Comparative diagnostic performance of renal resistive index and urinary KIM-1 for early detection of sepsis-associated acute kidney injury in critically ill patients

Jaka Herbiyanto[1], Ari Santri Palinrungi[1,2], Haizah Nurdin[1,2], Hisbullah[1,2], Faisal Muchtar[1,2], Andi Adil[1,2]

Abstract

***Objective*: This study compared the diagnostic performance of the renal resistive index (RRI) and urinary kidney injury molecule-1 (KIM-1) for early detection of acute kidney injury (AKI) in septic intensive care unit (ICU) patients.**

***Design*: Observational analytic study with a nested case–control design within a prospective cohort.**

***Setting*: Intensive Care Unit of Dr. Wahidin Sudirohusodo General Hospital, Makassar, Indonesia, with laboratory analyses at Hasanuddin University Hospital.**

***Patients and participants*: Forty-four septic adults (18–60 years) with normal baseline renal function were enrolled. Patients with chronic kidney disease, preexisting AKI, malignancy, or heart failure were excluded. Within 48 hours, 20 developed AKI based on Kidney Disease: Improving Global Outcomes (KDIGO) criteria.**

***Interventions*: None were applied. RRI was measured by Doppler ultrasonography, and urinary KIM-1 concentrations were determined by enzyme-linked immunosorbent assay (ELISA) within 24 hours of ICU admission and again 24 hours later.**

***Measurements and results*: Both RRI and urinary KIM-1 were significantly higher in patients who developed AKI. At admission, RRI showed better diagnostic performance (area under the curve [AUC]=0.881, sensitivity=75.0%, specificity=79.2%), than KIM-1 (AUC=0.781). After 24 hours, RRI accuracy declined (AUC=0.757), while KIM-1 improved (AUC=0.904).**

***Conclusions*: RRI reflects early functional hemodynamic changes, whereas urinary KIM-1 indicates structural tubular injury and becomes more predictive over time. Combined assessment of both biomarkers may enhance early detection of sepsis-associated AKI.**

Keywords: Sepsis, acute kidney injury, renal resistive index, urinary KIM-1.

[1.] Department of Anesthesiology, Intensive Care and Pain Management, Faculty of Medicine, Hasanuddin University, Makassar, Indonesia
[2.] Wahidin Sudirohusodo Hospital, Makassar, Indonesia

Address for correspondence:
Jaka Herbiyanto, MD
Department of Anesthesiology, Intensive Care and Pain Management, Faculty of Medicine, Hasanuddin University, Makassar, Indonesia
Perintis Kemerdekaan Street Km. 10, Makassar, South Sulawesi, Indonesia
Tel: +62-853-9452-1584
Email: jherbiyanto@yahoo.co.id

Introduction

Acute kidney injury (AKI) is one of the most frequent and severe complications in patients with sepsis. (1) It represents a major clinical problem in intensive care units, contributing substantially to morbidity, mortality, and prolonged hospital stay. (2) Sepsis-associated acute kidney injury (SA-AKI) is characterized by a sudden decline in renal function resulting from the systemic inflammatory response, hemodynamic instability, and cellular injury. (3) The incidence of SA-AKI continues to rise globally, posing a serious burden on healthcare systems. (4) The development of AKI in septic patients markedly worsens prognosis, leading to higher mortality rates and an increased risk of chronic kidney dis-

ease. (5) A significant proportion of these patients require renal replacement therapy to maintain homeostasis, which further increases treatment costs and complications. (6) Early identification and prompt intervention are therefore essential to improve patient survival and prevent irreversible renal damage. (7)

The pathophysiology of SA-AKI is complex and multifactorial. It involves dysregulation of immune and inflammatory pathways, endothelial dysfunction, oxidative stress, and alterations in renal microcirculation. (8) In contrast to traditional ischemic AKI, renal blood flow in sepsis may remain normal or even elevated. Yet the kidneys fail to maintain adequate filtration due to microvascular and cellular dysfunction. (9) These mechanisms highlight the need for more sensitive diagnostic markers beyond conventional renal function tests. (10)

Serum creatinine and urine output remain the standard diagnostic tools for AKI, but both have significant limitations. (11) Serum creatinine levels rise late after renal injury and are influenced by non-renal factors such as muscle mass, medication use, and fluid status. (12) Urine output is also unreliable in critically ill patients due to variations in diuretic use and fluid resuscitation. (13) These shortcomings make the detection of early kidney injury challenging in septic patients. (14)

The renal resistive index (RRI), measured noninvasively using Doppler ultrasonography, reflects intrarenal vascular resistance and provides real-time information about renal perfusion. (15) Meanwhile, kidney injury molecule-1 (KIM-1) is a transmembrane glycoprotein expressed in proximal tubular epithelial cells in response to ischemic or inflammatory stress. (16) Elevated urinary KIM-1 indicates tubular cell injury and may serve as an early biomarker of renal dysfunction before overt changes in serum creatinine occur. (17)

Given the clinical importance of timely recognition, accurate early detection tools are crucial for guiding management and preventing the progression of renal injury in sepsis. (18) Both RRI and urinary KIM-1 have potential roles in identifying subclinical renal dysfunction, yet their comparative diagnostic performance remains uncertain in the local context. (19) Although both RRI and urinary KIM-1 have shown promise as early biomarkers of renal injury, few studies have directly compared their diagnostic performance in sepsis-associated AKI, particularly in resource-limited settings such as Indonesia. This study aimed to address this gap by evaluating their comparative accuracy in critically ill septic patients, and to compare the diagnostic value of RRI and urinary KIM-1 for early detection of acute kidney injury in septic patients admitted to the intensive care unit of Dr. Wahidin Sudirohusodo General Hospital.

Materials and methods

Study design

This research employed an observational analytic approach with a nested case–control design within a prospective cohort of septic patients admitted to the Intensive Care Unit (ICU) of Dr. Wahidin Sudirohusodo General Hospital, Makassar, Indonesia. The study was designed to compare the diagnostic performance of RRI and urinary KIM-1 for early detection of AKI in sepsis.

Study setting and duration

The study was conducted at Dr. Wahidin Sudirohusodo General Hospital, with specimen collection performed in the ICU and urinary KIM-1 laboratory analysis performed at the Research Laboratory Unit of Hasanuddin University Hospital. The research was implemented from June 2025 until the minimum sample size was achieved.

Study population and sample

The study population consisted of all septic patients treated in the ICU during the study period. Subjects who fulfilled the inclusion criteria and agreed to participate were enrolled consecutively. The sample size was determined using a diagnostic test formula with an expected sensitivity of 84.2%, a prevalence of AKI in septic patients of 60.2%, a confidence level of 95% (α=0.05), and an allowable margin of error of 0.2, yielding a minimum of 22 participants.

Eligibility criteria

Patients were eligible for inclusion if they were adults aged 18 to 60 years, had a clinical diagnosis of sepsis with a Sequential Organ Failure Assessment (SOFA) score of at least 2, and had normal renal function before ICU admission. Patients were excluded if they had a malignancy, preexisting AKI, chronic kidney disease with an estimated glomerular filtration rate (eGFR) below 60 ml/min/1.73 m^2, a history of kidney transplantation, end-stage renal disease, or congestive heart failure. Subjects who developed other renal complications, withdrew from the study, or failed to complete follow-up examinations were classified as dropouts.

Data collection procedure

Eligible patients were recruited at the time of sepsis diagnosis, and baseline demographic and clinical data were recorded. Within the first twenty-four

hours, renal perfusion was assessed using Doppler ultrasonography to obtain RRI values, and urine samples were collected for KIM-1 analysis. The RRI was measured by calculating the difference between the peak systolic and end-diastolic velocities, divided by the peak systolic velocity, from interlobar or arcuate arteries under standardized conditions. RRI was measured using a convex 3.5–5 MHz probe (e.g., Philips CX50) with the insonation angle <60° in the interlobar arteries of the right kidney. Three consecutive measurements were averaged. Urinary KIM-1 concentration was quantified using a commercial enzyme-linked immunosorbent assay (ELISA) kit, with results expressed in nanograms per milliliter.

At forty-eight hours after sepsis diagnosis, each patient was evaluated for AKI development based on the Kidney Disease: Improving Global Outcomes (KDIGO) criteria. AKI was defined as an increase in serum creatinine of at least 0.3 mg/dl within forty-eight hours, or 50% within seven days, or a urine output of less than 0.5 ml/kg/hour for a minimum of six hours. Patients were then categorized into AKI and non-AKI groups accordingly.

Statistical nalysis

Data were analyzed using SPSS version 27.0 for Windows. Continuous variables were assessed for normality using the Shapiro–Wilk test and presented as mean with standard deviation or median with interquartile range. In contrast, categorical data were presented as frequencies and percentages. The differences between AKI and non-AKI groups were analyzed using an independent t-test or Mann-Whitney U test for continuous data, and chi-square or Fisher's exact test for categorical variables.

The diagnostic performance of RRI and urinary KIM-1 was evaluated through receiver operating characteristic (ROC) curve analysis, which provided the area under the curve (AUC), optimal cutoff points, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), likelihood ratios, and overall diagnostic accuracy. Comparative assessment between RRI and KIM-1 was conducted using binary logistic regression. A p-value below 0.05 was considered statistically significant.

Ethical approval and consent to participate

This study received ethical approval from the Health Research Ethics Committee of the Faculty of Medicine, Hasanuddin University, under protocol number 283/UN4.6.4.5.31/PP36/2025, with ethical clearance granted on May 6, 2025. The research protocol was reviewed through an expedited process. All study procedures adhered to institutional and national ethical standards, and written informed consent was obtained from all participants before inclusion, in accordance with the Declaration of Helsinki.

Result

Characteristics of research subjects

Table 1 presents the baseline characteristics of the study subjects according to AKI status. The mean age in the AKI group was 50.35±14.82 years, while in the non-AKI group it was 51.83±14.55 years, with a p-value of 0.740, indicating no significant difference. The mean body mass index (BMI) in the AKI group was 22.28±2.34 kg/m², compared with 22.75±4.52 kg/m² in the non-AKI group (p-value=0.673), indicating no significant difference. The distribution of sex was relatively balanced between the two groups, with males accounting for 65.0% and females 35.0% in the AKI group, and males 62.5% and females 37.5% in the non-AKI group (p=0.864). Conversely, the SOFA score showed a significant difference, with a mean of 6.75±1.65 in the AKI group and 4.67±1.86 in the non-AKI group (p<0.001).

Hemodynamic monitoring and acute kidney injury biomarkers at admission in critically ill patients in the ICU

Table 2 presents a comparison of hemodynamic parameters and renal biomarkers between patients who developed AKI and those who did not. Regarding hemodynamic parameters, patients with AKI had a lower mean systolic blood pressure (118.90±20.59 mmHg) than those without AKI (126.63±20.62 mmHg), although this difference was not statistically significant (p=0.223). Diastolic blood pressure also tended to be lower in the AKI group (69.50±15.18 mmHg) than in the non-AKI group (77.13±10.49 mmHg; p=0.056). In contrast, the mean arterial pressure (MAP) was significantly lower in patients with AKI (81.20±15.81 mmHg) than in those without AKI (90.75±13.60 mmHg; p=0.037).

In terms of inotropic and vasopressor support, dobutamine use was slightly higher among patients with AKI (5.0% vs. 0%), though the difference was not statistically significant (p=0.268). Conversely, norepinephrine use differed significantly, with half of the AKI patients requiring norepinephrine (50.0%) compared to only 16.7% of non-AKI patients (p=0.018).

Regarding renal biomarkers, highly significant dif-

ferences were observed. The RRI was higher in patients with AKI (0.715±0.035) compared to those without AKI (0.659±0.039; p<0.001). Similarly, urinary KIM-1 levels were markedly elevated in the AKI group (1.49±0.55) relative to the non-AKI group (0.96±0.31; p<0.001).

Predictive ability of RRI and urinary KIM-1 at admission for acute kidney injury occurrence

Table 3 and **Figure 1** show a comparison of the diagnostic performance of RRI and urinary KIM-1 at admission in predicting AKI among critically ill patients in the ICU of Wahidin Sudirohusodo Hospital illustrate the diagnostic ability of these two biomarkers in detecting AKI. ROC analysis revealed that RRI demonstrated the highest diagnostic value, with an AUC of 0.881 (95% CI: 0.779–0.984), sensitivity of 75.0%, and specificity of 79.2% at a cut-off point of 0.685 (p<0.001). This finding indicates that RRI is the most accurate predictor of AKI at admission. The urinary KIM-1 biomarker showed an AUC value of 0.781 (95% CI: 0.640–0.922), with a sensitivity of 70.0% and specificity of 70.8% at a cut-off point of 1.08 (p=0.001), demonstrating good diagnostic performance, although slightly lower than that of RRI.

Predictive ability of 24-hour RRI and urinary KIM-1 for acute kidney injury occurrence

Table 4 and **Figure 2** show a comparison of the diagnostic performance of 24-hour RRI and urinary KIM-1 in predicting AKI among septic patients in the ICU of Wahidin Sudirohusodo Hospital, demonstrating the diagnostic performance of both parameters after 24 hours of treatment. The RRI showed an AUC of 0.757 (95% CI: 0.616–0.900), with a sensitivity of 65.0% and a specificity of 66.7% at a cut-off point of 0.715 (p=0.004). This indicates that the diagnostic ability of RRI after 24 hours was lower compared to that at admission. Conversely, the urinary KIM-1 biomarker demonstrated excellent diagnostic performance, with an AUC of 0.904 (95% CI: 0.820–0.989), sensitivity of 75.0%, and specificity of 79.2% at a cut-off point of 1.827 (p<0.001). These findings confirm that urinary KIM-1 exhibits high accuracy in predicting AKI during the early phase of treatment.

Discussion

This study was conducted in the ICU of Dr. Wahidin Sudirohusodo Hospital, Makassar, to compare the diagnostic performance of the RRI and urinary KIM-1 in the early detection of AKI among septic patients.

In this study, the mean age of patients with AKI was 50.35±14.82 years, similar to that of patients without AKI. This finding contrasts with Kahar et al., who reported that aging was an independent predictor of AKI due to progressive glomerular filtration rate (GFR) decline and structural changes in renal vasculature. (20–22) BMI and gender distribution also showed no significant differences between groups, consistent with Peng et al., who found that AKI incidence and outcomes in sepsis were comparable between males and females. (23) Although Ju et al. reported that obesity increased AKI risk through glomerular hyperfiltration and inflammatory pathways, our results did not reflect this association, likely because subjects had a relatively homogeneous BMI profile. (24)

A significant difference in SOFA scores was observed, with higher mean values in the AKI group. This aligned with Widjanarko et al. and Lee et al., who identified the SOFA score as an independent predictor of AKI, reflecting the severity of multi-organ dysfunction. (24,25) Similarly, Zhang et al. demonstrated that higher SOFA scores were associated with earlier onset of AKI in coronavirus disease 2019 (COVID-19) patients. (26)

Hemodynamically, patients with AKI had lower MAP and required norepinephrine more frequently. These findings were consistent with Asfar et al., who reported that maintaining MAP between 85–90 mmHg reduced AKI incidence in septic patients with chronic hypertension. (27) The results reaffirm that adequate renal perfusion remains a critical determinant of septic AKI.

At ICU admission, RRI demonstrated strong diagnostic accuracy, outperforming urinary KIM-1. After 24 hours, RRI performance declined, while urinary KIM-1 improved markedly, indicating different diagnostic windows for each biomarker. The decrease in RRI diagnostic accuracy after 24 hours may reflect hemodynamic stabilization, vasopressor titration, or improved renal perfusion following resuscitation, which reduces its discriminatory power. These findings were consistent with Ghosh et al., Baidya et al., and Dawood et al., who demonstrated higher RRI values in septic AKI patients and strong predictive ability. (28–30) RRI, a Doppler-based noninvasive parameter, reflects renal perfusion and vascular resistance. It rises early in sepsis before changes in serum creatinine occur. (31) Local studies from Indonesia also support this, with Bossard et al. reporting high RRI diagnostic accuracy for postoperative and septic AKI. (32)

Meanwhile, urinary KIM-1 levels were significantly higher in AKI patients both at admission and after 24 hours, showing improved diagnostic performance over time. These findings are comparable to

Brozat et al., who found elevated serum KIM-1 in septic AKI and in those requiring renal replacement therapy. (33) Similarly, Elliyanti et al. and Tu et al. reported high sensitivity and specificity of urinary KIM-1 for early sepsis-associated AKI. (34,35) Mechanistically, KIM-1 is expressed on proximal tubular cells following ischemic or toxic injury, marking early tubular damage. (1,36)

Collectively, our data indicated that RRI serves as a rapid functional biomarker, reflecting early hemodynamic alterations in renal microcirculation, whereas KIM-1 reflected structural tubular injury and became more predictive after 24 hours. This temporal difference suggested that combining both biomarkers may improve diagnostic precision for septic AKI. Similar multi-marker approaches combining functional and structural indicators have been shown to enhance AKI prediction. Combining RRI (functional) and KIM-1 (structural) into a dual-marker approach could enhance the predictive accuracy of SA-AKI, as shown in previous multi-marker models involving neutrophil gelatinase-associated lipocalin (NGAL) and cystatin-C. (37,38)

Therefore, integrating RRI and KIM-1 assessments could form the basis for an early AKI diagnostic algorithm in ICU sepsis management. Although the sample size was limited and only two biomarkers were evaluated, this study provided critical regional data from eastern Indonesia and supported further multicenter validation. Future research should include larger, diverse populations, and additional biomarkers (e.g., NGAL, cystatin-C) to develop a comprehensive predictive model linked to clinical outcomes such as ICU stay, dialysis requirement, and mortality.

Limitation

This study had several limitations, including a relatively small sample size, a homogeneous population of septic ICU patients, and potential hemodynamic and vasopressor influences on RRI values. Only two biomarkers (RRI and urinary KIM-1) were evaluated, without inclusion of others such as NGAL or cystatin-C, limiting the scope of interpretation. The obtained cut-off values were population-specific and required validation in larger, multicenter studies. We also did not evaluate longitudinal outcomes such as the need for renal replacement therapy, ICU mortality, or renal recovery, which could strengthen the clinical applicability of these biomarkers. Future research should involve more diverse samples, additional biomarkers, and the assessment of clinical outcomes, such as ICU length of stay, renal replacement therapy requirements, and mortality.

Conclusion

At ICU admission, the RRI demonstrated the highest diagnostic performance for predicting AKI, with an AUC of 0.881, sensitivity of 75.0%, and specificity of 79.2%, outperforming urinary KIM-1. However, after 24 hours of treatment, the diagnostic accuracy of RRI declined, while urinary KIM-1 showed markedly improved validity.

Overall, RRI serves as an early functional biomarker that rapidly identifies patients at risk of AKI upon ICU admission. In contrast, urinary KIM-1 provides greater diagnostic precision after 24 hours by reflecting tubular injury. The combination of both biomarkers enhances the early detection and management of sepsis-associated AKI in critically ill patients.

Conflict of interest

The authors declare that there is no conflict of interest associated with this study.

Table 1. Characteristics of research subjects

Variable	AKI occurrence		p-value
	Yes (n=20)	No (n=24)	
Age (years)	50.35±14.82	51.83±14.55	0.740
BMI (kg/m²)	22.28±2.34	22.75±4.52	0.673
Sex - Male - Female	 13 (65.0%) 7 (35.0%)	 15 (62.5%) 9 (37.5%)	0.864
SOFA score	6.75±1.65	4.67±1.86	<0.001

Legend: AKI=acute kidney injury; BMI=body mass index; SOFA=Sequential Organ Failure Assessment.
Values are n (%) or mean±SD, unless stated otherwise. Continuous variables were compared using an independent-samples t-test and categorical variables were compared using the Pearson chi-square test.

Table 2. Hemodynamic monitoring and acute kidney injury biomarkers at admission in critically ill patients in the ICU

Variable	AKI occurrence		p-value
	Yes (n=20)	No (n=24)	
Systolic blood pressure	118.90±20.59	126.63±20.62	0.223
Diastolic blood pressure	69.50±15.18	77.13±10.49	0.056
Mean arterial pressure	81.20±15.81	90.75±13.60	0.037
Dobutamine - Yes - No	 1 (5.0%) 19 (95.0%)	 0 (0.0%) 24 (100.0%)	0.268
Norepinephrine - Yes - No	 10 (50.0%) 10 (50.0%)	 4 (16.7%) 20 (83.3%)	0.018
RRI	0.715±0.035	0.659±0.039	<0.001
Urinary KIM-1	1.49±0.55	0.96±0.31	<0.001

Legend: ICU=intensive care unit; AKI=acute kidney injury; RRI=renal resistive index; KIM-1=kidney injury molecule-1.
Values are n (%) or mean±SD, unless stated otherwise. Continuous variables were compared using an independent-samples t-test and categorical variables were compared using the Pearson chi-square test.

Table 3. Comparison of the diagnostic performance of RRI and urinary KIM-1 at admission in predicting acute kidney injury among septic patients in the ICU

Variable	AUC	Sensitivity	Specificity	Cut-off	p-value
RRI	0.881 (0.779–0.984)	75.0%	79.2%	0.685	<0.001
Urinary KIM-1	0.781 (0.640–0.922)	70.0%	70.8%	1.089	0.001

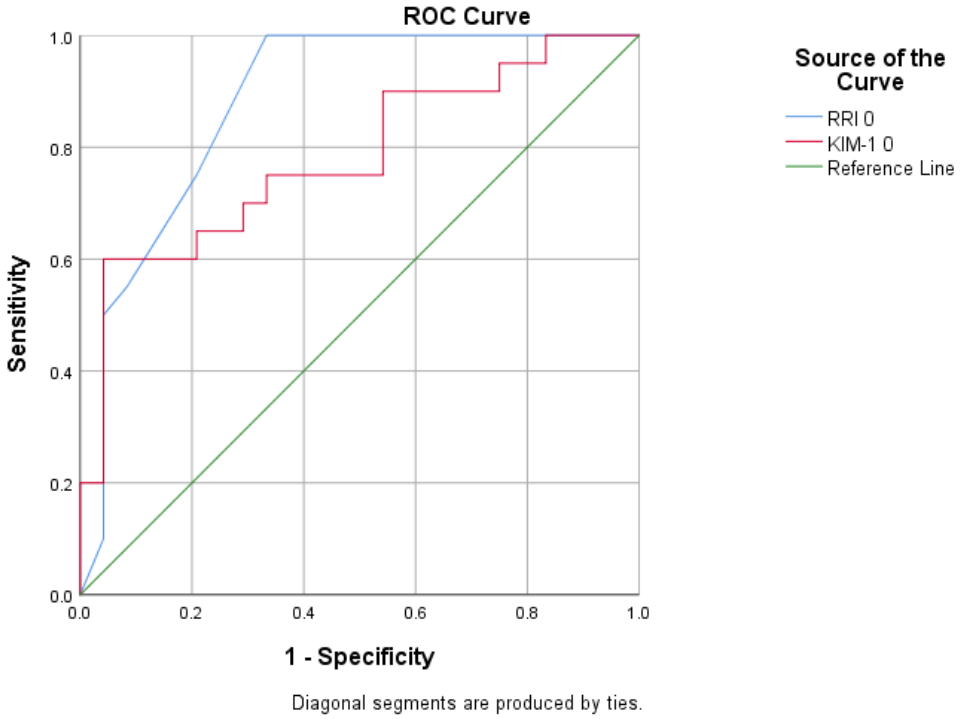
Legend: RRI=renal resistive index; KIM-1=kidney injury molecule-1; ICU=intensive care unit; AUC=area under the curve.

Table 4. Comparison of the diagnostic performance of 24-hour RRI and urinary KIM-1 in predicting acute kidney injury among septic patients in the ICU

Variable	AUC	Sensitivity	Specificity	Cut-off	P-Value
RRI	0.757 (0.616–0.900)	65.0%	66.7%	0.715	0.004
Urinary KIM-1	0.904 (0.820–0.989)	75.0%	79.2%	1.827	<0.001

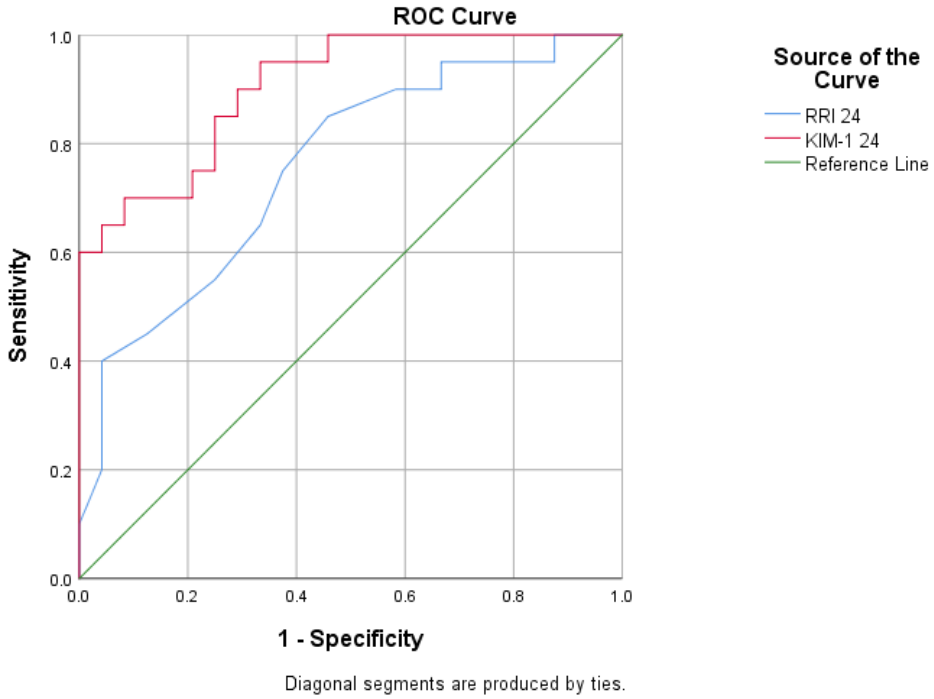
Legend: RRI=renal resistive index; KIM-1=kidney injury molecule-1; ICU=intensive care unit; AUC=area under the curve.

Figure 1. ROC curves of RRI and urinary KIM-1 at admission for predicting acute kidney injury



Legend: ROC=receiver operating characteristic; RRI=renal resistive index; KIM-1=kidney injury molecule-1.

Figure 2. ROC curves of 24-hour RRI and urinary KIM-1 in predicting acute kidney injury



Legend: ROC=receiver operating characteristic; RRI=renal resistive index; KIM-1=kidney injury molecule-1.

References

1. Peerapornratana S, Manrique-Caballero CL, Gómez H, Kellum JA. Acute kidney injury from sepsis: current concepts, epidemiology, pathophysiology, prevention and treatment. Kidney Int 2019;96:1083–99.
2. Pais T, Jorge S, Lopes JA. Acute Kidney Injury in Sepsis. Int J Mol Sci 2024;25:5924.
3. Manrique-Caballero CL, Del Rio-Pertuz G, Gomez H. Sepsis-Associated Acute Kidney Injury. Crit Care Clin 2021;37:279–301.
4. Claure-Del Granado R, James MT, Legrand M. Tackling sepsis-associated acute kidney injury using routinely collected data. Intensive Care Med 2023;49:1100–2.
5. Chang Y-M, Chou Y-T, Kan W-C, Shiao C-C. Sepsis and Acute Kidney Injury: A Review Focusing on the Bidirectional Interplay. Int J Mol Sci 2022;23:9159.
6. Kotanko P, Kuhlmann MK, Chan C, Levin NW. Hemodialysis: Principles and techniques. In: Johnson RJ, Floege J, Tonelli M, editors. Comprehensive Clinical Nephrology. 7th ed. Canada: Elsevier; 2023.
7. Vaidya SR, Aeddula NR. Chronic Kidney Disease. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 [cited 2025 Oct]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK535404/
8. Aguilar MG, AlHussen HA, Gandhi PD, Kaur P, Pothacamuri MA, Talikoti MAH, et al. Sepsis-Associated Acute Kidney Injury: Pathophysiology and Treatment Modalities. Cureus 2024;16:e75992.
9. Nian W, Tao W, Zhang H. Review of research progress in sepsis-associated acute kidney injury. Front Mol Biosci 2025;12:1603392.
10. Lee P-H, Huang SM, Tsai Y-C, Wang Y-T, Chew FY. Biomarkers in Contrast-Induced Nephropathy: Advances in Early Detection, Risk Assessment, and Prevention Strategies. Int J Mol Sci 2025;26:2869.
11. Ostermann M, Legrand M, Meersch M, Srisawat N, Zarbock A, Kellum JA. Biomarkers in acute kidney injury. Ann Intensive Care 2024;14:145.
12. Gounden V, Bhatt H, Jialal I. Renal Function Tests. Treasure Island, FL: StatPearls Publishing; 2025 [cited 2025 Oct 8]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK507821/
13. Ziaka M, Exadaktylos A. Fluid management strategies in critically ill patients with ARDS: a narrative review. Eur J Med Res 2025;30:401.
14. Li J, Zhu M, Yan L. Predictive models of sepsis-associated acute kidney injury based on machine learning: a scoping review. Ren Fail 2024;46:2380748.
15. Geraci G, Ferrara P, La Via L, Sorce A, Calabrese V, Cuttone G, et al. Renal Resistive Index from Renal Hemodynamics to Cardiovascular Risk: Diagnostic, Prognostic, and Therapeutic Implications. Diseases 2025;13:178.
16. Zhang PL, Liu M-L. From acute tubular injury to tubular repair and chronic kidney diseases – KIM-1 as a promising biomarker for predicting renal tubular pathology. Curr Res Physiol 2025;8:100152.
17. Yang H, Chen Y, He J, Li Y, Feng Y. Advances in the diagnosis of early biomarkers for acute kidney injury: a literature review. BMC Nephrol 2025;26:1–14.
18. Kim HI, Park S. Sepsis: Early Recognition and Optimized Treatment. Tuberc Respir Dis (Seoul) 2019;82:6–14.
19. Cuesta C, Fuentes-Calvo I, Sancho-Martinez SM, Valentijn FA, Düwel A, Hidalgo-Thomas OA, et al. Urinary KIM-1 Correlates with the Subclinical Sequelae of Tubular Damage Persisting after the Apparent Functional Recovery from Intrinsic Acute Kidney Injury. Biomedicines 2022;10:1106.
20. Kahar LA. Development of Acute Kidney Injury Predictor Score in Intensive Care Unit Patients in Padang, Indonesia. Acta Med Acad 2024;53:136–45.
21. Noronha IL, Santa-Catharina GP, Andrade L, Coelho VA, Jacob-Filho W, Elias RM. Glomerular filtration in the aging population. Front Med (Lausanne) 2022;9:769329.
22. Wu Y, Hao W, Chen Y, Chen S, Liu W, Yu F, et al. Clinical features, risk factors, and clinical burden of acute kidney injury in older adults. Ren Fail 2020;42:1127–34.
23. Peng J, Tang R, Yu Q, Wang D, Qi D. No sex differences in the incidence, risk factors and clinical impact of acute kidney injury in critically ill patients with sepsis. Front Immunol 2022;13:895018.
24. Ju S, Lee TW, Yoo JW, Lee SJ, Cho YJ, Jeong YY, et al. Body Mass Index as a Predictor of Acute Kidney Injury in Critically Ill Patients: A Retrospective Single-Center Study. Tuberc Respir Dis (Seoul) 2018;81:311–8.
25. Widjanarko ND, Tamio E, Alvianto S, Surya ND, Kuatama R, et al. Sequential organ failure

assessment (SOFA) score as a predictor of acute kidney injury in COVID-19 patients: a systematic review and meta-analysis. Jurnal Penyakit Dalam Udayana 2023;7:19–26.
26. Zhang X, Guo W, Hua J, Luo Z, Gao S, Ran L, et al. The Incidence, Risk Factors and Clinical Outcomes of Acute Kidney Injury in Critically Ill Patients with COVID-19: A Multicenter Study [Internet]. 2020 [cited 2025 Oct]. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3572908
27. Asfar P, Meziani F, Hamel J-F, Grelon F, Megarbane B, Anguel N, et al. High versus low blood-pressure target in patients with septic shock. N Engl J Med 2014;370:1583–93.
28. Ghosh D, Mamdapur AB. Renal Resistive Index As A Predictor of Acute Kidney Injury in Patients with Sepsis and Septic Shock: A Prospective Observational Study-interim Results. Indian J Crit Care Med 2024;28:S236–8.
29. Rajaraman B, Darlong V, Soni KD, Aggarwal R, Dehran M, Devasenathipathy K, et al. Renal Doppler ultrasound to predict acute kidney injury in critically ill patients with acute circulatory failure. J Clin Monit Comput 2025;39:757–65.
30. Dawood HF, Fouad HA, El-Shafei MM, Hussein HW, Abdel Razek A. Renal Restrictive Index (RRI) Versus Urinary Neutrophil Gelatinase-Associated Lipocalin (uNGAL) for early prediction of acute kidney injury (AKI) in adults undergoing elective cardiac surgeries with cardiopulmonary bypass: A prospective randomized observational study. Egypt J Anaesth 2022;38:166–73.
31. Cherry AD, Hauck JN, Andrew BY, Li Y-J, Privratsky JR, Kartha LD, et al. Intraoperative renal resistive index threshold as an acute kidney injury biomarker. J Clin Anesth 2020;61:109626.
32. Bossard G, Bourgoin P, Corbeau JJ, Huntzinger J, Beydon L. Early detection of postoperative acute kidney injury by Doppler renal resistive index in cardiac surgery with cardiopulmonary bypass. Br J Anaesth 2011;107:891–8.
33. Brozat JF, Harbalioğlu N, Hohlstein P, Jhaisha SA, Pollmanns MR, Adams JK, et al. Elevated Serum KIM-1 in Sepsis Correlates with Kidney Dysfunction and the Severity of Multi-Organ Critical Illness. Int J Mol Sci 2024;25:5819.
34. Balqis LF, Noormartany N, Gondodiputro RS, Rita C. Validitas Kidney Injury Molecule-1 Urin Metode Mikro Enzyme-Linked Immunosorbent Assay Sebagai Penanda Dini Gangguan Ginjal Akut pada Sepsis. Majalah Kedokteran Bandung 2016;48:19–25.
35. Tu Y, Wang H, Sun R, Ni Y, Ma L, Xv F, et al. Urinary netrin-1 and KIM-1 as early biomarkers for septic acute kidney injury. Ren Fail 2014;36:1559–63.
36. Shao X, Tian L, Xu W, Zhang Z, Wang C, Qi C, et al. Diagnostic value of urinary kidney injury molecule 1 for acute kidney injury: a meta-analysis. PLoS One 2014;9:e84131.
37. Bagshaw SM, Bellomo R, Devarajan P, Johnson C, Karvellas CJ, Kutsiogiannis DJ, et al. Review article: Acute kidney injury in critical illness. Can J Anaesth 2010;57:985–98.
38. Fani F, Regolisti G, Delsante M, Cantaluppi V, Castellano G, Gesualdo L, et al. Recent advances in the pathogenetic mechanisms of sepsis-associated acute kidney injury. J Nephrol 2018;31:351–9.