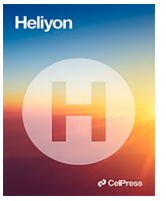
Heliyon 10 (2024) e33988

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Predicting pre- and post-operative acute kidney injury in elderly patients with coronary artery disease

Quanfang Wang, Yijing Zhang, Sihan Li, Jiaojiao Chen, Bo Yang, Chuqi Bai, Luting Yang, Yulan Qiu, Chuhui Wang, Yalin Dong, Taotao Wang *

Department of Pharmacy, The First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, 710061, China

ARTICLE INFO

Keywords:
Elderly patients
Acute kidney injury
Coronary artery disease
Interventional cardiac procedures
Clinical baseline characteristics
Classification and regression tree

ABSTRACT

Background: Limited evidence exists regarding the clinical baseline characteristics at admission for acute kidney injury (AKI) before and after interventional cardiac procedures (ICP) in elderly patients with coronary artery disease (CAD).

Methods: A total of 488 elderly patients were enrolled in this retrospective single-center study conducted from January 2019 to July 2022, and a classification and regression tree (CART) analysis was performed to identify the high-risk population.

Results: The AKI incidence was 21.1 % (103/488) in this study, with 27 and 76 individuals developing AKI before and after ICP, respectively. CART analysis revealed that exposure to nephrotoxic drugs and diuretics had the strongest predictive capacities for identifying patients at risk of developing pre-ICP AKI, with the incidence among these high-risk patients ranging from 6.5 % to 13.8 %. Meanwhile, the optimum discriminators for identifying those at high risk of post-ICP AKI were the administration of diuretics, D-value ≤ -860 mL, age >73 years, and administration of nephrotoxic drugs, and the latter model predicted that the AKI incidence among high-risk patients was between 50.0 % and 60.0 %.

Conclusions: Elderly patients with CAD exhibited an elevated incidence of AKI. CART models suggested that exposure to nephrotoxic drugs and diuretics, D-value, and age were significantly associated with AKI in the elderly with CAD. Importantly, these baseline characteristics at admission could be utilized to identify elderly patients at high risk of pre- and post-ICP AKI.

1. Background

Coronary artery disease (CAD) is a prevalent cardiovascular disease with significant morbidity and mortality globally [1]. In China, the death rate due to CAD is 118 per 100,000 individuals [2]. Interventional cardiac procedures (ICP), including coronary angiography (CAG) and percutaneous coronary intervention (PCI), have become increasingly implemented in the diagnosis and treatment of CAD, and the contrast media is routinely used to visualize the coronary arteries in these procedures. Acute kidney injury (AKI), however, is a common and serious complication associated with the use of contrast media [3], and the contrast-associated AKI incidence ranges from 3 % to 50 % [4]. Meanwhile, AKI is related with poor prognosis, including heart failure, chronic kidney disease, and mortality [5–7].

The pathophysiological processes underlying contrast-associated AKI are complicated and not yet entirely elucidated. Several risk factors have been identified as contributing to the higher likelihood of AKI, including advanced age, lower baseline creatinine

* Corresponding author. West Yanta Road, Xi'an, Shaanxi, China.
E-mail address: wangtaotao1989@mail.xjtu.edu.cn (T. Wang).

https://doi.org/10.1016/j.heliyon.2024.e33988
Received 6 September 2023; Received in revised form 1 July 2024; Accepted 1 July 2024
Available online 2 July 2024

clearance, diabetes mellitus, advanced congestive heart failure, liver disease, pre-existing chronic kidney disease, length of the procedure, large contrast volume, and use of intra-aortic balloon pump (IABP) [6–12]. Certain investigations have revealed some biomarkers associated with AKI, such as serum creatinine, cystatin C, neutrophil gelatinase-associated lipocalin, kidney injury molecule-1, and interleukin-18 [13,14]. Furthermore, studies have developed various prediction models for AKI [7,10,11,15–17] and have been focusing on AKI among elderly patients undergoing CAG [18]. However, the clinical baseline characteristics reflecting AKI are not thoroughly established in the above research. Given that the risk factors in the previous study included not only preprocedural but also procedure-related and postprocedural variables, many predictive models encounter challenges in accurately identifying patients at a high risk of AKI upon admission. It is thus especially crucial to construct a predictive model for AKI based on clinical baseline data at admission, which will be beneficial in aiding clinicians to identify patients with high risk of AKI at the time of admission.

In the process of evaluating AKI among patients with cardiovascular disease, the emergence time of AKI has often been overlooked and rarely reported. Contrast-associated AKI, factually, emerged after ICP (post-ICP AKI). However, some individuals do experience AKI before ICP (pre-ICP AKI), which can be explained by known risk factors such as advanced age and diabetes mellitus [19]. Few previous studies have investigated the risk factors for pre- and post-ICP AKI in elderly patients with CAD.

Therefore, we conducted a retrospective study that aimed to (1) estimate the AKI incidence among elderly patients with CAD, and (2) develop two classification and regression tree (CART) models to identify patients at high risks of pre- and post-ICP AKI based on clinical baseline characteristics at the time of admission.

2. Methods

2.1. Patients

A retrospective single-center study was conducted from January 2019 to July 2022 at the First Affiliated Hospital of Xi'an Jiaotong University. The study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee of the hospital (XJTU1AF2021LSK-409). Informed consent was not required from the patients since this study had a retrospective design. The inclusion criteria of this study were (1) age $\geq$65 years [20], (2) diagnosed with CAD (based on a combination of prior medical records, clinical symptoms, and diagnostic tests), (3) underwent ICP, and (4) a hospital stay $\geq$4 days. The length of hospital stay was limited to apply the Kidney Disease Improving Global Outcomes (KDIGO) criteria [21] for evaluating renal impairment. The exclusion criteria were (1) contrast exposure within 1 week of admission, (2) patients diagnosed with chronic kidney disease or patients with severe hypofiltration (creatinine clearance rate $<$30 mL/min) [22] (3) the time from ICP to discharge less than 48 h, or (4) incomplete medical records.

2.2. Data collection

Baseline demographic, clinical, and laboratory data were retrieved from the electronic medical record system of the hospital. Data collected in this study as follows: (1) demographics, including gender, age, height, and weight; (2) type of CAD and Killip class; (3) coexisting conditions, including hypertension, diabetes mellitus, pulmonary infection, and hyperlipidemia; (4) history of smoking and drinking; (5) laboratory data, including baseline routine blood tests, liver, and kidney function tests, cardiac enzyme tests, and B-type natriuretic peptide (BNP) levels. Serum creatinine clearance (CLcr) was calculated using the Cockcroft-Gault formula [23]. The estimated glomerular filtration rate (eGFR) was calculated using the Chronic Kidney Disease Epidemiology Collaboration equation [24]. (6) the intake and output fluids of patients on the second day of hospitalization, with the D-value defined as output minus intake fluids; (7) the type of ICP, including CAG, PCI, and IABP; (8) drug combinations, including diuretics and nephrotoxic drugs involving frusemide, spironolactone, β-lactam, and moxifloxacin. The reporting associations between the nephrotoxicity of these drugs and AKI have been confirmed by a large-scale study [25]. For patients with AKI, only the drug use data were collected before the onset of AKI. A minimal number of missing values in the case data were substituted with mean values.

2.3. Definition of AKI

AKI was defined based on the KDIGO criteria to provide a standardized and clinically relevant framework for categorizing the severity of AKI [21]. The severity of the AKI was assessed as follows: (1) grade 1: increased serum creatinine level by $\geq$ 26.5 μmol/L or by 1.5- to 2-fold within 48 h; (2) grade 2: $>$ 2- to 3-fold increase in creatinine level; (3) grade 3: $>$ 3-fold increase in creatinine level, or creatinine level $\geq$353.6 μmol/L. AKI was not defined based on urine output because case data from our center only records urine output and intake every 24 h, rather than at 6- or 12-h intervals. AKI below was grade 1 AKI unless otherwise noted.

2.4. Statistical analysis

The continuous data were presented as median (range) and compared by Student's t-test (for normally distributed data) or Mann-Whitney *U* test (for non-normally distributed data). Categorical variables are presented as counts and compared with the Chi-square test or Fisher exact test. The analysis was performed to evaluate the association between pre-ICP AKI or post-ICP AKI and potential risk factors, including gender, age, height, weight, hypertension, diabetes mellitus, pulmonary infection, hyperlipidemia, smoking history, drinking history, D-value, nephrotoxic drugs, diuretics, red blood cell, hemoglobin, hematocrit, platelet, white blood cell (WBC),

lymphocyte, monocytes, neutrophil, aspartate transaminase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP), total bilirubin, total cholesterol, albumin, urea nitrogen, serum creatinine, cystatin C, CLcr, blood sugar, uric acid, lactate dehydrogenase, hydroxybutyrate dehydrogenase, creatine kinase, creatine kinase isoenzyme, and BNP. Variables with a *P* value of <0.1 in Student's t-test, univariate Mann-Whitney *U* test, Chi-square test, or Fisher exact test analysis were included in the CART model. The CART model was applied to determine the optimum predictors of AKI, which could identify the characteristics of patients with a higher likelihood of AKI based on the significant variables included in previous statistical analyses. With this method, the variable that maximized the difference in AKI incidence was identified, and the patients could be divided into two groups: those at a high risk of developing AKI and those with a low likelihood of developing AKI. The performance of the CART model was evaluated using a 10-fold cross-validation method. All data were analyzed using SPSS and SPSS modeler statistical software (IBM Corp., Armonk, NY, USA). The code for constructing the CART model can be found in the appendix. Two-sided *P* values of <0.05 were considered statistically significant.

3. Results

3.1. The characteristics of baseline data and AKI

A total of 488 CAD patients who underwent ICP were included in this study. The median age of this population was 70 years (range 65~91), and 324 (66.4 %) of them were male. Among these patients, their most common complications were hypertension, diabetes mellitus, and pulmonary infection (Table 1). The AKI incidence in this population was 21.1 % (103/488). A total of 27 patients experienced AKI before ICP and 76 patients suffered AKI after ICP, and there were also 7 patients here who progressed to stage 2 of AKI. The median time from hospitalization to performing ICP was 2 days (range 0~10 days), and 25.8 % (126/488) patients underwent ICP on the day of admission. Fig. 1 shows the frequency and cumulative frequency of AKI at different times. The median time from hospitalization to AKI onset was 2 days (Fig. 1a), while the median time from ICP to AKI onset was 1 day (Fig. 1b).

3.2. AKI risk factors in elderly patients with CAD

Table 2 presents the clinical characteristics of pre-ICP AKI patients, post-ICP patients, and non-AKI patients. Compared with the non-AKI group, those with AKI were more likely to be older, to have a pulmonary infection, and to receive nephrotoxic drugs and diuretics. Patients with AKI also had higher levels of WBC, neutrophil, AST, ALT, ALP cystatin C, uric acid, BNP, and the biomarkers for myocardial injury with reduced D-value and lower levels of lymphocyte.

Table 1
The clinical characteristics of 488 patients.

Variables	Value
Gender (Male: Female)	324: 164
Age (years)	70 (65–91)
Height (cm)	168 (145–183)
Weight (kg)	67 (40–95)
AKI (yes/no)	103: 385
Type of CAD [n (%)]	
Stable angina	8 (1.6)
Unstable angina	75 (15.4)
Non-ST-segment elevation myocardial infarction	153 (31.4)
ST-segment elevation myocardial infarction	243 (49.8)
Ischemic cardiomyopathy	9 (1.8)
Killip class (n)	
Class I: II: III: IV	308: 120: 40: 20
Complications[a] [n (%)]	
Hypertension	292 (59.8)
Diabetes mellitus	160 (32.8)
Pulmonary infection	85 (17.4)
Hyperlipidemia	15 (3.1)
Other	29 (5.9)
Type of interventional cardiac procedure [n (%)]	
CAG	30 (6.1)
CAG + Pacemaker implantation	5 (1.0)
CAG + IABP	4 (0.8)
CAG + PCI	391 (80.1)
CAG + PCI + IAPB	58 (11.9)
Volume of contrast	
Iodixanol (mL)	120 (35–300)
Iohexol (mL)	120 (60–210)

The continuous data were presented as median (range). AKI: acute kidney injury; CAD, coronary artery disease; CAG, coronary angiography; PCI, percutaneous coronary intervention; IABP, intra-aortic balloon pump.

[a] Some patients suffered from multiple complications at the same time.

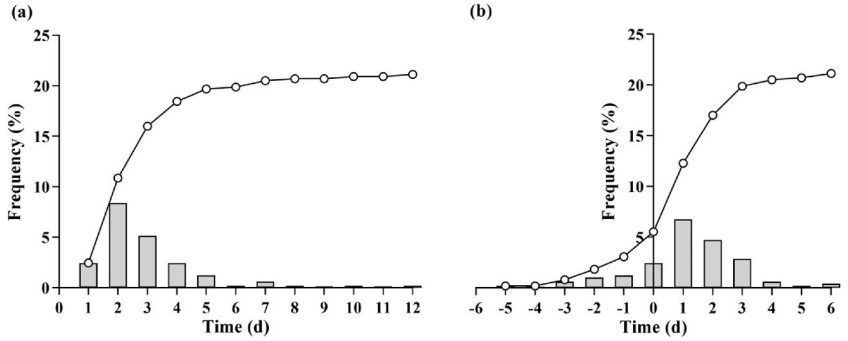


Fig. 1. The frequency and cumulative frequency of AKI during various periods. (a) The time from hospitalization to the occurrence of AKI; (b) The time from cardiac surgery to the occurrence of AKI. Bar, the frequency of AKI on the day; Open circle, the cumulative frequency of AKI on the day.

Table 2
The clinical characteristics among elderly patients with AKI and those without AKI.

Variables	Pre-ICP AKI group			Post-ICP AKI group		
	AKI (n = 27)	Non-Pre-ICP AKI (n = 461)	*P* value	AKI (n = 76)	Non-AKI (n = 385)	*P* value
Gender (male: female)	17: 10	307: 154	0.698	46: 30	261: 124	0.220
Age (years)	70 (65–89)	70 (65–91)	0.218	71 (65–91)	69 (65–90)	0.047
Height (cm)	167 (155–176)	165 (145–183)	0.986	165 (153–175)	165 (145–183)	0.497
Weight (kg)	66 (47–85)	66 (40–95)	0.817	66 (50–90)	66 (40–95)	0.818
Smoking history (yes/no)	12: 15	203: 258	0.967	28: 48	175: 210	0.167
Drinking history (yes/no)	3: 24	85: 376	0.481	11: 65	74: 311	0.329
Pulmonary infection (yes/no)	12: 15	73: 388	<0.001	21: 55	52: 333	0.002
Hypertension (yes/no)	20: 7	272: 189	0.120	47: 29	225: 160	0.582
Diabetes mellitus (yes/no)	9: 18	151: 310	0.950	20: 56	131: 254	0.191
Hyperlipidemia (yes/no)	0: 27	15: 446	1.000	1: 75	14: 371	0.491
Nephrotoxic drugs (yes/no)	13: 14	81: 380	<0.001	26: 50	55: 330	<0.001
Diuretics (yes/no)	18: 9	206: 255	0.026	52: 24	154: 231	<0.001
D-value (mL)	95 (−1665–2245)	180 (−2820–3150)	0.443	−30 (−2470–2123)	200 (−2820–3150)	0.010
Red blood cell (10^{12}/L)	4.33 (2.77–5.28)	4.38 (2.35–5.98)	0.303	4.39 (2.99–5.70)	4.37 (2.35–5.98)	0.975
Hemoglobin (g/L)	130 (82–166)	135 (63–184)	0.118	135 (88–177)	135 (63–184)	0.860
Hematocrit (%)	39.7 (25.4–51.6)	40.8 (19.7–53.6)	0.154	40.7 (25.5–52.7)	40.9 (19.7–53.6)	0.717
Platelet (10^9/L)	178 (123–326)	198 (11–548)	0.273	200 (102–493)	197 (11–548)	0.952
White blood cell (10^9/L)	9.40 (5.24–20.10)	8.90 (2.54–26.12)	0.255	10.30 (4.20–21.05)	8.77 (2.54–26.12)	0.005
Lymphocyte (10^9/L)	1.13 (0.33–2.44)	1.28 (0.25–9.91)	0.087	1.19 (0.25–9.91)	1.32 (0.27–5.43)	0.027
Monocytes (10^9/L)	0.56 (0.10–1.63)	0.43 (0.09–61.00)	0.016	0.41 (0.13–3.80)	0.44 (0.09–61.00)	0.359
Neutrophil (10^9/L)	7.77 (3.76–18.55)	6.93 (1.80–86.50)	0.166	7.86 (2.73–19.20)	6.72 (1.80–86.50)	0.003
Aspartate transaminase (U/L)	73 (19–384)	42 (12–978)	0.081	55 (14–887)	42 (12–978)	0.051
Alanine aminotransferase (U/L)	50 (12–133)	28 (3–899)	0.002	29 (9–503)	28 (3–899)	0.616
Alkaline phosphatase (U/L)	97 (53–136)	86 (3–488)	0.266	92 (35–166)	85 (3–488)	0.025
Total bilirubin (μmol/L)	16.0 (5.8–38.7)	13.5 (2.0–86.0)	0.129	13.7 (2.8–52.0)	13.4 (2.0–86.0)	0.587
Total cholesterol (mmol/L)	3.69 (2.54–7.55)	4.00 (1.60–14.54)	0.336	3.94 (2.31–6.83)	4.01 (1.60–14.54)	0.863
Albumin (g/L)	37.6 (22.9–48.1)	36.9 (20.9–60.7)	0.814	36.8 (25.9–46.3)	36.9 (20.9–60.7)	0.495
Urea nitrogen (mmol/L)	6.69 (3.08–15.35)	6.14 (1.76–40.47)	0.157	6.31 (3.21–17.62)	6.08 (1.76–40.47)	0.136
Serum creatinine (μmol/L)	66 (34–107)	64 (24–146)	0.723	65 (24–133)	64 (27–146)	0.346
CL_{cr} (ml/min)	80.4 (39.6–139.7)	84.5 (32.6–183.0)	0.343	81.7 (34.4–183.0)	84.7 (32.6–164.1)	0.271
eGFR (ml/min/1.73m^2)	89.1 (46.9–109.7)	91.3 (40.2–121.0)	0.556	89.0 (43.2–120.3)	91.8 (40.2–121.0)	0.113
Cystatin C (mg/L)	1.04 (0.59–1.85)	0.99 (0–2.40)	0.531	1.07 (0.09–2.05)	0.99 (0–2.40)	0.061
Blood sugar (mmol/L)	6.82 (4.87–15.65)	7.00 (3.45–28.34)	0.985	7.54 (3.72–20.36)	6.84 (3.45–28.34)	0.031
Uric acid (μmol/L)	314 (182–443)	302 (7–934)	0.960	325 (7–650)	295 (124–934)	0.036
Lactate dehydrogenase (U/L)	394 (184–814)	275 (142–2483)	0.085	321 (162–1891)	271 (142–2483)	0.066
Hydroxybutyrate dehydrogenase (U/L)	319 (153–1039)	226 (11–1459)	0.099	262 (124–1076)	214 (11–1459)	0.029
Creatine kinase (U/L)	549 (31–4715)	246 (18–9368)	0.258	463 (31–8806)	224 (18–9368)	0.007
Creatine kinase isoenzyme (U/L)	73.5 (5.0–402.9)	31.0 (3.0–1413.1)	0.047	51.0 (7.0–1413.1)	29.1 (3.0–985.0)	0.009
B-type natriuretic peptide (pg./mL)	2743 (152–22840)	961 (22–35000)	0.004	1086 (43–15315)	961 (22–35000)	0.170

D-value, the value of output fluids minus intake fluids; CLcr, creatinine clearance rate, eGFR, estimated glomerular filtration rate.

The main clinical factors identified for patients at a high risk of pre-ICP AKI are listed in Table 2. Compared with patients without pre-ICP AKI, those with pre-ICP AKI were more likely to have a pulmonary infection and to receive nephrotoxic drugs and diuretics with higher levels of monocytes, ALT, creatine kinase isoenzyme, and BNP.

3.3. Predictive model of pre-ICP AKI in elderly patients with CAD

The predictive model of pre-ICP AKI in patients with CAD is shown in Fig. 2. The overall classification accuracy of this predictive model was 94.5 % (Tables S1 and S2). In the CART model, the administration of nephrotoxic drugs and diuretics had the highest predictive abilities for identifying patients at risk of developing AKI. The CART analysis results indicated that pre-ICP AKI tended to occur in patients with nephrotoxic drug exposure, or with nephrotoxic drugs while without diuretics. The incidence of pre-ICP AKI among these high-risk patients was 6.5–13.8 %.

3.4. Predictive model of post-ICP AKI in elderly patients with CAD

Fig. 3 illustrates the results obtained by analyzing predictors among the baseline characteristics of post-ICP AKI. The overall classification accuracy was 84.4 % (Tables S1 and S2). Of the variables analyzed by the CART model, administration of diuretics, age, the D-value, and administration of nephrotoxic drugs were the most effective in distinguishing between patients with and without AKI. Patients who were under diuretics exposure had a high probability (25.2 %) of getting AKI. AKI was more likely to occur in the following groups: (1) administration of diuretics with D-value $\leq$ -860 mL; (2) age $>$ 73 years, administration of nephrotoxic drugs while without the use of diuretics. The incidence of post-ICP AKI among these high-risk patients was 50.0–60.0 %.

4. Discussion

Many studies performed over the past decades have explored the risk factors for contrast-associated AKI in patients undergoing ICP [3]. However, few studies have focused on the risk factors for AKI in elderly patients with CAD, and the clinical baseline characteristics were not clearly defined in previous studies. Furthermore, pre-ICP AKI is often ignored by clinicians. The main purpose of this study was to use baseline characteristics to predict pre- and post-ICP AKI in elderly patients who underwent ICP.

In the present research, the baseline characteristics such as age, co-existing conditions, drug combinations, routine blood tests, liver and kidney function, BNP, cardiac enzyme, and D-value were significantly different between patients with and without AKI. Previous studies have revealed consistent predictors of AKI in patients with heart disease, such as age [5,10], IABP [7,11,26], diuretic [7,11], white blood cells [7,10], biomarkers of cardiac damage [27], and hemoglobin [5,10,11,26].

One of the aims of this study was to develop a predictive model for pre-ICP AKI, which has rarely been addressed previously. Given the AKI incidence was 21.1 % (103/488) in this study, it deserves more attention from clinicians. The CART model indicated that AKI preceding ICP could be predicted by drug combinations, including nephrotoxic drugs and diuretics (Fig. 2), which can provide a target for interventions. A Pharmacovigilance Study of the FDA Adverse Event Reporting System found that 14 classes of antibiotics had significant reporting associations with AKI, including cephalosporins, carbapenems, and fluoroquinolones [25]. In this research, the pre-ICP AKI incidence rates were 13.8 % (13/94) and 3.6 % (14/394) in patients who did and did not receive nephrotoxic drugs, respectively. Notably, patients who received both nephrotoxic drugs and diuretics exhibited a higher probability of developing AKI. This is also easily explained because many diuretics also cause kidney damage, and are ineffective and even detrimental in the prevention and treatment of AKI [28].

The CART model was used to explore the association between post-ICP AKI and the baseline characteristics of elderly patients with

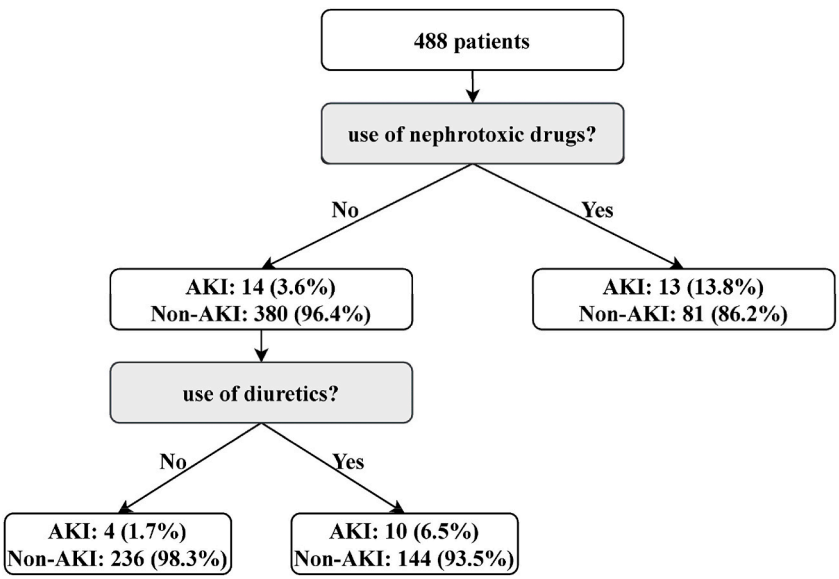


Fig. 2. Classification and regression tree predictive model for pre-ICP AKI.

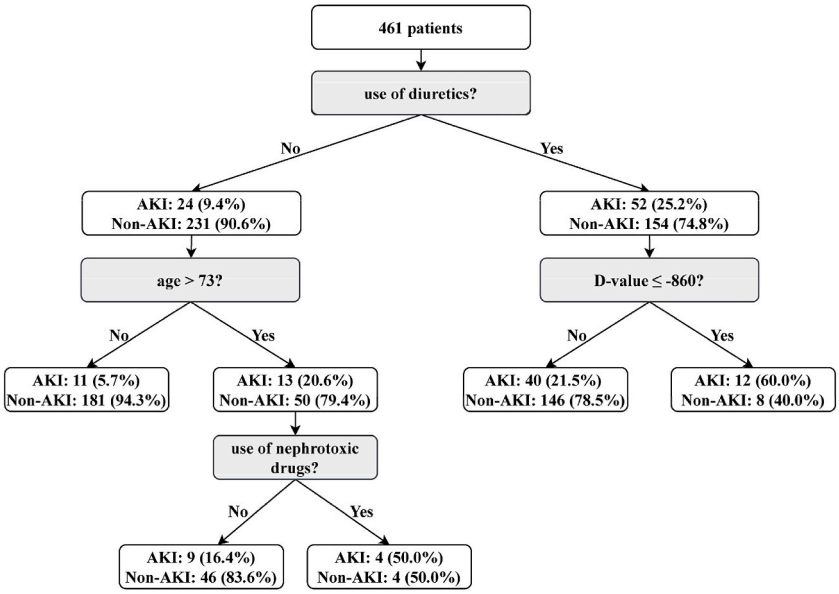


Fig. 3. Classification and regression tree predictive model for post-ICP AKI.

CAD, which revealed that age, the D-value, and administration of diuretics and nephrotoxic drugs were predictors of post-ICP AKI in elderly patients with CAD (Fig. 3). Compared with the CART model for pre-ICP AKI, two novel, relevant, and convenient predictors have been revealed for post-ICP AKI: the D-value and age. The latter CART model indicated that AKI incidence would reach 60.0 % in patients who were administrated diuretics with the D-value ≤ -860 mL. Urine output is a convenient indicator of kidney function, and reduced output is a commonly known indicator of AKI. Urine output reduction may be an early indicator of decreased kidney function [29]. In the present study, the D-value for patients with AKI was -30 ± 929 mL ($-2470 \sim 2123$ mL), which was significantly lower than that for patients without AKI. The fact that 25.8 % of patients underwent ICP on the day of admission suggests that a high hydration volume may be meaningful in reducing the occurrence of post-ICP AKI. Many researchers have demonstrated that AKI is more prevalent in elderly individuals, and have demonstrated a clear age-dependent relationship between AKI and older age [30]. This CART model indicated that the AKI incidence would reach 20.6 % in patients with age >73 years and diuretics exposure. The AKI risk generally increases with age, whereas organ functions deteriorate and glomerular filtration rates physiologically decrease with age [31]. The deterioration in kidney function may clarify why older patients are more likely to develop AKI.

Previous studies have also demonstrated the relationship between hemoglobin and AKI [5,32–35], which may be attributed to decreased oxygen supply to the kidney and renal hypoxia. However, this study did not reveal it, as no significant difference was found in elderly patients with CAD. Earlier investigations indicated that the preoperative elevated ratio of serum aspartate aminotransferase to alanine aminotransferase was a potential predictor of post-ICP AKI [36,37]. AST is a circulating enzyme that is primarily synthesized by the liver, and as we all know kidney dysfunction is a common complication of acute liver failure [38]. However, this research found that there is only a marginally significant for AKI with different AST levels in elderly patients. Unlike the above clinical design, our study focused on the elderly CAD population, which may be the source of the discrepancy.

Summarily, in elderly patients with CAD and a high risk of AKI, renal function should be carefully monitored before and after ICP. Furthermore, adequate hydration of the patient and discontinuation of diuretics and nephrotoxic drugs may be a strategy to prevent AKI in high-risk patients.

Within the present research, the collected covariates were screened, and only covariates with a *P* value below 0.1 were selected for subsequent analysis, which could ensure the potential risk factors of AKI to enter the CART model. This approach also serves to simplify the CART model and improve prediction accuracy. The reason why this study did not consider the effect of different types of contrast agents is that the risk of AKI is independent of the type of contrast utilized, which has been confirmed by a large cohort [39].

This study is not exempt from certain limitations. Firstly, it separated diuretics from nephrotoxic drugs and did not include more types of nephrotoxic drugs and diuretics. Then, this study had a single-center, non-large sample size, and retrospective design. The patient sample size was insufficient for conducting a robust decision tree analysis. Undoubtedly, prospective studies may be necessary in the future to validate the accuracy of these CART models.

5. Conclusions

This retrospective single-center study explored the association between the clinical baseline characteristics and pre- and post-ICP AKI in elderly patients with CAD. The AKI incidence among elderly patients with CAD was 21.1 %. Two CART models showed that the combination therapy of nephrotoxic drugs and diuretics were identified as predictors of pre-ICP AKI, by contrast, the age, D-value, and

administration of diuretics and nephrotoxic drugs as predictors of post-ICP AKI in elderly patients with CAD. These predictors could be used to identify elderly patients at a high risk of pre- and post-ICP AKI at the time of admission, which substantially contributes to the development of effective risk stratification strategies and informs the implementation of preventive interventions within clinical practice.

Funding

No funding was received.

Ethics approval and consent to participate

The study procedures were reviewed and approved by the Ethics Committee of the First Affiliated Hospital of Xi'an Jiaotong University (XJTU1AF2021LSK-409).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Quanfang Wang: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yijing Zhang:** Writing – original draft, Software, Project administration, Methodology, Investigation, Data curation. **Sihan Li:** Visualization, Resources, Project administration, Methodology, Investigation, Formal analysis. **Jiaojiao Chen:** Software, Resources, Methodology, Formal analysis, Data curation. **Bo Yang:** Visualization, Software, Formal analysis, Data curation. **Chuqi Bai:** Software, Resources, Data curation. **Luting Yang:** Software, Resources, Formal analysis, Data curation. **Yulan Qiu:** Software, Resources, Methodology, Data curation. **Chuhui Wang:** Supervision, Methodology, Data curation. **Yalin Dong:** Writing – review & editing, Validation, Supervision, Conceptualization. **Taotao Wang:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e33988.

References

[1] G.E. Shaya, T.M. Leucker, S.R. Jones, S.S. Martin, P.P. Toth, Coronary heart disease risk: low-density lipoprotein and beyond, Trends Cardiovasc. Med. 32 (4) (2022) 181–194, https://doi.org/10.1016/j.tcm.2021.04.002.

[2] L.Y. Ma, W.W. Chen, R.L. Gao, et al., China cardiovascular diseases report 2018: an updated summary, J Geriatr Cardiol 17 (1) (2020) 1–8, https://doi.org/10.11909/j.issn.1671-5411.2020.01.001.

[3] R. Mehran, G.D. Dangas, S.D. Weisbord, Contrast-associated acute kidney injury, N. Engl. J. Med. 380 (22) (2019) 2146–2155, https://doi.org/10.1056/NEJMra1805256.

[4] Z. Lun, L. Liu, G. Chen, et al., Correction to: the global incidence and mortality of contrast-associated acute kidney injury following coronary angiography: a meta-analysis of 1.2 million patients, J. Nephrol. 34 (5) (2021) 1785, https://doi.org/10.1007/s40620-021-01090-2.

[5] Y.T. Chen, C.C. Jenq, C.K. Hsu, et al., Acute kidney disease and acute kidney injury biomarkers in coronary care unit patients, BMC Nephrol. 21 (1) (2020) 207, https://doi.org/10.1186/s12882-020-01872-z.

[6] Y. Wang, R. Bellomo, Cardiac surgery-associated acute kidney injury: risk factors, pathophysiology and treatment, Nat. Rev. Nephrol. 13 (11) (2017) 697–711, https://doi.org/10.1038/nrneph.2017.119.

[7] R. Pavasini, M. Tebaldi, G. Bugani, et al., Contrast associated acute kidney injury and mortality in older adults with acute coronary syndrome: a pooled analysis of the fraser and hulk studies, J. Clin. Med. 10 (10) (2021) 2151, https://doi.org/10.3390/jcm10102151.

[8] C. Duan, Y. Cao, Y. Liu, et al., A new preprocedure risk score for predicting contrast-induced acute kidney injury, Can. J. Cardiol. 33 (6) (2017) 714–723, https://doi.org/10.1016/j.cjca.2017.01.015.

[9] R. Mehran, E.D. Aymong, E. Nikolsky, et al., A simple risk score for prediction of contrast-induced nephropathy after percutaneous coronary intervention: development and initial validation, J. Am. Coll. Cardiol. 44 (7) (2004) 1393–1399, https://doi.org/10.1016/j.jacc.2004.06.068.

[10] L. Sun, W. Zhu, X. Chen, et al., Machine learning to predict contrast-induced acute kidney injury in patients with acute myocardial infarction, Front. Med. 7 (2020) 592007, https://doi.org/10.3389/fmed.2020.592007.

[11] L. Lei, Y. He, Z. Guo, et al., A simple nomogram to predict contrast-induced acute kidney injury in patients with congestive heart failure undergoing coronary angiography, Cardiol. Res. Pract. 2021 (2021) 10, https://doi.org/10.1155/2021/9614953.

[12] M. Mach, W. Hasan, M. Andreas, et al., Evaluating the association between contrast medium dosage and acute kidney injury in transcatheter aortic valve replacement using different predictive models, J. Clin. Med. 9 (11) (2020) 3476, https://doi.org/10.3390/jcm9113476.

[13] C. Briguori, C. Quintavalle, E. Donnarumma, G. Condorelli, Novel biomarkers for contrast-induced acute kidney injury, BioMed Res. Int. 2014 (2014) 5, https://doi.org/10.1155/2014/568738.

[14] M. Andreucci, T. Faga, E. Riccio, M. Sabbatini, A. Pisani, A. Michael, The potential use of biomarkers in predicting contrast-induced acute kidney injury, Int. J. Nephrol. Renovascular Dis. 9 (2016) 205–221, https://doi.org/10.2147/IJNRD.S105124.

[15] X. Zhou, Z. Sun, Y. Zhuang, et al., Development and validation of nomogram to predict acute kidney injury in patients with acute myocardial infarction treated invasively, Sci. Rep. 8 (1) (2018) 9769, https://doi.org/10.1038/s41598-018-28088-4.

[16] C. Parco, M. Brockmeyer, L. Kosejian, et al., National Cardiovascular Data Registry-Acute Kidney Injury (NCDR) vs. Mehran risk models for prediction of contrast-induced nephropathy and need for dialysis after coronary angiography in a German patient cohort, J. Nephrol. 34 (5) (2021) 1491–1500, https://doi.org/10.1007/s40620-021-01124-9.

[17] S.C. Efe, M. Keskin, E. Toprak, et al., A novel risk assessment model using urinary system contrast blush grading to predict contrast-induced acute kidney injury in low-risk profile patients, Angiology 72 (6) (2021) 524–532, https://doi.org/10.1177/00033197211005206.

[18] J.A. Dodson, A. Hajduk, J. Curtis, et al., Acute kidney injury among older patients undergoing coronary angiography for acute myocardial infarction: the SILVER-AMI study, Am. J. Med. 132 (12) (2019) e817–e826, https://doi.org/10.1016/j.amjmed.2019.05.022.

[19] W.T. McBride, M.J. Kurth, G. McLean, et al., Stratifying risk of acute kidney injury in pre and post cardiac surgery patients using a novel biomarker-based algorithm and clinical risk score, Sci. Rep. 9 (1) (2019) 16963, https://doi.org/10.1038/s41598-019-53349-1.

[20] E.R. Vieira, R.C. Palmer, P.H. Chaves, Prevention of falls in older people living in the community, BMJ 353 (2016) i1419, https://doi.org/10.1136/bmj.i1419.

[21] A. Khwaja, KDIGO clinical practice guidelines for acute kidney injury, Nephron Clin. Pract. 120 (4) (2012) c179–c184, https://doi.org/10.1159/000339789.

[22] J.A. Kellum, N. Lameire, P. Aspelin, et al., Kidney disease: improving global outcomes (KDIGO) acute kidney injury work group. KDIGO clinical practice guideline for acute kidney injury, Kidney Int. Suppl. 2 (1) (2012) 1–138, https://doi.org/10.1038/kisup.2012.1.

[23] W.M. Michels, D.C. Grootendorst, M. Verduijn, E.G. Elliott, F.W. Dekker, R.T. Krediet, Performance of the Cockcroft-Gault, MDRD, and new CKD-EPI formulas in relation to GFR, age, and body size, Clin. J. Am. Soc. Nephrol. 5 (6) (2010) 1003–1009, https://doi.org/10.2215/CJN.06870909.

[24] A new equation to estimate glomerular filtration rate, Ann. Intern. Med. 150 (9) (2009) 604–612, https://doi.org/10.7326/0003-4819-150-9-200905050-00006.

[25] T.M. Patek, C. Teng, K.E. Kennedy, C.A. Alvarez, C.R. Frei, Comparing acute kidney injury reports among antibiotics: a pharmacovigilance study of the FDA Adverse event reporting system (faers), Drug Saf. 43 (1) (2020) 17–22, https://doi.org/10.1007/s40264-019-00873-8.

[26] G. Yan, D. Wang, C. Tang, G. Ma, The association of serum lactate level with the occurrence of contrast-induced acute kidney injury and long-term prognosis in patients undergoing emergency percutaneous coronary intervention, Int. J. Gen. Med. 14 (2021) 3087–3097, https://doi.org/10.2147/IJGM.S316036.

[27] E.C. Alves, J.A.G. Sachett, V.S. Sampaio, et al., Predicting acute renal failure in Bothrops snakebite patients in a tertiary reference center, Western Brazilian Amazon, PLoS One 13 (8) (2018) e0202361, https://doi.org/10.1371/journal.pone.0202361.

[28] A.A. Ejaz, R. Mohandas, Are diuretics harmful in the management of acute kidney injury? Curr. Opin. Nephrol. Hypertens. 23 (2) (2014) 155–160, https://doi.org/10.1097/01.mnh.0000441150.17202.be.

[29] A. Md Ralib, J.W. Pickering, G.M. Shaw, Z.H. Endre, The urine output definition of acute kidney injury is too liberal, Crit. Care 17 (3) (2013) R112, https://doi.org/10.1186/cc12784.

[30] S.G. Coca, Acute kidney injury in elderly persons, Am. J. Kidney Dis. 56 (1) (2010) 122–131, https://doi.org/10.1053/j.ajkd.2009.12.034.

[31] A. Denic, R.J. Glassock, A.D. Rule, Structural and functional changes with the aging kidney, Adv. Chron. Kidney Dis. 23 (1) (2016) 19–28, https://doi.org/10.1053/j.ackd.2015.08.004.

[32] A.A. Brescia, X. Wu, G. Paone, et al., Effect of sex on nadir hematocrit and rates of acute kidney injury in coronary artery bypass, J. Thorac. Cardiovasc. Surg. 158 (4) (2019) 1073–10780 e4, https://doi.org/10.1016/j.jtcvs.2019.03.042.

[33] H. Liu, S.Q. Zheng, S.C. Qian, H.H. He, J.R. Xue, Haematocrit differences modify the association of cardiopulmonary bypass reoxygenation with acute kidney injury after paediatric Tetralogy of Fallot repair, Perfusion 35 (4) (2020) 284–289, https://doi.org/10.1177/0267659119871777.

[34] J. Crosina, J. Lerner, J. Ho, et al., Improving the prediction of cardiac surgery-associated acute kidney injury, Kidney Int Rep 2 (2) (2017) 172–179, https://doi.org/10.1016/j.ekir.2016.10.003.

[35] J. Fulla, P. Prasanchaimontri, H.C. Wright, et al., Acute kidney injury and percutaneous nephrolithotomy: incidence and predictive factors, World J. Urol. 40 (2) (2022) 563–567, https://doi.org/10.1007/s00345-021-03874-4.

[36] J. Xu, Y. Xia, S. Li, et al., A retrospective pilot study to examine the potential of aspartate aminotransferase to alanine aminotransferase ratio as a predictor of postoperative acute kidney injury in patients with hepatocellular carcinoma, Ann. Clin. Biochem. 56 (3) (2019) 357–366, https://doi.org/10.1177/0004563218817797.

[37] K. Pilarczyk, H. Carstens, J. Heckmann, et al., The aspartate transaminase/alanine transaminase (DeRitis) ratio predicts mid-term mortality and renal and respiratory dysfunction after left ventricular assist device implantation, Eur. J. Cardio. Thorac. Surg. 52 (4) (2017) 781–788, https://doi.org/10.1093/ejcts/ezx247.

[38] J.A. Leithead, J.W. Ferguson, C.M. Bates, et al., The systemic inflammatory response syndrome is predictive of renal dysfunction in patients with non-paracetamol-induced acute liver failure, Gut 58 (3) (2009) 443–449, https://doi.org/10.1136/gut.2008.154120.

[39] L. Azzalini, L.M. Vilca, F. Lombardo, et al., Incidence of contrast-induced acute kidney injury in a large cohort of all-comers undergoing percutaneous coronary intervention: comparison of five contrast media, Int. J. Cardiol. 273 (2018) 69–73, https://doi.org/10.1016/j.ijcard.2018.08.097.