J Renal Inj Prev. 2026: e38726.

https://journalrip.com doi: 10.34172/jrip.38726

Journal of Renal Injury Prevention

Urinary gamma-glutamyl transferase as a predictor of vancomycin-induced acute kidney injury; a prospective diagnostic and observational study

Farzaneh Futuhi[1], Zahra Sahraei[2], Seyed Mehdi Panahandeh[3], Masood Zangi[4], Mohammadreza Hajiesmaeili[4], Sara Rashki Ghalehnoo[5], Zahra Abbasi[6], Mahdi Amirdosara[4*], Seyyed Mohammad Hosein Ahooie[7*]

[1]Department of Adult Nephrology, School of Medicine, Loghman Hakim Hospital, Shahid Beheshti University of Medical Science, Tehran, Iran
[2]Department of Clinical Pharmacy, School of Pharmacy, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[3]Department of Internal Medicine, Taleghani Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[4]Critical Care Quality Improvement Research Center, Loghman Hakim Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[5]Department of Cardiology, School of Medicine, Amir Al-momenin Hospital, Zabol University of Medical Sciences, Zabol, Iran
[6]Department of Otorhinolaryngology, School of Medicine, Hearing Disorders Research Center, Loghman Hakim Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[7]Faculty of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran

ARTICLE INFO

Article Type:
Original

Article History:
Received: 9 Dec. 2025
Revised: 27 Dec. 2025
Accepted: 14 Mar. 2026
Published online: 25 May 2026

Keywords:
Vancomycin,
Acute kidney injury,
Urinary gamma-glutamyl transferase,
GGT biomarker,
Nephrotoxicity

ABSTRACT

Introduction: Vancomycin is widely used for treating serious gram-positive infections; however, its clinical utility can be limited by nephrotoxicity. Early detection of vancomycin-induced acute kidney injury (AKI) remains a clinical challenge, as traditional markers such as serum creatinine often rise only after significant renal damage has occurred.
Objectives: Urinary gamma-glutamyl transferase (GGT), an early tubular injury biomarker, may provide a sensitive indicator for detecting nephrotoxicity before overt renal impairment develops.
Materials and Methods: This prospective observational study was conducted between 2023 and 2024 at Loghman Hakim Hospital, Tehran, involving 14 patients receiving vancomycin who had no prior kidney disease. Demographic and clinical data were collected, and urinary GGT levels were measured on days 1, 3, and 6 after treatment initiation. The outcome was to compare urinary GGT levels between patients with and without AKI, to evaluate GGT as a potential biomarker for predicting vancomycin-associated AKI.
Results: The results demonstrated that urinary GGT in relation to the occurrence of vancomycin-induced AKI demonstrated no statistically significant associations across different time points of day 1, 3, and 3 after the administration of vancomycin. The area under the curve (AUC) values for predicting the occurrence of AKI were non-significant and were 0.633 on day 1, 0.556 on day 3, and 0.733 on day 6, respectively ($P > 0.05$). The optimal urinary GGT cut-off values for AKI occurrence were 31 on day 1, 33.5 on day 3, and 47.35 on day 6, yielding sensitivities of 40%, 60%, and 60% and specificities of 56%, 67%, and 67%, respectively, suggesting only modest discriminative ability of urinary GGT for AKI.
Conclusion: In conclusion, urinary GGT showed no clinically meaningful or statistically significant ability to predict vancomycin-induced AKI at any evaluated time point and therefore cannot be recommended as a reliable standalone biomarker in this setting.

Implication for health policy/practice/research/medical education:
In this study, we found that urinary gamma-glutamyl transferase (GGT) showed no clinically meaningful or statistically significant ability to predict vancomycin-induced acute kidney injury (AKI), indicating that it should not be used as a standalone biomarker in this context and that clinicians should instead rely on established renal function indices, therapeutic drug monitoring, and more validated biomarkers when assessing nephrotoxicity risk and guiding vancomycin therapy.

Please cite this paper as: Futuhi F, Sahraei Z, Panahandeh SM, Zangi M, Hajiesmaeili M, Rashki Ghalehnoo S, Abbasi Z, Amirdosara M, Ahooie SMH. Urinary gamma-glutamyl transferase as a predictor of vancomycin-induced acute kidney injury; a prospective diagnostic and observational study. J Renal Inj Prev. 2026; x(x): e38726. doi: 10.34172/jrip.38726.

Original

***Corresponding author**: Mahdi Amirdosara, Email: dr.amirdosara@gmail.com, and Seyed Mohammad Hosein Ahooie, Email: mrahooie@gmail.com

Introduction

Acute kidney injury (AKI) is a frequent complication in hospitalized adults, affecting over 20% of admissions and exceeding 50% among intensive care unit (ICU) patients (1,2). The AKI carries mortality rates up to 24% and, even in mild cases (3), may require renal replacement therapy, extend hospitalization, and impose substantial economic costs (4). Furthermore, this injury can cause permanent kidney damage, leading to chronic kidney disease (CKD) (5). Drug-induced nephropathy is a common yet preventable cause of AKI, accounting for approximately one-fifth of all AKI cases during hospitalization (6). Antibiotics, including aminoglycosides, glycopeptides, β-lactams, sulfonamides, tetracyclines, fluoroquinolones, and polymyxin, are common causative agents of kidney injury, acting through mechanisms such as acute tubular necrosis, altered glomerular hemodynamics, acute interstitial nephritis, crystal nephropathy, and Fanconi syndrome (7). With the rising prevalence of methicillin-resistant *Staphylococcus aureus* (MRSA), especially in hospital-acquired infections, vancomycin has become a widely used antibiotic in hospitalized patients (8). Vancomycin-induced nephrotoxicity, reported in 5–43% of treated patients (9), results from proximal tubular injury driven by oxidative stress and non-crystalline cast formation, underscoring the importance of early clinical detection (7).

According to Kidney Disease/Improving Global Outcomes (KDIGO) criteria, AKI is diagnosed by an increase in serum creatinine of ≥0.3 mg/dL within 48 hours, or ≥1.5 times baseline within seven days, or by urine output <0.5 mL/kg/h for at least six hours (10). A false elevation in serum creatinine may result from increased protein intake, greater muscle mass, fasting, diabetic ketoacidosis, hemolysis, or the use of medications such as trimethoprim, cefazolin, cimetidine, and N-acetylcysteine (11). Moreover, serum creatinine is a late indicator that elevates 24–36 hours after kidney injury, when the injury has already occurred, delaying early measures to prevent complications. This necessitates practical options for the timely diagnosis of AKI (12).

In recent years, several biomarkers have been proposed for the early detection of tubular injury, such as Liver-type fatty acid-binding protein (L-FABP), Kidney injury molecule-1 (KIM-1), neutrophil gelatinase-associated lipocalin (NGAL), and interleukin-18 (IL-18) (12,13). These markers can be released into the urine and plasma after tubular injury before functional evidence, such as a creatinine rise, is observed (14). Urinary gamma-glutamyl transferase (GGT), an enzyme integral to glutathione metabolism and oxidative stress defense, is localized to the brush border of proximal tubular epithelial cells, the principal site of vancomycin toxicity, from which it is released into the tubular lumen and subsequently detected in urine (15). The predictive utility of urinary GGT has been examined in conditions involving direct proximal tubular injury, including contrast-induced nephropathy (15), drug-related nephrotoxicity (16), and ischemic AKI (17). Although the predictive role of several biomarkers in vancomycin-induced AKI has been explored, the utility of urinary GGT as an early predictor in humans remains uncertain; accordingly, this study sought to evaluate its diagnostic value as an early biomarker of AKI in ICU patients receiving vancomycin.

Objectives

This study aimed to evaluate the predictive value of urinary GGT levels for vancomycin-induced AKI in ICU patients by comparing biomarker concentrations between those who developed AKI and those who did not, and assessing diagnostic performance through receiver operating characteristic (ROC) curve analysis.

Materials and Methods

Study design and participants

This prospective diagnostic and observational study was conducted from February 2023 to January 2024 at Loghman Hakim Hospital in Tehran, Iran, enrolling ICU patients receiving vancomycin treatment. Adult patients lacking a history of AKI or CKD, who gave written informed consent, were enrolled and prospectively followed for vancomycin-associated AKI during their ICU stay.

Inclusion and exclusion criteria

Inclusion criteria included patients receiving vancomycin therapy who had no prior history of AKI or CKD, and who provided informed written consent (from patients or their legally authorized representatives) to participate. Exclusion criteria included unwilling patients to continue the study, those with incomplete clinical or laboratory data necessary for AKI assessment according to the KDIGO criteria. Patients were also excluded if they had received vancomycin treatment for less than the minimum duration required for meaningful evaluation of nephrotoxicity.

Data collection

In this study, written informed consent was obtained from all participants or their legally authorized representatives before enrollment, and data were collected from 14 ICU patients receiving vancomycin treatment, including demographic characteristics (age, gender, diabetes mellitus, and hypertension) and clinical outcomes such as the occurrence of AKI, which was defined according to the KDIGO criteria. Serial urinary GGT levels were measured on days 1, 3, and 6 post-vancomycin initiation to assess biomarker utility. All relevant information was extracted from medical records, laboratory reports, and patients' interviews for analysis.

AKI definition according to KDIGO

The AKI was defined in accordance with the KDIGO.

criteria, which classify AKI based on an increase in serum creatinine of at least 0.3 mg/dL within 48 hours or a 1.5-fold increase from baseline within seven days, and/or a reduction in urine output to less than 0.5 mL/kg/h for six hours or longer (10).

Outcome measurement

The primary outcome focused on comparing urinary GGT levels between patients who developed AKI and those who did not, to evaluate the association between GGT levels and vancomycin-induced AKI. This comparison aimed to determine whether urinary GGT could serve as an effective predictive biomarker for AKI by analyzing differences in GGT levels at various time points during treatment, assessing its diagnostic potential, and correlating with AKI occurrence in the study population.

Statistical analysis

Statistical analyses were conducted using SPSS version 27 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was assessed using the Shapiro–Wilk test, and homogeneity of variances was examined with Levene's test. As both parametric and corresponding nonparametric tests yielded concordant results in terms of effect direction and comparable *P* values, parametric tests were chosen for reporting due to their superior statistical power and precision, including the independent samples T test for comparisons of continuous variables between AKI and non-AKI groups, the chi-square test for comparisons of categorical variables, binary logistic regression (univariate and multivariate) to estimate odds ratios and 95% confidence intervals for the association between urinary GGT and AKI, and ROC curve analysis to determine the diagnostic performance of urinary GGT and optimal cut-off values.

Results

This study included 14 patients with a mean age of 43.28 years who were in the ICU and received vancomycin treatment. The majority were male, without diabetes mellitus, and without hypertension. The AKI occurred in 5 patients (35.7%). The urinary GGT levels were monitored across several time points of day 1, 3, and 6, with values showing variation over the course of follow-up (Table 1). In the comparative analysis of patients with and without AKI, most demographic and clinical variables did not show statistically significant differences. Gender distribution, presence of hypertension, and urinary GGT levels across the measured days were not significantly associated with AKI occurrence. Diabetes mellitus, however, approached statistical significance, being more common among patients with AKI. Age was the only variable that demonstrated a significant difference, with patients who developed AKI being older than those who did not (Table 2).

The analysis of urinary GGT in relation to the occurrence of vancomycin-induced AKI demonstrated no statistically significant associations across different time points. In the univariate logistic regression, urinary GGT measured on the first, third, and sixth days did not show a meaningful correlation with AKI risk. Similarly, when the models were adjusted for potential confounders such as age, gender, and underlying conditions, including diabetes and hypertension, the findings remained nonsignificant. Across both unadjusted and adjusted analyses, the odds ratios indicated no clear predictive value of urinary GGT for AKI (Table 3).

The results indicated that the diagnostic performance of urinary GGT as a biomarker for the occurrence of AKI at several time points of day 1, 3, and 3 after the administration of vancomycin, indicating only modest discrimination with wide uncertainty around the estimates. The table shows that the statistical significance of this marker is limited at all assessed times, reflecting inconsistency in its ability to reliably distinguish patients who develop AKI from those who do not. Despite the identification of specific thresholds for urinary GGT on different days, the associated diagnostic characteristics

Table 1. Demographic characteristics and clinical features of included patients

Patient clinical-demographic characteristics		Frequency	Percent
Gender	Male	9	64.3
	Female	5	35.7
Diabetes mellitus	Yes	4	28.6
	No	10	71.4
Hypertension	Yes	6	42.9
	No	8	57.1
Occurrence of AKI	Yes	5	35.7
	No	9	64.3
		Mean ± SD	
Age (year)		43.28 ± 15.61	
Urinary GGT (U/L; Mean ± SD)	Day 1	38.36 ± 26.15	
	Day 3	30.91 ± 17.09	
	Day 6	44.23 ± 25.36	

AKI: Acute kidney injury; GGT: Gamma-glutamyl transferase; SD: Standard deviation.

Table 2. The distribution of demographic characteristics and clinical features of included patients according to the occurrence of AKI

Patient clinical-demographic characteristics		Occurrence of AKI		*P* value
		No (n = 9)	Yes (n= 5)	
Gender n (%)	Male	5 (55.6)	4 (80)	0.360*
	Female	4 (44.4)	1 (20)	
Diabetes mellitus n (%)	Yes	1 (11.1)	3 (60)	0.052*
	No	8 (88.9)	2 (40)	
Hypertension n (%)	Yes	3 (33.3)	3 (60)	0.334*
	No	6 (66.7)	2 (40)	
		Mean ± SD	Mean ± SD	*P* value
Age (year)		36.44 ± 13.97	55.60 ± 10.35	0.021**
Urinary GGT (U/L; Mean ± SD)	Day 1	34.90 ± 25.42	44.60 ± 29.24	0.528**
	Day 3	29.40 ± 16.92	33.64 ± 19.04	0.650**
	Day 6	37.63 ± 23.89	56.12 ± 25.96	0.203**

AKI: Acute kidney injury; GGT: Gamma-glutamyl transferase; SD: Standard deviation.
*Chi-square, **Independent T-test.

Table 3. The correlation between urinary GGT and the occurrence of AKI using univariate and multivariate binary logistic regression

Urinary GGT (U/L)		Occurrence of AKI		
		P value	OR	95% CI
Unadjusted	Day 1	0.495	1.01	0.97 – 1.06
	Day 3	0.646	1.02	0.95 – 1.08
	Day 6	0.190	1.03	0.98 – 1.08
Adjusted	Day 1	0.973	0.99	0.91 – 1.09
	Day 3	0.820	0.93	0.54 – 1.61
	Day 6	0.504	1.09	0.84 – 1.40

AKI: Acute kidney injury; GGT: Gamma-glutamyl transferase; OR: Odds ratio; CI: Confidence interval.

suggest that its clinical utility as a standalone test for early detection of AKI remains restricted (Table 4 and Figure 1).

Discussion

Our results indicated that urinary GGT did not demonstrate a significant or clinically useful capacity to predict vancomycin-induced AKI, indicating that it lacks reliability as a standalone biomarker for this condition. In contrast to our findings, Westhuyzen et al examined a comparable cohort of 26 critically ill ICU patients and demonstrated that urinary GGT possessed excellent discriminatory ability for predicting acute renal failure, with an AUC of 0.950. Notably, GGT elevation identified patients at risk 12 hours to 4 days before serum creatinine levels increased. In contrast, our study yielded only fair and statistically nonsignificant diagnostic accuracy. This divergence in findings may reflect differences in the underlying etiologies of AKI. Whereas Westhuyzen et al focused on acute renal failure secondary to sepsis and ischemia, our investigation centered on vancomycin-induced nephrotoxicity. The pathophysiological mechanisms of vancomycin toxicity may provoke a distinct pattern or magnitude of GGT release compared with ischemic or septic injury, thereby accounting for the reduced predictive performance observed in our cohort (18). Similarly, in a study by

Table 4. Diagnostic value of urinary GGT in the diagnosis of AKI occurrence

Urinary GGT (U/L)	Occurrence of AKI						
	AUC (0-1)	*P* value	95% CI		Cut Off (ng/mL)	Sensitivity (%)	Specificity (%)
			Lower	Upper			
Day 1	0.633	0.424	0.327	0.939	31	40	56
Day 3	0.556	0.739	0.222	0.889	33.5	60	67
Day 6	0.733	0.162	0.450	1.00	47.35	60	67

AUC, Area under curve; CI: Confidence interval.

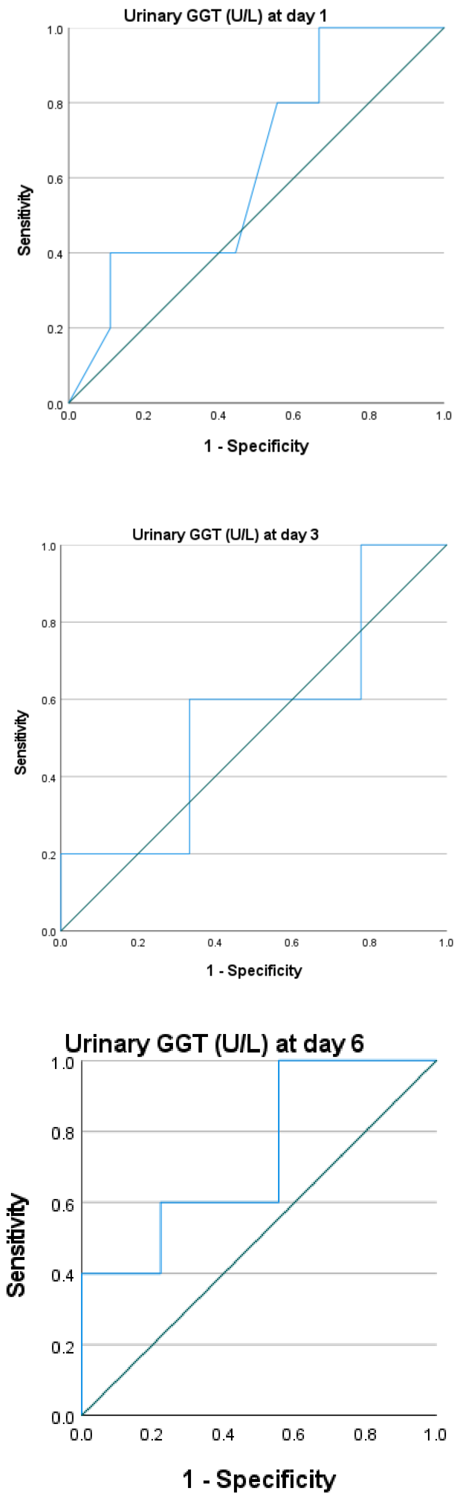

Figure 1. Urinary GGT as a diagnostic marker of AKI occurrence using ROC curve analysis.

Aygun et al, the results demonstrated that initial serum GGT levels were significantly correlated with the development of AKI in critically ill pediatric patients, and stated that GGT may serve as an early biomarker to identify children at risk for renal dysfunction (19). Davis et al found that urinary GGT levels increased rapidly following ischemia-reperfusion injury, correlating with early proximal tubular damage before serum creatinine changes were detectable; this supports urinary GGT as a sensitive biomarker for the early diagnosis of AKI (20). An animal study also indicated that cats with urethral obstruction exhibited elevated urinary GGT activity at presentation, consistent with early renal tubular damage and risk of AKI, supporting urinary GGT as a useful biomarker for detecting AKI in post-renal obstruction (21). However, the inconsistency of urinary biomarkers in the specific context of vancomycin-associated injury is supported by recent prospective studies, which found that while markers like KIM-1 and NGAL demonstrated significant diagnostic accuracy, enzymatic markers often failed to show similar predictive reliability (12,13,22). In addition to the findings, Carvalho et al identified GGT as a significant diagnostic marker for chronic diabetic nephropathy with the AUC of 0.77 in 112 patients, whereas our study of vancomycin-induced acute toxicity (AUC 0.73, n=14) did not reach statistical significance, likely reflecting both differing pathologies and limited sample size (23).

The limited predictive capacity of GGT observed in this study may be attributed to the distinct pathophysiology of vancomycin-induced nephrotoxicity in critically ill patients, where oxidative stress mechanisms may not trigger the same magnitude of brush-border enzymatic release as seen in direct ischemic or contrast-mediated injury (21). Since urinary GGT levels may also increase in hepatobiliary disease or certain tumors, relying on this marker alone for AKI detection—especially in critically ill ICU patients-can be misleading. Consequently, recent research has shifted toward more kidney-specific biomarkers, such as NGAL and KIM-1 (22,24-26). To improve diagnostic accuracy, recent studies advocate simultaneous detection of multiple interrelated biomarkers (e.g., GGT, alanine aminopeptidase, N-acetyl-β-glucosaminidase) and the application of machine learning algorithms to identify complex biomarker patterns and predict AKI with high precision (27). Overall, the diagnostic performance data indicate that urinary GGT does not possess the necessary sensitivity or specificity to serve as a routine screening tool for vancomycin nephrotoxicity when used in isolation. Clinical monitoring should instead prioritize validated functional indices and multi-marker panels, as reliance on single enzymatic markers like GGT may lead to missed opportunities for early intervention. Our results indicated that urinary GGT did not demonstrate a significant or clinically useful capacity to predict vancomycin-induced AKI, indicating that it lacks reliability as a standalone biomarker for this condition

Conclusion

These findings indicate that urinary GGT does not provide meaningful predictive value for vancomycin-induced AKI across the evaluated time points, as its overall discriminative performance remained limited and statistically non-significant despite variation in test thresholds. Although different cutoff levels yielded modest sensitivities and specificities on successive days after vancomycin administration, these diagnostic characteristics are insufficient to support urinary GGT as a reliable standalone biomarker for the early detection of such nephrotoxicity in clinical practice. Consequently, the results suggest that urinary GGT should be interpreted with caution and, if used at all, only in conjunction with other established clinical indicators and more robust biomarkers of kidney injury.

Limitations of the study

The primary limitation of this study is its small sample size of 14 ICU patients, which restricts statistical power and increases the risk of type II errors, potentially limiting the generalizability of urinary GGT as a biomarker for vancomycin-induced AKI. As a single-center observational study at Loghman Hakim Hospital, findings may not represent diverse populations or settings, with potential selection bias from exclusion criteria such as prior AKI, incomplete data, or short vancomycin duration. Additionally, unmeasured confounders like concomitant nephrotoxic drugs, exact vancomycin dosing, or serum levels were not fully detailed, alongside reliance on KDIGO criteria, which may delay AKI detection in critically ill patients. Larger, multicenter prospective trials are needed to validate these results.

Acknowledgments

The authors express their gratitude to the staff of Loghman Hakim Hospital for their valuable cooperation and support during data collection. Special thanks are extended to the ICU medical and nursing teams for their assistance in patient care and sample collection. The authors also appreciate the contributions of the participants and their families for their commitment to this study.

Authors' contribution

Conceptualization: Farzaneh Futuhi and Zahra Sahraei.
Data curation: Mahdi Amirdosara, Seyyed Mohammad Hosein Ahooie, and Zahra Abbasi.
Formal analysis: Seyed Mehdi Panahandeh and Sara Rashki Ghalehnoo.
Investigation: Masood Zangi and Mohammadreza Hajiesmaeili.
Methodology: Seyed Mehdi Panahandeh and Zahra Sahraei.
Project management: Seyyed Mohammad Hosein Ahooie and Farzaneh Futuhi.
Resources: All authors.
Supervision: All authors.
Validation: Masood Zangi and Sara Rashki Ghalehnoo.
Writing–original draft: All authors.
Writing–review and editing: All authors.

Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of generative artificial intelligence (AI) and AI-assisted technologies in the writing process

While preparing this work, the authors utilized AI (Grammarly, Perplexity.ai, and Copilot) to refine grammar points and language style. Subsequently, they thoroughly reviewed and edited the content as necessary, assuming full responsibility for the publication's content.

Ethical issues

The research was conducted in accordance with the principles the Declaration of Helsinki. Informed written consent was taken from all participants or their legally authorized representatives. This study was conducted at Loghman Hakim Hospital and was derived from the thesis work of an anesthesiology student (Thesis #43002660), approved by the ethics committee of the School of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran, under the ethical code (IR.SBMU.MSP.REC.1401.446; https://ethics.research.ac.ir/form/17dsgarmv7lejkwm.pdf) registered on November 29, 2022. Besides, the authors have ultimately observed ethical issues (including plagiarism, data fabrication, and double publication).

Funding/Support

The funding was supported by the Shahid Beheshti University of Medical Sciences, Tehran, Iran (Grant #43002660).

References

1. Alessandri F, Pistolesi V, Manganelli C, Ruberto F, Ceccarelli G, Morabito S, et al. Acute Kidney Injury and COVID-19: A Picture from an Intensive Care Unit. Blood Purif. 2021;50:767–71. doi: 10.1159/000513153.
2. Hoste EA, Bagshaw SM, Bellomo R, Cely CM, Colman R, Cruz DN, et al. Epidemiology of acute kidney injury in critically ill patients: the multinational AKI-EPI study. Intensive Care Med. 2015;41:1411–23. doi: 10.1007/s00134-015-3934-7.
3. Susantitaphong P, Cruz DN, Cerda J, Abulfaraj M, Alqahtani F, Koulouridis I, et al. World incidence of AKI: a meta-analysis. Clin J Am Soc Nephrol. 2013;8:1482–93. doi: 10.2215/cjn.00710113.
4. Veltkamp DMJ, Porras CP, Gant CM, Groenestege WMT, Kok MB, Verhaar MC, et al. Long-term risks of adverse kidney outcomes after acute kidney injury: a systematic review and meta-analysis. Nephrol Dial Transplant. 2025;40:2143–58. doi: 10.1093/ndt/gfaf093.
5. Chawla LS, Eggers PW, Star RA, Kimmel PL. Acute kidney

injury and chronic kidney disease as interconnected syndromes. N Engl J Med. 2014;371:58–66. doi: 10.1056/NEJMra1214243.
6. Garcia G, Pacchini VR, Zamoner W, Balbi AL, Ponce D. Drug-induced acute kidney injury: a cohort study on incidence, identification of pathophysiological mechanisms, and prognostic factors. Front Med (Lausanne). 2024;11:1459170. doi: 10.3389/fmed.2024.1459170.
7. Campbell RE, Chen CH, Edelstein CL. Overview of Antibiotic-Induced Nephrotoxicity. Kidney Int Rep. 2023;8:2211–25. doi: 10.1016/j.ekir.2023.08.031.
8. Hassoun A, Linden PK, Friedman B. Incidence, prevalence, and management of MRSA bacteremia across patient populations-a review of recent developments in MRSA management and treatment. Crit Care. 2017;21:211. doi: 10.1186/s13054-017-1801-3.
9. van Hal SJ, Paterson DL, Lodise TP. Systematic review and meta-analysis of vancomycin-induced nephrotoxicity associated with dosing schedules that maintain troughs between 15 and 20 milligrams per liter. Antimicrob Agents Chemother. 2013;57:734–44. doi: 10.1128/aac.01568-12.
10. Matuszkiewicz-Rowińska J, Małyszko J. Acute kidney injury, its definition, and treatment in adults: guidelines and reality. Pol Arch Intern Med. 2020;130:1074–80. doi: 10.20452/pamw.15373.
11. Samra M, Abcar AC. False estimates of elevated creatinine. Perm J. 2012;16:51–2. doi: 10.7812/tpp/11-121.
12. Bufkin KB, Karim ZA, Silva J. Review of the limitations of current biomarkers in acute kidney injury clinical practices. SAGE Open Med. 2024;12:20503121241228446. doi: 10.1177/20503121241228446.
13. Schrezenmeier EV, Barasch J, Budde K, Westhoff T, Schmidt-Ott KM. Biomarkers in acute kidney injury - pathophysiological basis and clinical performance. Acta Physiol (Oxf). 2017;219:554–72. doi: 10.1111/apha.12764.
14. Devarajan P. Biomarkers for the early detection of acute kidney injury. Curr Opin Pediatr. 2011;23:194–200. doi: 10.1097/MOP.0b013e328343f4dd.
15. Mitrić A, Castellano I. Targeting gamma-glutamyl transpeptidase: A pleiotropic enzyme involved in glutathione metabolism and in the control of redox homeostasis. Free Radic Biol Med. 2023;208:672–83. doi: 10.1016/j.freeradbiomed.2023.09.020.
16. van der Harst MR, Bull S, Laffont CM, Klein WR. Gentamicin nephrotoxicity--a comparison of in vitro findings with in vivo experiments in equines. Vet Res Commun. 2005;29:247–61. doi: 10.1023/b:verc.0000047492.05882.bb.
17. Marcelino P, Tavares I, Carvalho D, Marques C, Silvestre MJ, Perdigoto R, et al. Is urinary γ-glutamyl transpeptidase superior to urinary neutrophil gelatinase-associated lipocalin for early prediction of acute kidney injury after liver transplantation? Transplant Proc. 2014;46:1812–8. doi: 10.1016/j.transproceed.2014.05.052.
18. Westhuyzen J, Endre ZH, Reece G, Reith DM, Saltissi D, Morgan TJ. Measurement of tubular enzymuria facilitates early detection of acute renal impairment in the intensive care unit. Nephrol Dial Transplant. 2003;18:543–51. doi: 10.1093/ndt/18.3.543.
19. Aygun F, Kirkoc R, Aygun D, Cam H. Gamma Glutamyl Transferase and Uric Acid Levels Can Be Associated with the Prognosis of Patients in the Pediatric Intensive Care Unit. Children (Basel). 2018;5:147. doi: 10.3390/children5110147.
20. Davis J, Rossi G, Cianciolo RE, Ho KM, Hosgood GL, Miller DW, et al. Early diagnosis of acute kidney injury subsequent to severe hypotension and fluid resuscitation in anaesthetized dogs. Vet Anaesth Analg. 2022;49:344–53. doi: 10.1016/j.vaa.2022.02.006.
21. Xavier Júnior FAF, Morais GB, Silveira JAM, Sampaio TL, Martins AMC, Silva ING, et al. Kidney injury molecule-1 and urinary gamma-glutamyl transferase as biomarkers of acute kidney injury in cats. J Small Anim Pract. 2022;63:203–10. doi: 10.1111/jsap.13440.
22. Sampaio de Souza Garms D, Cardoso Eid KZ, Burdmann EA, Marçal LJ, Antonângelo L, Dos Santos A, et al. The Role of Urinary Biomarkers as Diagnostic and Prognostic Predictors of Acute Kidney Injury Associated With Vancomycin. Front Pharmacol. 2021;12:705636. doi: 10.3389/fphar.2021.705636.
23. De Carvalho JA, Piva SJ, Hausen BS, Bochi GV, Kaefer M, Coelho AC, et al. Assessment of urinary γ-glutamyltransferase and alkaline phosphatase for diagnosis of diabetic nephropathy. Clin Chim Acta. 2011; 412:1407–11. doi: 10.1016/j.cca.2011.04.015.
24. Park SI, Yu U, Oh WS, Ryu SW, Son S, Lee S, et al. Serum and urinary biomarkers of vancomycin-induced acute kidney injury: A prospective, observational analysis. Medicine (Baltimore). 2024;103:e39202. doi: 10.1097/md.0000000000039202.
25. Spyhalsky AM, Kim SJ, Meaney CJ, Smith NM, Shah DK, Hassinger AB, et al. Urinary biomarkers as indicators of acute kidney injury in critically ill children exposed to vancomycin. Pharmacotherapy. 2024;44:163–70. doi: 10.1002/phar.2893.
26. Pais GM, Avedissian SN, O'Donnell JN, Rhodes NJ, Lodise TP, Prozialeck WC, et al. Comparative Performance of Urinary Biomarkers for Vancomycin-Induced Kidney Injury According to Timeline of Injury. Antimicrob Agents Chemother. 2019;63:e00079. doi: 10.1128/aac.00079-19.
27. Wang WG, Sun WX, Gao BS, Lian X, Zhou HL. Cell Cycle Arrest as a Therapeutic Target of Acute Kidney Injury. Curr Protein Pept Sci. 2017;18:1224–31. doi: 10.2174/1389203717666160915162238.