JURNAL KOMPLIKASI ANESTESI
VOLUME 13 NOMOR 1, November 2025

LITERATURE REVIEW

# Transesophageal Echocardiography–Derived Renal Resistive Index after Cardiopulmonary Bypass: A Novel Hemodynamic Marker of Postoperative Renal Vulnerability

Dian Raseka Parna, Juni Kurniawaty
Department of Anesthesiology and Intensive Care Faculty of Medicine, Public Health, and Nursing Gadjah Mada University-Dr. Sardjito General Hospital Yogyakarta Indonesia
*Coresponden author: Dian Raseka Parna, Department of Anesthesiology and Intensive Care Faculty of Medicine, Public Health, and Nursing Gadjah Mada University-Dr. Sardjito General Hospital Yogyakarta Indonesia (dianraseka@gmail.com)

How to cite: Parna DR, et al, Transesophageal Echocardiography–Derived Renal Resistive Index after Cardiopulmonary Bypass: A Novel Hemodynamic Marker of Postoperative Renal Vulnerability. Jurnal Komplikasi Anestesi. 13(1):2025.

Receive: January 15, 2026
Accepted: January 23, 2026

## ABSTRACT

Acute kidney injury (AKI) remains a frequent and clinically significant complication following cardiopulmonary bypass (CPB), often developing despite apparently stable systemic hemodynamics. Conventional renal monitoring relies on delayed biochemical markers that fail to capture early disturbances in renal microcirculation. The renal resistive index (RRI) has emerged as a dynamic indicator of renal vascular resistance and microcirculatory stress, but its perioperative application has been limited by the practicality of transabdominal ultrasonography. Transesophageal echocardiography (TEE), routinely used during cardiac surgery, offers a unique opportunity for real-time assessment of renal hemodynamics during and immediately after CPB. This literature review synthesizes current evidence on the feasibility, physiological basis, and clinical relevance of TEE-derived RRI measurement in the post-CPB setting. The reviewed studies suggest that elevated RRI values reflect a complex interaction of renal vascular resistance, venous congestion, altered pulsatility, and inflammatory endothelial dysfunction rather than isolated reductions in renal blood flow. Importantly, RRI elevation frequently precedes changes in serum creatinine or urine output and has been associated with an increased risk of postoperative renal dysfunction, even in patients without overt hypotension or low cardiac output. TEE-derived RRI therefore represents a promising, underutilized hemodynamic marker for early identification of postoperative renal vulnerability and may support more proactive, organ-protective hemodynamic management strategies following cardiopulmonary bypass.

**Keywords**: Acute kidney injury, cardiac surgery, cardiopulmonary bypass, renal resistive index, transesophageal echocardiography

## INTRODUCTION

Acute kidney injury (AKI) remains one of the most prevalent and prognostically significant complications following cardiac surgery with cardiopulmonary bypass (CPB), affecting up to 30–40% of patients depending on diagnostic criteria and surgical complexity.[1,2] Even mild postoperative renal dysfunction has been consistently associated with increased morbidity, prolonged intensive care unit stay, higher healthcare costs, and long-term mortality.[3,4] Despite advances in perfusion strategies, myocardial protection, and perioperative hemodynamic monitoring, the incidence of CPB-associated AKI has remained largely unchanged, suggesting persistent gaps in early detection and pathophysiological understanding.[5]

Current perioperative renal monitoring predominantly relies on systemic parameters and delayed biochemical markers, such as serum creatinine and urine output. These indices, however, reflect renal injury only after substantial functional impairment has already occurred and provide limited insight into dynamic changes in renal microcirculation.[6] Importantly, AKI following CPB frequently develops in patients without sustained hypotension or overt low cardiac output syndrome, underscoring that macrocirculatory stability does not necessarily equate to preserved renal perfusion.[7] This dissociation highlights the need for real-time, physiology-based markers capable of detecting early renal vascular stress before irreversible injury ensues.

The renal resistive index (RRI), derived from Doppler assessment of intrarenal arterial waveforms, has gained attention as a surrogate marker of renal vascular resistance and microcirculatory integrity.8 Elevated RRI values have been associated with adverse renal outcomes in various clinical settings, including critical illness, sepsis, and heart failure.[9,10] Traditionally, RRI is measured using transabdominal ultrasonography; however, this technique is often impractical or unreliable in the immediate perioperative period following cardiac surgery due to surgical dressings, mechanical ventilation, obesity, and limited acoustic windows.[11] These limitations significantly restrict its applicability precisely when early renal assessment would be most valuable.

Transesophageal echocardiography (TEE) is routinely employed during cardiac surgery and in the early postoperative period to guide hemodynamic management and assess cardiac function. Beyond conventional cardiac imaging, TEE enables visualization of descending thoracic and abdominal vascular structures, providing an opportunity to assess renal arterial flow indirectly and derive RRI measurements without additional equipment or patient repositioning.[12,13] Emerging evidence suggests that TEE-derived RRI can be obtained safely and reproducibly during and immediately after CPB, offering real-time insight into renal vascular dynamics at a critical juncture of systemic inflammatory activation, altered pulsatility, and venous congestion.[14]

Importantly, growing data indicate that postoperative elevations in RRI reflect a complex interplay of renal venous hypertension, increased intrarenal vascular stiffness, inflammatory endothelial dysfunction, and neurohormonal activation rather than isolated reductions in renal blood flow.[15–17] As such, RRI may represent an integrative marker of renal vulnerability rather than a simple perfusion metric. However, the clinical role of TEE-derived RRI in the context of CPB remains incompletely defined, and its potential value for early risk stratification and targeted hemodynamic optimization has not been systematically synthesized.

Therefore, the purpose of this literature review is to critically evaluate the physiological rationale, technical feasibility, and clinical relevance of TEE-derived renal resistive index measurement in patients undergoing cardiac surgery with CPB. By integrating existing evidence, this review aims to clarify the potential role of RRI as an early hemodynamic marker of postoperative renal vulnerability and to identify knowledge gaps that may inform future research and perioperative monitoring strategies.

### Feasibility of TEE-Derived Renal Resistive Index Assessment After CPB

The reviewed literature demonstrates that assessment of the renal resistive index (RRI) using echocardiographic techniques is technically feasible in the perioperative cardiac surgery setting. While most early studies utilized transabdominal Doppler ultrasonography, several experimental and clinical investigations have shown that renal arterial flow signals can be obtained using transesophageal echocardiography (TEE), particularly during and immediately after cardiopulmonary bypass (CPB).[8,12,14] This is clinically relevant, as the immediate post-CPB period represents a critical window during which renal hemodynamics are most vulnerable, yet conventional transabdominal access is frequently limited by surgical dressings, mechanical ventilation, and patient positioning.

TEE-based assessment offers a practical advantage by enabling real-time renal vascular evaluation without interrupting standard perioperative monitoring. Given that TEE is routinely employed during cardiac surgery, extending its use to include RRI measurement does not require additional equipment and may be seamlessly integrated into existing workflows.[12] This feasibility positions TEE-derived RRI as a potentially scalable monitoring tool in high-risk cardiac surgical populations.

## Physiological Determinants of RRI in the Post-CPB Setting

Across the reviewed studies, elevated RRI values after CPB were consistently associated with adverse renal physiology rather than isolated reductions in renal blood flow. Experimental and clinical data suggest that RRI reflects a composite of intrarenal vascular resistance, arterial compliance, pulsatility, and downstream venous pressure.[8,15] Following CPB, these factors are profoundly influenced by systemic inflammatory responses, endothelial dysfunction, neurohormonal activation, and non-physiological flow patterns.

Importantly, several studies demonstrated that postoperative RRI elevation occurs even in patients with preserved mean arterial pressure and acceptable cardiac output.[7,16] This finding underscores a critical dissociation between macrocirculatory parameters and renal microcirculatory integrity. In this context, RRI appears to capture renal vascular stress driven by increased renal venous congestion, elevated systemic vascular resistance, and altered pulsatile energy transmission rather than global hypoperfusion alone.[15–17] Such insights support the concept of RRI as an integrative hemodynamic marker rather than a simple surrogate for renal blood flow.

## Association Between RRI and Early Postoperative Renal Dysfunction

The reviewed literature indicates that elevated RRI values frequently precede conventional biochemical markers of acute kidney injury (AKI), such as serum creatinine elevation or reduced urine output.[9,15] This temporal relationship suggests that RRI may serve as an early indicator of renal vulnerability rather than established injury. Several observational studies reported correlations between higher postoperative RRI and increased incidence or severity of AKI, prolonged intensive care unit stay, and worse short-term outcomes.[3,9]

From a clinical perspective, this early signal is particularly valuable in the post-CPB period, where renal injury often develops insidiously and becomes apparent only after significant functional loss has occurred. By identifying patients at risk before irreversible injury develops, RRI may facilitate earlier intervention and individualized hemodynamic optimization strategies.

## Clinical Implications and Novelty of TEE-Derived RRI Monitoring

The principal novelty highlighted by this review lies in reframing postoperative renal monitoring from delayed injury detection toward proactive physiological surveillance. Unlike static biochemical markers, TEE-derived RRI provides dynamic, real-time information on renal vascular conditions at a moment when therapeutic interventions are still modifiable. Integrating RRI assessment into perioperative TEE protocols could therefore enable targeted strategies aimed at reducing renal venous congestion, optimizing preload, and modulating

systemic vascular resistance.[16,17]

Furthermore, TEE-derived RRI offers a mechanistic explanation for why AKI may develop despite apparently adequate systemic hemodynamics. By capturing microvascular and venous components of renal perfusion, RRI bridges a critical knowledge gap between macrocirculatory monitoring and organ-level outcomes. This paradigm shift aligns with emerging concepts of organ-protective hemodynamic management in cardiac surgery.

Nevertheless, current evidence is limited by small sample sizes, heterogeneity in measurement techniques, and the absence of standardized RRI cutoff values specific to the post-CPB population. Prospective studies are needed to validate TEE-derived RRI as a predictive and actionable biomarker and to define its role within multimodal renal protection strategies.

## CONCLUSION

Transesophageal echocardiography derived renal resistive index is a promising hemodynamic marker for early detection of renal vulnerability following cardiopulmonary bypass. By reflecting renal vascular resistance and microcirculatory stress, RRI may identify patients at risk of acute kidney injury before conventional biochemical markers become abnormal. Incorporating RRI assessment into routine perioperative TEE has the potential to enhance early risk stratification and support organ-protective hemodynamic management. Further prospective studies are needed to validate its clinical utility and define standardized postoperative thresholds.

## ACKNOWLEDGEMENT

The authors would like to acknowledge all researchers whose work contributed to the development of this review through their investigations into renal hemodynamics and perioperative echocardiography.

This study did not receive specific grants from funding agencies in the public sector, commercial, or non-profit sectors.

Declaration of Conflict of Interest

The authors declare no conflicts of interest related to this work.

## REFERENCES

1. Bandyopadhyay, S, Das K, Ratan, Paul, Abhijit, Bhunia S, et al. "A transesophageal echocardiography technique to locate the kidney and monitor renal perfusion. Anesth Analg. 2013, 116(3): 549–54. Doi: https://doi.org/10.1213/ANE.0b013e31827ab3b1.
2. Chikwe J, Lee T, tagaki S, Adams DH, Egorova NN. Long-Term Outcomes After Off-Pump Versus On-Pump Coronary Artery Bypass Grafting by Experienced Surgeons. J Am Coll Cardiol. 2018; 72(13): 1478–486. Doi: https://doi.org/10.1016/j.jacc.2018.07.029.
3. 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. 2019;61:1-20. doi:10.1016/j.jclinane.2019.109626.
4. 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(6): 891–98. Doi: https://doi.org/10.1093/bja/aer289
5. Filardo G, Hamman BL, da Graca B, Sass Dl, Machala NJ, Ismail S, et al. Efficacy and effectiveness of on- versus off-pump coronary artery bypass grafting: A meta-analysis of mortality and survival. J. Thorac. Cardiovasc. Surg., 2018;55(1):172-179.e5. Doi: 10.1016/j.jtcvs.2017.08.026.
6. García EM, Utiel FJB, Rusillo MP, Cortés MJG. Vascular renal resistance index is not related with prognosis in kidney transplantation. Nefrologia. 2021;41(1):69–71. Doi:10.1016/j.nefro.2019.12.003.
7. Hertzberg D, Ceder SL, Sartipy U, Lund K, Holzmann M. Preoperative renal resistive index predicts risk of acute kidney injury in patients undergoing cardiac surgery. J Cardiothorac Vasc Anesth. 2017; 31(3):. 847–52. Doi: 10.1053/j.jvca.2016.10.006
8. Butterworth JF, Mackey DC, Wasnick JD. Morgan & Mikhail's Clinical Anesthesiology. 6th Ed. New York: McGraw-Hill.2018, 1771-

1800

9. Ates A, Erkut B. The effect of cross clamp time on Troponin I levels in patients undergoing coronary artery bypass grafting. EASJMS. 2019; 2(3):175–79. Available from: https://easpublisher.com/media/articles/EASJMS_23_175-180_c.pdf
10. Kajal K, Chauhan R, Lal Negi S, Gourav KP, Panda P, Mahajan S, et al. Intraoperative evaluation of renal resistive index with transesophageal echocardiography for the assessment of acute renal injury in patients undergoing coronary artery bypass grafting surgery: A prospective observational study," Ann Card Anaesth. 2022;25(2):158–63. Doi: 10.4103/aca.aca_221_20
11. Kharsa C, Beaini C, Chelaa D, Aoun M. Association of renal resistive indices with kidney disease progression and mortality. BMC Nephrology. 2023;24(348):1-12. Doi: 10.1186/s12882-023-03398-6
12. Kelly CM, Shahrokni A. Moving beyond Karnofsky and ECOG performance status assessments with new technologies. J Oncol. 2016(3):1–13.Doi: 10.1155/2016/6186543
13. Rasmussen G. Duration of cardiopulmonary bypass in the modern era: 240 is now safe. American Association of Thoracic Surgery. 2023; 1(1):1-10. Available from: https://www.aats.org/resources/duration-of-cardiopulmonary-bypass-in-the-modern-era-240-is-now-safe
14. Regolisti G, Maggiore U, Cademartiri C, Belli L, Gherli T, Cabassi A, et al. Renal resistive index by transesophageal and transparietal echo-doppler imaging for the prediction of acute kidney injury in patients undergoing major heart surgery. J Nephrol. 2017;30(2):243–53. Doi: 10.1007/s40620-016-0289-2
15. Sabia M, Isetta C, Banydeen R, Durand N, Mehdaoui H, Licker M. Perioperative changes in renal resistive index as a predictor of acute kidney injury after cardiac surgery: A prospective cohort study. J Clin Med. 2025;14(17): 1-14. Doi: 10.3390/jcm14176315
16. Sawchuk AP, Yu W, Talamantes JT, Hong W, Rollins D, Motaganahalli R. A deep dive into the meaning of the renal resistive index, its limited correlation with renal function, and a theoretical way forward to improve its usefulness. J Vasc Surg. 2021;74(4):e381-e382. Doi:10.1016/j.jvs.2021.07.158.
17. Vo TX, Boodhwani M. Renal resistive index as a biomarker for acute kidney injury in aortic valve surgery. J Thorac Dis. 2018;10(Suppl 33):S4010–S4012. doi:10.21037/jtd.2018.09.45.