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Nephrotoxic versus nephroprotective: What is the role of antenatal steroids in preterm neonates

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Abstract

Background: Antenatal corticosteroids (ANS) enhance pulmonary maturation in preterm neonates, but their renal effects remain incompletely understood. This study evaluated the association ANS exposure with the prevalence and severity of acute kidney injury (AKI) in preterm neonates.

Methodology: This prospective cross-sectional study was conducted in NICU, Fatima Memorial Hospital, Shadman, Lahore, Pakistan from March 2023 to January 2025. It included 399 preterm neonates of 28–36 + 6 weeks gestation. Neonates were categorized based on antenatal steroids exposure as complete, incomplete, or no ANS groups. AKI was defined and staged according to KDIGO criteria during the first 14 days of life. All variables in descriptive statistics with $p < 0.05$ incorporated into multivariate logistic regression. The model fit was assessed using Hosmer–Lemeshow test.

Results: Of 399 neonates, 64 (16%) of neonates received a complete ANS course, 51.4% incomplete, and 32.6% none. The incidence of AKI was significantly lower in the complete ANS group compared with the incomplete and no-ANS groups (23.4% vs 47.3% and 45.4%, respectively ($p = 0.003$). On multivariate analysis, complete ANS remained an independent protective factor ($p = 0.006$, AOR 0.33, 95% CI 0.15–0.73) reducing the odds of renal failure by approximately 63%.

Conclusion: Complete antenatal steroid (ANS) exposure in preterm neonates was associated with lower incidence and severity of acute kidney injury, with multivariate analysis confirming reduced odds of AKI.

Keywords

acute kidney injury (AKI), antenatal corticosteroid therapy (ANS), gestational age, nephroprotection, perinatal outcomes, preterm neonate, renal maturation

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Neonates born prematurely, or before 37 weeks of gestation, face a higher likelihood of health issues and even mortality across the globe. Providing pregnant women with antenatal corticosteroids (ANS) with imminent preterm birth is considered one of the most crucial prenatal treatments to enhance the well-being of premature newborns.

Although, the primary purpose of ANS is to enhance lung maturation of fetus, it also has profound effects on the development and function of several other vital organ systems.[1] Due to the recognized benefits documented with ANS, international guidelines advise its use for pregnant women at risk of premature birth.[2,3] This recommendation is:

- Women $24^{0}/^{7}$ to $33^{6}/^{7}$ weeks of gestation at risk of preterm birth within next 7 days, regardless of membrane status or fetal number.
- Considered for late preterm pregnancies ($34^{0}/^{7}$ to $36^{6}/^{7}$ weeks) if:
  - Preterm delivery is anticipated within 7 days, and
  - No prior course of corticosteroids has been given

Despite clear recommendations for ANS administration, many preterm neonates delivered before the completion of the steroid course or without receiving even a single dose,

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often due to urgent maternal or fetal indications. There is wide variation in the use of antenatal corticosteroids ranging from 30% North American, 45% Scotland, and 98% in United Kingdom.[4]

The combination of disturbances in fluid and electrolyte balance, impaired excretion of nitrogenous waste products along with significant decline in renal function constitute AKI.[5] The KDIGO (Kidney disease: improved global outcome) guidelines modified for neonates are most accepted and widely used for diagnosing and staging AKI.[6] AKI prevalence has been documented 30%–50% in the preterm neonates.[7]

Maternal and neonatal factors increase risk of renal injury in preterm neonates. Maternal factors include antennal steroids exposure, preterm prelabor repture of membranes (PPROM), Pregnancy induced hypertension (PIH), drugs like non-steroidal anti-inflammatory drugs.[7,8] Neonatal factors include sepsis, hemodynamic instability, necrotizing enterocolitis (NEC), hypoxic-ischemic injury (HIE), or exposure to nephrotoxic medications. These factors results in compromised renal perfusion and tubular function, making the immature kidney highly vulnerable to insult.[8,9]

Antenatal corticosteroids (ANS) are routinely used to improve pulmonary outcomes in preterm birth, but their impact on renal development is not well defined. While ANS may promote nephron maturation and hemodynamic stability, concerns persist regarding potential adverse renal effects. The relationship between ANS exposure and renal maturity in preterm neonates remains uncertain. Whether antenatal steroids have nephrotoxic properties, nephroprotective benefits, or neutral effect is a topic of ongoing debate and represents a billion dollar question for neonatologists with substantial implications.[10–13]

The severity, clinical impact, and outcomes of AKI among preterm infants who have received complete, partial, or no antenatal steroids remain underreported. To the best of our knowledge, international and national literature regarding neonatal AKI and the role of ANS are limited. To bridge this knowledge gap, current research study was planned to investigate (i) the correlation between the varying impacts of no antenatal steroids, partial antenatal steroids, and complete antenatal steroids exposure on AKI incidence and its severity of in preterm, and (ii) to determine the nephroprotective versus the nephrotoxic role of antenatal steroids in preterm neonates.

Material and methods

Following approval from the Institutional Review Board (IRB# FMH-13/10/2022-IRB-1115), a prospective cross-sectional study was conducted in the Department of Neonatology, Fatima Memorial Hospital, Lahore, from March 2023 to January 2025.

A total of 399 preterm neonates were enrolled. The sample size was determined using a 95% confidence level, 10% margin of error, and 5% level of significance, assuming an average 40% incidence of AKI among preterm infants. The calculation was performed using an online sample size calculator available at OpenEpi.

All preterm neonates admitted to the neonatal ICU (NICU) during the study period were screened for eligibility after obtaining informed consent from parents or guardians. All neonates were excluded if they had major congenital anomalies incompatible with life, structural renal malformations, death within the first 72 h of life, anuria or renal failure within 72 h, uncertain exposure to antenatal corticosteroids, or if parental consent was not granted. Serum creatinine levels were analyzed using cytometric methodology on the Roche C311 analyzer.

Data collection

All preterm neonates of gestation age 28–36^{+6} weeks admitted to our NICU, satisfying inclusion criteria with any clinical diagnosis were registered in the study and were managed as per standard unit protocols. The baseline serum creatinine (S. creatinine) level of all neonates was measured within 24 h after enrollment in the study. Subsequent serum creatinine levels were tested after every 48 to 72 h till 14 days of life in case-specific conditions. In the current study, serum creatinine level was used to classify the grade of AKI following KDIGO guidelines. KDIGO diagnoses and classifies AKI as "0–3" stages using urine output and serum creatinine values. However, as per KDIGO guidelines, no neonate was labeled with AKI within the first 72 h of life.

Acute Kidney Injury (AKI) Staging (KDIGO Criteria).[6]

- Stage 0: No change in serum creatinine (S/Cr) or an increase of <0.3 mg/dL, or urine output ≥0.5 mL/kg/hour.
- Stage 1: Increase in S/Cr of ≥0.3 mg/dL within 48 h or 1.5–1.9 times baseline, or urine output <0.5 mL/kg/hour for 6–12 h.
- Stage 2: Increase in S/Cr of 2.0–2.9 times baseline, or urine output <0.5 mL/kg/hour for ≥12 h.
- Stage 3: Increase in S/Cr of ≥3.0 times baseline, or S/Cr ≥2.5 mg/dL (eGFR <10 mL/min/1.73 m^2), or requirement for renal replacement therapy, or urine output <0.3 mL/kg/hour for ≥24 h, or anuria for ≥12 h.

GFR calculated as eGFR using Schwartz's formula[8] as follows

$$\text{eGFR} = \text{k}(0.4) \times \text{length of neonate(cm)} / \text{S.creatinine max(mg/dl)}$$

S. creatinine max is maximum serum creatinine of neonate.

Maternal characteristics including diabetes mellitus, hypertensive disorders of pregnancy, antepartum hemorrhage

(APH), parity, anemia, and ANS administration status during pregnancy. Our obstetric unit follows standard guidelines for antenatal steroids (2–4) and is categorized as

- Complete ANS: completed course (2 doses of dexamethasone 12 mg 12 h apart given at least 24 h before delivery)
- Incomplete ANS: received single dose or delivery occurring before 24 h of the second dose
- No ANS: no dexamethasone administered

Neonatal data included demographic variables (gestational age, birth weight, length, and gender), clinical factors (requirement for mechanical ventilation, insertion of central lines such as umbilical catheterization, and use of medications including inotropic agents and nephrotoxic drugs specially vancomycin and aminoglycoside. Comorbidities assessed were sepsis (defined by leukocytosis or leukopenia, ANC <1500, elevated CRP, thrombocytopenia <150 $\times 10^9$/L, and/or positive blood culture), hemodynamically significant patent ductus arteriosus (hsPDA), intraventricular hemorrhage (IVH), intracranial hemorrhage (ICH), disseminated intravascular coagulopathy (DIC), and necrotizing enterocolitis (NEC) based on modified Bell's criteria stage II or III.

All neonates were closely monitored based on ANS for the severity of renal failure, duration of stay in hospital and their outcome (discharge home or death). Results were also tabulated to determine the nephroprotective versus the nephrotoxic role of antenatal steroids in preterm neonates.

Data analysis

Data analysis was performed using SPSS version 20.0. According to Shapiro–Wilk test, the continuous variables were non-normally distributed, so presented as median (IQR). Comparisons of continuous variables performed using the Kruskal–Wallis test, while categorical variables were analyzed with Pearson's chi-square or Fisher's exact test, as appropriate. Post hoc z-tests with Bonferroni correction. Statistical significance was set at $p < 0.05$.

Maternal and neonatal demographics were compared according to antenatal steroid exposure (complete, partial, or none). All variables linked to AKI in univariate analysis ($p < 0.05$) were included in a multivariate logistic regression model, with significant associations reported as odds ratios (OR) with 95% confidence intervals. Model fit assessment was made by using the Hosmer–Lemeshow test.

Results

During the study period, 437 preterm neonates were admitted to our NICU, while 399 (91.3%) had finally completed data for final analysis. Thirty-eight neonates were excluded because of parental refusal (n = 19), incomplete data (n = 15), or death within 72 h of admission (n = 4).

Of these 399 preterm neonates, only 64 (16%) neonates have received complete antenatal steroids as per protocol, while 205 (51.4%) received incomplete steroids and 130 (32.6%) received no antenatal steroids at all.

Among the 399 preterm neonates included, 171 (42.9%) developed acute kidney injury (AKI) of any stage. Of these, 51 (12.8%) had Stage 1 AKI, while 103 (25.8%) had Stage 2, and 17 (4.3%) had Stage 3 AKI.

Maternal and neonatal demographics were compared across the three groups—no ANS, incomplete ANS, and complete ANS (Table 1). Significant differences were observed for primigravida status, maternal hypertension, maternal anemia, birth weight, neonatal length, male gender, birth asphyxia, necrotizing enterocolitis (NEC), intraventricular/intracranial hemorrhage or disseminated intravascular coagulation (IVH/ICH/DIC), hemodynamically significant patent ductus arteriosus (hsPDA), and sepsis (all $p < 0.05$). However, antenatal steroid exposure had no significant impact on neonatal mortality.

Complete antenatal corticosteroid (ANS) exposure was associated with a significantly lower incidence of neonatal acute kidney injury (AKI). Only 15 (23.4%) neonates with complete ANS developed AKI as compared to preterm neonates in no ANS group 59 (45.4%) and incomplete ANS 97 (47.4%) (p 0.018).

AKI incidence was significantly lower with complete ANS (23.4%) compared to incomplete (47.3%) and no ANS (45.4%) ($p = 0.018$). Serum creatinine was lowest [0.88 mg/dL, IQR 0.75–0.94] and GFR highest [80.7 mL/min/1.73 m^2, IQR 48.1–132.5] in the complete ANS group ($p < 0.001$ and $p = 0.015$, respectively), indicating better renal function with complete steroid exposure (Table 2).

Univariate analysis was performed to evaluate all potential risk factors contributing to neonatal AKI ($p < 0.05$). Baseline differences were observed across gestational age, birth weight, maternal anemia, sepsis, NEC, IVH, and exposure to nephrotoxic drugs and are mentioned in Table 1. These variables were subsequently included in multivariable analyses to account for potential confounding; however, residual confounding cannot be entirely excluded (Table 3).

In the adjusted analysis, complete antenatal steroid exposure demonstrated a significant nephron-protective effect, reducing the odds of AKI by 67% ($p = 0.006$). In contrast, maternal anemia 6 times increased the risk of AKI ($p = 0.024$). Similarly, gestational age 33–34 weeks ($p = 0.005$) and mechanical ventilation ($p = 0.004$) were identified as significant independent possible factors leading to AKI.

The multivariate logistic regression analysis revealed that the model significantly predicted renal failure status, ($\chi^2 = 14.82$, $p = 0.001$), with good model fit (Hosmer–Lemeshow $\chi^2 = 6.74$, $p = 0.565$). The model explained between 3.6% (Cox & Snell R^2) and 6.1% (Nagelkerke R^2) of the variance and correctly classified 78.4% of cases. Standard antenatal

Table 1. Maternal and neonatal demographics according to ANS.

Characteristics	Antenatal steroids (ANS) 399			*p*-value
	Complete ANS 64 (16%)	Incomplete ANS 205 (51.4%)	No ANS 130 (32.6%)	
Maternal				
LSCS	54 (84.4%)	180 (87.8%)	110 (84.6%)	0.638
Primary gravida	28 (43.8%)	129 (62.9%)	63 (48.5%)	0.005
APH	62 (96.9%)	191 (93.2%)	118 (90.8%)	0.290
Hypertension	6 (9.4%)	61 (29.8%)	45 (34.6%)	0.001
Diabetes mellitus	1 (1.6%)	11 (5.4%)	11 (8.5%)	0.144
Maternal anemia	53 (82.8%)	201 (98%)	125 (96.2%)	<0.001
Neonatal				
Gesta-tion age (weeks)				
$28–32^{+6}$	20 (31.2%)	61 (29.8%)	38 (29.2%)	0.976
$33–34^{+6}$	16 (25.0%)	60 (29.3%)	37 (28.5%)	
$35–36^{+6}$	28 (43.8%)	84 (41.0%)	55 (42.3%)	
Birth weight (kg)				
<1	7 (10.9%)	9 (4.4%)	12 (9.2%)	0.001
1.1–1.5	6 (9.4%)	87 (42.4%)	46 (35.4%)	
1.6–2.5	40 (62.5%)	93 (45.4%)	62 (47.7%)	
>2.5	11 (17.2%)	16 (7.8%)	10 (7.7%)	
Mean	2.3 (1.6–2.5)	1.6 (1.4–2.4)	1.6 (1.5–2.4)	
Length of neonate	43 (41–46)	41 (39–44)	42 (39–44)	<0.001
Gender				
Male	52 (81.2%)	115 (56.1%)	76 (58.5%)	0.01
Female	12 (18.8%)	90 (43.9%)	54 (41.5%)	
Birth asphyxia	0 (0%)	9 (4.4%)	12 (9.2%)	0.019
NEC	1 (1.6%)	33 (16.1%)	19 (14.6%)	0.010
Mechanical ventilation	35 (54.7%)	132 (64.4%)	86 (66.2%)	0.272
IVH/ICH/DIC	4 (6.2%)	28 (13.7%)	27 (20.8%)	0.022
Central lines	16 (25%)	40 (19.5%)	24 (18.5%)	0.543
Nephrotoxic drugs	60 (93.8%)	177 (86.3%)	103 (79.2%)	0.022
HsPDA	19 (29.7%)	39 (19%)	32 (24.6%)	0.162
Sepsis	39 (60.9%)	77 (37.6%)	63 (48.5%)	0.003
Inotropic agents	15 (23.4%)	36 (17.6%)	22 (16.9%)	0.504
Renal failure	15 (23.4%)	97 (47.3%)	59 (45.4%)	0.003
Length of stay	9 (6.25–17)	7 (6–11.5)	7 (6–14.25)	0.226
Expiry	4 (6.2%)	14 (6.8%)	13 (10%)	0.506

steroid administration emerged as a significant protective factor against renal failure (B = −0.999, $p = 0.004$, OR = 0.368), reducing the odds of renal failure by approximately 63%. Incomplete antenatal steroid administration was not a significant predictor ($p = 0.730$). Overall, complete antenatal steroid therapy was associated with low risk of renal failure, highlighting its importance in improving neonatal renal outcomes (Table 4).

Discussion

AKI is a common complication in preterm neonates and is associated with morbidity and mortality. Preterm neonates are frequently exposed to multiple medications in utero aimed at improving survival and clinical outcomes; however, several of these interventions may influence nephrogenesis and renal maturation. Among these, antenatal steroids (ANS) are of particular importance due to their widespread use and potential effects on renal development.

In this study, we evaluated the comparative association of complete, incomplete, and no ANS exposure on the occurrence and severity of AKI during the first 14 days of life in preterm neonates. Our findings indicate that neonates who received a complete course of ANS in-utero were significantly protected against the development of AKI.

It is important to note that baseline illness severity and established AKI risk factors differed across ANS exposure groups. Gestational age, birth weight, maternal anemia, sepsis, NEC, IVH, and exposure to nephrotoxic medications were not evenly distributed. These differences may have influenced the observed protective effect of complete ANS exposure. Although we adjusted for these variables in multivariable analyses, residual confounding cannot be entirely excluded. Therefore, while our findings support a

Table 2. Renal function status using KDIGO guidelines among study groups.

KDIGO	Antenatal steroids (ANS) 399			*p*-value
	Complete ANS 64 (16%)	Incomplete ANS 205 (51.4%)	No ANS 130 (32.6%)	
No	49 (76.6%)	108 (52.7%)	71 (54.6%)	0.018
Stage 1	4 (6.2%)	30 (14.6%)	17 (13.1%)	
Stage 2	11 (17.2%)	59 (28.8%)	33 (25.4%)	
Stage 3	0 (0.0%)	8 (3.9%)	9 (6.9%)	
AKI (any stage)	15 (23.4%)	97 (47.3%)	59 (45.4%)	
S. Creatinine	0.88 (0.75 0.94)	0.96 (0.84–1.14)	0.96 (0.85–1.30)	<0.001
GFR (ml/min/1.73 m^2)	80.7 (48.1–132.5)	65.3 (42.7–123.1)	61.85 (36.6–119.5)	0.015

nephroprotective role of complete ANS, caution is warranted when interpreting causality.

The impact of antenatal corticosteroid therapy on AKI in preterm neonates remains under-documented. Moreover, previous studies have often grouped all steroid-exposed neonates together as a single "ANS group," potentially confounding the true effect of partial versus complete ANS exposure on renal outcomes.

A review of the literature indicates that antenatal corticosteroids (ANS) can enhance renal function in preterm infants and exert a nephroprotective effect. Ustun et al. reported that 79% of preterm neonates who received ANS did not develop AKI during the early neonatal period ($p < 0.05$).[10] Similarly, Jetton and Charlton observed a significant nephroprotective role of ANS, with AKI-free rates of 71% and 74%, respectively.[13,14] Consistent with these findings, our study confirms the protective effect of complete ANS exposure, which reduced the risk of AKI by approximately 63%. Moreover, neonates who received a complete course of ANS were less likely to progress to advanced stages of renal impairment. This protective effect may be attributed to the enhanced nephron maturation that occur when the full course of antenatal steroids is completed.

International guidelines always recommend the use of ANS for fetal lung maturation. Although ANS expedite the development of fetal lungs, their effect on the maturation of other fetal organs is under-reported. Animal studies show that corticosteroids affect kidney development. They are believed to cause early nephron maturation and stop further nephron branching.[15] Steroids therapy also improves mean arterial pressure, renal blood flow, and GFR in preterm animals (lambs and baboons), as well as human neonates, indicating stimulation of kidney maturation. The steroid exposure during pregnancy may also result in accelerated development and tubular development of the fetal kidney.[12]

The research conducted by Elmas, Lee CC, and Bruel does not provide a definitive conclusion, as they were unable to establish a clear association between ANS and the occurrence of AKI ($p > 0.05$).[16–18] Conversely, Gul and to Garg et al. reported a nephrotoxic effect associated with ANS.[11,19]

Maternal anemia is linked to adverse outcomes in newborns including prematurity.[13] However, the studies showing the link between maternal anemia and preterm neonate AKI are scarce. According to our study, maternal anemia 6 times increases the risk of AKI in preterm neonates. One plausible explanation for this association could be that the development of fetal nephrons is closely tied to the nutritional, micronutrients specially iron and folic acid status of the mother.[19] Maternal malnutrition and anemia during pregnancy effects fetal epigenome through DNA methylation and influences "fetal programming."[19]

Total number of nephrons in fetus correlates with birth weight, estimating an additional 2.3×10^5 nephrons in each kidney for each 1 kg of birth weight.[20] Until what postmenstrual age (PMA) nephrogenesis continues is a big debate. One school of thought believes that the kidneys just like lungs share similar ontogenesis and morphogenesis with branching that normally continues around 32–34 weeks of gestation.[21] On the other hand, it is believed that with preterm delivery there is an early arrest of renal maturation that rises the risk for renal dysfunction in preterm neonates.[22–24] Does any association exists between gestation age of neonate at time of delivery and AKI? When we talk about preterm neonates, literature regarding AKI prevalence among different gestation age is lacking. Our data shows that gestation age of 32–34 weeks was significant risk factor for AKI. Only possible explanation could be that during ex-utero period, a number of factors can affect healthy nephrogenesis and the hemodynamic transition at birth is one of them.

Table 3. Risk factors for AKI.

Risk factors for AKI	AOR	95% CI	p value
Complete ANS	0.330	0.150–0.725	0.006
Maternal anemia	6.136	1.273–29.587	0.024
Gestation age 33–34 weeks	2.275	1.289–4.014	0.005
Mechanical ventilation	2.176	1.288–3.676	0.004

Table 4. Binary logistic regression predicting likelihood of AKI based on ANS.

Predictor	B	SE	Wald	Df	P	Exp(B)
Standard antenatal steroids	−0.999	0.344	8.444	1	.004	0.368
Incomplete antenatal steroids	0.078	0.225	0.119	1	.730	1.081
Constant	2.027	0.840	5.820	1	.016	7.591

Mechanical ventilation potentiates renal insult in neonates specially in settings of prematurity. Alaro and Fan have found that prematurity and increased use of invasive mechanical ventilation were independent risk factors for AKI in ventilated neonates ($p < 0.05$).[25,26] In our study, mechanical ventilation increased risk of AKI by 117%. This pattern of results has been echoed in studies conducted by other medical institutions.[6,15,19] The exacerbation of AKI in mechanically ventilated neonates can be attributed to a combination of complex mechanisms.

During mechanical ventilation due to high-pressure ventilation, elevated intrathoracic pressure, and permissive hypercapnia, renal perfusion is diminished. Furthermore, the presence of an endotracheal tube can cause local biotrauma and the release of local and subsequently systemic inflammatory mediators, compounding the insult to the kidneys.[25]

In addition, baseline differences in these risk factors between ANS exposure groups may have contributed to variations in AKI incidence. Other factors contributing to AKI include low birth weight, male gender, birth asphyxia, NEC, mechanical ventilation, IVH/ICH/DIC, use of nephrotoxic drugs, sepsis along with mother maternal hypertension, and primigravida all contribute to increase the risk for development of AKI.[11–15,26–30]

In summary, complete antenatal steroid (ANS) exposure appears to reduce both the risk and severity of AKI in preterm neonates, suggesting a potential nephroprotective effect in addition to its established pulmonary benefits. These findings may inform early neonatal risk stratification, allowing clinicians to identify infants at higher risk—particularly those with incomplete or no ANS exposure—for closer monitoring and timely interventions. Furthermore, our results highlight the need for prospective longitudinal studies to evaluate long-term renal outcomes and to elucidate the mechanisms linking ANS exposure to kidney development and AKI susceptibility.[31]

Limitations

Several limitations should be considered when interpreting our findings. The relatively small sample size specially those who received ANS, may have reduced the power to detect indirect associations and limits extrapolation to larger populations. Extremely preterm neonates (<28 weeks' gestation) were excluded, which may influence the applicability of findings to this subgroup. Furthermore, inclusion of high-risk and outborn neonates could have introduced variability in clinical management practices. Urine output criteria were not incorporated into the AKI definition because reliable measurements were unavailable, which may have resulted in underestimation of AKI incidence. Finally, the incidence of AKI may have been underestimated, as daily serum creatinine monitoring was not feasible—transient elevations could have been missed. This was an unblinded study; however, AKI was diagnosed based on objective KDIGO criteria, and maternal antenatal steroid exposure data were retrieved only after AKI assessment, minimizing the potential for observer bias. Nevertheless, residual bias cannot be entirely excluded. Importantly, the prospective cross-sectional design precludes establishing temporality or causality between antenatal steroid exposure and AKI. This limitation reflects both ethical concerns regarding frequent blood sampling in preterm infants and financial constraints inherent to resource-limited settings.

Conclusion

In preterm neonates, complete antenatal steroid (ANS) exposure was associated with lower incidence and severity of acute kidney injury ($p = 0.003$). Multivariate analysis confirmed that complete ANS remained independently associated with reduced odds of AKI (AOR = 0.33, 95% CI: 0.15–0.73, $p = 0.006$). These findings indicate an associative link between complete ANS and reduced AKI risk, emphasizing the need for further studies to confirm these observations.

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Ethical considerations

Ethical approval was obtained from the Institutional Review Board (IRB), Fatima Memorial Hospital, Lahore, Pakistan (IRB# FMH-13/10/2022 – IRB-1115).

Consent to participate

Written informed consent was obtained from the parents or legal guardians of all neonates before enrollment.

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Declaration of conflicting interests

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Data Availability Statement

All data generated or analyzed during this study are included in this published article.

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