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Renal resistive index as an early predictor of acute kidney injury in major abdominal surgery patients

Prisia Riane Polii[1], Haizah Nurdin[2], Ari Santri Palinrungi[2], Syafri Kamsul Arif[2], Alamsyah Ambo Ala Husain[1], Charles Wijaya Tan[1]

Abstract

***Objective*: This study aimed to test the validity and accuracy of renal resistive index (RRI) as an early predictor of acute kidney injury (AKI) in patients undergoing major abdominal surgery, compared with serum neutrophil gelatinase-associated lipocalin (NGAL).**

***Design*: This was an observational study with a prospective cohort design.**

***Setting*: The study was conducted at the Emergency Department and Intensive Care Unit of Wahidin Sudirohusodo Hospital, Makassar, from January to March 2025.**

***Patients and participants*: All patients undergoing emergency major abdominal surgery with general anesthesia.**

***Measurement and results*: RRI and serum NGAL levels were measured preoperatively and 24 hours postoperatively. To diagnose AKI according to the Kidney Disease: Improving Global Outcomes (KDIGO) guidelines, serum creatinine was measured within 48 hours after surgery. The results showed that preoperative and 24-hour postoperative serum RRI and NGAL levels were valid predictors of AKI in patients undergoing major abdominal surgery. Preoperative RRI obtained a sensitivity of 0.706 and a specificity of 0.737. Twenty-four-hour postoperative RRI obtained a sensitivity of 0.765 and a specificity of 0.789. Preoperative serum NGAL obtained a sensitivity of 0.647 and a specificity of 0.685. Twenty-four-hour postoperative serum NGAL obtained a sensitivity of 0.764 and a specificity of 0.737. Twenty-four-hour postoperative RRI produced the highest diagnostic accuracy of 77.78%.**

***Conclusions*: The 24-hour postoperative RRI demonstrated the best validity and accuracy for predicting AKI in patients undergoing major abdominal surgery, compared with the preoperative RRI, NGAL, and 24-hour postoperative NGAL.**

Keywords: Acute renal injury, major abdominal surgery, neutrophil gelatinase-associated lipocalin, renal resistive index.

[1.] Department of Anesthesiology, Intensive Therapy, and Pain Management, Faculty of Medicine, Hasanuddin University, Makassar, South Sulawesi, Indonesia

[2.] Department of Anesthesiology, Intensive Therapy, and Pain Management, Faculty of Medicine, Hasanuddin University/Dr. Wahidin Sudirohusodo Hospital, Makassar, South Sulawesi, Indonesia

Address for correspondence:
Prisia Riane Polii
Department of Anesthesiology, Intensive Therapy, and Pain Management, Faculty of Medicine, Hasanuddin University
Perintis Kemerdekaan Km 10 St, Tamalanrea Indah, Tamalanrea, Makassar, South Sulawesi, Indonesia.
Tel: +6281241881290
Fax: +62411587581
Email: prisiapolii89@gmail.com

Introduction

Acute kidney injury (AKI) is a heterogeneous group of conditions that result in impaired filtration and excretion of nitrogenous products. (1) The prevalence of AKI in patients undergoing major abdominal surgery reaches 35%. (2) The pathogenesis of AKI following major abdominal surgery is complex and different from that observed after cardiac or vascular surgery. AKI results from fluid loss, neuroendocrine responses to general anesthesia and surgery, injury-induced inflammation, urinary tract obstruction, and intra-abdominal pressure. (2) AKI can lead to prolonged hospitalization, increased morbidity, and mortality rates postoperatively. (3) AKI significantly increases the risk of death within

90 days after major abdominal surgery. (4) Therefore, early detection of AKI after major surgery is essential as an effort to take preventive measures against postoperative AKI.

Neutrophil gelatinase-associated lipocalin (NGAL) is a 25 kDa protein synthesized in the bone marrow during granulocyte maturation. NGAL is an early indicator of tubular damage. (2) NGAL can be secreted by damaged tubular cells and transferred into the serum and urine, a mechanism that underlies its use as a kidney injury biomarker. (5) The weakness of using NGAL as an early predictor of AKI is that detection takes a long time and cannot be done at any time. (6) In addition, it is about 12 times more expensive than creatinine, so it cannot be done at any time and is only available at certain health facilities. (7)

The renal resistive index (RRI) is said to predict the early stages of AKI. (8) RRI is a non-invasive instrument that can provide rapid measurements of renal hemodynamics. It is obtained by analyzing intrarenal arterial waves using Doppler ultrasound. (1) Intrarenal vasoconstriction is an early manifestation of AKI. RRI reflects the relationship between the decrease in flow loss rate between peak systole and end diastole in the (renal) vasculature. (9)

Currently, NGAL is the gold standard for early predictors of AKI. Current research has extensively examined the usefulness of NGAL as an early predictor of AKI in major abdominal surgery. Still, research on RRI as an early predictor of AKI has only been conducted in the general population in the intensive care unit (ICU). It has never been performed before in a major abdominal surgery. Research by Ginting et al. found that RRI was more sensitive than NGAL for predicting AKI. The study was conducted in critically ill patients in the ICU. (8) Comparison of NGAL and RRI as early predictors of AKI is still minimal and has never been done in major abdominal surgery. This study aimed to compare the validity and accuracy of using RRI and serum NGAL as early predictors of AKI in patients with major abdominal surgery.

Methods

An observational prospective cohort study was conducted on patients undergoing emergency major abdominal surgery with general anesthesia at Dr. Wahidin Sudirohusodo Hospital from January to March 2025. Inclusion criteria included patients aged 18–65, body mass index (BMI)<30 kg/m², American Society of Anesthesiologists Physical Status (ASA PS) I–III, and willingness to participate in the study. Exclusion criteria included a history of kidney disease, other severe organ disorders, use of certain drugs, and postoperative conditions that made assessment difficult. Patients who experienced other complications, used high doses of norepinephrine, used norepinephrine combined with other vasopressors, or died were dropped out of the analysis. RRI and serum NGAL levels were measured preoperatively and 24 hours postoperatively. To diagnose AKI according to the classification of the Kidney Disease: Improving Global Outcomes (KDIGO), serum creatinine was measured within 48 hours after surgery. RRI was the difference between peak systolic and end-diastolic velocities divided by peak systolic velocity, which was calculated using the GE Logiq V2 arterial Doppler ultrasound waveform. Serum NGAL was measured using an ELISA kit at the Research Laboratory of Hasanuddin University Hospital. Data were analyzed using SPSS 27.

Results

This study involved 36 patients who underwent emergency major abdominal surgery with general anesthesia, in which 47.2% of them experienced postoperative AKI, with the majority being in stage 1 (64.71%). Age, gender, BMI, and ASA PS were not significantly different between the AKI and non-AKI groups ($p>0.05$), but were significantly different by duration of surgery and bleeding volume ($p<0.05$) (**Tables 1 and 2**).

Serum RRI and NGAL, both preoperatively and 24 hours postoperatively, were significantly associated with the incidence of AKI after major abdominal surgery ($p<0.05$) (**Table 3**). The area under the curve (AUC) values of each parameter: preoperative RRI was 0.768 (95% confidence interval [CI]: 0.597–0.939, p=0.002), 24-hour postoperative RRI was 0.882 (95% CI: 0.671–0.973, $p<0.001$), preoperative serum NGAL was 0.715 (95% CI: 0.548–0.883, p=0.012), and 24-hour postoperative serum NGAL was 0.783 (95% CI: 0.628–0.938, $p<0.001$) (**Figure 1**). All four parameters showed AUC values ≥0.70, indicating good discriminatory ability in predicting AKI.

The 24-hour postoperative RRI had the highest sensitivity, specificity, positive predictive value (PPV), and positive likelihood ratio (PLR), as well as the highest negative predictive value (NPV) and lowest negative likelihood ratio (NLR), making it the most accurate measure in predicting AKI after major abdominal surgery (**Table 4**). All measures showed a significant relationship ($p<0.05$), with the highest odds ratio (OR) observed at 24 hours postoperatively (OR=12.188). This result indicated that patients with RRI≥0.745 had a 12.188 times greater risk of developing AKI. The 24-hour postoperative RRI also showed the highest diagnostic accuracy

(77.78%), making it the most powerful indicator (**Table 5**).

Discussion

In this study, 47.2% of patients experienced acute kidney failure after undergoing major abdominal surgery. The study by Mikkelsen et al. reported that the incidence of acute kidney failure in patients after major emergency abdominal surgery was 17.4%, with 67.2% stage 1, 21.3% stage 2, and 11.5% stage 3. (4) In an international multi-center study in 30 countries conducted by Zarbock et al. in patients undergoing major surgery with a duration of surgery >2 hours, it was found that 18.4% of patients experienced post-surgery acute kidney failure, of which 63.5% were stage 1, 25.7% were stage 2, and 10.7% were stage 3. (10) The prevalence of AKI after major abdominal surgery in this study was greater than in previous studies because various factors influenced the incidence of AKI after surgery, including advanced age, comorbidities (hypertension, diabetes, chronic kidney disease), type, duration of surgery, and urgency of surgery, as well as intraoperative vasopressors and administration of aminoglycosides. (10)

Serum NGAL 24 hours after surgery better predicted AKI than preoperative serum NGAL. This result was supported by a meta-analysis showing that plasma NGAL measured 4–8 hours after cessation of cardiopulmonary bypass (CPB) in cardiac surgery patients was superior to plasma NGAL measured at <4 hours or 24 hours for early diagnosis of AKI. Plasma NGAL levels peak at 6 hours after cardiac surgery. There are differences in the mechanism of AKI between postcardiac surgery and abdominal surgery. In cardiac surgery, NGAL increases significantly at 6 hours after surgery because the systemic inflammatory response triggered by CPB will activate circulating neutrophils to release their granular contents, including NGAL. (11) Hunsicker et al.'s study determined the diagnostic value of plasma NGAL for AKI in patients undergoing major abdominal surgery. The results showed that plasma NGAL levels at ICU admission had diagnostic value for predicting 6-hour AKI and total AKI. (12) The study by Mustafayeva et al. reported an increase in plasma NGAL levels at 6 hours postoperatively, demonstrating that plasma NGAL was an early predictive biomarker of AKI in patients undergoing major abdominal surgery. NGAL values measured at 6 and 24 hours postoperatively were higher than those measured intraoperatively. NGAL values showed an early response (6 hours postoperatively) compared to creatinine values in major abdominal surgery. (2) In the study by Perrotti et al., at 6 hours postoperatively, NGAL greater than 155 ng/ml was shown to be an independent predictor of AKI. (13) However, in this study, serum NGAL measurements were obtained only before and 24 hours after surgery.

NGAL is released in response to proximal renal tubular ischemia, and NGAL values immediately after surgery can predict the duration and severity of acute renal impairment. Furthermore, NGAL can independently predict a decline in renal function and may be helpful even in the context of pre-existing renal impairment. (13)

Thus, the results of this study indicated that high NGAL exceeding normal values before surgery and especially at 24 hours post-surgery was an early warning signal of AKI after major abdominal surgery. Therefore, serum NGAL measurement before surgery and follow-up at 24 hours post-surgery could help as an additional tool for early detection of AKI after major abdominal surgery.

Serum RRI and NGAL, both before and 24 hours after surgery, can be good predictors of AKI after major abdominal surgery. A study by Dawood et al. reported that urinary NGAL and RRI 1 hour and 6 hours after surgery were accurate as early indicators of AKI. (14)

RRI 24 hours postoperatively was a predictor of AKI after major abdominal surgery, with the highest sensitivity, specificity, and accuracy compared with preoperative RRI and preoperative and 24-hour postoperative serum NGAL levels. These results were similar to those of the study by Ginting et al., which found that RRI had greater sensitivity than NGAL for predicting AKI. RRI had better sensitivity than NGAL in predicting the occurrence of AKI in critically ill patients. However, high NGAL values can also be a marker of AKI because they have high sensitivity. NGAL is a glycoprotein stored in mature neutrophil granules and is found to be released by renal tubular cells after acute tubular damage. Laboratory tests can detect increased NGAL several hours after tubular damage occurs. (8) The study by Zaiotun et al. compared the performance of RRI levels, serum NGAL (sNGAL), urinary NGAL (uNGAL), and serum Cys C as early predictors of sepsis-related AKI diagnosis and persistence. The RRI value measured directly ≥0.72 is the best predictor of AKI diagnosis. (15) This result is consistent with the findings of Shan et al., who reported that serum NGAL is not specific for AKI. (16)

The low specificity and sensitivity of serum NGAL were due to high serum NGAL levels being influenced by several concomitant factors, including chronic hypertension, systemic infection, inflam-

matory conditions, anemia, and hypoxia. (13) High serum NGAL concentrations are observed in atherosclerosis, myocardial infarction, and heart disorders. (17)

This study was conducted in a single hospital emergency department, among patients undergoing major abdominal surgery. This study did not measure serum NGAL levels and RRI values at 6 hours postoperatively.

Conclusion

The prevalence of AKI after major abdominal surgery reached 47.2%. RRI and serum NGAL showed good discriminatory ability as predictors of AKI, with RRI 24 hours postoperatively demonstrating the highest sensitivity, specificity, and accuracy. It is recommended to evaluate RRI and serum NGAL levels before surgery and 24 hours postoperatively as an initial step in preventing and early detection of AKI in patients undergoing major abdominal surgery. In addition, adequate ultrasonography equipment needs to be available in the emergency unit and intensive care to support rapid and accurate diagnostics by medical personnel.

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Conflict of interest and funding sources

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Ethical approval

This study has obtained ethical approval from the Research Ethics Committee of the Faculty of Medicine, Hasanuddin University, Makassar, under approval number 1031/UN4.6.45.31/PP36/2024, issued on 22 November 2024.

Table 1. Sample characteristics

Characteristics	AKI (n=17)	Non-AKI (n=19)	p-value
Age (years), mean±SD	44.11±12.41	46.31±13.95	0.622[a]
Gender, n (%) - Male - Female	 11 (64.7) 6 (35.3)	 9 (47.4) 10 (52.6)	0.296[b]
BMI (kg/m^2), mean±SD	20.46±3.89	22.58±4.13	0.124[a]
ASA PS - II - III	 14 (82.4) 3 (17.6)	 18 (94.7) 1 (5.3)	0.326[c]
Operation time (minutes), mean±SD	205.58±92.73	120.00±45.82	0.002[d]
Bleeding (ml), mean±SD	685.29±870.30	133.68±122.66	<0.001[a]

Legend: AKI=acute kidney injury; SD=standard deviation; BMI=body mass index; ASA PS=American Society of Anesthesiologists Physical Status.
[a]Independent sample t-test, [b]chi-square test, [c]Fisher exact test, [d]Mann-Whitney test.

Table 2. Frequency of AKI by stage

Stages of AKI	n (%)
Stage 1	11 (64.71)
Stage 2	4 (23.53)
Stage 3	2 (11.76)

Legend: AKI=acute kidney injury.

Table 3. Relationship between RRI and serum NGAL with AKI after major abdominal surgery

Parameter	AKI (n=17)	Non-AKI (n=19)	p-value
RRI preoperative	0.75±0.14	0.66±0.07	0.020[a]
RRI 24 hours postoperative	0.81±0.09	0.69±0.09	<0.001[b]
NGAL preoperative (ng/ml)	96.04±25.89	72.53±29.96	0.017[a]
NGAL 24 hours postoperative (ng/ml)	129.47±49.14	89.27±27.21	0.003[b]

Legend: RRI=renal resistive index; NGAL=neutrophil gelatinase-associated lipocalin; AKI=acute kidney injury.
Values are in mean±SD. [a]Independent sample t test, [b]Mann-Whitney test.

Table 4. Comparison of RRI and serum NGAL diagnostic test results for predicting AKI after major abdominal surgery

Parameter	RRI preoperative	RRI 24 hours postoperative	NGAL preoperative	NGAL 24 hours postoperative
AUC	0.768	0.822	0.715	0.783
Sensitivity	0.706	0.765	0.647	0.764
Specificity	0.737	0.789	0.685	0.737
Cut-off	0.705	0.745	90.930	104.360
PPV	0.706	0.765	0.647	0.764
NPV	0.737	0.789	0.684	0.737
PLR	2.684	3.626	2.054	2.905
NLR	0.399	0.298	0.515	0.320

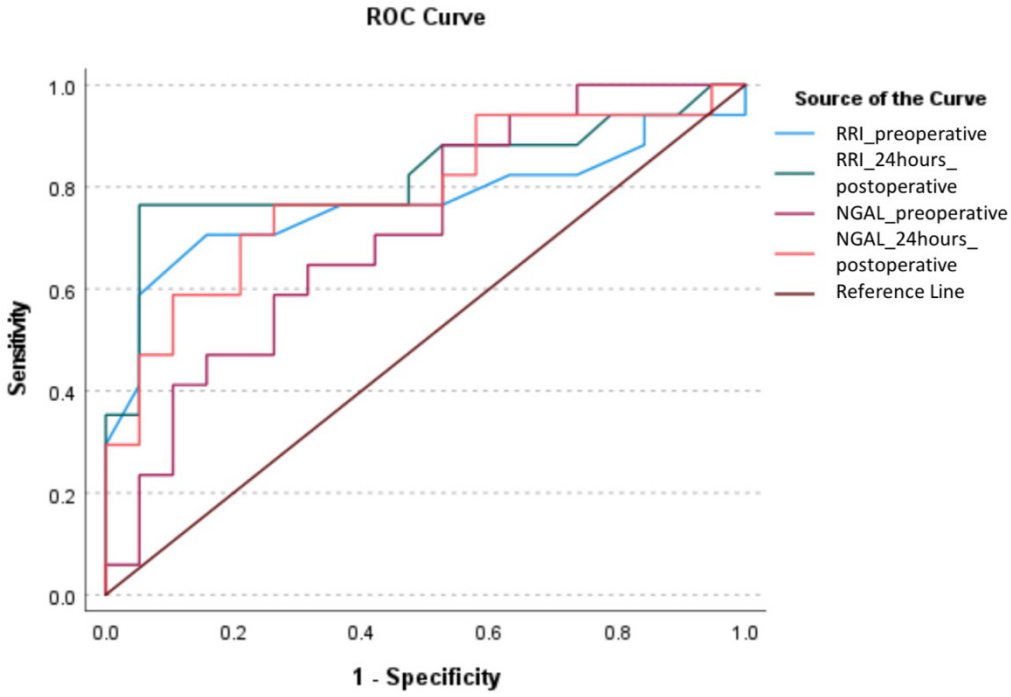
Legend: RRI=renal resistive index; NGAL=neutrophil gelatinase-associated lipocalin; AKI=acute kidney injury; AUC=area under the curve; PPV=positive predictive value; NPV=negative predictive value; PLR=positive likelihood ratio; NLR=negative likelihood ratio.

Table 5. Relationship between RRI and serum NGAL categories with the incidence of AKI after major abdominal surgery

	AKI, n (%)	Non-AKI, n (%)	Total, n (%)	p-value	OR	Accuracy (%)
RRI preoperative						
- ≥0.705	12 (70.6)	5 (26.3)	17 (47.2)	0.008	6.720	72.22
- <0.705	5 (29.4)	14 (73.7)	19 (52.8)			
RRI 24 hours postoperative						
- ≥0.745	13 (76.5)	4 (21.1)	17 (47.2)	0.001	12.188	77.78
- <0.745	4 (23.5)	15 (78.9)	19 (52.8)			
NGAL preoperative (ng/ml)						
- ≥90.93	11 (64.7)	6 (31.6)	17 (47.2)	0.047	3.972	66.67
- <90.93	6 (35.3)	13 (68.4)	19 (52.8)			
NGAL 24 hours postoperative (ng/ml)						
- ≥104.36	13 (72.2)	4 (22.2)	17 (47.2)	0.003	9.100	75.00
- <104.36	5 (27.8)	14 (77.8)	19 (52.8)			

Legend: RRI=renal resistive index; NGAL=neutrophil gelatinase-associated lipocalin; AKI=acute kidney injury; OR=odds ratio.

Figure 1. ROC curve of serum RRI and NGAL for the prediction of AKI



Legend: ROC=receiver operating characteristic; RRI=renal resistive index; NGAL=neutrophil gelatinase-associated lipocalin; AKI=acute kidney injury.

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