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ORIGINAL RESEARCH

The Ratio of Contrast Volume/Glomerular Filtration Rate and Urine NGAL Predicts the Progression of Acute Kidney Injury to Chronic Kidney Disease in Patients After Planned Percutaneous Coronary Intervention

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Objective: To evaluate the value of contrast volume/glomerular filtration ratio (Vc/eGFR ratio) and urine Neutrophil Gelatinase-Associated Lipocalin (uNGAL) in predicting the progression contract associated-acute kidney injury (CA-AKI) to chronic kidney disease (CKD) in planned percutaneous coronary intervention (PCI) patients.

Patients and Methods: We examined 387 adult patients who had undergone planned percutaneous coronary intervention (PCI). We determined acute kidney injury (AKI) and chronic kidney disease (CKD) using the criteria set by the Kidney Disease: Improving Global Outcomes (KDIGO). We calculated the estimated glomerular filtration rate (eGFR) using the CKD-EPI formula based on serum creatinine levels. To determine the Vc/eGFR ratio, we considered the contrast medium volume and eGFR for each patient. Additionally, we measured urine NGAL levels using the ELISA method.

Results: The percentage of CA-AKI patients who developed CKD after planned PCI was 36.36%. Within the CA-AKI to CKD group, the Vc/eGFR ratio was 2.82, and uNGAL levels were significantly higher at 72.74 ng/mL compared to 1.93 ng/mL for Vc/eGFR ratio and 46.57 ng/mL for uNGAL in the recovery CA-AKI group. This difference was statistically significant ($p<0.001$). Diabetic mellitus, urine NGAL concentration, and Vc/eGFR ratio were found to be independent factors in the progression of CA-AKI to CKD. The Vc/eGFR ratio and uNGAL showed predictive capabilities for progressing CA-AKI to CKD with an AUC of 0.884 and 0.878, respectively. The sensitivity was 81.3% for both, while the specificity was 89.3% for Vc/eGFR ratio and 85.7% for uNGAL.

Conclusion: The Vc/eGFR ratio and uNGAL were good predictors for CA-AKI to CKD in planned PCI patients.

Keywords: planned percutaneous coronary intervention, contract associated-acute kidney injury, CA-AKI progression to CKD, Vc/eGFR ratio, uNGAL

Introduction

Chronic kidney disease (CKD) is a significant worldwide health issue and a strong determining factor for mortality in general.[1–3] Chronic kidney disease (CKD) and acute kidney injury (AKI) are interconnected.[4,5] The close inter-connected in both clinical and experimental studies has been recognized in the last decade.[6,7] In recent years, there has been significant research focused on the transition from AKI to CKD[4,5] as well as investigations into the predictive value of AKI and various other indicators for both short-term and long-term mortality among patients with myocardial infarction.[8–10]

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Contract-associated acute kidney injury (CA-AKI) is a common occurrence after undergoing percutaneous coronary intervention (PCI). The rate of acute kidney injury varies between 4.2% and 50% based on different studies.[11–13] CA-AKI following PCI is commonly linked to the use of contrast drugs, instability in blood flow, advanced age, pre-existing chronic kidney disease, and a combination of diabetes and hypertension.[12,14] Clinical studies have reported cases of mild AKI that appear to recover fully, but these individuals may later develop CKD.[15,16] The connection between getting older and experiencing inflammation is essential when considering the risk factors for the progression of CKD following an AKI.[17,18] In clinical practice, identifying predictors of AKI progression to CKD may benefit patients in reducing the proportion of patients with AKI to CKD. The presence of tubular injury markers, including serum and urine Neutrophil Gelatinase-Associated Lipocalin (uNGAL), has been shown to have prognostic value in the progression of CKD from AKI in patients with AKI associated with sepsis.[19]

Using more significant amounts of contrast during PCI is directly linked to an increased risk of developing AKI caused by the contrast.[20] It has been determined that having a ratio of contrast media to creatinine clearance higher than 3.7 is a significant and separate factor that puts one at risk of CA-AKI.[21] However, many studies have not mentioned whether this rate is a predictor for CA-AKI progression to CKD. Hence, we conducted this study to investigate if the ratio of contrast volume to glomerular filtration rate and uNGAL are predictors for the progression of CA-AKI to CKD in patients following planned PCI.

Materials and Methods

We enrolled a total of 387 patients who had chronic coronary artery disease and had already undergone scheduled percutaneous coronary intervention at the Cardiovascular Center, Military Hospital 103, Hanoi, Vietnam, and Department of Cardiovascular Intervention, Tam Duc Hospital, Ho Chi Minh, Vietnam, from January 2016 to January 2018. We did not include patients who were under 18 years old or who had undergone percutaneous coronary intervention in the past. Furthermore, we excluded chronic kidney disease patients with albuminuria ≥ 30 mg/24 hours and one of the following abnormalities on kidney ultrasound such as reduced kidney size, hyperechoic kidneys, kidney stone, kidney cysts prior to intervention. Before participating in our study, all patients were given written information about the study and gave their consent. The study design was performed as in Figure 1.

At the start of the study, we gathered information on clinical characteristics and laboratory parameters. This included analyzing fasting morning venous blood plasma for glucose, urea, creatinine, CRP-hs, TnT-hs, ALT, AST, cholesterol, triglyceride, HDL-C, LDL-C, and electrolyte concentrations. An experienced echocardiographer utilized Simpson's method to measure the patient's left ventricular ejection fraction (LVEF%). We also obtained a 24-hour urine sample to measure urine NGAL concentration using the BioVendor Human Lipocalin-2/NGAL ELISA kit, which employs the sandwich enzyme immunoassay technique. Moreover, all patient's glomerular filtration rate (eGFR) was calculated using the MDRD formula.

We observed pre-existing co-morbidities, including diabetes mellitus, hypertension, and medications. Diabetes mellitus was determined based on a doctor's diagnosis, treatment with antidiabetic drugs, or two consecutive tests showing fasting blood glucose levels of ≥126 mg/dL (or ≥ 7.0 mmol/L). Hypertension was defined as the regular use of antihypertensive drugs to control blood pressure or having blood pressure readings of ≥140/90 mm Hg in at least two measurements.

Additionally, the study recorded the contrast volume and type, calculating the contrast agent volume/glomerular filtration rate ratio. In this study, we used a uniform type of non-ionic contrast agent (Xenetix 300 mg/mL, 695 mOsm/kg H2O) and a single type of access (right radial artery) for all patients to eliminate the effects of interventional techniques.

All patients had their urine monitored, and 48 hours post-procedure, serum creatinine (sCr) was measured to detect the presence of AKI and estimate the GFR. The definition of acute kidney injury was determined based on the criteria established by Kidney Disease: Improving Global Outcomes (KDIGO) based on an increase of serum creatinine by ≥ 0.3 mg/dl (≥ 26.5 micromol/l) within 48 hours.[22] The patients with CA-AKI were given standard routine care according to the guidelines set by the Vietnam Ministry of Health and KDIGO 2012.[22]

Following their discharge from the hospital, every CA-AKI patient underwent monthly revisions for at least 3 months, consisting of urine analysis, blood tests for complete blood count, serum urea, creatinine, eGFR calculation, and kidney ultrasound.

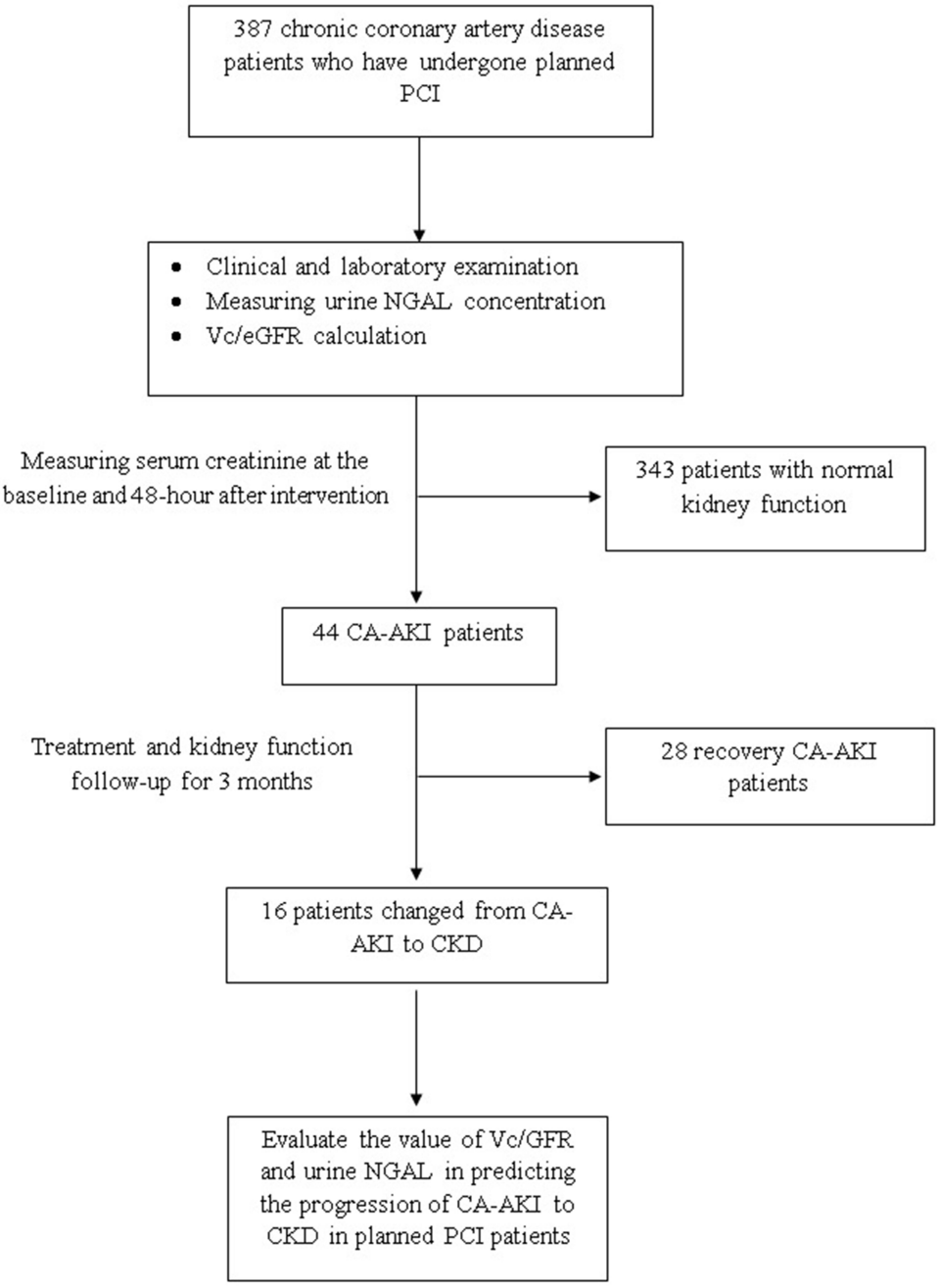

Figure 1 Study diagram.

CKD is characterized as kidney damage for a minimum of three months (equivalent to 90 days) accompanied by either[23]: (1) abnormalities in the structure or function of the kidney, with or without a reduced glomerular filtration rate (GFR), as observed through pathological abnormalities or kidney damage identified by marker's abnormalities in the blood or urine (albuminuria ≥ 30 mg/24 hours), or abnormalities observed on imaging, OR (2) a GFR that is less than 60 mL/min/1.73 m2, regardless of the presence of kidney damage.

Statistical Analyses

We represented all continuous data by the mean and standard deviation (for normal distribution) or the median and interquartile range (for non-normal distribution). We compared two continuous variables using the Student's *T*-test or Mann–Whitney *U*-test. More than two variables were compared using the ANOVA test or the Kruskal–Wallis test. We presented the categorical data by the frequency with percentage and were analyzed using the Chi-square test. We used multivariable-adjusted regression analysis to determine the factors contributing to acute kidney injury (AKI) progression to chronic kidney disease (CKD). Receiver operating characteristic (ROC) curves were utilized to assess the accuracy of predicting this progression in all patients, with the area under the curve (AUC) calculated. The Statistical Package for Social Science (SPSS) version 20.0 (Chicago, IL, USA) was employed for statistical analysis. A p-value of less than 0.05 was considered statistically significant.

Results

Our results in Table 1 show that the ratio of hypertension and diabetes in the CA-AKI group was significantly higher compared with those of the non-AKI group, p< 0.001. Similarly, mean age, uNGAL concentration, and Vc/eGFR ratio in the CA-AKI group were significantly higher than in the non-AKI group, p< 0.001.

Table 2 shows that the ratio of hypertension and diabetes in the CA-AKI to CKD group was significantly higher than those of the recovery group, p< 0.01. Similarly, uNGAL concentration and Vc/eGFR ratio in the CA-AKI to CKD group were also significantly higher than in the recovery group, p< 0.001.

Table 1 Comparison of Demographic and Laboratory Characteristics in CA-AKI Group and Non-AKI One

Clinical Characteristics and Laboratory Parameters	Total (n=387)	CA-AKI Group (n=44)	Non-AKI Group (n=343)	p
Ages (Years)	60.12 ± 9.89	66.52 ± 7.85	59.3 ± 9.83	**< 0.001**
Number of males (n,%)	257 (66.4)	32 (72.7)	225 (65.6)	0.346
Hypertension • Yes (n,%) • No (n,%)	 81 (20.9) 306 (79.1)	 27 (61.4) 17 (38.6)	 54 (15.7) 289 (84.3)	 **< 0.001**
Diabetic Mellitus • Yes (n,%) • No (n,%)	 67 (17.3) 320 (82.7)	 25 (56.8) 19 (43.2)	 42 (12.2) 301 (87.8)	 **< 0.001**
BMI (kg/m^2) • < 18.5 (n,%) • 18.5–22.9 (n,%) • ≥ 23.0 (n,%) • Mean	 3 (0.8) 98 (25.4) 25 (56.8) 24.83 ± 3.15	 1 (2.3) 18 (40.9) 25 (56.8) 23.38 ± 2.81	 2 (0.6) 80 (23.4) 260 (76) 25.01 ± 3.15	 **0.012** **0.001**
Anemia (n,%)	83 (21.4)	11 (25)	72 (21)	0.542
Hemoglobin (g/L)	137.29 ± 16.85	135.09 ± 14.75	137.57 ± 17.1	0.359
Creatinine (μmol/L)	82 (73–92)	78 (66–87)	83 (74–93)	**0.015**
hs-CRP (mg/L) • > 2.0 (n,%) • Median	 271 (70.2) 2.8 (1.9–4.5)	 23 (52.3) 2.1 (1.6–5.45)	 248 (72.5) 2.85 (1.97–4.5)	 **0.006** 0.263
TnT-hs (ng/L) • > 14.0 (n,%) • Median	 261 (67.4) 40.03 (10.39–278.5)	 31 (70.5) 30.11 (11.25–301.57)	 230 (67.1) 41 (10.39–278.5)	 0.651 0.989

(*Continued*)

Table 1 (Continued).

Clinical Characteristics and Laboratory Parameters	Total (n=387)	CA-AKI Group (n=44)	Non-AKI Group (n=343)	p
ALT (UI/L)				
• > 40.0	118 (30.5)	11 (25)	107 (31.2)	0.401
• Median	31 (23–45)	29.5 (23–41.5)	32 (23–45)	0.395
AST (UI/L)				
• > 40.0	141 (36.4)	14 (31.8)	127 (37)	0.499
• Median	34 (25–52)	34 (28.25–44.5)	34 (25–52)	0.663
Cholesterol (mmol/L)				
• ≥ 5.2	122 (31.5)	11 (25)	111 (32.4)	0.322
• Median	4.72 (3.69–5.52)	4.64 (3.58–5.38)	4.72 (3.74–5.53)	0.37
Triglyceride (mmol/L)				
• ≥ 2.3	153 (39.5)	17 (38.6)	136 (39.7)	0.897
• Median	2.03 (1.36–3.01)	2.03 (1.38–2.93)	2.03 (1.35–3.09)	0.635
LDL-C (mmol/L)				
• ≥ 3.2	162 (41.9)	19 (43.2)	143 (41.7)	0.85
• Median	2.9 (2.2–3.54)	2.8 (1.9–3.4)	2.9 (2.2–3.6)	0.092
HDL-C (mmol/L)				
• ≤ 0.9	79 (20.4)	9 (20.5)	70 (20.4)	0.994
• Median	1.15 (0.95–1.33)	1.13 (0.96–1.32)	1.15 (0.95–1.34)	0.852
Lipid disorder (n,%)	302 (78)	32 (72.7)	270 (78.7)	0.366
Na+ (mmol/L)	137.6 ± 3.44	137.36 ± 3.6	137.63 ± 3.43	0.631
K+ (mmol/L)	3.79 ± 0.36	3.8 ± 0.41	3.78 ± 0.35	0.76
EF%				
• < 50.0%	94 (24.3)	11 (25)	83 (24.2)	0.907
• Median	62 (50–71)	62 (47–74.75)	62 (50–71)	0.604
Urine NGAL (ng/mL)	19.87 (13.22–27.6)	51.44 (44.1–67.7)	18.17 (12.71–23.19)	**< 0.001**
eGFR (mL/min/1.73m^2)				
• < 60	5 (1.3)	5 (11.4)	0 (0)	**< 0.001**
• Median	72.74 (65.19–84.9)	63.82 (61.09–66.73)	74.1 (66.3–88.2)	**< 0.001**
Vc/eGFR ratio	1.5 (1.27–1.85)	2.27 (1.86–2.80)	1.47 (1.24–1.75)	**< 0.001**
Number of stents				
• 1 (n,%)	245 (63.3)	13 (29.5)	232 (67.6)	**< 0.001**
• 2 (n,%)	80 (20.7)	9 (20.5)	71 (20.7)	
• 3 (n,%)	62 (16)	22 (50)	40 (11.7)	
• Mean	1.53 ± 0.75	2.2 ± 0.87	1.44 ± 0.69	**< 0.001**
CA-AKI to CKD (n,%)	16 (4.13)	16 (36.36)	0 (0)	-

Note: Bold values: statistically significant difference.

Abbreviations: CA-AKI, Contract associated-Acute Kidney Injury; BMI, Body Mass Index; CRP-hs, C Reactive Protein-high sensitive; TnT-hs, Troponin T-high sensitive; ALT, Alanine Aminotransferase; AST, Aspartate Aminotransferase; LDL-C, Low-Density Lipoprotein Cholesterol; HDL-C, High-Density Lipoprotein Cholesterol; EF, Ejection Fraction; NGAL, Neutrophil Gelatinase-associated Lipocalin; eGFR, estimated Glomerular Filtration Rate; Vc, Contrast Drug Volume; CKD, Chronic Kidney Disease.

Table 2 Comparing Demographic and Laboratory Characteristics in CA-AKI to CKD Group and Recovery One

Clinical Characteristics and Laboratory Parameters	Total (n=44)	CA-AKI to CKD Group (n=16)	Recovery Group (n=28)	p
Ages (Years)	66.52 ± 7.85	64.81 ± 7.22	67.5 ± 8.15	0.28
Number of males (n,%)	32 (72.7)	12 (75)	20 (71.4)	1.000
Hypertension • Yes (n,%) • No (n,%)	 27 (61.4) 17 (38.6)	 14 (87.5) 2 (12.5)	 13 (46.4) 15 (53.6)	 **0.007**
Diabetic Mellitus • Yes (n,%) • No (n,%)	 25 (56.8) 19 (43.2)	 14 (87.5) 2 (12.5)	 11 (39.3) 17 (60.7)	 **0.002**
BMI (kg/m^2) • < 18.5 (n,%) • 18.5–22.9 (n,%) • ≥ 23.0 (n,%) • Mean	 1 (2.3) 18 (40.9) 25 (56.8) 23.38 ± 2.81	 1 (6.3) 5 (31.3) 10 (62.5) 22.99 ± 2.93	 0 (0) 13 (46.4) 15 (53.6) 23.61 ± 2.77	 - 0.489
Anemia (n,%)	11 (25)	4 (25)	7 (25)	1.000
Hemoglobin (g/L)	135.09 ± 14.75	135.87 ± 11.1	134.64 ± 16.66	0.793
Creatinine (μmol/L)	78 (66–87)	80 (71.5–87)	78 (63.5–87)	0.732
hs-CRP (mg/L) • > 2.0 (n,%) • Median	 23 (52.3) 2.1 (1.6–5.45)	 7 (43.8) 1.85 (1.52–7.6)	 16 (57.1) 2.1 (1.72–4.7)	 0.392 0.807
TnT-hs (ng/L) • > 14.0 (n,%) • Median	 31 (70.5) 30.11 (11.25–301.57)	 12 (75) 38.14 (12.02–695.55)	 19 (67.9) 30.11 (8.49–260.47)	 0.738 0.591
ALT (UI/L) • > 40.0 • Median	 11 (25) 29.5 (23–41.5)	 5 (31.3) 31.5 (23.75–50.75)	 6 (21.4) 28.5 (20–39.5)	 0.492 0.427
AST (UI/L) • > 40.0 • Median	 14 (31.8) 34 (28.25–44.5)	 7 (43.8) 36 (29.75–98.75)	 7 (25) 33.5 (26.5–40.75)	 0.199 0.246
Cholesterol (mmol/L) • ≥ 5.2 • Median	 11 (25) 4.64 (3.58–5.38)	 5 (31.3) 5.03 (4.04–5.7)	 6 (21.4) 4.42 (3.27–5.15)	 0.492 0.121
Triglyceride (mmol/L) • ≥ 2.3 • Median	 17 (38.6) 2.03 (1.38–2.93)	 5 (31.3) 1.74 (1.38–2.84)	 12 (42.9) 2.07 (1.33–2.93)	 0.447 0.705
LDL-C (mmol/L) • ≥ 3.2 • Median	 19 (43.2) 2.8 (1.9–3.4)	 8 (50) 3.05 (2.3–3.82)	 11 (39.3) 2.55 (1.57–3.22)	 0.49 **0.035**
HDL-C (mmol/L) • ≤ 0.9 • Median	 9 (20.5) 1.13 (0.96–1.32)	 4 (25) 1.05 (0.91–1.32)	 5 (17.9) 1.17 (1.0–1.37)	 0.702 0.479

(*Continued*)

Table 2 (Continued).

Clinical Characteristics and Laboratory Parameters	Total (n=44)	CA-AKI to CKD Group (n=16)	Recovery Group (n=28)	p
Lipid disorder (n,%)	32 (72.7)	13 (81.3)	19 (67.9)	0.487
Na+ (mmol/L)	137.36 ± 3.6	137.19 ± 3.03	137.46 ± 3.93	0.81
K+ (mmol/L)	3.8 ± 0.41	3.76 ± 0.54	3.82 ± 0.32	0.676
EF% • < 50.0% • Median	 11 (25) 62 (47–74.75)	 6 (37.5) 53.5 (36.25–65)	 5 (17.9) 68.5 (55–75.75)	 0.169 **0.022**
Urine NGAL (ng/mL)	51.44 (44.1–67.7)	72.74 (65.76–78.18)	46.57 (42.15–55.45)	**< 0.001**
eGFR (mL/min/1.73m^2) • < 60 • Median Vc/eGFR ratio	 5 (11.4) 63.82 (61.09–66.73) 2.27 (1.86–2.80)	 5 (31.3) 60.87 (58.7–63.39) 2.82 (2.7–2.99)	 0 (0) 64.95 (63.27–68.6) 1.93 (1.6–2.24)	 - **0.001** **< 0.001**
Number of stents • 1 (n,%) • 2 (n,%) • 3 (n,%) • Mean	 13 (29.5) 9 (20.5) 22 (50) 2.2 ± 0.87	 1 (6.3) 1 (6.3) 14 (87.5) 2.81 ± 0.54	 12 (42.9) 8 (28.6) 8 (28.6) 1.86 ± 0.84	 **0.001** **< 0.001**

Note: Bold values: statistically significant difference.
Abbreviations: CA-AKI, Contract associated-Acute Kidney Injury; CKD, Chronic Kidney Disease; BMI, Body Mass Index; CRP-hs, C Reactive Protein-high sensitive; TnT-hs, Troponin T-high sensitive; ALT, Alanine Aminotransferase; AST, Aspartate Aminotransferase; LDL-C, Low-Density Lipoprotein Cholesterol; HDL-C, High-Density Lipoprotein Cholesterol; EF, Ejection Fraction; NGAL, Neutrophil Gelatinase-associated Lipocalin; eGFR, estimated Glomerular Filtration Rate; Vc, Contrast Drug Volume.

The results of multivariate logistics regression in Table 3 show diabetes, Vc/eGFR ratio, and uNGAL at the baseline time were the independent risk factors predicting the progression of AKI to CKD in patients after planned percutaneous coronary intervention (p= 0.017; 0.029 and = 0.021, respectively).

Figure 2 shows the ROC curve for Vc/eGFR, uNGAL, eGFR, and EF% to predict the progression of CA-AKI to CKD in patients after planned PCI, in which Vc/eGFR ratio and uNGAL were the best ones (AUC: 0.884, p < 0.001, Sen. 81.3%, Spe=89.3%; and AUC = 0.878; p < 0.001; Sen. = 81.3%; Spe. = 85.7%, respectively).

Table 3 Multivariate Logistic Regression Analysis of Some Clinical Variables Related to the Progression of CA-AKI to CKD

Variable	OR	95% CI	p
Diabetes	78.18	2.14–2843.80	**0.017**
Vc/eGFR ratio	97.16	1.60–5893.40	**0.029**
uNGAL	1.22	1.03–1.44	**0.021**

Note: Bold values: statistically significant difference.
Abbreviations: CA-AKI, Contract associated-Acute Kidney Injury; CKD, Chronic Kidney Disease; eGFR, estimated Glomerular Filtration Rate; Vc, Contrast Drug Volume; uNGAL, Urine Neutrophil Gelatinase-associated Lipocalin.

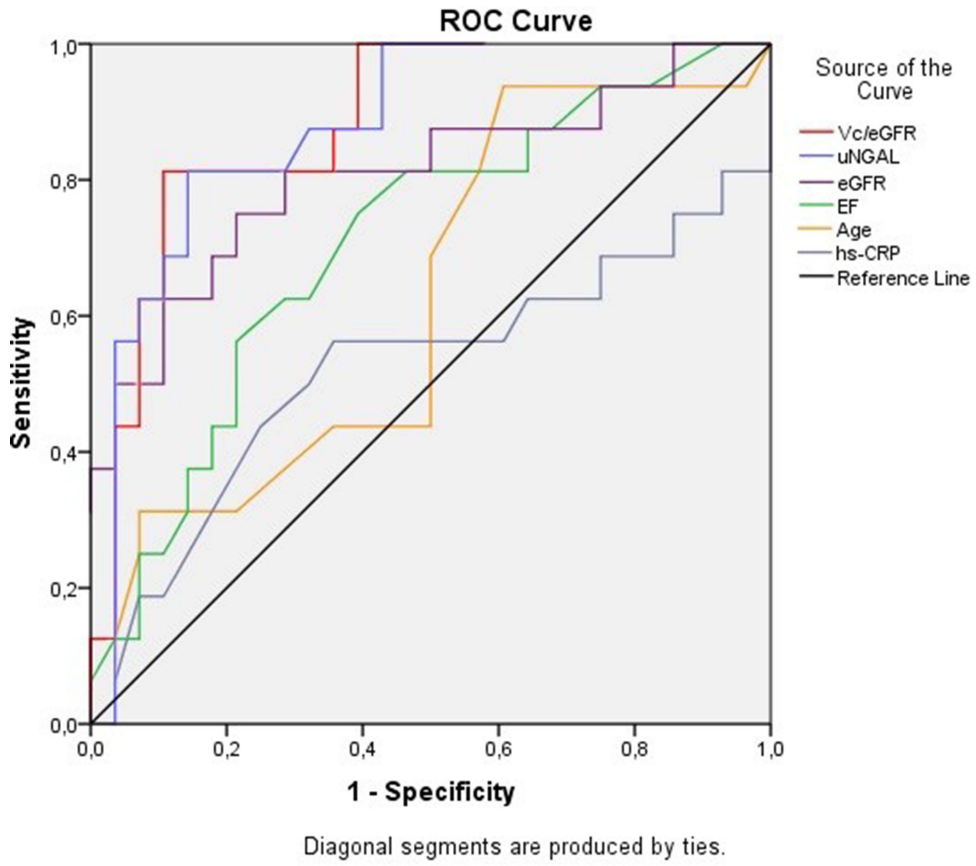

Figure 2 Receiver-operating characteristic (ROC) curves of Age, CRP-hs, EF%, eGFR, Vc/eGFR and uNGAL for prediction of CA-AKI to CKD. Vc/eGFR ratio: AUC = 0.884; p < 0.001; cut-off value = 2.4; Sensitivity = 81.3%; Specificity = 89.3%; uNGAL: AUC = 0.878; p < 0.001; cut-off value = 58 ng/mL; Sensitivity = 81.3%; Specificity = 85.7%; eGFR: AUC = 0.808; p = 0.001; cut-off value = 63.08 mL/min/1.73m^2; Sensitivity = 75%; Specificity = 78.6%; EF%: AUC = 0.709; p = 0.023; cut-off value = 64%; Sensitivity = 75%; Specificity = 60.7%).

Discussion

Ratio of Progression CA-AKI to CKD

Of our total 387 patients undergoing PCI, 44 (11.37%) patients developed CA-AKI (Table 1). The relationship between radiocontrast agents and AKI has been well established.[24] It is believed that the free iodide released from the contrast agent causes direct cytotoxicity on vascular endothelial cells leading to the formation of free radicals with consequently prolonged vasoconstriction.[24,25] Prolonged vasoconstriction reduces the GFR, causes hypoperfusion in the renal medulla, and impedes oxygen supply, leading to ischemic damage to the renal tubules. In addition, water-soluble contrast media can cause kidney damage due to the difference in osmolality compared with surrounding tissue.[25] The consequence is increased renal cell degeneration, apoptosis, and the clinical presentation is that the patient leads to CA-AKI.

The rate of CA-AKI to CKD was 4.13% (if calculated on a total of 387 patients studied) and 36.36% (if calculated on 44 CA-AKI patients) in our study (Table 1). Compared with the study results of other authors, we found no similarity in the rate of AKI converted to CKD in patients after cardiac surgery or PCI. Xu et al[26] followed 1295 patients with AKI after cardiac surgery for 2 years and detected 6.8% of patients from AKI to CKD. Xu et al[27] also followed 3869 cardiac surgery patients. The results showed that the ratio of AKI to CKD patients was 7.7% (113/1468 patients). In particular, according to KDIGO, determining the status of kidney function changes in the AKI patients group shows that up to 31.40% (461/1468 patients) of the patients have partially recovered kidney function.[25] In a study by Zhou et al[28] on 5865 patients undergoing percutaneous coronary angiography, also using KDIGO's criteria to diagnose CKD after CA-AKI, the study results showed: 75.04% (4401 patients) without CA-AKI, 5.76% (338 patients) recovered CA-AKI and 19.20% (1126 patients) non-recovered CA-AKI. Thus, the rate of CA-AKI conversion to CKD is high for patients with coronary artery disease who use contrast agents in angiography and/or PCI. In our study, the rate of CA-AKI patients converted to

CKD was higher than in other studies because the characteristics of our CA-AKI group had many factors relating to the progression of CKD, such as high average age (66.52 ± 7.85 years old), the rate of hypertension is 61.4%, the rate of diabetes is 56.8% (Table 1).

The processes leading to the progression of AKI to CKD, which involve multiple interactions between injured tubules, immune cells, endothelial cells, and fibroblasts, were recently explained.[29] Roles of injured tubules, vascular cells, immune cells, and fibroblasts suggest a crucial connection between AKI and CKD, as they share similar pathologic mechanisms that persist even after AKI.[29–31] Recently, AI systems have demonstrated a high level of accuracy in predicting the development of AKI and the transition to chronic disease in a significant number of patients.[32,33]

Predictive Value AKI to CKD of Vc/eGFR Ratio

We observed that the ratio of hypertension and diabetes in CA-AKI patients compared to CKD patients who had recovered was significantly higher, with $p< 0.01$. (Table 2). Besides, the CA-AKI to CKD group had a higher urine NGAL concentration, higher Vc/eGFR ratio, and lower EF% than the recovery group, $p<0.05$ (Table 2). However, in multivariable analysis, we only found diabetes mellitus, Vc/eGFR ratio, and urinary NGAL concentration as independent variables related to CA-AKI progression to CKD in patients undergoing planned PCI, $p< 0.05$ (Table 3). We also found Vc/eGFR ratio was a good predictor for AKI to CKD transition (AUC = 0.884, $p < 0.001$; Se=81.3%, Sp=89.3%) (Figure 2).

Finding factors before PCI that predict the progression of CA-AKI to CKD is significant in clinical, which can be intervened to reduce the rate of CA-AKI progression to CKD as well as the severity of CKD. The uNGAL is a valuable predictor of progression from AKI to CKD in patients with SA-AKI,[19] and we also found that uNGAl has a good predictive value for progression from CA-AKI to CKD in patients with planned PCI with AUC = 0.878; $p < 0.001$; Sensitivity = 81.3%; Specificity = 85.7% (Figure 2). The NGAL protein was mainly found in actively dividing and regenerating tubule epithelial cells, indicating its involvement in the process of tissue repair.[34] The primary urine source NGAL originates from the epithelial cells of the distal nephron located in the affected kidneys. The findings of this research indicate that NGAL serves as an indirect indicator of kidney injury, given that higher levels of NGAL correspond to more severe kidney damage. Consequently, patients with severe kidney damage are likely to experience a slower recovery process, and the risk of transitioning from acute kidney injury (AKI) to chronic kidney disease (CKD) is elevated.

Besides, we found that the Vc/eGFR ratio is also a good predictor of CA-AKI progression to CKD with AUC = 0.884; $p < 0.001$; Sensitivity = 81.3%; Specificity = 89.3% (Figure 2). The ratio of Vc/eGFR is composed of two components: the volume of contrast agent used in PCI patients and the GFR, which represents the kidney's filtering function to eliminate contrast from blood. Our results show that patients with this high ratio (the volume of contrast used was high, and the glomerular filtration rate was reduced) have an increased risk of CA-AKI and progression to CKD. This suggests that vascular interventionists must use the appropriate amount of contrast agents for each patient. In patients with low GFR, contrast reduction is needed to limit the progression of CA-AKI and CKD.

We still have several limitations in this study. Firstly, this study has not evaluated changes in kidney filtration function based on the slope of GFR, so the detailed transformation process from AKI to CKD has not been clearly seen. Secondly, we only identify kidney injury by the development of microalbuminuria and assess renal function through GFR calculated from endogenous creatinine. It is impossible to determine kidney damage more accurately than through biopsy, and it is impossible to assess kidney function more precisely than through measuring Cystatin C levels or kidney scintigraphy.

Conclusion

In conclusion, the ratio of AKI to CKD in CA-AKI patients after planned PCI was 36.36%. In CA-AKI to CKD patients, Vc/eGFR ratio and uNGAL concentration were significantly higher than those of recovery CA-AKI patients. Vc/eGFR ratio and uNGAL were good predictive indicators of CA-AKI to CKD in planned PCI patients.

Data Sharing Statement

Authors can provide additional relevant original data underpinning their research if requested by the Editor or reviewers.

Ethical Disclosure

Animals did not participate in this research. All human research procedures followed the committee's ethical standards for human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. This study was approved by the Ethical Committee of Vietnam Military Medical University (No. 2890/QĐ-HVQY).

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Disclosure

The authors declare no conflicts of interest in this work.

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