Analysis of Renal Resistive Index As A Predictor of Acute Kidney Injury in Critical Care Patients

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Abstract

Acute kidney injury (AKI) is a common complication in critically ill patients and is associated with increased length of hospital stay. Early detection of renal dysfunction by measuring the renal resistive index (RRI) using Doppler ultrasound is a non-invasive parameter that reflects intrarenal vascular resistance and has the potential to predict AKI occurrence in critically ill patients. This study aims to compare RRI values between patients with and without AKI based on severity levels classification from AKIN criteria, and to establish the RRI value as a predictor of AKI occurrence in critically ill patients. This study was an analytical observational study with a prospective cohort design conducted on critically ill patients treated in the ICU of dr. Zainal Abidin Banda Aceh General Hospital from June to August 2025. Data were obtained through Doppler ultrasound RRI examination performed within the first 24 hours and medical record data during treatment. Data were analyzed using ANOVA and ROC curve analysis to determine the cut-off value of RRI as an AKI predictor. Out of the 60 critically ill patients who met inclusion criteria, 30 patients (50%) developed AKI during treatment. There were significant differences (p<0.0001) between RRI and AKI occurrence as well as AKI severity, for both the right and left kidneys. ROC curve analysis identified an RRI cut-off value of 0.7 for predicting AKI, with a Receiver Operating Characteristic Area Under the Curve (AUC) of 0.9628 and CI 95% : 0.9155 – 1.000, yielding a sensitivity and specificity of 90%. *There are significant differences in RRI values between non-AKI patients and AKI patients at stages 1, 2, and 3. RRI value can be used as a predictor for AKI occurrence in critically ill patients.*

Keywords: Acute Kidney Injury, Critically Ill, Doppler Ultrasonography, Renal Resistive Index.

INTRODUCTION

Acute kidney injury (AKI) is a clinical syndrome characterized by a rapid decline in renal function, affecting approximately 20%–50% of patients in intensive care units (ICU) (Grilli & Webb, 2023; Maskoen, et al., 2023; Ma'rifat, et al., 2024). Data from 2025 at Malawi Tertiary Hospital showed that out of the 493 ICU patients included, 282 (57.2%) died, highlighting the high mortality associated with acute kidney injury in the intensive care setting (Shah et al., 2025). In its severe form, AKI may necessitate renal replacement therapy, which is required in 5–13% of critically ill patients (Haitsma Mulier et al., 2018). The prevalence of this condition is still elevated across Indonesia, leading to substantial financial burdens on the healthcare system and worsening death rates. Even though the impact is severe, relying primarily on serum creatinine for diagnosis poses major challenges. Since creatinine acts as a late-stage indicator, it usually misses the immediate physiological shifts that happen right when kidney damage begins. To overcome this gap, critical care units are increasingly adopting Doppler ultrasound for routine screening. This imaging technique is highly favored because it avoids radiation and toxic contrast dyes while being completely non-invasive. Through this method, clinicians can track the renal resistive index (RRI) to observe how blood actually flows and encounters resistance within the intrarenal arteries. Because adequate renal perfusion is critical in critically ill patients, changes in blood flow within the interlobar or arcuate arteries provide valuable non-invasive insight into renal hemodynamics (Reizine et al., 2023; Cuttone et al., 2025).

RRI has been used to assess renal perfusion, predict renal dysfunction, and evaluate recovery from AKI in ICU settings. Several clinical factors, including advanced age and comorbidities such as diabetes, dyslipidemia, and hypertension, are associated with increased arterial stiffness and fluid overload, both of which may exacerbate renal hypoxia and block renal recovery (Fu et al., 2022). While evidence from multiple studies supports the relationship between RRI and AKI, there remains limited synthesis regarding its performance across varying AKI severities in diverse clinical settings, particularly where advanced biomarkers are unavailable (Cruz et al., 2022; Ginting et al., 2021; Pinanditas, et al., 2024; Zaitoun et al., 2024; Zhu et al., 2021).

Beyond its regional implementation, this study evaluates the clinical utility of RRI as a primary predictor of AKI in this specific critically ill demographic. The findings are intended to support practical clinical decision-making in resource-limited settings by highlighting the integration of point-of-care ultrasound (POCUS) for dynamic renal perfusion monitoring. We primarily sought to identify the most effective renal resistive index (RRI) threshold to predict acute kidney injury (AKI) shortly after a patient enters the ICU—specifically within the first 24 hours. Additionally, we examined how RRI scores vary with the severity of kidney damage and how they relate to patient outcomes, such as survival and total days spent in intensive care. Setting these targets helps demonstrate how practical RRI can be when doctors need a quick, bedside ultrasound to assess kidney blood flow dynamically. We hypothesized that detecting a high RRI immediately after ICU admission would reliably signal both the onset and the severity of AKI, acting much more quickly than waiting for delayed spikes in creatinine.

METHODS

Study Design and Patient Selection

We organized an observational, prospective cohort investigation involving 60 qualifying ICU patients. Each participant had their RRI measured in both kidneys no later than 24 hours after being admitted. Since our data collection window was limited to June-August 2025, we used a total sampling strategy. In other words, every single critical care patient who matched our criteria during those months was included. This approach ensured that our sample closely mirrored the local ICU's actual demographics during that timeframe. We relied on the standard AKIN guidelines to diagnose and categorize kidney injury stages. To maintain strict diagnostic uniformity, we grouped patients solely by their serum creatinine changes during the first 48 hours in the unit. We did keep track of urine production, but we intentionally excluded it from the final staging decisions to avoid confusing the data. All clinical observations and measurements were conducted in the ICU of RSUD Dr. Zainoel Abidin in Banda Aceh, Indonesia, spanning three months.

Anyone treated in the intensive care facility during the research timeline was considered for the study. By using consecutive enrollment, we captured everyone who fit our requirements: individuals had to be at least 18 years old, require intensive care, and grant informed consent (or have family members sign on their behalf). However, we had to leave out individuals whose abdomens were too difficult to scan with ultrasound. We also excluded pregnant women and patients dealing with major pre-existing kidney issues—such as an eGFR under 30, active dialysis treatment, past kidney transplants, narrow renal arteries, tumors, having only one working kidney, or any severe structural defects in their urinary tract. For the physical scans, our team used a GE LOGIQ P7 ultrasound device, and creatinine data came directly from routine lab tests ordered by the ICU physicians. The scanning process began by mapping the renal blood vessels with color Doppler. Next, we captured spectral waveforms from three distinct zones inside each kidney: the top, middle, and bottom sections. To ensure accuracy at every spot, we carefully kept the scanning angle below 60 degrees. After logging the peak systolic and end-diastolic velocities from all three areas, we averaged the values to generate a single final RRI score for that kidney. This study was conducted following approval from the Ethics Committee of Dr. Zainoel Abidin Regional General Hospital (RSUDZA), Banda Aceh (number: 134/ETIK-RSUDZA/2025). All procedures were performed in accordance with ethical standards and institutional regulations.

Statistical analysis

Normality of numerical variables was tested using the Kolmogorov–Smirnov method. Differences in RRI values among non-AKI patients and those with AKI stages 1, 2, or 3 were analyzed using analysis of variance (ANOVA). The diagnostic accuracy of RRI was evaluated using Receiver Operating Characteristic (ROC) curve analysis to calculate the area under the curve (AUC) and corresponding 90% confidence interval. The ROC curve also identified the optimal cut-off point with its associated sensitivity and specificity. A p-value of less than 0.05 was considered statistically significant. All analyses were conducted using computer-based statistical software.

RESULTS

Table 1. Study characteristics (n=60)

Variables	Non AKI (n=30)	Stage 1 AKI (n=19)	Stage 2 AKI (n=6)	Stage 3 AKI (n=5)
Gender (n,%)				
Male	10 (33.3)	11 (57.9)	1 (16.7)	3 (60.0)
Female	20 (66.7)	8 (42.1)	5 (83.3)	2 (40.0)
Age (years) (mean±SD)	49.1 ± 18.7	52.4 ± 19.4	52.0 ± 11.7	56.6 ± 20.1
Weight (kg) (mean±SD)	62.8 ± 7.4	67.1 ± 8.7	70.0 ± 16.7	68.0 ± 11.0
Hemoglobin (g%)	11.5 ± 1.9	11.5 ± 2.6	9.7 ± 2.9	10.6 ± 4.0
(mean±SD)	15.0 ± 6.8	16.9 ± 7,2	16.4 ± 12.0	18.4 ± 9.6
WBC (x10^3 sel/ µL)	283 ± 97	215.9 ± 113	147 ± 72.3	229.2 ± 120
(mean±SD)	11 (36.7)	17 (89.5)	4 (66.7)	4 (80.0)
Platelets (x10^{3}sel/ µL)	17 (56.7)	17 (89.5)	5 (83.3)	4 (80.0)
(mean±SD)	4.0 ± 2.5	6.6 ± 5.2	3 ± 1.3	5.4 ± 3.0
Sepsis (n, %)	3 (10.0)	4 (21.0)	1 (16.7)	0
Ventilator use (n, %)				
Length of stay (days)				
(mean±SD)				
Death outcome (n,%)				
History of Diabetes	5 (16.7)	6 (31.6)	2 (33.3)	3 (60.0)
Mellitus	(0.66/0.67)	(0.76/0.74)	(0.76/0.79)	(0.79/0.79)
Mean RRI (right kidney/left kidney)				
History of hypertension	9 (30.0)	9 (47.4)	3 (50.0)	3 (60)
Mean RRI (right kidney/left kidney)	(0.66/0.66)	(0.75/0.74)	(0.77/0.77)	(0.81/0.81)

A total of 60 patients admitted to the Intensive Care Unit were included in this study. Of these, 30 patients did not develop acute kidney injury (AKI), while 19 patients developed AKI stage 1, six patients developed AKI stage 2, and five patients developed AKI stage 3. Table 1 outlines the clinical and personal backgrounds of our participants. Women accounted for a slightly larger share of the group, at 58.3% of the total. When looking at age, the averages shifted noticeably with increasing kidney damage severity. Interestingly, individuals who avoided AKI tended to weigh less than those who ultimately suffered from the complication. While blood platelet and hemoglobin numbers stayed fairly uniform across the board, white blood cell counts spiked in almost everyone. This surge in leukocytes makes sense given how many AKI sufferers were simultaneously battling sepsis. Alarmingly, over 80% of those who developed any stage of kidney injury ended up needing mechanical ventilation. Furthermore, survival rates and the total number of days spent in the ICU fluctuated widely across patient groups. We also noticed a clear trend among diabetics and individuals with chronic high blood pressure: they generally started with higher RRI readings, and those numbers only climbed as their kidney function deteriorated.

Table 2. Comparison of Kidney Parameters between AKI Groups

Variables	Non AKI	Stage 1 AKI	Stage 2 AKI	Stage 3 AKI	P value
Ureum (mg/dl) (mean±SD)	32.9 ± 16.0	85.8 ± 61.0	161 ± 113	145 ± 80.7	<0.0001
Creatinin baseline (mg/dl) (mean±SD)	0.6 ± 0.2	1.2 ± 0.6	1.6 ± 0.6	2.9 ± 2.8	<0.0001
Creatinin >48 jam (mg/dl) (mean±SD)	0.6 ± 0.2	1.6 ± 0.9	3.3 ± 1.5	4.5 ± 3.2	<0.0001
Urine output (ml/kg/hour) (median, min-max)	0.95 (0.3-3.3)	0.6 (0.3-2.8)	0.4 (0.2-0.4)	0.4 (0.2-0.4)	0.005

Renal functional parameters evaluated in this study included blood urea levels, baseline serum creatinine at ICU admission, serum creatinine at 48 hours, average urine output per kilogram per hour on the second day, and RRI values of the right and left kidneys. These parameters were compared between groups and are summarized in Table 2. Significant differences were observed between non-AKI patients and those with AKI stages 1, 2, and 3 across all renal parameters (p-values <0.05). The classification of AKI severity in this study was based exclusively on changes in serum creatinine within 48 hours of ICU admission.

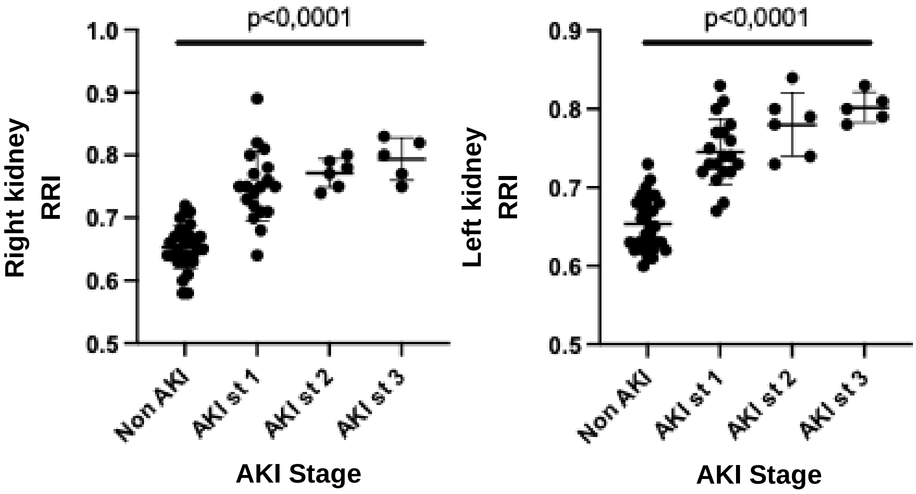

Figure 1. Comparison of Right Kidney and Left Kidney RRI based on AKI stage

Figure 1 illustrates the progressive increase in RRI values in both kidneys corresponding to the severity of AKI. The increase in RRI across groups was statistically significant ($p < 0.0001$) for both the right and left kidneys.

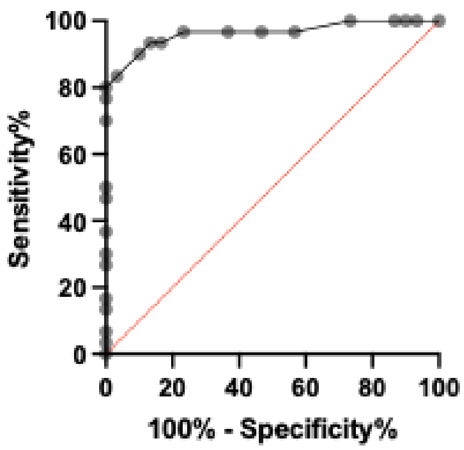

Figure 2. ROC curve of RRI values as a predictor of AKI events in ICU patients

Diagnostic performance analysis using the Receiver Operating Characteristic (ROC) curve is presented in Figure 2. The optimal RRI cut-off value for predicting AKI was >0.70, yielding an area under the curve (AUC) of 0.9628 with CI 95% : 0.9155 – 1.000. Both sensitivity and specificity were 90%, indicating strong predictive accuracy.

DISCUSSION

This study evaluated the renal resistive index (RRI) as a predictor of acute kidney injury (AKI) in critically ill patients admitted to the ICU. The demographic characteristics of the study population showed that females accounted for 58.3% of the sample, with a mean age above 49 years. These findings are consistent with previous studies. Hägglöf et al., reported that 42.8% of 303,875 ICU patients were female and predominantly above 60 years of age (Hägglöf et al., 2026). Similarly, Jonny et al., found that more than 58.7% of ICU patients in the Gatot Subroto Army Hospital were female with a mean age exceeding 50 years(Jonny et al., 2020). These similarities support the representativeness of the population evaluated in the present study. The predominance of elderly patients in this cohort is theoretically consistent with the progressive physiological decline in renal reserve and the higher prevalence of chronic comorbidities, such as hypertension and diabetes that are associated with advancing age. Such underlying conditions make patients far more vulnerable to sudden blood pressure drops and blood flow disruptions while in critical care. The impact of a patient's sex is still heavily debated, but earlier research hints that natural hormonal differences and varying degrees of blood vessel stiffness might explain why certain people are more prone to tissue damage after temporary blood flow loss in the kidneys. Looking at the routine lab work, it became obvious that the majority of our subjects were dealing with elevated white blood cells and a mild drop in red blood cells. Seeing pervasive anemia among the critically ill is quite standard; it perfectly mirrors observations by researchers like Thomas and Hajjar, who noted that roughly 70 percent of ICU populations suffer from depleted blood counts (Yadav et al., 2024; Yataco et al., 2025). Recent study further demonstrated that anemia increases mortality among ICU patients (Chow et al., 2025). Leukocytosis is also a well-recognized finding in ICU settings, often associated with infection or sepsis (de Bruin et al., 2022). The present study also identified sepsis as one of the most frequent complications in AKI patients, consistent with extensive literature demonstrating that sepsis is a major contributor to mortality in the ICU (Arbous et al., 2024; Bennett, 2015; Sakr et al., 2018).

Ventilator use was common among AKI patients, exceeding 80% across all AKI stages. This supports prior evidence that mechanical ventilation increases the risk of AKI threefold. Ventilator-associated AKI may result from impaired gas exchange leading to hypoxemia and hypercapnia, both of which affect afferent arteriolar tone and renal perfusion. Additionally, mechanical ventilation induces the release of inflammatory mediators from the lungs that may cause secondary renal tubular injury (Raasveld et al., 2023). The present findings also highlight that patients with diabetes mellitus and hypertension exhibited higher RRI values. This is consistent with Zhang et al., who found that an RRI ≥0.70 serves as an early marker of diabetic nephropathy, even before reductions in glomerular filtration rate occur (Zhang et al., 2021). Hypertension-induced arteriolar hypertrophy and sclerosis also elevate renal vascular resistance and RRI values (Andrikou et al., 2018).

Renal function parameters including serum creatinine, urea, and urine output—showed worsening values with increasing AKI severity. This is consistent with findings with previous study which also reported frequent renal impairment among ICU patients (Jonny et al., 2020). Furthermore, this study demonstrated a significant correlation between RRI and AKI severity, with higher RRI values observed in patients with more advanced AKI. Zhang et al., similarly noted that RRI elevations serve as early indicators of renal disease and vascular impairment (Zhang et al., 2021; Parami et al., 2025) also emphasized that Doppler-derived RRI is a cost-effective, non-invasive modality with prognostic potential for AKI, despite limitations in specificity (Parami et al., 2025).

The present study identified an RRI cut-off value of >0.70 for predicting AKI, with an AUC of 0.9628 and sensitivity and specificity of 90%. These results align with prior research. Zhu et al., reported an RRI threshold of 0.85 for predicting AKI in critically ill patients (Zhu et al., 2021; Cruz et al., 2022) demonstrated that RRI ≥0.70 predicted AKI requiring renal replacement therapy and was associated with increased mortality (Cruz et al., 2022). Zaitoun et al., also identified RRI ≥ 0.72 as predictive of AKI occurrence (Zaitoun et al., 2024). Studies conducted in Indonesia yielded similar findings, with reported RRI cut-off values of 0.873 and

≥0.70, respectively (Ginting et al., 2021; Pinanditas, et al., 2024). However, this high performance should be interpreted with caution. The substantial area under the curve in our cohort may be attributed to the early timing of the measurement (within 24 hours of admission) and the high prevalence of severe cases (AKI stage 2 and 3) in our ICU population, which tends to sharpen the contrast in resistive index values between groups. These results collectively strengthen the evidence supporting the role of RRI as an early, non-invasive predictor of AKI in critically ill patients.

We must acknowledge a few constraints in our work. The data come from a relatively small group at a single hospital, and we cannot ignore how overall systemic blood pressure fluctuations might skew the RRI readings. We also could not entirely isolate the effects of various background issues—ranging from old age, smoking habits, and kidney stones to severe conditions like atherosclerosis, diabetes, and autoimmune disorders. Even the use of certain harsh medications or contrast dyes could have subtly tweaked the vascular resistance in the kidneys. Still, this project breaks new ground as the first attempt in Aceh to test RRI for early AKI detection among ICU patients, providing local practitioners with a solid baseline to work from. Bringing these ultrasound checks into daily ICU routines might sharpen how doctors manage care, prompting them to adjust blood pressure targets earlier or pull back on kidney-damaging drugs before it is too late. For hospitals operating on tight budgets, using point-of-care ultrasound to measure these indices could speed up patient triage. Doctors do need to be careful, though. Misinterpreting the data could trigger false alarms, pushing medical staff to pump in too much IV fluid unnecessarily or prematurely stop crucial medications. Hospital administrators also have to factor in the extra time and training required to get their staff up to speed. Moving forward, researchers should track these unmeasured variables more rigorously across multiple hospitals to see whether the trends hold up everywhere. Ultimately, making Doppler scans a standard part of the ICU toolkit could drastically improve how fast we catch and treat kidney failure.

CONCLUSIONS

To summarize the findings, patients who suffered from acute kidney injury displayed drastically different RRI patterns compared to those whose kidneys remained healthy. These scores did not just separate the sick from the healthy; they also shifted significantly as patients progressed from stage 1 to stage 3 of the disease. Our ROC curve analyses confirmed that checking vascular resistance yields a highly accurate warning signal, cementing its value as a dependable forecasting tool in critical care. Of course, the extremely high AUC score of 0.9628 is somewhat unusual and should be carefully evaluated, particularly given our limited sample size and the presence of unmeasured health variables. Because of this, the medical community needs broader, multi-hospital trials that cover a wider range of patient backgrounds. Securing such extensive data is a necessary step before we can confidently draft universal guidelines for using RRI in everyday intensive care.

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