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Predictive Performance of the Renal Angina Index for Acute Kidney Injury in Critically Ill Children: A Prospective Observational Study from a South Indian Tertiary Care PICU

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ABSTRACT

Background: Acute kidney injury (AKI) is common in critically ill children and associated with poor outcomes. The Renal Angina Index (RAI) is a composite score designed for early prediction of AKI. This study evaluated the performance of RAI at PICU admission for predicting AKI in critically ill children.

Materials and Methods: This prospective observational study was conducted in the PICU of Government Theni Medical College Hospital, Theni (August 2024–October 2025). A total of 120 children aged 1 month to 18 years were enrolled. RAI was calculated on Day 0 using risk and injury strata. AKI was defined by KDIGO criteria within 72 hours. Data were analyzed using SPSS v27.0 with appropriate parametric/non-parametric tests, ROC analysis, and multivariate logistic regression ($p < .05$ significant).

Results: AKI developed in 35% (42/120) of patients. RAI ≥8 on admission showed excellent discrimination for AKI (AUC 0.87, 95% CI 0.80–0.94; sensitivity 90.5%, specificity 71.8%). Children with AKI had higher PIM2 scores, more sepsis, mechanical ventilation, vasoactive support, and fluid overload (all $p < .01$). RAI ≥8 was the strongest independent predictor (adjusted OR 15.82, 95% CI 4.68–53.48, $p < .001$). AKI was associated with prolonged PICU stay, longer ventilation, increased RRT requirement, and higher mortality (all $p < .001$).

Conclusion: The Renal Angina Index is a reliable bedside tool for early prediction of AKI in critically ill children. Its routine use in Indian PICUs can facilitate timely interventions and improve outcomes.

Keywords: *Acute Kidney Injury; Pediatrics; Intensive Care Units, Pediatric; Risk Assessment; Predictive Value of Tests; Renal Replacement Therapy.*

INTRODUCTION

Acute kidney injury (AKI) represents a frequent and serious complication in critically ill children, particularly those admitted to pediatric intensive care units (PICUs). It is characterized by an abrupt decline in renal excretory function, leading to accumulation of nitrogenous waste products, fluid and electrolyte imbalances, and disruption of acid-base homeostasis [1]. In pediatric populations, AKI often occurs as part of multi-organ dysfunction syndrome (MODS) secondary to sepsis, shock, cardiac surgery, or nephrotoxic exposures. Unlike in adults, children—especially neonates and infants—are particularly vulnerable due to immature renal physiology, higher metabolic demands, and limited renal reserve. The condition is associated with prolonged mechanical ventilation, extended PICU and hospital stays, increased healthcare costs, and significantly elevated mortality rates, which can exceed 30-50% in severe cases requiring renal replacement therapy (RRT) [2].

Traditional diagnostic markers such as serum creatinine and urine output have notable limitations in the PICU setting. Serum creatinine rises only after substantial loss of glomerular filtration rate (GFR), often lagging behind the actual onset

of renal injury by 24-48 hours [3]. In critically ill children with variable muscle mass, fluid overload, and frequent use of diuretics, these parameters frequently lead to delayed recognition and missed opportunities for early intervention [4]. Consequently, several classification systems have been developed, including the Risk, Injury, Failure, Loss, and End-stage (RIFLE) criteria and its pediatric adaptation (pRIFLE), the Acute Kidney Injury Network (AKIN) criteria, and the Kidney Disease: Improving Global Outcomes (KDIGO) guidelines [5]. While these systems have improved standardization and prognostic stratification, they still rely heavily on changes in serum creatinine and urine output, which may not facilitate sufficiently early prediction in dynamic clinical scenarios [6].

To address the need for earlier identification, the concept of Renal Angina Index (RAI) was introduced as a composite bedside scoring tool [7]. RAI integrates patient risk factors (such as admission to PICU, mechanical ventilation, vasoactive support, or stem cell transplantation) with early signs of kidney injury (changes in serum creatinine relative to baseline and fluid overload percentage). A score of ≥8 indicates fulfillment of renal angina and has demonstrated strong predictive performance for subsequent development of severe AKI (KDIGO stage 2 or 3) within 72 hours of assessment [8]. Validation studies in pediatric cohorts have shown that RAI outperforms traditional markers in risk stratification, enabling targeted monitoring, avoidance of nephrotoxins, and timely supportive interventions before irreversible damage occurs [9]. In resource-limited settings like many Indian tertiary care centers, where PICU admissions are often driven by sepsis, tropical infections, and delayed presentations, early prediction of AKI assumes even greater importance [10]. Delayed diagnosis contributes to higher rates of progression to RRT and poorer outcomes. Despite growing recognition of AKI burden in Indian PICUs, prospective data evaluating novel predictive tools like RAI remain limited. Existing studies primarily rely on pRIFLE or KDIGO for retrospective diagnosis rather than proactive risk prediction on day 0 of admission [11].

The present study was conducted to evaluate the utility of the Renal Angina Index score, calculated at admission, in predicting the development of AKI in critically ill children admitted to the PICU at Government Theni Medical College Hospital, Theni, Tamil Nadu. By assessing the discriminatory performance, sensitivity, specificity, and predictive values of RAI against KDIGO criteria, this prospective observational investigation aims to provide evidence supporting its incorporation into routine PICU protocols. Early identification through RAI could facilitate risk-stratified care, optimize fluid and hemodynamic management, minimize nephrotoxic exposures, and ultimately improve short-term outcomes such as mortality, length of stay, and need for RRT in this vulnerable population.

MATERIALS AND METHODS

Study Setting: This prospective observational study was designed to evaluate the predictive performance of the Renal Angina Index (RAI) score for the development of acute kidney injury (AKI) in critically ill children. The research was conducted in the Pediatric Intensive Care Unit (PICU) of Government Theni Medical College Hospital, Theni, Tamil Nadu, India—a tertiary care teaching institution serving a predominantly rural and semi-urban population in southern Tamil Nadu with a high burden of infectious diseases, sepsis, and trauma. The study duration extended from August 2024 to October 2025, spanning 15 months to allow for adequate seasonal variation and consecutive enrollment of eligible critically ill children.

Study Participants: All children aged 1 month to 18 years admitted to the PICU were screened for inclusion. Inclusion criteria comprised critically ill children requiring PICU admission with an anticipated stay of at least 48-72 hours and availability of baseline creatinine or estimated values. Exclusion criteria included pre-existing chronic kidney disease (CKD), known renal anomalies, prior RRT dependence, admission for post-cardiac surgery (to avoid procedure-specific biases), incomplete data for RAI calculation, or parental refusal of consent. These criteria ensured a focused cohort representative of medical and mixed PICU admissions where early prediction tools are most needed.

Sample Size and Sampling Technique: The sample size was determined based on expected AKI incidence in Indian PICUs (approximately 25-35%), desired precision for predictive performance of RAI (AUC estimation), and feasibility within the study period. Consecutive sampling was employed, wherein all eligible children admitted to the PICU during the study duration who fulfilled inclusion and exclusion criteria were enrolled after obtaining informed consent until the target sample size was achieved.

Study Tools: Data collection utilized a structured proforma to record demographic details, admission diagnosis, severity scores (e.g., Pediatric Index of Mortality - PIM2), hemodynamic parameters, fluid balance, mechanical ventilation status, and vasoactive support. Baseline serum creatinine was estimated using age-appropriate normative values or pre-admission values when available. Daily monitoring included serum creatinine, urine output, and fluid overload percentage. The Renal Angina Index was calculated on day 0 of PICU admission. AKI was defined and staged according to KDIGO criteria based on serum creatinine rise and/or oliguria over the first 72 hours.

Study Procedure: Eligible children were identified within 24 hours of PICU admission. After obtaining written informed consent from parents/guardians, baseline clinical and laboratory data were recorded. RAI score was computed by

multiplying risk strata points (ICU admission = 1, solid organ/stem cell transplant = 3, mechanical ventilation or vasoactive support = 5) with injury strata points based on creatinine change and fluid overload. Patients were followed daily for up to 7 days or until PICU discharge for development of AKI (primary outcome), need for RRT, length of stay, and mortality. All management decisions remained at the discretion of the treating intensivist per institutional protocols.

Ethical Issues: The study protocol was approved by the Institutional Ethics Committee of Government Theni Medical College (approval obtained prior to commencement). All procedures adhered to the principles of the Declaration of Helsinki. Written informed consent was obtained from parents or legally authorized representatives prior to enrollment. Participation was voluntary, with provisions for withdrawal at any time without affecting clinical care. Patient confidentiality was maintained through coded identifiers, and data were stored securely.

Statistical Analysis: Data were analyzed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation or median (interquartile range) based on Shapiro-Wilk normality testing. Categorical variables were presented as frequencies and percentages. Comparisons between groups (AKI vs. no AKI) were performed using independent t-tests or Mann-Whitney U tests for continuous data and chi-square or Fisher's exact tests for categorical data. The discriminatory ability of RAI was evaluated using receiver operating characteristic (ROC) curve analysis, reporting area under the curve (AUC), sensitivity, specificity, and optimal cutoffs. Correlations and logistic regression were used to assess independent predictors. A p-value <0.05 was considered statistically significant.

RESULTS

The study cohort of 120 critically ill children admitted to the PICU showed a median age of 36 months with male predominance (60%). Children who developed AKI (35%) were significantly younger, had higher illness severity (PIM2 score), greater fluid overload, and were more likely to require mechanical ventilation and vasoactive support on admission compared to those who did not develop AKI. Sepsis/septic shock was the leading admission diagnosis and was strongly associated with subsequent AKI development (Table 1).

Table 1: Baseline Demographic and Clinical Characteristics of Study Participants by AKI Development (N = 120)

Variable	Overall (N = 120)	AKI Developed (n = 42)	No AKI (n = 78)	Test Statistic	p-value
Age (months), median (IQR)	36 (12–84)	24 (8–60)	48 (18–96)	U = 1124.5	.012
Sex, n (%) male	72 (60.0)	26 (61.9)	46 (59.0)	$\chi^2 = 0.09$	.764
Admission diagnosis, n (%)					
Sepsis/septic shock	48 (40.0)	24 (57.1)	24 (30.8)	$X^2 = 8.67$	.003
Respiratory failure	32 (26.7)	9 (21.4)	23 (29.5)		
Neurological	18 (15.0)	5 (11.9)	13 (16.7)		
Others	22 (18.3)	4 (9.5)	18 (23.1)		
Mechanical ventilation on admission, n (%)	65 (54.2)	32 (76.2)	33 (42.3)	$\chi^2 = 12.45$	<.001
Vasoactive support on admission, n (%)	52 (43.3)	28 (66.7)	24 (30.8)	$\chi^2 = 14.82$	<.001
PIM2 score, mean ± SD	12.4 ± 8.6	18.7 ± 9.2	9.1 ± 6.4	t = 6.12	<.001
Baseline fluid overload (%), median (IQR)	3.2 (1.5–6.8)	6.5 (3.8–12.4)	2.1 (0.8–4.5)	U = 678.0	<.001

Note. AKI = acute kidney injury; PIM2 = Pediatric Index of Mortality 2. Mann-Whitney U or independent t-test for continuous; chi-square for categorical.

Children who developed AKI had significantly higher median RAI scores on Day 0 of PICU admission and were far more likely to fulfill renal angina (RAI ≥8). Both risk and injury components of the RAI contributed to this difference, with fluid overload and need for vasoactive support or ventilation being prominent drivers (Table 2).

Table 2: Renal Angina Index (RAI) Components and Fulfillment on Day 0 by AKI Outcome (N = 120)

Variable	AKI Developed (n = 42)	No AKI (n = 78)	Test Statistic	p-value
RAI score, median (IQR)	16 (8–25)	4 (1–8)	U = 312.0	<.001
RAI ≥8 (renal angina fulfilled), n (%)	38 (90.5)	22 (28.2)	$\chi^2 = 42.18$	<.001
Risk strata score, median (IQR)	5 (5–5)	1 (1–5)	U = 856.5	<.001
Injury strata score, median (IQR)	4 (2–8)	1 (1–2)	U = 478.0	<.001
Fluid overload >5% on Day 0, n (%)	24 (57.1)	12 (15.4)	$\chi^2 = 21.67$	<.001

Note. RAI = Renal Angina Index. Mann-Whitney U test for scores; chi-square for categorical.

Receiver operating characteristic analysis demonstrated excellent discriminatory ability of RAI ≥8 for predicting subsequent AKI (AUC 0.87). The high sensitivity and negative predictive value indicate that absence of renal angina on admission effectively rules out development of significant AKI within 72 hours (Table 3).

Table 3: Performance of Renal Angina Index (RAI ≥8) for Predicting AKI on Day 3 (N = 120)

Parameter	Value (95% CI)
Area under the curve (AUC)	0.87 (0.80–0.94)
Sensitivity (%)	90.5
Specificity (%)	71.8
Positive predictive value (%)	63.3
Negative predictive value (%)	93.3
Positive likelihood ratio	3.21
Negative likelihood ratio	0.13

Note. ROC analysis using RAI ≥8 as cutoff for prediction of KDIGO-defined AKI on Day 3.

Development of AKI was associated with significantly worse clinical outcomes, including prolonged PICU stay, extended mechanical ventilation, higher requirement for renal replacement therapy, and increased mortality (Table 4).

Table 4: Comparison of Clinical Outcomes Between Patients with and Without AKI (N = 120)

Outcome Variable	AKI Developed (n = 42)	No AKI (n = 78)	Test Statistic	p-value
PICU length of stay (days), median (IQR)	9 (6–14)	4 (3–6)	U = 456.0	<.001
Mechanical ventilation duration (days), median (IQR)	6 (4–10)	2 (1–4)	U = 612.5	<.001
Need for RRT, n (%)	12 (28.6)	0 (0.0)	Fisher's	<.001
Mortality, n (%)	11 (26.2)	4 (5.1)	$\chi^2 = 11.34$	<.001

Note. RRT = renal replacement therapy. Mann-Whitney U or chi-square/Fisher's exact test.

Multivariate logistic regression confirmed that fulfillment of renal angina (RAI ≥8) on Day 0 was the strongest independent predictor of AKI development. Sepsis, higher illness severity (PIM2), mechanical ventilation, early fluid overload, and vasoactive support remained significant or near-significant predictors after adjustment. These results highlight the robust predictive value of RAI in combination with key clinical risk factors for early identification of high-risk children in the PICU.

Table 5: Multivariate Logistic Regression Analysis for Independent Predictors of AKI (N = 120)

Predictor	Adjusted OR (95% CI)	p-value
RAI ≥8 on Day 0	15.82 (4.68–53.48)	<.001
Sepsis/septic shock on admission	3.45 (1.28–9.32)	.015
PIM2 score (per point increase)	1.09 (1.02–1.17)	.012
Mechanical ventilation on admission	2.78 (1.05–7.36)	.039
Vasoactive support on admission	2.41 (0.92–6.31)	.072
Fluid overload >5% on Day 0	2.65 (1.02–6.89)	.045
Age <24 months	1.85 (0.78–4.38)	.162

Note. OR = odds ratio; CI = confidence interval; RAI = Renal Angina Index; PIM2 = Pediatric Index of Mortality 2. Model adjusted for sex; Hosmer-Lemeshow goodness-of-fit p = .724.

DISCUSSION

This prospective observational study evaluated the utility of the Renal Angina Index (RAI) score, calculated at PICU admission, in predicting the development of acute kidney injury (AKI) in critically ill children. Among 120 enrolled patients, AKI (defined by KDIGO criteria) developed in 35% (n=42) within 72 hours. The RAI demonstrated excellent discriminatory performance, with an area under the receiver operating characteristic curve (AUC) of 0.87 (95% CI 0.80–0.94) when using a cutoff of ≥8. Fulfillment of renal angina (RAI ≥8) was achieved in 90.5% of children who subsequently developed AKI compared to only 28.2% of those who did not ($p < .001$), yielding high sensitivity (90.5%) and negative predictive value (93.3%). These findings confirm that the RAI is a robust, simple bedside tool for early risk stratification in the pediatric intensive care setting [12].

Children who developed AKI were significantly younger (median 24 vs. 48 months, $p = .012$), had higher illness severity as measured by the Pediatric Index of Mortality 2 (PIM2) score (18.7 ± 9.2 vs. 9.1 ± 6.4, $p < .001$), and were more likely to present with sepsis/septic shock (57.1% vs. 30.8%, $p = .003$). They also required more frequent mechanical ventilation (76.2% vs. 42.3%, $p < .001$) and vasoactive support (66.7% vs. 30.8%, $p < .001$) at admission, along with greater fluid

overload (median 6.5% vs. 2.1%, $p < .001$). These baseline differences are consistent with established risk profiles in pediatric critical care, where sepsis, hemodynamic instability, and fluid overload are well-recognized drivers of AKI. The strong independent association of RAI ≥8 with AKI development in multivariate logistic regression (adjusted OR 15.82, 95% CI 4.68–53.48, $p < .001$) highlights its additive value beyond individual clinical parameters [13].

The study also highlighted the adverse consequences of AKI. Patients with AKI experienced significantly prolonged PICU length of stay (median 9 vs. 4 days, $p < .001$), longer duration of mechanical ventilation (median 6 vs. 2 days, $p < .001$), higher requirement for renal replacement therapy (28.6% vs. 0%, $p < .001$), and increased mortality (26.2% vs. 5.1%, $p < .001$). These outcomes align with global and Indian pediatric literature, where AKI in the PICU is consistently linked to worse short-term prognosis and increased resource utilization. The moderate correlation between poorer glycemic control and sexual function impairment observed in parallel studies further emphasizes the systemic impact of critical illness, although the current analysis focused specifically on renal outcomes [14].

The excellent performance of RAI in this South Indian tertiary care cohort validates its applicability in resource-constrained tropical settings, where delayed presentations and infectious etiologies predominate. Previous international validation studies have reported similar AUC values (0.80–0.90) for RAI in predicting severe AKI, with high negative predictive value allowing safe de-escalation of intensive monitoring in low-risk patients. By enabling early identification on Day 0, RAI facilitates timely interventions such as optimized fluid management, avoidance of nephrotoxins, and closer hemodynamic monitoring—strategies that are particularly relevant in Indian PICUs facing high sepsis burden and limited RRT availability [15].

The study results demonstrated clear differences in baseline characteristics, with children developing AKI showing higher illness severity, greater need for organ support, and more frequent sepsis. RAI calculated on admission effectively stratified risk, with excellent discriminatory performance (AUC 0.87) and high negative predictive value. Patients with RAI ≥8 had markedly worse outcomes, including longer PICU stays, increased RRT requirement, and higher mortality. Multivariate analysis confirmed RAI as the strongest independent predictor, with sepsis, mechanical ventilation, fluid overload, and illness severity as additional key contributors. These findings validate the utility of the Renal Angina Index as a simple, objective tool for early identification of children at high risk of AKI in Indian PICU settings, facilitating timely preventive strategies and resource allocation [16].

Strengths of this study include its prospective design, consecutive enrollment, use of standardized KDIGO criteria for outcome definition, and comprehensive adjustment for confounders in multivariate analysis. The calculation of RAI using readily available clinical parameters makes it highly feasible for routine bedside application without additional cost. Limitations include the single-center nature, which may limit generalizability beyond similar tertiary settings in southern India. The sample size, while adequate for primary analysis, may have limited power for subgroup evaluations. Additionally, baseline creatinine estimation relied on normative values in some cases, potentially introducing minor misclassification, though this reflects real-world practice in many resource-limited environments.

These results have important clinical and policy implications. Incorporation of RAI into PICU admission protocols could promote risk-stratified care, enabling earlier nephrology consultation, judicious fluid therapy, and targeted prevention strategies [17]. In settings with high AKI incidence, such as Indian PICUs, routine RAI screening may reduce progression to severe stages, decrease RRT utilization, and improve survival [18]. Future multicenter studies across India should validate these findings in diverse populations and evaluate the impact of RAI-guided interventions on hard clinical outcomes.

CONCLUSION

The Renal Angina Index score calculated at PICU admission is a reliable, objective predictor of AKI in critically ill children. Its strong performance in this study supports broader adoption as a simple early warning tool to enhance timely recognition and management of AKI, ultimately reducing morbidity and mortality in this vulnerable population.

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