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Full Length Research Article

A SURVIVAL ANALYSIS OF INFANT MORTALITY RATE: EVIDENCE FROM BARAU DIKKO TEACHING HOSPITAL, KADUNA, NIGERIA

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ABSTRACT
Infant mortality remains a major public health concern, particularly in low- and middle-income countries, where neonatal and infant deaths contribute substantially to under-five mortality. This study investigated the factors associated with infant mortality among infants admitted to Barau Dikko Teaching Hospital, Kaduna, Nigeria, using survival analysis techniques. A retrospective cohort design was adopted, utilising secondary data extracted from hospital records covering the period from 2015 to 2025. The Cox proportional hazards model was employed to examine the effects of birth weight, gestational age, five-minute Apgar score, maternal age, maternal educational attainment, and the number of antenatal care visits on infant survival. A total of 100 infants were included in the analysis, of whom 20 experienced the event of interest (death) during the follow-up period, while the remaining observations were right-censored. The findings revealed that gestational age was the only statistically significant predictor of infant mortality (HR = 0.755, 95% CI: 0.572–0.995, p = 0.046). Specifically, each additional week of gestation was associated with an approximately 24.5% reduction in the hazard of infant death. Although birth weight exhibited a protective effect (HR = 0.999, p= 0.081), its association with infant mortality was not statistically significant at the 5% significance level. Likewise, five-minute Apgar score, maternal age, maternal educational attainment, and the number of antenatal care visits did not significantly influence infant survival. The fitted Cox model demonstrated good predictive performance, with a concordance statistic of 0.874. However, assessment of the proportional hazards assumption using Schoenfeld residuals indicated significant violations for gestational age and the number of antenatal care visits, suggesting that the effects of these covariates varied over time. These findings indicate that extended Cox models incorporating time-dependent covariates may provide a more appropriate framework for future analyses. The study concludes that gestational age is the most important determinant of infant survival among the factors examined. The findings underscore the importance of interventions aimed at preventing preterm births, improving the quality and utilisation of antenatal care services, and strengthening neonatal healthcare to reduce infant mortality. The study further contributes hospital-based empirical evidence from Northern Nigeria, thereby enriching the existing literature on infant survival and providing useful information for healthcare practitioners and policymakers.

Keywords: Infant mortality; Survival analysis; Cox proportional hazards model; Gestational age; Birth weight; Antenatal care; Neonatal survival; Kaduna State; Nigeria.

INTRODUCTION
Infant mortality remains one of the most important indicators of population health, socioeconomic development and the effectiveness of healthcare systems. It is defined as the death of a child before reaching one year of age. It reflects the quality of maternal and child healthcare, nutritional status, environmental conditions and access to essential health services. Consequently, the infant mortality rate is widely used to assess population health and to evaluate national and global health interventions (World Health Organization [WHO], 2024).

Although remarkable progress has been made in reducing infant mortality worldwide over the past three decades, the burden remains disproportionately high in low- and middle-income countries, particularly in sub-Saharan Africa (You et al., 2015). Improvements in maternal healthcare, childhood immunisation, nutrition and disease prevention have contributed substantially to reductions in infant deaths; nevertheless, preventable causes such as prematurity, birth asphyxia, neonatal infections and congenital abnormalities continue to account for a large proportion of infant mortality (Lawn et al., 2014; Black et al., 2016; Liu et al., 2016; UNICEF, 2023).

Nigeria continues to experience one of the highest infant mortality rates globally despite sustained efforts by government agencies and international organisations to improve maternal and child health. Evidence from the Nigeria Demographic and Health Survey (NDHS) (2018) indicates that infant deaths contribute substantially to under-five mortality and that considerable disparities exist across geographical regions, socioeconomic groups and levels of access to healthcare services (National Population Commission [NPC] & ICF International (formerly Inner City Fund), 2019). These disparities underscore the need for continued investigation into the factors influencing infant survival, particularly within tertiary healthcare facilities where high-risk pregnancies and neonatal complications are frequently managed.

The determinants of infant mortality are complex and involve biological, maternal, socioeconomic and healthcare-related factors. Among the biological determinants, gestational age and birth weight have consistently been identified as strong predictors of infant survival (Kramer, 1987; Victora et al., 1987; Ananth & Platt, 2004). Premature infants are especially vulnerable because physiological immaturity increases the risk of respiratory distress, infections, feeding difficulties and other neonatal complications, all of which contribute to increased mortality. Likewise, infants with low birth weight are more susceptible to adverse health outcomes and have lower survival probabilities than infants born with normal birth weight (Kramer, 1987; Victora et al., 1987).

Maternal characteristics also play a significant role in determining infant survival. Maternal educational attainment has been

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associated with improved health literacy, greater utilisation of maternal healthcare services, better infant feeding practices and improved childcare behaviours, all of which contribute to enhanced infant survival (Kim & Saada, 2013; Kunnuji et al., 2021). Similarly, maternal age has been shown to influence neonatal and infant outcomes, with pregnancies occurring during adolescence or advanced maternal age being associated with increased risks of preterm delivery, low birth weight and infant mortality (Rutstein, 2005). In addition, adequate antenatal care enables the early detection and management of pregnancy-related complications, thereby improving maternal and neonatal health outcomes (Federal Ministry of Health, 2020; WHO, 2023).

From a methodological perspective, studies of infant mortality require statistical methods that incorporate both the occurrence and timing of death and appropriately account for censored observations. Conventional regression techniques, such as logistic regression, focus primarily on whether an event occurs and do not adequately account for variation in survival time. Survival analysis provides a more suitable analytical framework because it simultaneously considers the timing of events and the presence of censoring (Hosmer et al., 2008). Among survival models, the Cox proportional hazards model remains one of the most widely applied owing to its flexibility, ease of interpretation and ability to estimate the effects of multiple explanatory variables without specifying the baseline hazard function (Cox, 1972; Kleinbaum & Klein, 2012).

Several studies have employed survival analysis to investigate the determinants of infant and child mortality (Ananth & Platt, 2004; Lawn et al., 2014; Liu et al., 2016; Musa et al., 2020; Kunnuji et al., 2021). Kunnuji et al. (2021), using data from the 2018 Nigeria Demographic and Health Survey, reported that maternal education, household wealth and utilisation of healthcare services significantly influenced infant survival. Musa et al. (2020) similarly identified birth weight as a significant predictor of child survival and emphasised the importance of maternal healthcare services. Furthermore, Eke and Ewere (2021) reported significant associations between infant mortality and maternal education, socioeconomic status and healthcare accessibility in Nigeria.

Despite these important contributions, existing studies have relied predominantly on nationally representative survey data, with relatively few investigations based on clinical records from tertiary healthcare institutions. Consequently, there is limited evidence on survival patterns among hospitalised infants in Northern Nigeria, particularly at Barau Dikko Teaching Hospital in Kaduna State. Hospital-based studies are essential because they provide detailed clinical information often unavailable in population surveys and enable a more comprehensive assessment of factors influencing infant survival in high-risk populations.

This study, therefore, applies the Cox proportional hazards model to examine factors associated with infant mortality among infants admitted to Barau Dikko Teaching Hospital in Kaduna between 2015 and 2025. Specifically, the study investigates the effects of birth weight, gestational age, five-minute Apgar score, maternal age, maternal educational attainment and the number of antenatal care visits on infant survival. In addition to identifying significant predictors of infant mortality, the study evaluates the proportional hazards assumption using Schoenfeld residual diagnostics. By utilising hospital-based clinical data from one of the major tertiary healthcare institutions in Northern Nigeria, the study provides context-specific evidence that complements findings from nationally representative surveys and contributes to the development of evidence-based strategies to improve infant survival and reduce infant mortality in Nigeria.

Concept of Infant Mortality

Infant mortality refers to the death of a live-born child before reaching one year of age. It is commonly measured by the infant mortality rate (IMR), defined as the number of infant deaths per 1,000 live births in a given year. The infant mortality rate is widely recognised as one of the most important indicators of a country's health status, socioeconomic development and the effectiveness of its healthcare system because it reflects the combined influence of maternal health, nutrition, environmental conditions, healthcare accessibility and public health interventions (World Health Organization [WHO], 2024).

Over the past three decades, substantial reductions in infant mortality have been achieved globally through improvements in maternal and neonatal healthcare, expanded immunisation programmes, better nutrition, improved sanitation and advances in medical technology. Nevertheless, infant mortality remains unacceptably high in many low- and middle-income countries, particularly in sub-Saharan Africa, where inadequate healthcare infrastructure, poverty and limited access to quality healthcare continue to hinder progress (UNICEF, 2023).

According to UNICEF (2023), the leading causes of infant mortality include complications arising from preterm birth, birth asphyxia, neonatal infections, congenital anomalies and low birth weight. Most of these causes are preventable through timely access to quality maternal healthcare, skilled birth attendance and effective neonatal care.

Nigeria continues to record one of the highest infant mortality rates globally despite considerable investments in maternal and child health programmes. The Nigeria Demographic and Health Survey (NDHS) 2018 reported marked regional and socioeconomic disparities in infant mortality, indicating that children born in disadvantaged households and underserved communities remain at substantially higher risk of death during infancy (National Population Commission [NPC] & ICF, 2019). Consequently, identifying the determinants of infant mortality remains essential for developing effective public health interventions and achieving the Sustainable Development Goals relating to child survival.

Determinants of Infant Mortality

Infant mortality is influenced by a complex interaction of biological, maternal, socioeconomic and healthcare-related factors. Previous studies have consistently demonstrated that gestational age, birth weight, maternal characteristics and healthcare utilisation are among the most important determinants of infant survival.

Gestational age is one of the strongest predictors of infant survival. Infants born prematurely are more susceptible to respiratory distress syndrome, infections, neurological disorders and feeding difficulties because of physiological immaturity. Consequently, the risk of infant mortality decreases as gestational age increases (Kramer, 1987; Ananth & Platt, 2004). Numerous epidemiological studies have identified prematurity as one of the leading causes of neonatal and infant mortality worldwide.

Birth weight is another important determinant of infant survival. The World Health Organization classifies infants weighing less than 2,500 grams at birth as having low birth weight. Such infants experience significantly higher risks of illness, impaired growth and mortality because of underdeveloped physiological systems and increased vulnerability to infections (Kramer, 1987). Victora et al.

(1987) reported a strong inverse relationship between birth weight and infant mortality, demonstrating that infants with higher birth weights generally have better survival outcomes.

Maternal education plays a significant role in improving infant survival by enhancing health literacy, promoting appropriate healthcare-seeking behaviour and increasing adherence to recommended maternal and child healthcare practices. Educated mothers are more likely to attend antenatal clinics, deliver in health facilities and adopt appropriate infant feeding practices, thereby improving child survival (Kim & Saada, 2013; Kunnuji et al., 2021).

Maternal age has also been identified as an important determinant of infant mortality. Pregnancies occurring among adolescent mothers and women of advanced maternal age are associated with increased risks of preterm birth, low birth weight and neonatal complications. Consequently, infants born to mothers at the extremes of reproductive age generally experience higher mortality rates than those born to mothers within the optimal reproductive age group (Rutstein, 2005).

Antenatal care provides an opportunity for the early detection and management of pregnancy-related complications, nutritional counselling, health education and routine monitoring of maternal and fetal wellbeing. Adequate antenatal care has been associated with improved pregnancy outcomes and reduced risks of neonatal and infant mortality (Federal Ministry of Health, 2020; World Health Organization, 2023). However, the effectiveness of antenatal care depends not only on the number of visits attended but also on the quality and timing of the services provided.

Socioeconomic Factors such as household income, maternal employment, educational attainment, place of residence and access to healthcare facilities also influence infant survival. Infants born into economically disadvantaged households are often exposed to poor nutrition, overcrowding, inadequate sanitation and delayed access to healthcare services, all of which increase the risk of infant mortality (Kim & Saada, 2013).

Empirical Review

Several studies have applied survival analysis to investigate the determinants of infant and child mortality.

Kunnuji et al. (2021) analysed data from the Nigeria Demographic and Health Survey using survival analysis techniques. They reported that maternal education, household wealth, healthcare utilisation and place of residence significantly influenced infant survival.

Musa et al. (2020) applied the Cox proportional hazards model to examine determinants of under-five mortality in Nigeria. They found that birth weight was a significant predictor of child survival, emphasising the importance of quality maternal healthcare services.

Similarly, Eke and Ewere (2021) reported significant associations between infant mortality and maternal education, socioeconomic status and healthcare accessibility, highlighting the importance of improving maternal education and strengthening healthcare infrastructure.

Ananth and Platt (2004) demonstrated that gestational age remains one of the strongest predictors of neonatal mortality, while Victora et al. (1987) established a strong inverse relationship between birth weight and infant mortality.

At the global level, Lawn et al. (2014) and Liu et al. (2016) identified prematurity, birth complications and neonatal infections as the leading causes of neonatal mortality. They emphasised the need to strengthen maternal and newborn healthcare services.

Although these studies have significantly advanced the understanding of infant mortality, most have relied on nationally representative survey data. Comparatively few investigations have utilised hospital-based clinical records, particularly within tertiary healthcare institutions in Northern Nigeria. Moreover, relatively little attention has been devoted to assessing the proportional hazards assumption when modelling infant survival.

The present study addresses these gaps by applying the Cox proportional hazards model to hospital-based clinical data obtained from Barau Dikko Teaching Hospital, Kaduna. In addition to identifying factors associated with infant mortality, the study evaluates the proportional hazards assumption using Schoenfeld residual diagnostics. This provides context-specific evidence from a tertiary healthcare institution and complements findings from previous population-based studies.

MATERIALS AND METHODS

Study Area

This study was conducted at Barau Dikko Teaching Hospital (BDTH), Kaduna State, Nigeria. The hospital is one of the leading tertiary healthcare institutions in Northern Nigeria and serves as a major referral centre for maternal, neonatal and paediatric healthcare services. It receives patients from Kaduna State and neighbouring states and plays a critical role in the management of high-risk pregnancies, preterm births and neonatal complications. The availability of detailed clinical records made the hospital an appropriate setting for investigating factors associated with infant survival.

Study Design

A retrospective cohort study design was employed. This design is widely used in epidemiological and clinical research because it enables the investigation of time-to-event outcomes using existing patient records (Hosmer, Lemeshow, & May, 2008).

The study utilised hospital records of infants admitted to Barau Dikko Teaching Hospital between 2015 and 2025. The event of interest was infant mortality, defined as death occurring before the infant's first birthday. Infants who survived beyond the observation period or who were discharged alive without experiencing the event were treated as right-censored observations.

The retrospective cohort design was considered appropriate because it allows the application of survival analysis techniques while accounting for differences in follow-up time among infants.

Data Source and Sample Size

Secondary data were obtained from the medical records of Barau Dikko Teaching Hospital. Information was extracted from neonatal admission registers, delivery records, maternal health records and patients' case files.

A total of 100 infants with complete information on survival time, survival status and the explanatory variables were included in the analysis. Of these infants, 20 experienced the event of interest (death) during the follow-up period, while the remaining 80 observations were right-censored.

The inclusion criteria were: infants admitted to Barau Dikko Teaching Hospital between 2015 and 2025; complete information on survival time and event status; and complete records for all explanatory variables included in the analysis.

Records containing substantial missing information on key study variables were excluded.

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Study Variables

Outcome Variable

The outcome variable was infant survival time, measured as the duration from birth (or hospital admission where appropriate) until either death or censoring.

The event indicator was defined as:

$\delta = 1,$ if the infant died during follow-up;

$\delta = 0,$ if the infant survived or was censored.

Explanatory Variables

Based on previous empirical studies on infant mortality (Ananth & Platt, 2004; Kunnuji *et al*., 2021; Musa *et al*., 2020), the following explanatory variables were included in the analysis:

Variable	Description
Birth Weight	Infant's weight at birth measured in grams.
Gestational Age	Number of completed weeks of pregnancy at delivery
Apgar Score (5 Minutes)	The clinical assessment score was recorded five minutes after birth
Maternal Age	Age of mother at delivery measured in years
Maternal Education Level	The highest educational attainment of the mother
Number of Antenatal Visits	Total antenatal clinic visits attended during pregnancy

Although these variables have been examined in previous studies (Ananth & Platt, 2004; Musa et al., 2020; Kunnuji et al., 2021), the present study differs in three important respects.

First, it uses hospital-based clinical records rather than nationally representative survey data. Second, it focuses specifically on infants admitted to a tertiary healthcare institution in Northern Nigeria, where high-risk pregnancies and neonatal complications are commonly managed. Third, in addition to estimating the Cox proportional hazards model, the study rigorously evaluates the proportional hazards assumption using Schoenfeld residual diagnostics. These methodological features provide additional clinical evidence and distinguish the present study from earlier investigations.

Survival Analysis Framework

Survival analysis was employed to investigate the relationship between infant mortality and the selected explanatory variables. Unlike conventional regression methods, survival analysis simultaneously accounts for both the occurrence and timing of an event while appropriately handling censored observations (Kleinbaum & Klein, 2012).

Let (T) denote the survival time of an infant. The survival function is defined as: $S(t) = P(T > t)$

which represents the probability that an infant survives beyond time (t).

The corresponding hazard function is

$$h(t) = \lim_{\Delta t \to 0} \frac{P(t \le T < t + \Delta t | T \ge t)}{\Delta t}$$

which measures the instantaneous risk of death at time (t), conditional upon survival up to that time.

Cox Proportional Hazards Model

The relationship between infant mortality and the explanatory variables was examined using the Cox proportional hazards regression model (Cox, 1972).

The model is expressed as:

$$h(t|X) = h_0(t) exp(\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_P X_P)$$

Where: $h_0(t)$ = baseline hazard function, $X_1, X_2, \dots, X_P$ = explanatory variables, $\beta_1, \beta_2, \dots, \beta_P$= regression coefficients

The regression coefficients were estimated using the partial likelihood estimation procedure.

For interpretation, the exponential of each regression coefficient,

$$exp(\beta)$$

was computed.

A hazard ratio greater than one indicates an increased risk of mortality, whereas a hazard ratio less than one indicates a reduced risk of mortality. Also, a hazard ratio of one indicates that the explanatory variable does not affect the hazard of infant mortality.

Assessment of Model Adequacy

The adequacy of the fitted Cox proportional hazards model was evaluated using three complementary statistical tests:

1. Likelihood Ratio Test;
2. Wald Test;
3. Score (Log-Rank) Test.

These tests were used to determine whether the explanatory variables jointly contributed significantly to the prediction of infant mortality.

The predictive ability of the fitted model was further evaluated using Harrell's Concordance Statistic (C-statistic), which measures the model's ability to discriminate correctly between infants with different survival outcomes. Values closer to one indicate better predictive performance.

The results of these model adequacy tests are presented in Table 2 of the Results section.

Assessment of the Proportional Hazards Assumption

The proportional hazards assumption was assessed using both statistical and graphical diagnostic procedures based on Schoenfeld residuals (Grambsch & Therneau, 1994).

The statistical assessment examined the relationship between scaled Schoenfeld residuals and survival time. A statistically significant result indicates evidence against the proportional hazards assumption.

Graphically, scaled Schoenfeld residuals were plotted against survival time together with a smoothed trend line and approximate 95% confidence bands. A systematic trend away from a horizontal line was interpreted as evidence that the effect of the corresponding covariate varied over time.

3.9 Statistical Software

Data management and statistical analyses were conducted using R Statistical Software (Version 4.5). The analyses were performed using the survival package for fitting the Cox proportional hazards model and the survminer package for model diagnostics and graphical presentation of Schoenfeld residuals.

Statistical significance was assessed at the 5% significance level.

Ethical Considerations

Ethical approval for the study was obtained from the appropriate Research Ethics Committee of Barau Dikko Teaching Hospital, Kaduna State, Nigeria.

The study utilised secondary clinical data, and strict confidentiality

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was maintained throughout the research process. No personally identifiable information was collected or reported. All procedures were conducted in accordance with internationally accepted ethical principles governing research involving human health records.

RESULTS AND DISCUSSION

Cox Proportional Hazards Regression Analysis

A Cox proportional hazards regression model was fitted to identify factors associated with infant mortality among infants admitted to Barau Dikko Teaching Hospital, Kaduna State, Nigeria, between 2015 and 2025. The analysis included 100 infants, of whom 20 experienced the event of interest (death) during the follow-up period, while the remaining 80 observations were right-censored.

Table 1: Cox Proportional Hazards Regression Results

Variable	Coefficient (β)	Hazard Ratio (HR)	95% Confidence Interval	p-value
Birth Weight (g)	-0.001137	0.9989	0.9976 - 1.0001	0.0814
Gestational Age (weeks)	-0.281416	0.7547	0.5723 - 0.9953	0.0462 *
Apgar Score (5 min)	0.008069	1.0081	0.8175 - 1.2431	0.9398
Mother's Age (years)	-0.031180	0.9693	0.9078 - 1.0350	0.3513
Mother's Education Level	-0.303841	0.7380	0.4360 - 1.2490	0.2578
Number of Antenatal Visits	0.193347	1.2133	0.9346 - 1.5752	0.1465

Significant at the 5% level.

The results presented in Table 1 indicate that gestational age was the only statistically significant predictor of infant mortality at the 5% significance level (HR = 0.755, 95% CI: 0.5723–0.9953, p = 0.0462). The hazard ratio of less than one indicates that increasing gestational age significantly reduced the risk of infant death. Specifically, each additional week of gestation was associated with an approximately 24.5% reduction in the hazard of infant mortality. Birth weight also exhibited a protective effect (HR = 0.9989), suggesting that infants with higher birth weights were less likely to die than those with lower birth weights. However, this relationship did not reach statistical significance at the 5% level (p = 0.0814).
Similarly, the five-minute Apgar score, maternal age, maternal educational attainment and the number of antenatal care visits were not statistically significant predictors of infant mortality in the fitted Cox model.

Table 2: Overall Model Adequacy Tests

Test	Chi-square	Degrees of Freedom	p-value	Decision
Likelihood Ratio Test	27.93	6	0.001	Significant
Wald Test	18.90	6	0.004	Significant
Score (Log-rank) Test	25.03	6	0.001	Significant

The overall adequacy of the fitted Cox proportional hazards model was evaluated using the likelihood ratio, Wald and score (log-rank) tests. As shown in Table 2, all three tests were statistically significant ($p < 0.05$), indicating that the explanatory variables jointly contributed to predicting infant mortality. Furthermore, the model yielded a concordance statistic (C-statistic) of 0.874, indicating excellent discriminatory ability and suggesting that it accurately distinguished infants who survived from those who died during the follow-up period.

Assessment of the Proportional Hazards Assumption

The proportional hazards assumption was evaluated using Schoenfeld residual tests together with graphical diagnostic procedures.

Table 4: Schoenfeld Residual Test Results

Variable	Chi-Square	p-value
Birth Weight (g)	1.630	0.2017
Gestational Age (weeks)	7.539	0.0060*
Apgar Score (5 min)	1.199	0.2736
Mother's Age (years)	3.534	0.0601
Mother's Education Level	0.225	0.6352
Number of Antenatal Visits	4.154	0.0415*
GLOBAL	25.619	0.00026*

Significant at the 5% level.

The results in Table 4 indicate that gestational age (p = 0.0060) and number of antenatal care visits (p = 0.0415) violated the proportional hazards assumption. Furthermore, the statistically significant global test (p = 0.00026) suggests that the proportional hazards assumption may not hold for the fitted model as a whole.

Figure 1: Schoenfeld Residual Plot for Number of Antenatal Visits

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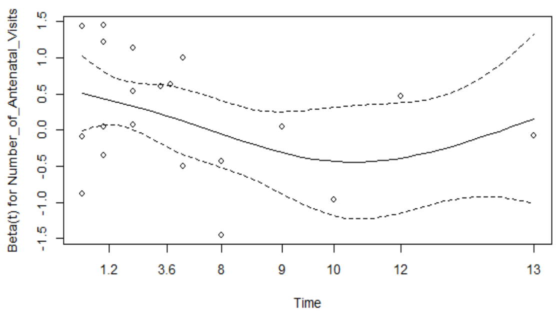

Figure 1 illustrates the scaled Schoenfeld residuals for the number of antenatal care visits. The solid curve represents the estimated time-varying regression coefficient, while the dashed curves denote the approximate 95% confidence limits.

The plot shows a noticeable departure from horizontal, indicating that the effect of antenatal care visits on infant mortality changed over the follow-up period rather than remaining constant. This graphical evidence is consistent with the statistical results presented in Table 4 and confirms a violation of the proportional hazards assumption for this variable.
This finding implies that a single hazard ratio may not adequately describe the effect of antenatal care visits throughout the study period. Consequently, future studies should consider fitting extended Cox proportional hazards models that incorporate time-dependent covariates, or alternative survival models that accommodate non-proportional hazards.

DISCUSSION

The present study identified gestational age as the most important determinant of infant survival among the variables considered. The significant protective effect observed indicates that infants born closer to full term were substantially less likely to die than those born preterm. This finding is consistent with those of Ananth and Platt (2004), who reported gestational age as one of the strongest predictors of neonatal mortality. It also agrees with the findings of Lawn et al. (2014) and Liu et al. (2016), who identified prematurity as one of the leading causes of neonatal and infant mortality globally.
Birth weight also exhibited a protective effect on infant survival, although its association was not statistically significant at the 5% level. Nevertheless, the observed negative regression coefficient suggests that infants with higher birth weights experienced better survival outcomes than those with lower birth weights. This finding corroborates earlier studies by Kramer (1987) and Victora et al. (1987), both of whom reported a strong inverse relationship between birth weight and infant mortality.
The five-minute Apgar score was not significantly associated with infant mortality in the present study. Although the Apgar score remains an important clinical indicator of neonatal wellbeing immediately after birth, its predictive ability may diminish when other biological and maternal factors are simultaneously considered within a multivariable survival model.
Maternal age and maternal educational attainment were likewise not statistically significant predictors of infant mortality. This contrasts with the findings of Kunnuji et al. (2021) and Eke and Ewere (2021), who reported significant associations between maternal education and infant survival. The discrepancy may be attributable to differences in study design, sample size and data source. Whereas previous studies relied primarily on nationally representative survey data, the present investigation utilised hospital-based clinical records from a tertiary healthcare institution that manages high-risk pregnancies and neonatal complications.
Although the number of antenatal care visits was not statistically significant in the Cox regression model, diagnostic analysis using Schoenfeld residuals showed that its effect varied over time. This suggests that the influence of antenatal care depends not only on the number of visits attended but also on the timing, quality and content of antenatal services received during pregnancy. Similar observations have been reported in previous studies emphasising that effective antenatal care extends beyond the frequency of clinic attendance to include the quality of healthcare provided (World Health Organization, 2023).
Finally, the statistically significant global proportional hazards test indicates that some covariate effects changed during the follow-up period. Consequently, the estimated hazard ratios should be interpreted with caution. Future studies should consider extended Cox proportional hazards models with time-dependent covariates or other flexible survival modelling approaches that accommodate non-proportional hazards.

Conclusion

This study employed the Cox proportional hazards model to investigate factors associated with infant mortality among infants admitted to Barau Dikko Teaching Hospital, Kaduna State, Nigeria, between 2015 and 2025. Survival analysis was considered appropriate because it accounts for both the timing of death and the presence of right-censored observations, thereby providing a more comprehensive assessment of infant survival than conventional regression techniques.
The findings identified gestational age as the most important predictor of infant survival. Specifically, increasing gestational age significantly reduced the hazard of infant mortality, highlighting the critical role of prematurity in determining infant outcomes. Although birth weight exhibited a protective association with infant survival, its effect was not statistically significant at the 5% significance level. Similarly, the five-minute Apgar score, maternal age, maternal educational attainment, and the number of antenatal care visits did not show statistically significant associations with infant mortality in the study population.
Diagnostic assessment showed that the fitted Cox proportional hazards model possessed good predictive performance. However, Schoenfeld residual diagnostics indicated violations of the proportional hazards assumption for gestational age and the number of antenatal care visits, suggesting that the effects of these variables changed over time. Consequently, future studies should consider employing extended Cox proportional hazards models that incorporate time-dependent covariates to obtain more reliable estimates when the proportional hazards assumption is violated.
The present study contributes to the existing literature by providing hospital-based clinical evidence on the determinants of infant mortality from a tertiary healthcare institution in Northern Nigeria. Unlike many previous studies that relied primarily on nationally representative survey data, this research utilised detailed clinical records, thereby offering context-specific insights into infant survival among hospitalised infants.
From a policy perspective, the findings underscore the need to strengthen interventions aimed at preventing preterm births

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through improved maternal healthcare, early identification and management of high-risk pregnancies, and enhanced neonatal care services. Efforts should also focus on impro
ving the quality and effectiveness of antenatal care rather than merely increasing the number of clinic visits. Such interventions are expected to improve infant survival and help reduce infant mortality in Kaduna State and Nigeria more broadly.
Despite its contributions, the study has certain limitations. The analysis was based on data from a single tertiary healthcare institution with a relatively modest sample size, which may limit the generalisability of the findings to the wider population. Furthermore, some potentially important determinants of infant mortality, including household socioeconomic status, maternal nutritional status, environmental factors and genetic conditions, were not available in the hospital records and therefore could not be included in the analysis.
Future research should consider multi-centre studies involving larger sample sizes and more diverse populations. Incorporating additional clinical, demographic and socioeconomic variables, together with advanced survival models that accommodate non-proportional hazards, would provide a more comprehensive understanding of the determinants of infant mortality and support the development of more effective evidence-based interventions.
In conclusion, this study demonstrates that gestational age remains the principal determinant of infant survival among the variables examined. The findings provide valuable evidence for clinicians, hospital administrators, public health practitioners and policymakers seeking to develop targeted strategies to reduce infant mortality and improve child health outcomes in Nigeria.

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