

Association between RRI, IVCCI, and CVP for the incidence of AKI in critically ill patients with risk of AKI in the Intensive Care Unit

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Abstract

Objective: To evaluate the predictive value of renal resistive index (RRI), inferior vena cava collapsibility index (IVCCI), and central venous pressure (CVP) to the incidence of acute kidney injury (AKI) in critically ill patients with risk of AKI in the intensive care unit (ICU).

Design: This study used an analytic observational study with a prospective cohort design.

Setting: The study was conducted in January 2025. The study used primary and secondary data (medical records) from patients in the ICU of Dr. Wahidin Sudirohusodo Hospital, Makassar.

Patients: The study included 54 patients who met the inclusion criteria, including 17 with AKI and 37 without AKI.

Measurements: Parameters measured included RRI, IVCCI, and CVP to predict AKI. In addition, urea and creatinine levels were also measured.

Results: RRI showed a strong, significant correlation with urea ($r=0.724$, $p<0.001$) and creatinine ($r=0.738$, $p<0.001$). Receiver operating

characteristic (ROC) curve analysis indicated RRI had the highest predictive ability of AKI incidence (area under the curve [AUC] 0.96, sensitivity 94.1%, specificity 94.6%, $p<0.001$). RRI was also significantly correlated with AKI according to the Kidney Disease: Improving Global Outcomes (KDIGO) classification, with the majority of patients with $RRI\geq 0.75$ in grades 1–3, whereas those with $RRI<0.75$ were in grade 0 ($p<0.001$). IVCCI showed no significant correlation; meanwhile, CVP showed only a weakly significant correlation to urea ($r=0.273$, $p=0.048$), with a low AUC value (0.63) and no significance ($p>0.05$) for AKI prediction.

Conclusions: RRI had a significant predictive value for the incidence of AKI in critically ill patients in the ICU and correlated with the severity of AKI based on the KDIGO classification. In contrast, IVCCI and CVP did not show a significant relationship with the incidence of AKI. Therefore, RRI can be used as a potential non-invasive tool for early detection and risk assessment of AKI in critically ill patients.

Keywords: Acute kidney injury, renal resistive index, inferior vena cava collapsibility index, central venous pressure, ICU.

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Background

Acute kidney injury (AKI) is common in critically ill patients and is associated with increased mortality, length of hospitalization, and risk of chronic kidney disease (CKD). The incidence of AKI continues to grow with population aging, increasing comorbidities, use of nephrotoxic agents, and invasive procedures. AKI occurs in approximately 10–15% of hospitalized patients and more than 50% of patients in the intensive care unit (ICU). (1) Early detection of AKI is very important so that therapeutic intervention can be carried out immediately before creatinine elevation occurs. Currently, several biomarkers, such as cystatin C, neutrophil gelatinase-associated lipocalin (NGAL), kidney in-

jury molecule-1 (KIM-1), and interleukin-18 (IL-18), have been used to detect AKI early, but have not been validated for diagnosing and managing sepsis with AKI. (2)

Renal Doppler ultrasonography is increasingly used as a screening tool in critically ill patients. (3) Renal resistive index (RRI) is a non-invasive sonographic parameter that reflects intrarenal vascular resistance as well as systemic hemodynamic changes. The average normal RRI is about 0.60, while a value of 0.70 is considered the upper limit of normal. (4)

Central venous pressure (CVP) serves dual functions: as an indicator of success and as a determinant of microcirculatory perfusion pressure; high CVP is associated with impaired microvascular circulation and the development of AKI. In addition, the inferior vena cava (IVC) diameter and IVC collapsibility index (IVCCI) in spontaneously breathing patients have been shown to correlate with volume status and CVP values. (5)

Therefore, this study aimed to evaluate the relationship between renal resistive index, inferior vena cava collapsibility index, and central venous pressure as predictors of acute kidney injury in critically ill patients in the ICU.

Methods

Study design, population, and sampling method

This study used a prospective cohort study of critically ill patients in the Intensive Care Unit (ICU) of Dr. Wahidin Sudirohusodo Hospital, Makassar, from January 2025 until the sample size was reached. Inclusion criteria included patients aged 18–65 years with complete anamnesis, laboratory examinations, and radiology results who were experiencing critical illness. Exclusion criteria: patients with a history of acute kidney injury or chronic kidney disease, patients staying for less than 24 hours, morbid obesity, severe congestive heart failure, or pregnancy. Patients would be considered dropouts if they died within 72 hours of ICU admission. Sampling was conducted by consecutive sampling, with all patients who met the inclusion criteria included until a minimum sample size of 54 subjects was reached.

Data collection

Data were collected primarily through radiological and laboratory examinations, and secondary data from medical records. Ultrasound examination to assess RRI and IVCCI diameter was performed within 6–48 hours of ICU admission, followed by measurement of CVP through a central venous catheter. Urine output and creatinine clearance were measured to assess AKI incidence according to the

Kidney Disease: Improving Global Outcomes (KDIGO) criteria, with urea and creatinine measurements on the first and second days. Patients were observed for up to 7 days or until hospital discharge or death.

Data analysis

Data were analyzed using diagnostic tests and correlation analysis according to the study objectives, with a significance level of 5%.

Ethical approval

This study has obtained ethical approval from the Health Research Ethics Committee of Hasanuddin University, with permission letter number 213/UN4.6.4.5.31/PP36/2025, prior to the implementation of the study.

Results

Sample characteristics

The total sample in this study comprised 54 patients who met the inclusion criteria and were admitted to the ICU at Dr. Wahidin Sudirohusodo Hospital, Makassar. Of these, 17 patients had AKI, while 37 patients did not.

Table 1 presents the baseline characteristics of 54 patients. The mean age of the patients was 46.82 years. The majority of patients were male (53.7%). The mean urea was 145.54 mg/dl, and the mean creatinine was 4.90 mg/dl. The mean CVP was 10.95 mmHg. A total of 28 patients (51.9%) died during hospitalization, and the average length of stay in the ICU was 8.38 days.

Table 2 shows the correlation between RRI, IVCCI, and CVP with urea and creatinine levels. RRI showed a strong, significant correlation with urea ($r=0.724$, $p<0.001$) and creatinine ($r=0.738$, $p<0.001$). In contrast, IVCCI showed no significant correlation with urea ($r=0.122$, $p=0.386$) or creatinine ($r=0.092$, $p=0.510$). CVP showed a weak but significant correlation with urea ($r=0.273$, $p=0.048$), but not with creatinine ($r=0.211$, $p=0.125$).

Table 3 presents the diagnostic value of RRI, IVCCI, and CVP on the incidence of AKI. Receiver operating characteristic (ROC) curve analysis showed that RRI had the highest predictive ability for AKI incidence (area under the curve [AUC] 0.96, $p<0.001$), with a cut-off value of 0.75, sensitivity of 94.1%, and specificity of 94.6%. Meanwhile, IVCCI and CVP showed low AUC values (0.63 each) and were not statistically significant predictors of AKI ($p>0.05$).

Table 4 shows the association between RRI, IVCCI, and CVP with the incidence of AKI. This

study found that only RRI showed a significant association with AKI incidence ($p < 0.001$), with a risk ratio (RR) of 29.4 and an accuracy of 92.6%. IVCCI and CVP parameters did not show statistical significance in the incidence of AKI.

Table 5 shows the relationships between RRI, IVCCI, and CVP and AKI severity according to KDIGO classification. RRI was significantly correlated with AKI severity ($p < 0.001$), with the majority of patients showing $RRI \geq 0.75$ in grades 1–3, while almost all patients with $RRI < 0.75$ were in grade 0. In contrast, IVCCI and CVP showed no significant correlation with AKI severity.

Discussion

The results showed that the basic characteristics of the sample, such as age ($p = 0.435$), body mass index (BMI) ($p = 0.995$), gender ($p = 0.333$), history of comorbidities (hypertension, diabetes mellitus [DM], coronary artery disease [CAD]), and ventilator use, did not show significant differences between the AKI and non-AKI groups. The mean age was consistent with Yokota et al.'s study, which found that AKI was associated with advanced age. However, the BMI findings differed from those of Ju et al., who reported that obesity increased the risk of AKI. (6,7) Gender distribution and ventilator use were in line with the studies of Peng et al. and Mo et al., respectively. (8,9)

At 6 and 48 hours, hemodynamic monitoring showed no significant difference in blood pressure (systolic, diastolic, or mean arterial pressure [MAP]) between the two groups, in contrast to Li-Wei et al.'s study, which found that hypotension was associated with an increased risk of AKI. (10) However, the vasoactive-inotropic score (VIS) was significantly higher in the AKI group, consistent with Zhang et al., as increased VIS may cause systemic vasoconstriction that decreases renal perfusion. (11) RRI values were also consistently higher in the AKI group, in line with Mulier et al.'s study, which explained that increased RRI reflects intrarenal vasoconstriction due to shock, impaired chronic renal vascular disease, a reliable predictive parameter for detecting AKI in critical patients in the ICU. RRI correlates strongly with urea and creatinine, demonstrates high diagnostic accuracy, and is significantly associated with AKI severity, renal replacement therapy (RRT) requirement, compliance, and increased CVP. (3)

Although neither IVCCI diameter nor CVP values showed significant differences between the two groups, a study by Sun et al. showed that higher CVP was strongly associated with increased risk and severity of AKI through the mechanism of renal venous congestion. (12) Echeverry et al. also em-

phasized serial IVCCI monitoring in assessing the volemic status of critical patients. (13)

This study confirmed that RRI showed a strong, significant correlation with urea and creatinine levels. From the ROC curve analysis, RRI demonstrated the highest predictive ability for AKI events. These results were supported by Baidya et al., Dawood et al., and Shen et al., underscoring the potential of RRI as a non-invasive early screening tool. (14–16) Shen et al. even reported that combining RRI with renal oxygen saturation (RrSO₂) increased its predictive value. (16)

In contrast, both IVCCI and CVP showed low AUC values and were not significant as predictors of AKI. Only RRI showed a significant association with AKI incidence, with an RR of 29.4 and an accuracy of 92.6%. RRI was also significantly correlated with AKI severity according to KDIGO classification, with $RRI > 0.75$ observed in higher grades, consistent with the study by Mulier et al.

Although RRI is only a marker of renal vascular resistance and not a direct indicator of renal function, increased RRI is associated with a more rapid decline in renal function and severity of renal damage in diabetic patients. (17) In addition, all patients undergoing RRT in this study had RRI values > 0.75 , indicating a potential relationship between increased RRI and the need for RRT. There was no significant difference in hospitalization length, but $RRI > 0.75$ was significantly associated with increased mortality, consistent with the study by Boddi et al. RRI reflects the integration between renal perfusion, vasoconstriction, and tubulointerstitial damage, making it a sensitive early biomarker and a strong predictor of mortality. (18) Limitations of this study include the relatively small sample size, the lack of serial measurements of RRI, IVCCI, and CVP to assess dynamic changes, and the potential bias introduced by not differentiating the specific etiology of AKI.

Conclusion

RRI demonstrated strong predictive accuracy for AKI in critically ill ICU patients; it correlated with renal biomarkers and AKI severity and may be used for early risk stratification and prognosis. In contrast, the IVCCI and CVP were not significant predictors. As shown, further studies with multicentric prospective designs and larger samples are needed to strengthen the external validity of these findings across various ICU subpopulations.

Conflict of interest

All authors have no conflict of interest regarding this article. This research did not receive research funding from any party.

Table 1. Characteristics of research subjects

Variable	Incidence of AKI		p-value
	Yes (n=17)	No (n=37)	
Age (years)	49.29±16.38	45.84± 14.32	0.435 [#]
BMI (kg/m ²)	23.04±3.12	23.05± 3.60	0.995 [#]
Gender			
- Male	12 (70.6%)	21 (56.8%)	0.333*
- Female	5 (29.4%)	16 (32.2%)	
Hypertension			
- Yes	6 (35.3%)	12 (32.4%)	0.836*
- No	11 (64.7%)	25 (67.6%)	
Diabetes mellitus			
- Yes	4 (23.5%)	6 (16.2%)	0.521*
- No	13 (76.5%)	31 (83.8%)	
History of CAD			
- Yes	4 (23.5%)	7 (18.9%)	0.696*
- No	13 (76.5%)	30 (81.1%)	
Ventilated			
- Yes	11 (64.7%)	28 (75.7%)	0.403*
- No	6 (35.3%)	9 (24.3%)	
Pre-ICU urea (mg/dl)	58.47±54.52	32.19±22.63	0.016 [#]
Pre-ICU creatinine (mg/dl)	1.01±0.27	0.80±0.21	0.003 [#]

Legend: AKI=acute kidney injury; BMI=body mass index; CAD=coronary artery disease; ICU=intensive care unit.

Values are n (%) or mean±standard deviation (SD). [#]Continuous variables were compared using an independent-samples t-test, *categorical variables with the Pearson chi-square test (p<0.05).

Table 2. Relationship of RRI, IVCCI, and CVP with urea and creatinine levels

Variable	Urea		Creatinine	
	r	p-value	r	p-value
Renal resistive index	0.724	<0.001	0.738	<0.001
Inferior vena cava collapsibility index	0.122	0.386	0.092	0.510
Central venous pressure	0.273	0.048	0.211	0.125

Legend: RRI=renal resistive index; IVCCI=inferior vena cava collapsibility index; CVP=central venous pressure.

Table 3. Comparison of diagnostic test results of RRI, IVCCI, and CVP in predicting the incidence of AKI

Variable	AUC	Sensitivity	Specificity	Cut-off point	p-value
RRI	0.96 (0.91–1.00)	94.1%	94.6%	0.75	<0.001
IVCCI	0.63 (0.46–0.79)	58.8%	54.1%	20.5	0.124
CVP	0.63 (0.47–0.80)	52.9%	64.9%	10.5	0.103

Legend: RRI=renal resistive index; IVCCI=inferior vena cava collapsibility index; CVP=central venous pressure; AKI=acute kidney injury; AUC=area under the curve.

Table 4. Comparison of relative risk ratio and accuracy of RRI, IVCCI, and CVP in predicting the incidence of AKI

Variable	AKI, n (%)		p-value	RR	Accuracy
	Yes (n=17)	No (n=37)			
RRI					
- RRI \geq 0.75	16 (94.1%)	3 (8.1%)	<0.001	29.4	92.6%
- RRI<0.75	1 (5.9%)	34 (91.9%)			
IVCCI					
- IVCCI \geq 20.5	12 (70.6%)	25 (67.6%)	0.824	1.10	68.5%
- IVCCI<20.5	5 (29.4%)	12 (32.4%)			
CVP (mmHg)					
- CVP \geq 10.5	9 (52.9%)	13 (35.1%)	0.216	1.64	61.1%
- CVP<10.5	8 (47.1%)	24 (64.9%)			

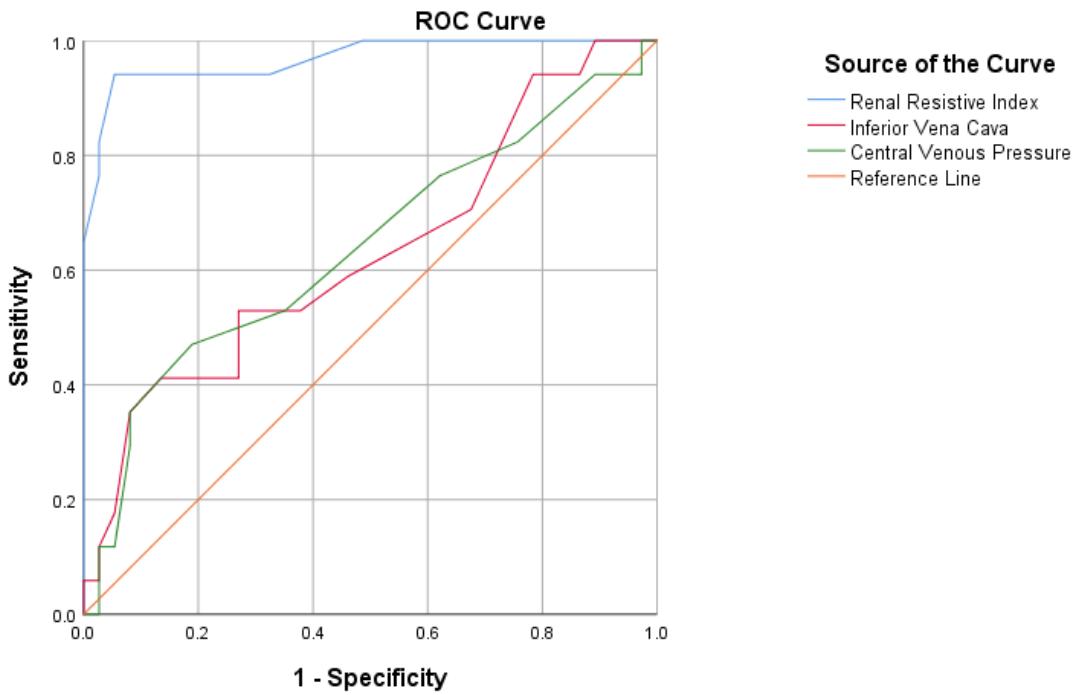
Legend: RRI=renal resistive index; IVCCI=inferior vena cava collapsibility index; CVP=central venous pressure; AKI=acute kidney injury; RR=relative risk.

Table 5. Association of RRI, IVCCI, and CVP with KDIGO grading in AKI

Variable	Category	Grades, n (%)				p-value
		0	1	2	3	
RRI	>0.75	3 (8.1%)	11 (91.7%)	4 (100.0%)	1 (100.0%)	<0.001
	<0.75	34 (91.9%)	1 (8.3%)	0 (0.0%)	0 (0.0%)	
IVCCI	>20.5	25 (67.6%)	8 (66.7%)	4 (100.0%)	0 (0.0%)	0.256
	<20.5	12 (32.4%)	4 (33.3%)	0 (0.0%)	1 (100.0%)	
CVP (mmHg)	>10.5	13 (35.1%)	5 (41.7%)	3 (75.0%)	1 (100.0%)	0.274
	<10.5	24 (64.9%)	7 (58.3%)	1 (25.0%)	0 (0.0%)	

Legend: RRI=renal resistive index; IVCCI=inferior vena cava collapsibility index; CVP=central venous pressure; KDIGO=Kidney Disease: Improving Global Outcomes; AKI=acute kidney injury.

Figure 1. ROC curve of RRI, IVCCI, and CVP in predicting the incidence of AKI



Legend: ROC=receiver operating characteristics; RRI=renal resistive index; IVCCI=inferior vena cava collapsibility index; CVP=central venous pressure; AKI=acute kidney injury.

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