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Original Research Article

Renal Function and Hydration Status of Exclusively Breastfed Neonates Across Varying Environmental Temperatures: A Prospective Observational Study from a Tertiary Care Centre in Rajasthan

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Abstract:

Background: The World Health Organization recommends exclusive breastfeeding for the first six months of life. Whether breast milk alone meets the fluid requirement of a newborn in a hot tropical climate is still debated, and prospective Indian data on neonatal renal biochemistry across seasons are scarce.

Objectives: To assess the hydration status of exclusively breastfed term neonates exposed to three distinct ambient temperature ranges, and to estimate the incidence of acute renal failure (ARF) and pre-renal ARF in this cohort.

Methods: A hospital-based prospective observational study was carried out in the Department of Pediatrics, SMS Medical College, Jaipur, between November 2012 and June 2013. Sixty stable neonates of gestational age ≥ 36 weeks on exclusive breastfeeding were enrolled and stratified by season into three groups of 20: Group A (15 November - 15 December, 18-29 °C), Group B (15 February - 15 March, 25-38 °C) and Group C (15 May - 15 June, 33-42 °C). Clinical hydration assessment using WHO IMNCI criteria, complete haemogram, renal function tests, serum electrolytes, urine output and fractional excretion of sodium (FENa) were recorded. ARF was defined as serum creatinine > 0.8 mg/dL beyond 48 hours; pre-renal ARF as FENa < 2.5 % with BUN/creatinine > 20.

Results: Baseline demographic variables were comparable across groups ($p > 0.05$). ARF developed in 8 (40 %), 11 (55 %) and 16 (80 %) neonates of Groups A, B and C, respectively ($p = 0.024$). Pre-renal ARF was identified in 6, 4 and 13 cases. Clinical dehydration was observed only in Group C (6/20, 30 %). The frequency of pre-renal ARF and dehydration rose with ambient temperature.

Conclusion: Rising environmental temperature is associated with a significantly higher burden of dehydration and pre-renal acute renal failure in exclusively breastfed neonates. Supplementary fluid in the hottest months may be biologically reasonable, but larger multicentric data are needed before any change in guideline-level advice.

Keywords: Exclusive Breastfeeding; Acute Kidney Injury; Dehydration; Environmental Temperature; Neonate; Tropical Climate.

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Introduction

Exclusive breastfeeding during the first six months of life is the foundation of optimal infant nutrition and is endorsed by the World Health Organization along with virtually every national pediatric body [1-3]. Breast milk supplies balanced macronutrients, immunoglobulins, growth factors and bioactive peptides, and is generally considered sufficient to meet the entire fluid requirement of a healthy term newborn [4]. Mortality from diarrhoeal disease, lower respiratory tract infection and hospitalisation is consistently lower among exclusively breastfed infants when compared with those receiving mixed feeds or formula [2, 3, 5].

Despite uniform international guidance, offering plain water, sugar water, herbal teas and dilute juices to breastfed infants in the first months of life remains common across the Indian subcontinent, parts of Africa and the Middle East [6-9].

Caregivers usually cite extreme heat, perceived thirst in the baby, scanty urine output or long-standing cultural beliefs as the reason. Early work from hot climates, including studies from rural India, Bangladesh, Peru and Jamaica, has shown that breast milk alone is adequate to maintain water balance even in summer [6-9]. Those studies, however, relied largely on clinical signs and urine osmolality and did not specifically examine biochemical evidence of reduced renal perfusion.

The neonatal kidney has a limited concentrating capacity. Maximum urinary osmolality reaches only about 600-700 mOsm/kg in the term newborn compared with around 1 200 mOsm/kg in the adult [10, 11]. Add a high body-surface-area-to-weight ratio and an immature thermoregulatory response, and the neonate becomes particularly vulnerable to insensible water loss in hot ambient conditions. Sub-clinical volume depletion may therefore appear as transient pre-renal azotaemia long before overt dehydration becomes detectable on examination. Pre-renal acute kidney injury is the commonest cause of renal dysfunction in term babies, accounting for roughly 70 % of cases in some series [12, 13].

Jaipur lies in a semi-arid zone with one of the widest seasonal temperature swings in northern India, summer maxima crossing 42 °C and winter minima dipping below 5 °C. The city therefore offers a natural setting to study the influence of ambient temperature on neonatal hydration. To the best of our knowledge, there is a paucity of prospective Indian data evaluating renal biochemical parameters in exclusively breastfed neonates across changing seasons. The present study was undertaken to address this gap.

The specific objectives were: (i) to assess the hydration status of exclusively breastfed term neonates across three different environmental temperature ranges representing winter, spring and peak summer; and (ii) to estimate the incidence of acute renal failure and pre-renal acute renal failure in this cohort.

Materials and Methods

Study Design and Setting: This was a hospital-based, single-centre, prospective observational study carried out in the Department of Pediatrics, SMS Medical College and the attached Sir Padampat Mother and Child Health Institute, Jaipur, Rajasthan, India. The recruitment window ran from 15 November 2012 to 15 June 2013 and was structured to capture three meteorologically distinct seasons of the region.

Ethical Considerations: The study protocol was reviewed and approved by the Institutional Ethics Committee of SMS Medical College, Jaipur (Ref. No.: IEC/SMS/2012/PED-47). Written informed consent was obtained from one of the parents of every enrolled neonate after a verbal explanation in the local language. Parents were free to withdraw consent at any stage without affecting routine clinical care. The study was conducted in accordance with the principles of the Declaration of Helsinki and the Indian Council of Medical Research National Ethical Guidelines for Biomedical and Health Research Involving Human Participants.

Sample Size: Based on previously reported incidence of pre-renal acute renal failure of about 20 % in term neonates admitted in the cool season and an expected rise to 60 % during peak summer at our setting, with two-sided $\alpha = 0.05$ and power 80 %, a minimum of 18 neonates per group was required. We enrolled 20 per group to allow for missing data, giving a total sample of 60.

Participants: Consecutively admitted neonates were screened for eligibility. Inclusion criteria were: (i) gestational age $\geq$ 36 weeks confirmed by Ballard scoring and obstetric records; (ii) clinically stable at the time of enrolment; and (iii) exclusively breastfed from birth. Exclusion criteria comprised prematurity, perinatal asphyxia (Apgar < 7 at 5 minutes), metabolic acidosis (pH < 7.25), symptomatic hypoglycaemia, respiratory distress syndrome, clinical or microbiological evidence of sepsis, major congenital malformation, congenital heart disease, and any infant receiving intravenous fluids or formula supplementation prior to or at admission.

Group Allocation: Enrolment was carried out across three predefined calendar windows chosen to represent distinct ambient temperatures recorded by the regional Meteorological Department station at Jaipur:

- Group A (n = 20): 15 November - 15 December 2012; ambient temperature 18-29 °C (winter).
- Group B (n = 20): 15 February - 15 March 2013; ambient temperature 25-38 °C (spring).
- Group C (n = 20): 15 May - 15 June 2013; ambient temperature 33-42 °C (peak summer).

Data Collection and Clinical Assessment: Demographic and obstetric details, including maternal age, parity, gestational age, mode of delivery, sex of the neonate, birth weight, postnatal age at admission, weight at admission and socio-economic status (modified Kuppuswamy scale), were recorded on a predesigned proforma. Hydration status was assessed clinically using the WHO Integrated Management of Neonatal and Childhood Illness (IMNCI) criteria, namely general condition, sensorium, sunken eyes, depressed anterior fontanelle, mucosal moisture, skin turgor and capillary refill time [14]. Dehydration was

graded as none, some (mild-moderate, 5-10 % weight loss) or severe (> 10 % weight loss). Each neonate was examined within 6 hours of admission and again at 24 and 48 hours by the principal investigator.

Laboratory Investigations: A peripheral venous sample (1.5 mL) was obtained from every infant for complete haemogram, blood urea nitrogen (BUN), serum creatinine (Jaffe kinetic method), serum sodium, potassium, chloride and capillary blood gas where clinically indicated. A spot urine sample was collected by perineal bag for urinary sodium, urinary creatinine and urinary osmolality. The fractional excretion of sodium (FeNa %) was calculated as:

FeNa = [(Urine Na × Plasma creatinine) / (Plasma Na × Urine creatinine)] × 100

Total urine output was recorded by weighing pre- and post-voided diapers over 24 hours and expressed as mL/kg/hour. All assays were carried out in the central biochemistry laboratory of the hospital using auto-analyser methods on the same platform throughout the study.

Operational definitions

- **Acute renal failure (ARF)** was defined as a serum creatinine of more than 0.8 mg/dL beyond 48 hours of life, in line with the criteria proposed by Karlowicz and Adelman for term neonates [12].
- **Pre-renal ARF** was diagnosed when the FeNa was less than 2.5 % and the BUN-to-creatinine ratio was greater than 20, indicating preserved tubular function with reduced renal perfusion [12, 15].
- **Clinical dehydration** was graded according to WHO IMNCI [14].

Management: Neonates with established ARF received standard management according to its underlying aetiology. Pre-renal cases were treated with cautious enteral rehydration through expressed breast milk feeds, with parenteral isotonic fluids reserved for those unable to feed orally or with moderate-to-severe dehydration. None of the enrolled infants required peritoneal dialysis or transfer for renal replacement therapy.

Statistical Analysis: Data were entered in Microsoft Excel 2010 and analysed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequency and percentage and compared between the three groups by the chi-square test, or by Fisher's exact test when an expected cell value was less than 5. Continuous variables were expressed as mean ± standard deviation when normally distributed and compared by one-way analysis of variance (ANOVA) followed by post-hoc Tukey honest significant difference test. Non-normally distributed continuous variables were compared by the Kruskal-Wallis test. A two-sided p value of less than 0.05 was considered statistically significant.

Results

Over the eight-month recruitment window, 78 neonates were screened, of whom 60 met the inclusion criteria and were enrolled in equal numbers across the three seasonal groups. Eighteen babies were excluded mainly on account of late preterm gestation, mixed feeding before admission and intercurrent sepsis. None of the enrolled neonates was lost to follow-up during the 48-hour observation window.

Baseline Characteristics: Baseline characteristics including sex of the neonate, mode of delivery, parity of the mother and socio-economic status were comparable across the three groups, with no statistically significant differences (all $p > 0.05$) (Table 1). Mean birth weight (2.78 ± 0.32 kg in Group A, 2.81 ± 0.29 kg in Group B and 2.74 ± 0.34 kg in Group C; $p = 0.74$) and mean postnatal age at admission (5.6 ± 1.8 days, 5.4 ± 2.1 days and 5.9 ± 2.0 days respectively; $p = 0.69$) were also similar. The three groups were therefore comparable for analysis of the primary outcomes.

Table 1: Baseline characteristics of the study population across the three seasonal groups

Variable	Group A (n = 20)	Group B (n = 20)	Group C (n = 20)	p value
Sex				0.720
Male	15 (75 %)	13 (65 %)	15 (75 %)	
Female	5 (25 %)	7 (35 %)	5 (25 %)	
Mode of delivery				0.671
Vaginal	17 (85 %)	18 (90 %)	16 (80 %)	
LSCS	3 (15 %)	2 (10 %)	4 (20 %)	
Parity of mother				0.810
Primigravida	8 (40 %)	9 (45 %)	10 (50 %)	
Multigravida	12 (60 %)	11 (55 %)	10 (50 %)	
Socio-economic status				0.810
Lower	12 (60 %)	11 (55 %)	10 (50 %)	
Average / Upper	8 (40 %)	9 (45 %)	10 (50 %)	

Values are number (percentage). Comparisons by chi-square test. LSCS = lower segment caesarean section.

Acute Renal Failure: The overall incidence of acute renal failure showed a clear gradient with rising ambient temperature. In Group A, 8 of 20 neonates (40 %) developed ARF, of whom 6 (75 %) were of pre-renal aetiology, and no infant in this group was clinically dehydrated. In Group B, 11 of 20 (55 %) developed ARF, with pre-renal ARF in 4 (36.4 %); again no clinical dehydration was documented. In Group C, the corresponding figures rose sharply to 16 of 20 (80 %) for ARF and 13 of 16 (81.3 %) for pre-renal ARF, while clinical dehydration was observed in 6 of 20 (30 %) infants (Table 2).

Comparison across the three groups by chi-square test demonstrated a statistically significant increase in the overall frequency of ARF with rising ambient temperature ($\chi^2 = 7.42$, df = 2, $p = 0.024$). The trend for pre-renal ARF was even stronger ($\chi^2 = 10.84$, df = 2, $p = 0.004$). Clinical dehydration was confined exclusively to the peak summer group ($p = 0.001$, Fisher's exact test). Mean serum creatinine in Group C (1.02 ± 0.27 mg/dL) was significantly higher than in Group A (0.74 ± 0.19 mg/dL) and Group B (0.82 ± 0.21 mg/dL) on one-way ANOVA ($F = 8.62$, $p < 0.001$), with a significant Group C versus Group A pairwise difference on post-hoc Tukey testing ($p < 0.001$).

Table 2: Frequency distribution of acute renal failure and dehydration across the three groups

Renal outcome	Group A (n = 20)	Group B (n = 20)	Group C (n = 20)	p value
Acute renal failure (ARF)	8 (40 %)	11 (55 %)	16 (80 %)	0.024*
Pre-renal ARF	6 (30 %)	4 (20 %)	13 (65 %)	0.004*
Intrinsic / unspecified ARF	2 (10 %)	7 (35 %)	3 (15 %)	0.118
Clinical dehydration	0 (0 %)	0 (0 %)	6 (30 %)	0.001*

Values are number (percentage). *Statistically significant ($p < 0.05$). ARF = acute renal failure.

Associated Morbidities: The morbidity profile of the cohort is summarised in Table 3. Neonatal jaundice was the commonest associated morbidity overall, particularly in Group C where 6 of 20 (30 %) infants were affected. Fever was again seen more often in Group C (3/20, 15 %) than in the cooler groups. Other morbidities, including haemorrhagic disease of the newborn, gastro-oesophageal reflux and minor skin disorders, were distributed more evenly. The clustering of jaundice, dehydration and pre-renal ARF in the same season suggests a common contribution from increased insensible water loss and reduced effective milk intake during the early days of life in hot weather.

Table 3: Frequency distribution of associated morbidities across the three groups

Morbidity	Group A (n = 20)	Group B (n = 20)	Group C (n = 20)
Fever	2 (10 %)	0 (0 %)	3 (15 %)
Neonatal jaundice (NNJ)	3 (15 %)	0 (0 %)	6 (30 %)
Dehydration	0 (0 %)	0 (0 %)	6 (30 %)
Others (HDN, GER, skin disorders)	1 (5 %)	4 (20 %)	0 (0 %)

Values are number (percentage). HDN = haemorrhagic disease of the newborn; GER = gastro-oesophageal reflux.

Clinical Course: All neonates with pre-renal ARF responded promptly to enhanced breast feeding with or without short-term parenteral isotonic fluid. Serum creatinine returned to less than 0.6 mg/dL within 72 hours of correction in 22 of 23 infants. One infant in Group C with severe dehydration developed transient hyperkalaemia (serum K^+ 6.4 mEq/L) which was managed conservatively. No infant required dialysis, and there were no deaths in the cohort.

Discussion

This prospective study from a tertiary care centre in western India found a clear stepwise rise in the incidence of acute renal failure, and particularly of pre-renal ARF, as the ambient temperature increased from winter through spring to peak summer. Clinical dehydration was seen only in the hottest cohort and clustered with the highest rates of neonatal jaundice. The finding is biologically plausible and clinically important. It suggests that exclusive breastfeeding alone, while sufficient for water balance under most environmental conditions, may be tested at the limits of neonatal homeostatic reserve when ambient temperatures cross 38-40 °C.

Our results are partly at odds with the body of work that has historically underpinned the WHO position on exclusive breastfeeding in hot climates. Almroth, working in Jamaica and later with Bidinger in rural India, showed that the breast-fed infant under six months remains in water balance even in hot, dry weather [6, 7]. Sachdev and colleagues, in the seminal Indian study from the

same era, concluded that water supplementation was unnecessary for healthy breast-fed infants in tropical summer [8]. Ashraf and colleagues reached an identical conclusion in the Pakistani sub-cohort of the Lahore Longitudinal Growth Study [9]. None of these studies, however, prospectively measured serum creatinine, BUN or FENa in the neonatal period. The biochemical lens we have used here therefore captures a sub-clinical signal that the earlier urine-osmolality-based studies were not designed to detect.

Two physiological observations help reconcile the findings. First, the term neonatal kidney concentrates urine to a maximum of about 600-700 mOsm/kg, roughly half the adult capacity [10, 11]. Even modest reductions in renal perfusion are therefore reflected in measurable elevations of creatinine and BUN. Second, the neonate loses water primarily through the skin and the respiratory tract, and insensible water loss rises by roughly 20-30 % for every 5 °C increase in ambient temperature above the thermoneutral zone of 32-34 °C [16]. In the early days of life, lactogenesis II is also incomplete, and milk volumes may not fully match an accelerated obligate water loss. The combination would be expected to produce exactly the picture we observed: rising pre-renal azotaemia with preserved tubular handling of sodium, manifesting as low FENa and an elevated BUN/creatinine ratio.

Several recent series support this interpretation. Selewski and colleagues, in the multicentric AWAKEN cohort, reported that neonatal acute kidney injury is far commoner than previously appreciated, affecting around 30 % of admissions to neonatal intensive care, and that volume status is the single most important modifiable contributor [17, 18]. Dass and colleagues from Lucknow described a 22 % incidence of acute kidney injury among community-born term neonates admitted in summer, with pre-renal physiology in the majority [19]. Trivedi and colleagues from Ahmedabad reported a strong correlation between maximum daytime ambient temperature in June and hospital admissions for hypernatraemic dehydration in the first 10 days of life [20]. The present study adds prospective Indian data from a single referral centre to that growing body of evidence.

The rise in neonatal jaundice in the peak-summer group also fits this picture. Reduced milk transfer in the first 72 hours, whether because of inadequate latch, perceived heat-related distress in the mother or simply higher insensible loss in the baby, can produce dehydration-associated breastfeeding jaundice, which in turn raises the threshold for kernicterus. Vigilant lactation support and proactive weight monitoring in the first week of life may matter more in summer admissions than is currently appreciated.

Clinical Implications: Two practical points follow. The first is that biochemical assessment of renal function, in particular serum creatinine and FENa, should be considered early in any breastfed neonate admitted in the summer months with poor feeding, lethargy, exaggerated weight loss or jaundice. Waiting for overt signs of dehydration is likely to miss a substantial proportion of pre-renal injury. The second is that supplementary fluid in the form of expressed breast milk, supervised by trained lactation staff, rather than free water by spoon or bottle, may be a more physiologically appropriate response than blanket reassurance during heatwaves. Routine water supplementation for all healthy breast-fed neonates is not supported by our data and should not be inferred from this study [21].

Strengths and Limitations: The chief strength of this study is its prospective design with three biologically meaningful seasonal cohorts recruited from the same hospital catchment population, allowing temperature to vary while other determinants of neonatal physiology stay relatively constant. All laboratory measurements were performed in a single accredited laboratory, reducing analytical variability. The hydration assessment was undertaken by a single observer, removing inter-observer variability.

Several limitations should be acknowledged. The sample size of 20 per group, although adequate for the primary outcome of pre-renal ARF, limits statistical power for secondary outcomes such as the intrinsic ARF subgroup. The study was hospital-based and therefore enriched for unwell babies; the incidence figures should not be extrapolated to community-born neonates without admission. Maternal milk intake was not directly quantified, although test weighing was used in clinically suspicious cases. Indoor temperature and humidity, which may differ substantially from outdoor meteorological readings, were not separately recorded. Finally, the study was conducted in a single semi-arid Indian city; coastal humid and high-altitude cold settings may produce different patterns and warrant separate evaluation [22].

Conclusion

Rising environmental temperature is significantly associated with a higher burden of dehydration and pre-renal acute renal failure in exclusively breastfed term neonates admitted to a tertiary care centre in western India. The signal appears at the biochemical level well before overt clinical dehydration becomes evident, and it clusters with neonatal jaundice in the same season. While these data do not justify a change in the well-established WHO recommendation of exclusive breastfeeding for the first six months of life, they argue for

heightened clinical vigilance, proactive lactation support and early renal biochemistry in breastfed neonates admitted during the peak summer months in tropical settings. Larger multicentric studies, ideally with continuous indoor-temperature monitoring and prospective milk-volume measurement, are required before any guideline-level recommendation regarding supplementary fluid in tropical summer can be considered.

Declarations

Ethics approval and consent to participate: The study protocol was approved by the Institutional Ethics Committee, SMS Medical College, Jaipur (Ref. No.: IEC/SMS/2012/PED-47). Written informed consent was obtained from the parent of every enrolled neonate.

Consent for Publication: Not applicable. No individual-level identifying images or details are included.

Availability of Data and Material: The de-identified dataset analysed for the present study is available from the corresponding author on reasonable academic request.

Competing Interests: The author declares no competing interests, financial or non-financial.

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Author Contributions: SK conceived and designed the study, recruited the participants, performed the clinical assessments, collated and analysed the data, drafted the manuscript and approved the final version for submission.

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