (1.3)	107 (1.1)	229 (1.4)
APGAR score at 5 minutes (median, IQR)	10.0 (9.0, 10.0)	10.0 (9.0, 10.0)	10.0 (9.0, 10.0)
Missing	343 (1.4)	112 (1.2)	231 (1.5)
Neonatal outcomes			
Newborn death[15]			
Yes	165 (0.6)	65 (0.7)	100 (0.6)
No	25065 (99.3)	9390 (96.8)	15675 (96.7)
Neonate alive at discharge[16]			
Yes	23654 (91.3)	8724 (92.3)	14930 (94.6)
No	158 (0.6)	60 (0.6)	98 (0.6)
Missing	1418 (5.5)	671 (7.1)	747 (4.7)

Abbreviations: NICU = neonatal intensive care unit; IQR = interquartile range; LBW = low birth weight; SGA = small gestational age

[1] A total of *n* = 25,911 neonates were born to a total of *n* = 25,247 pregnant persons, with information on unique pregnant persons conveyed in Supplementary Table 1, Additional File 1

[2] Maternal medical conditions and medical complications of pregnancy consists of complications such as maternal age < 18 or > 35 years, chronic hypertension, hypertensive complications of pregnancy, including preeclampsia or eclampsia, pregnancy-induced hypertension, and gestational hypertension, anemia, asthma, diabetes, other conditions including the heart, kidney, etc.; infectious complications, such as syphilis; alcohol, tobacco, or other illicit drug use during pregnancy; negative rhesus status; peripartum complications, including gestational hypertension, preeclampsia, eclampsia, cardiomyopathy/cardiac disease, psychosis, endometritis, postpartum metritis, puerperal sepsis

[3] Obstetric complications consists of prior C-section, concern for the baby, fetal distress, preterm premature rupture of membranes, premature labor, antepartum hemorrhage, bad history of poor obstetric outcomes, including recurrent pregnancy loss or previous stillbirth, cephalo-pelvic disproportion, adverse presentation of the baby (e.g., breech, footling), failed induction, multiparous/grand multiparous, placenta previa, twin or triplet pregnancy

[4] Fetal complications consists of congenital abnormality of infant noted during antenatal care

[5] Hemorrhage within 24 h postpartum, ≥ 500 ml for vaginal,≥ 1000 ml for c-section

[6] Non-live birth with gestational age ≥ 28 weeks

[7] Non-live birth with gestational age < 28 weeks

[8] Live birth with a gestational age < 37 weeks

[9] Live birth with a gestational age < 32 week

[10] Neonate below the 10th percentile for weight for gestational age based on sex-specific intergrowth-21 standards

[11] Neonate below the 3rd percentile for weight for gestational age based on sex-specific intergrowth-21 standards

[12] Infant birth weight for both live births and stillbirths

[13] Birth weight < 2500 g

[14] Birth weight < 1500 g

[15] Newborn death, defined as death ≤ 28 days or prior to discharge after live birth. Discharge is typically within 24 h after birth

[16] Reflects neonate's vital status at time of discharge, typically within 24 h after birth

Table 2 The association between nighttime/weekend deliveries and adverse composite maternal outcomes (maternal death, prolonged labor, postpartum hemorrhage, and emergency Cesarean section), MANGO study, September 2020-November 2023 ($n = 25,247$ pregnant persons)

Characteristics	Adverse maternal outcome	No adverse maternal outcome	Unadjusted RR (95% CI)[1]	*p*-value	Adjusted RR (95% CI)[2]	*p*-value
Nighttime/weekend delivery						
Yes	3937 (27.81)	10222 (72.19)	**0.92 (0.89, 0.96)**	< 0.001	**0.92 (0.88, 0.96)**	< 0.001
No	2420 (30.05)	5632 (69.95)	Ref.		Ref.	
Maternal age						
< 24	1670 (25.83)	4795 (74.17)	**0.88 (0.84, 0.93)**	< 0.001	**0.86 (0.81, 0.91)**	< 0.001
24–35	3850 (29.16)	9353 (70.84)	Ref.		Ref.	
> 35	831 (33.29)	1665 (66.71)	**1.14 (1.07, 1.21)**	< 0.001	**1.13 (1.06, 1.21)**	< 0.001
Parity						
0	2449 (27.37)	6500 (72.63)	**0.95 (0.90, 0.99)**	0.05	1.00 (0.94, 1.05)	0.92
1	1814 (28.81)	4482 (71.19)	Ref.		Ref.	
2	1119 (29.77)	2640 (70.23)	1.03 (0.97, 1.10)	0.31	0.98 (0.92, 1.05)	0.59
3 or more	972 (30.41)	2224 (69.59)	1.05 (0.99, 1.13)	0.104	**0.94 (0.87, 1.01)**	0.01
Gravidity[3]						
1	2295 (27.17)	6152 (72.83)	0.96 (0.91, 1.01)	0.1		
2	1772 (28.41)	4465 (71.59)	Ref.			
3	1128 (29.79)	2658 (70.21)	1.04 (0.98, 1.11)	0.14		
4 or more	1155 (31.00)	2571 (69.00)	**1.08 (1.02, 1.16)**	0.006		
Maternal HIV status						
Positive	227 (28.95)	557 (71.05)	1.01 (0.90, 1.13)	0.83		
Negative	6130 (28.61)	15297 (71.39)	Ref.			
Maternal medical conditions & medical complications of pregnancy						
Yes	1164 (37.78)	1917 (62.22)	**1.40 (1.33, 1.47)**	< 0.001	**1.25 (1.19, 1.32)**	< 0.001
No	5116 (27.04)	13802 (72.96)	Ref.		Ref.	
Obstetric complications			.			
Yes	763 (71.78)	300 (28.22)	**2.71 (2.59, 2.83)**	< 0.001	**2.16 (2.02, 2.31)**	< 0.001
No	5594 (26.45)	15554 (73.55)	Ref.		Ref.	
Fetal complications						
Yes	9 (50.00)	9 (50.00)	**1.75 (1.10, 2.77)**	0.02	**1.06 (0.67, 1.68)**	0.79
No	6348 (28.60)	15845 (71.40)	Ref.		Ref.	
Maternal transfer-in						
Yes	896 (58.60)	633 (41.40)	**2.22 (2.11, 2.33)**	< 0.001	**1.42 (1.32, 1.52)**	< 0.001
No	5435 (26.40)	15152 (73.60)	Ref.		Ref.	

Abbreviations: RR = risk ratio; CI = confidence interval

Bold text indicates estimates with *p*-values < 0.05.

[1] The unadjusted models were modeled for each variable separately for the outcome using Poisson regression with natural logarithm (log) as the link function and robust standard errors.

[2] The adjusted model included the primary exposure (nighttime/weekend delivery) and any covariates with *p*-value < 0.20 in the unadjusted models, and used Poisson regression with natural log link and robust standard errors.

[3] Though parity and gravidity each have *p*-values < 0.20 in the unadjusted models, we included only parity in the adjusted model based on presumed collinearity between the two variables

1.29) compared to pregnant persons with no maternal complications. Pregnant persons with obstetric complications had an increased risk of adverse composite birth outcomes (aRR 2.10; 95% CI: 1.97, 2.24) compared to pregnant persons with no obstetric complications. Pregnant persons who were admitted to the ICU had a higher risk of adverse composite birth outcomes (aRR 1.53, 95% CI: 1.45, 1.62) compared to pregnant persons who were not admitted to the ICU. Pregnant persons transferred in for delivery had an increased risk of adverse composite birth outcomes (aRR 1.28, 95% CI: 1.19, 1.38) compared to non-transferred pregnant persons.

Associations with adverse neonatal outcomes

In multivariate modeling, there was no association between nighttime/weekend delivery time and neonatal

Table 3 The association between nighttime/weekend deliveries and adverse composite birth outcomes (non-live birth, preterm birth, small for gestational age, low birth weight, Apgar score < 7), MANGO study, September 2020-November 2023 ($n = 25,911$ neonates)

Characteristics	Adverse birth outcome	No adverse birth outcome	Unadjusted RR (95% CI)[1]	*p*-value	Adjusted RR (95% CI)[2]	*p*-value
Nighttime/weekend delivery						
Yes	5347 (34.79)	10024 (65.21)	0.99 (0.95, 1.02)	0.52	**0.92 (0.88, 0.96)**	< 0.001
No	3244 (35.19)	5974 (64.81)	Ref.		Ref.	
Maternal age						
< 24	2866 (39.64)	4364 (60.36)	**1.22 (1.18, 1.27)**	< 0.001	**0.85 (0.81, 0.90)**	< 0.001
24–25	4731 (32.43)	9856 (67.57)	Ref.		Ref.	
> 35	978 (35.94)	1743 (64.06)	**1.11 (1.05, 1.17)**	< 0.001	**1.13 (1.05, 1.21)**	< 0.001
Parity						
0	3616 (36.57)	6271 (63.43)	**1.13 (1.08, 1.18)**	< 0.001	0.99 (0.93, 1.04)	0.66
1	2253 (32.35)	4711 (67.65)	Ref.		Ref.	
2	1396 (33.35)	2790 (66.65)	1.03 (0.97, 1.09)	0.28	0.99 (0.93, 1.05)	0.72
3 or more	1320 (37.29)	2220 (62.71)	**1.15 (1.09, 1.22)**	< 0.001	0.94 (0.88, 1.01)	0.1
Gravidity[3]						
1	3418 (36.55)	5934 (63.45)	**1.13 (1.08, 1.18)**	< 0.001		
2	2232 (32.43)	4651 (67.57)	Ref.			
3	1394 (33.10)	2817 (66.90)	1.02 (0.97, 1.08)	0.46		
4 or more	1540 (37.32)	2587 (62.68)	**1.15 (1.09, 1.21)**	< 0.001		
ICU admission						
Yes	1112 (66.15)	569 (33.85)	**2.02 (1.94, 2.10)**	< 0.001	**1.53 (1.45, 1.62)**	< 0.001
No	7212 (32.73)	14825 (67.27)	Ref.		Ref.	
Maternal HIV status						
Yes	397 (44.86)	488 (55.14)	**1.29 (1.20, 1.39)**	< 0.001	0.96 (0.86, 1.07)	0.45
No	8194 (34.57)	15510 (65.43)	Ref.		Ref.	
Maternal medical conditions & medical complications of pregnancy						
Yes	1557 (46.39)	1799 (53.61)	**1.41 (1.35, 1.47)**	< 0.001	**1.23 (1.17, 1.29)**	< 0.001
No	6899 (32.87)	14088 (67.13)	Ref.		Ref.	
Obstetric complications						
Yes	619 (52.15)	568 (47.85)	**1.53 (1.44, 1.62)**	< 0.001	**2.10 (1.97, 2.24)**	< 0.001
No	7972 (34.07)	15430 (65.93)	Ref.		Ref.	
Fetal complications						
Yes	17 (80.95)	4 (19.05)	**2.32 (1.88, 2.86)**	< 0.001	0.91 (0.61, 1.37)	0.67
No	8574 (34.90)	15994 (65.10)	Ref.		Ref.	
Maternal transfer-in status						
Yes	925 (53.81)	794 (46.19)	**1.61 (1.53, 1.68)**	< 0.001	**1.28 (1.19, 1.38)**	< 0.001
No	7629 (33.50)	15145 (66.50)	Ref.		Ref.	

Abbreviations: RR = risk ratio; CI = confidence interval; ICU = intensive care unit

Bold text indicates estimates with *p*-values < 0.05.

[1] The unadjusted models were modeled for each variable separately for the outcome using Poisson regression with natural logarithm (log) as the link function, robust standard errors, and clustered on pregnant persons for multiple gestations.

[2] The adjusted model included the primary exposure (nighttime/weekend delivery) and any covariates with *p*-value < 0.20 in the unadjusted models, and used Poisson regression with natural log link and robust standard errors, robust standard errors, and clustered on pregnant persons for multiple gestations.

[3] Though parity and gravidity each have *p*-values < 0.20 in the unadjusted models, we included only parity in the adjusted model based on presumed collinearity between the two variables

death (aRR 0.96, 95% CI: 0.70, 1.30; Table 4). However, the following factors were associated with neonatal death: lower APGAR score, maternal parity of 4 or more, and maternal transfer-in status. Neonates with 5-minute APGAR scores of < 7 had an increased risk of neonatal death (aRR 68; 95% CI: 37, 126) compared to neonates with higher APGAR scores. Neonates born to maternal parity of 4 or more had an increased risk of neonatal death (aRR 2.17; 95% CI: 1.38, 3.39) compared to pregnant persons with parity of 2. Neonates born to pregnant people who were transferred in for delivery were at an increased risk of neonatal death (aRR 2.23; 95% CI: 1.58,

Table 4 The association between nighttime/weekend deliveries and adverse neonatal outcome of neonatal death, MANGO study, September 2020-November 2023 ($n = 25,911$ neonates)

Characteristics	Adverse outcome	No adverse outcome	Unadjusted RR (95% CI)[1]	*p*-value	Adjusted RR (95% CI)[2]	*p*-value
Nighttime/weekend delivery						
Yes	100 (0.63)	15675 (99.37)	0.92 (0.67. 1.26)	0.61	0.96 (0.70, 1.30)	0.79
No	65 (0.69)	9390 (99.31)	Ref.		Ref.	
Poor apgar score (< 7 at 5 min.)						
Yes	123 (13.53)	786 (86.47)	**92.7 (64.06, 134.15)**	< 0.001	**68.00 (36.77, 125.75)**	< 0.001
No	35 (0.15)	23943 (99.85)	Ref.		Ref.	
NICU admission						
Yes	80 (4.56)	1673 (95.44)	**13.39 (9.83, 18.25)**	< 0.001	1.18 (0.70, 2.00)	0.52
No	77 (0.34)	22525 (99.66)	Ref.		Ref.	
Parity						
0	63 (0.63)	10008 (99.37)	1.24 (0.83, 1.87)	0.29	0.97 (0.64, 1.47)	0.9
1	36 (0.50)	7132 (99.50)	Ref.		Ref.	
2	26 (0.60)	4275 (99.40)	1.20 (0.73, 1.99)	0.47	1.02 (0.65, 1.68)	0.95
3 or more	40 (1.09)	3635 (98.91)	**2.17 (1.38, 3.39)**	< 0.001	**1.81 (1.17, 2.80)**	0.01
Gravidity[3]						
1	57 (0.60)	9476 (99.40)	1.14 (0.76, 1.73)	0.52		
2	37 (0.52)	7038 (99.48)	Ref.			
3	28 (0.65)	4311 (99.35)	1.23 (0.76, 2.01)	0.39		
4 or more	43 (1.01)	4221 (98.99)	**1.93 (1.24, 2.99)**	0.003		
Maternal HIV status						
Yes	9 (0.91)	978 (99.09)	1.42 (0.73, 2.77)	0.31		
No	156 (0.64)	24087 (99.36)	Ref.			
Maternal transfer-in status						
Yes	45 (2.70)	1623 (97.30)	**5.32 (3.79, 7.47)**	< 0.001	**2.23 (1.58, 3.15)**	< 0.001
No	119 (0.51)	23344 (99.49)	Ref.		Ref.	

Abbreviations: RR = risk ratio; CI = confidence interval; NICU = neonatal intensive care unit

Bold text indicates estimates with *p*-values < 0.05.

[1] The unadjusted models were modeled for each variable separately for the outcome using Poisson regression with natural logarithm (log) as the link function, robust standard errors, and clustered on pregnant persons for multiple gestations.

[2] The adjusted model included the primary exposure (nighttime/weekend delivery) and any covariates with *p*-value < 0.20 in the unadjusted models, and used Poisson regression with natural log link, robust standard errors, and clustered on pregnant persons for multiple gestations.

[3] Though parity and gravidity each have *p*-values < 0.20 in the unadjusted models, we included only parity in the adjusted model based on presumed collinearity between the two variables

3.15) compared to neonates born to non-transferred pregnant persons.

Sensitivity analyses

After separating the primary exposure by nighttime (weekdays only) and weekends, we saw a significant protective association between weekend deliveries and composite adverse maternal outcomes (aRR 0.91; 95% CI: 0.87, 0.95; Supplementary Tables 2 and 3, Additional File 1) and composite adverse birth outcomes (aRR 0.91; 95% CI: 0.87, 0.95; Supplementary Tables 3 and 4, Additional File 1). We conducted further analyses separating each unadjusted model by each maternal or birth outcome that varied by primary exposure group. Based on this analysis, emergency Caesarean deliveries occurred less frequently on weekends (unadjusted risk ratio [uRR] 0.91; 95% CI: 0.87, 0.96) but maternal deaths were more frequent with weekend deliveries, though not statistically significantly potentially due to small numbers (uRR 1.66; 95% CI 0.68, 4.07; Supplementary Table 5, Additional File 1). Similarly, when separating each unadjusted model by each birth outcome that varied by the primary exposure group, we saw that both LBW (uRR 0.93; 95% CI 0.86, 0.99) and preterm birth (uRR 0.92; 95% CI 0.87, 0.98) occurred less frequently on weekends (Supplementary Table 6, Additional File 1).

Discussion

In this study assessing associations between nighttime/weekend delivery and adverse maternal, birth, or neonatal outcomes, we found a subtle, protective association between nighttime/weekend deliveries and our

composite maternal and birth outcomes. We found no significant associations between the timing of delivery and neonatal death. Our analysis did reveal that other individual-level factors, such as maternal transfer-in status or obstetric complications, were significantly associated with these adverse pregnancy outcomes. Greater attention to these individual-level factors may be considered in overall pregnancy care in order to promote better outcomes for pregnant persons and their neonates.

We originally hypothesized that nighttime and weekend deliveries in the MANGO study might be associated with an increased risk of adverse pregnancy outcomes compared to daytime and weekday deliveries. We did not observe these associations, and, furthermore, saw a slight protective association between weekend deliveries and composite maternal and birth outcomes. It is possible that clinical staff at nighttime and on weekends, while fewer in numbers, may be more skilled, experienced, or attentive than weekday staff; one analysis suggested deliveries with senior staff are associated with fewer adverse neonatal outcomes [23]. Our subsequent *post-hoc* analyses suggest that emergency Caesarean deliveries, LBW, and preterm birth occurred less frequently on weekends. Emergency Caesarean deliveries for high-risk pregnancies may have been less commonly performed during these times. A possible explanation for this pattern is that it is common practice, in HIC and LMIC alike, for pregnant persons to labor longer on weekends [46]. Similarly, labor might have been more likely to be induced during daytime on weekdays while pregnant persons were more likely to labor without being induced during the nighttime [46–48]. It is also possible that misclassification for elective vs. emergency Caesarean deliveries was a factor, resulting in some Caesarean deliveries being classified as elective more often during the daytime compared to nighttime. Lastly, the subtle protective associations with weekend deliveries we observed may be capturing other phenomena external to the health system but correlated with weekend deliveries; arguably, birth outcomes such as preterm birth, LBW, or SGA have few direct pathophysiologic connections to delivery timings, as these outcomes often develop over weeks or longer, so an association with delivery timings may suggest another phenomenon. Ultimately, that we did not observe adverse associations with nighttime or weekend deliveries is reassuring overall. These findings may in part be attributed to our study site, which is the second largest medical training facility in Kenya and is a relatively well-resourced delivery center as compared to lower tier health centers in Kenya or other LMICs. It is also possible that staffing overall is relatively robust at this urban facility and that staff at our study site were already well equipped to handle some of the delivery complications that require additional levels of care [49, 50]. Thus, the observed findings may not reflect those of other, lower-tier or rural facilities in Kenya. Overall, we suggest interpreting these findings as exploratory; future analyses should further adjudicate this possible association and provide granularity in both exposure and outcome ascertainment.

Apart from our primary exposure-outcome relationship, we found other factors more strongly associated with our outcomes of interest other than the timing of delivery. For example, we found a strong association between transfer-in status and adverse composite maternal, birth, and neonatal outcomes. A potential and likely reason for this pattern is that pregnant persons may need to be transferred if they are experiencing a more severe condition (as the study site is a referral tertiary hospital and complex cases are transferred in), in which case, they may also already be at a higher risk of adverse pregnancy outcomes. Secondly, there are associated factors with transferring pregnant persons that may add inherent risks such as, travel time, distance, and handling possible complications during transport [51]. We also observed significant associations between maternal and obstetric complications, ICU or neonatal ICU admissions, higher parity, and some of our adverse pregnancy outcomes. Other studies have found an association between non-communicable disease complications, higher parity, and ICU admission and adverse pregnancy outcomes [33, 36].

We considered the timing of delivery a proxy for staffing numbers in maternity delivery units, as suggested by others [23, 52]. Moussa et al. discuss the potential influence of shift schedules on this association; they found that patients hospitalized during a shift change and being cared for by varying providers could affect birth outcomes [52]. Timing of access to care has been associated with adverse outcomes in other areas in medicine [53–55]; for instance, presenting during the weekend with a heart attack was associated with worse outcomes than presenting during the weekday [56–58]. However, it is possible that timing of delivery does not serve as a good surrogate for actual staffing ratios. Ultimately, enumeration of actual staffing ratios and roles, inclusion of a greater distribution of types of facilities, and a comprehensive understanding of maternity ward patterns would help better elicit the relationship between health systems factors and adverse outcomes.

Strengths and limitations

Our work exhibits several strengths. It is one of the few studies attempting to investigate the potential influence that staffing and timing of deliveries may have on adverse pregnancy outcomes in a LMIC setting. Other studies investigating timing of deliveries and adverse pregnancy outcomes focused on pregnancies with particular conditions, rather than the general pregnant population, or focused on a particular adverse outcome [52, 59–61].

Additionally, healthcare system factors were often overlooked in these studies, however our study discussed how these factors could potentially influence this exposure-outcome relationship. Moreover, these studies were largely conducted within HIC. This is especially important as adequately staffing delivery units in various LMIC settings is a major challenge for public sectors in LMICs, driven by various factors, including poor compensation, "brain drain", and more [62–64].

Nonetheless, our work faces limitations. One, the study sample is derived entirely from a large, relatively-well resourced, tertiary care facility, meaning that this study may not capture the relationship between nighttime/weekend delivery and adverse birth outcomes on a broader scale, limiting generalizability to lower level and rural facilities, that may not be as well-resourced. More diverse sampling of health facilities should be pursued in future research. Two, we used the timing of delivery as a gross proxy for staffing, and while this has been an adequate proxy in other areas of research, actual enumeration of staff availability might have better illuminated the relationships of interest in this work. Three, we did not track differential data capture or quality by timing of deliveries, where it is plausible data quality at nighttime or weekends lags behind quality at daytime. Four, our study did not track induced labor well; thus, we are not able to further ascertain induced vs. "natural" preterm birth. Similarly, indications for elective vs. emergency Caesearan deliveries would help better elucidate exact patterns of these deliveries on weekends vs. weekdays. Five, our ability to fully account for the variety of potential confounders, such as socioeconomic status, access to care, or community-level influences, was limited.

Conclusions

In this analysis of 25,911 neonates delivered in western Kenya, we observed a slightly protective association between nighttime/weekend delivery and adverse maternal and birth outcomes and no significant association between nighttime/weekend delivery and early neonatal death. However, other factors, such as maternal transfer-in status, maternal and obstetric complications, higher parity, and intensive care admissions, were significantly associated with adverse pregnancy outcomes. Overall, we suggest interpreting these findings as exploratory. Future analyses should further adjudicate this possible association and provide granularity in both exposure and outcome ascertainment, particularly regarding staffing, to ensure effective clinical practices are in place to reduce maternal and neonatal health risks. Factors within the hospital, such as skilled staffing, sufficient staffing, and shift schedules may be important to consider in optimizing healthy deliveries. These findings may also help hospital systems identify individual-level factors for pregnant persons with greater risk of adverse pregnancy outcomes. Given the global push to encourage in-facility deliveries, future work needs to help articulate what health systems factors may influence adverse pregnancy outcomes in LMIC settings.

Abbreviations

LMIC	Low-middle income country
HIC	High income country
MANGO	Measuring Adverse Pregnancy and Newborn Congenital Outcomes study
MTRH	Moi Teaching and Referral Hospital
ANC	Antenatal clinic
AMPATH	Academic Model for Providing Access to Healthcare
MOH	Ministry of Health
SGA	Small for gestational age
LBW	Low birth weight
aRR	Adjusted risk ratio
95% CI	95% confidence intervals
IQR	Interquartile range
ICU	Intensive care unit
uRR	Unadjusted risk ratio

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12884-025-07581-5.

Supplementary Material 1

Acknowledgements

We are most grateful for the participants' support, study sites' clinical care staff, including the nurses, and facility leadership. We would also like to thank the larger East Africa International Epidemiology Databases for AIDS (EA-IeDEA) for their overall support of this project.

Author contributions

M.K.V., J.S., J.H., E.W., A.C., and R.C.P. were involved in the conceptualization of the manuscript. P.M., H.E.K., B.M., C.T.Y., M.K.V., J.S., and R.C.P. aided in data curation and analysis. The initial draft of the manuscript was written by M.K.V., J.S., R.C.P., and P.M. All authors partook in critical review of the manuscript and full review of the manuscript. Decisions for the submission of the manuscript were made by M.K.V., J.S., and R.C.P.

Funding

The East Africa International Epidemiology Databases to Evaluate AIDS (IeDEA) is supported by the U.S. National Institutes of Health's National Institute of Allergy and Infectious Diseases, the ***Eunice Kennedy Shriver*** National Institute of Child Health and Human Development (NICHD), the National Cancer Institute, the National Institute of Mental Health, the National Institute on Drug Abuse, the National Heart, Lung, and Blood Institute, the National Institute on Alcohol Abuse and Alcoholism, the National Institute of Diabetes and Digestive and Kidney Diseases, the Fogarty International Center, and the National Library of Medicine (#U01AI069911). Additionally, the following individuals' efforts were supported by additional funding from the ***Eunice Kennedy Shriver*** National Institute of Child Health and Human Development: James G. Carlucci (K23HD109056) and John Humphrey (K23HD105495). The funders had no role in study design, analysis, or decision to publish.

Data availability

Datasets utilized in this analysis can be made available upon request to the senior author (RCP) with appropriate documentation of ethics reviews and data sharing agreements.

Declarations

Ethics approval and consent to participate

The MANGO study was conducted in accordance with the Declaration of Helsinki, and approved by the Moi University/Moi Teaching and Referral Hospital Institutional Research and Ethics Committee in Kenya (#0004301) and the Indiana University Institutional Review Board in the United States (#16976). A research permit to conduct the study was also granted by the National Commission for Science, Technology and Innovation (NACOSTI) in Kenya (#NACOSTI/P/24/32597). Written informed consent was obtained from women approached to participate in C1 and for their infant's participation in C3. A waiver of consent was granted for the activities in C2 by the Moi University/Moi Teaching and Referral Hospital Institutional Research and Ethics Committee and the Indiana University Institutional Review Board.

Consent for publication

No consent for publication itself was obtained from study participants, though participants consented to use of their de-identified data in publications.

Competing interests

The authors declare no competing interests.

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Received: 16 April 2024 / Accepted: 8 April 2025
Published online: 25 April 2025

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