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Risk factors for acute kidney injury following coronary artery bypass graft surgery in a Chinese population and development of a prediction model

Yang LI[1], Xue-Jian HOU[1], Tao-Shuai LIU[1], Shi-Jun XU[1], Zhu-Hui HUANG[1], Peng-Yun YAN[1], Xiao-Yu XU[2], Ran DONG[1,✉]

1. Department of Cardiac Surgery, Beijing Anzhen Hospital, Capital Medical University, Beijing, China; 2. Department of pharmacy, Beijing Anzhen Hospital, Capital Medical University, Beijing, China
✉ Correspondence to: dongran6618@hotmail.com
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ABSTRACT

BACKGROUND Acute kidney injury (AKI) after coronary artery bypass graft (CABG) surgery is associated with significant morbidity and mortality. This retrospective study aimed to establish a risk score for postoperative AKI in a Chinese population.

METHODS A total of 1138 patients undergoing CABG were collected from September 2018 to May 2020 and divided into a derivation and validation cohort. AKI was defined according to the Kidney Disease Improving Global Outcomes (KDIGO) criteria. Multivariable logistic regression analysis was used to determine the independent predictors of AKI, and the predictive ability of the model was determined using a receiver operating characteristic (ROC) curve.

RESULTS The incidence of cardiac surgery–associated acute kidney injury (CSA-AKI) was 24.17%, and 0.53% of AKI patients required dialysis (AKI-D). Among the derivation cohort, multivariable logistic regression showed that age ≥ 70 years, body mass index (BMI) ≥ 25 kg/m^2, estimated glomerular filtration rate (eGFR) ≤ 60 mL/min per 1.73 m^2, ejection fraction (EF) ≤ 45%, use of statins, red blood cell transfusion, use of adrenaline, intra-aortic balloon pump (IABP) implantation, postoperative low cardiac output syndrome (LCOS) and reoperation for bleeding were independent predictors. The predictive model was scored from 0 to 32 points with three risk categories. The AKI frequencies were as follows: 0–8 points (15.9%), 9–17points (36.5%) and ≥ 18 points (90.4%). The area under of the ROC curve was 0.730 (95% CI: 0.691–0.768) in the derivation cohort. The predictive index had good discrimination in the validation cohort, with an area under the curve of 0.735 (95% CI: 0.655–0.815). The model was well calibrated according to the Hosmer-Lemeshow test (P = 0.372).

CONCLUSION The performance of the prediction model was valid and accurate in predicting KDIGO-AKI after CABG surgery in Chinese patients, and could improve the early prognosis and clinical interventions.

Acute kidney injury (AKI) is a frequent and common complication after heart surgery, with reported incidences ranging from 5%–45%,[1,2] and it is associated with increased mortality, morbidity and medical cost.[3–6] According to the 2012 Kidney Disease Improving Global Outcomes (KDIGO) criteria, AKI is defined as an absolute value of an serum creatinine (SCr) increase ≥ 0.3 mg/dL (≥ 26.5 μmol/L) within 48 h or an increase ≥ 1.5 times baseline levels within seven days, or a urine output < 0.5 mL/kg per hour lasting over 6 h.[7] The in-hospital mortality rate of AKI is increased 2–5 folds, and KDIGO stage 1 cardiac surgery–associated acute kidney injury (CSA-AKI) accounts for 80% of all AKI patients.[8]

The coronary artery bypass graft (CABG) procedure is an effective and widely developed treatment for coronary artery disease or myocardial infarction. Nevertheless, there is a lack of predictive model for AKI patients after CABG; the recruited sample sizes have not been large enough and only risk factors before the operation have been analyzed. Therefore, the aim of this retrospective study was to establish a risk predictive score of AKI after CABG for Chinese patients using both preoperative and perioperative variables.

METHODS

Ethical Considerations

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board and Ethics Committee of Beijing Anzhen Hospital (2010043X) and all consents were obtained from the study participants oral.

Study Design

A total of 1138 coronary artery disease (CAD) patients who underwent CABG surgery were retrospectively enrolled from September 2018 to May 2020 in our ward in this study. The inclusion criteria were adult patients who underwent coronary artery bypass grafting, including off-pump coronary artery bypass graft (OPCABG) and on-pump CABG. Exclusion criteria were preoperative dialysis or renal transplant recipients, age < 18 years, serious infection, data lacked, preoperative surgical procedures (heart transplantation, ventricular assist device implantation, Implantable Cardioverter Defibrillator) and preoperative support of intubation. All the patients were randomly assigned to two cohorts: a derivation set of 907 cases (80%) and a validation set of 231 cases (20%) according to SPSS 22.0 (SPSS IBM, New York, USA). CSA-AKI was observed in 275 patients and the other 863 patients remained normal kidney function.

Definition of AKI

AKI was defined according to the KDIGO criteria: an increase in SCr ≥ 26.5 μmol/L, or an increase in SCr ≥ 1.5 times baseline in seven days after surgery. KDIGO-AKI stage 1 was defined with an increase of SCr by 1.5−1.9 times baseline or ≥ 26.5 μmol/L from baseline. KDIGO-AKI stage 2 was defined as an increase of SCr of 2.0−2.9 times baseline. KDIGO-AKI stage 3 was defined as an increase in SCr by ≥ 3.0 times baseline or with SCr of ≥ 353.6 μmol/L or with the initiation of renal replacement therapy.[7]

Date Collection

Preoperative characteristics included sex, age, body mass index (BMI), family history, smoking, and comorbidities including diabetes, hypertension, chronic obstructive pulmonary disease(COPD), peripheral-artery disease, and previous myocardial infarction more within three weeks, as well as the number of diseased vessels, presence of left main disease, prior percutaneous coronary intervention (PCI), a left ventricular ejection fraction and less than 40%, and the New York Heart Association (NYHA) functional classification. Renal function including SCr, estimated glomerular filtration rate (eGFR), serum urea nitrogen, serum uric acid, proteinuria, and eGFR was calculated with MDRD equations.[9] Other biochemical indicators included haemoglobin, platelets, serum triglyceride and serum cholesterol. Medication usage before surgery included angiotensin-converting enzyme inhibitors (ACEI) or angiotensin receptor blockers (ARB), β-blockers, calcium channel blockers, diuretics, statins and aspirin. Intraoperative characteristics included emergent and urgent priority, surgical approach, operation time, number of grafts, cardiopulmonary bypass (CPB) usage, cardiopulmonary bypass time and red blood cell transfusion. Postoperative characteristics included the use of an intra-aortic balloon pump (IABP) or extracorporeal membrane oxygenation (ECMO), intubation time, and length of intensive care unit (ICU) stay. Complications included death, renal function insufficiency, low cardiac output syndrome (LCOS), reoperation for bleeding, stroke, new onset atrial fibrillation, serious infection, inotropic drugs and medical cost.

Statistical Analysis

Continuous variables were reported as the mean ± SD or median (interquartile range) (IQR). Student *t*-test was applied for continuous data with equal or unequal variances. The Mann-Whitney *U* test was applied for continuous data that were not normally distributed. Pearson's χ^2 and Fisher's exact tests were used for categorical data. Univariate analysis was performed on all variables which were believed to be predictors of AKI and the variables with statistically significant (P < 0.05) were utilized in a logistic multivariate model. If the same characteristic was found with significance, the one with a higher odds ratio (OR) was included in the multivariate model. Variables were removed from the multivariate model in stepwise fashion if they were found with no statistical significance (P < 0.05). A clinical risk score card was created to identify patients at risk of developing severe renal insufficiency, and the patients were stratified by scores to predict CSA-AKI. To measure and compare the accuracy of prediction in the generation and validation of datasets, an ROC curve was generated, the area under curve was calculated, and the Hosmer-Lemeshow goodness-of-fit test was applied. Internal validation using our risk prediction score model was performed to assess the predictive model. The number of points attributable to each risk factor in our score was determined by rounding the OR from the multivariate logistic model to the nearest 0.5. A two-sided P-value of < 0.05 was considered as statistically significant, and all statistical analyses were performed using IBM SPSS 22.0 (SPSS IBM, New York, USA).

RESULTS

Patient Characteristics

In total, 1 138 CAD patients who underwent the CABG procedure were enrolled in this research, of which OPCABG accounted for 83.22% of the total (947 cases), and the other 191 patients underwent on-pump CABG. A total of 829 patients were male (72.85%), with an average age of 61.81 ± 8.77 years, and 309 patients were female (27.15%), with an average age of 64.09 ± 7.05 years. The rate of CSA-AKI for all patients was 24.17% (275 cases), and it was 18.28%, 3.51% and 2.37% for patients with KDIGO-AKI stage 1, stage 2 and stage 3 disease, respectively. Furthermore, the incidence of AKI in male or female patients were 23.50% and 25.94%, respectively, with no significant difference (P = 0.481). Six patents needed dialysis after the operation. The average age in the AKI group was 63.49 ± 8.73 *vs.* 62.19 ± 8.50 in the non-AKI group. The in-hospital mortality rate was 1.32% (15/1 138), and no patient died in the non-AKI set. In the CSA-AKI group, the mortality was 5.45% (15/275), and it as 2.40%, 10.00%, and 22.22%, respectively, in patients with KDIGO-AKI stage 1, stage 2, and stage 3 disease. All patients were divided into a derivation cohort (907 cases) and a validation cohort (231 cases). The incidence of CSA-AKI and mortality in the derivation cohort were 24.15% (219/907) and 1.10% (10/907), respectively, whereas in the validation cohort, they were 24.24% (56/231) and 2.16% (5/231), respectively.

Risk Factor Analysis

The preoperative and perioperative characteristics of the derivation cohort are presented in Table 1 and Table 2. There were statistically significant differences between the unaffected group and the CSA-AKI patients including age, sex, preoperative renal function, and some comorbidities such as hypertension and peripheral-artery disease (P < 0.05). There was no significant difference between the two cohort in the number of diseased vessels, left main disease, preoperative heart condition or NYHA functional classification (P > 0.05). The surgical approach and operation time were also without difference among two group (P > 0.05). The intubation time, IABP implantation and other postoperative complications, such as LCOS, reoperation for bleeding, stroke, new onset atrial fibrillation or serious infection were significantly higher in the AKI group, and were associated with higher in-hospital death (P < 0.05). Furthermore, we categorized the following variables for subgroup observation: age (< 70, ≥ 70 years), BMI (< 25, ≥ 25), eGFR (≤ 60, > 60 mL/min per 1.73 m^2), left ventricular ejection fraction (LVEF) (≤ 45, > 45%), number of narrowed coronary arteries (< 3, ≥ 3 vessel disease) and NYHA classification (< 2, ≥ 2).

All of the risk factors and other characteristics with clinical significance were included in the multivariate analysis for predicting CSA-AKI. Multivariable logistic regression showed that age ≥ 70 years, BMI ≥ 25 kg/m^2, eGFR ≤ 60 mL/min per 1.73 m^2, LVEF ≤ 45%, use of statins, red blood cell (RBC) transfusion, use of adrenaline, IABP implantation, postoperative LCOS and reoperation for bleeding were independently associated with the development of AKI (P < 0.05) (Table 3).

Score Development

The independent risk factors in the multivariate analysis were selected for the final scoring model. The clinical score (Table 4) ranged from a minim-

Table 1 Univariate analysis of preoperative risk factors for the development of AKI in derivation cohort.

Characteristics	AKI (n = 219)	Non-AKI (n = 688)	Global cohort (n = 907)	P-value
Demographics				
Age, yrs	63.94 ± 8.56	61.96 ± 8.51	62.44 ± 8.56	0.003
Age ≥ 70 yrs	56 (25.57%)	121 (17.59%)	177 (19.51%)	0.011
Male gender	157 (71.68%)	511 (74.27%)	668 (73.65%)	0.481
BMI, kg/m^2	26.26 ± 3.69	25.69 ± 3.22	25.80 ± 3.34	0.002
≥ 25 kg/m^2	137 (62.56%)	346 (50.29%)	483 (53.25%)	0.042
Renal function				
eGFR, mL/min per 1.73 m^2	83.66 ± 20.05	93.24 ± 15.55	90.93 ± 17.23	0.000
> 60 mL/min	186 (84.93%)	653 (94.91%)	839 (92.50%)	0.000
≤ 60 ml/min	33 (15.07%)	35 (5.09%)	68 (7.50%)	0.000
Serum Creatinine, mg/dL	74.82 ± 23.18	74.21 ± 22.47	74.35 ± 24.25	0.746
Comorbidities				
Family history	19 (8.68%)	45 (6.54%)	64 (7.06%)	0.290
Hypertension	161 (73.52%)	427 (62.06%)	588 (64.83%)	0.002
Smoking	100 (45.66%)	343 (49.85%)	443 (48.84%)	0.313
peripheral-artery disease	62 (28.31%)	149 (21.66%)	211 (23.26%)	0.044
Stroke	5 (2.28%)	11 (1.60%)	16 (1.76%)	0.555
Diabetes	88 (40.18%)	256 (37.21%)	344 (37.93%)	0.472
Chronic obstructive pulmonary disease	1 (0.47%)	0	1 (0.11%)	0.241
Cardiac status				
Recent MI (< 3 weeks)	28 (12.79%)	102 (14.83%)	130 (14.33%)	0.507
MI (> 3 weeks)	30 (13.70%)	82 (11.92%)	112 (12.35%)	0.481
Previous PCI	28 (12.79%)	118 (17.15%)	146 (16.10%)	0.238
Left main stenosis > 50%	38 (17.35%)	136 (19.77%)	174 (19.18%)	0.490
No. of narrowed coronary arteries	3.26 ± 0.67	3.31 ± 0.68	3.29 ± 0.81	0.349
≥ three vessel disease	202 (92.23%)	641 (93.17%)	843 (92.94%)	0.650
LVEF, %	58.80 ± 8.26	58.74 ± 7.21	58.76 ± 7.47	0.952
LVEF ≤ 0.45	21 (9.60%)	38 (5.52%)	59 (6.50%)	0.041
NYHA classification ≥ 2	39 (17.81%)	148 (21.51%)	187 (20.62%)	0.251
Baseline laboratory findings				
Haemoglobin, g/L	136.49 ± 18.57	142.01 ± 15.48	140.68 ± 16.44	0.000
Haemoglobin < 120 g/L	32 (14.61%)	50 (7.27%)	82 (9.04%)	0.002
Platelet, g/L	220.81 ± 64.77	227.70 ± 61.38	226.04 ± 62.25	0.154
Serum urea nitrogen, mg/dL	6.81 ± 2.35	5.92 ± 2.08	6.13 ± 2.19	0.000
Serum uric acid	364.34 ± 99.34	334.76 ± 88.02	341.90 ± 91.71	0.000
Proteinuria	58 (26.48%)	137 (19.60%)	195 (21.50%)	0.047
Serum triglyceride, mmol/L	1.77 ± 1.22	1.91 ± 1.27	1.88 ± 1.26	0.127
Serum cholesterol, mmol/L	4.26 ± 1.13	4.31 ± 1.12	4.30 ± 1.12	0.581
Preoperative medication				
ACEI or ARB	65 (29.68%)	182 (26.45%)	247 (27.23%)	0.383
β-blockers	174 (79.45%)	540 (78.49%)	714 (78.72%)	0.850
Calcium channel blockers	30 (13.70%)	81 (11.77%)	111 (12.24%)	0.478
Diuretics	27 (12.33%)	90 (13.08%)	117 (12.90%)	0.818
Statins	196 (89.50%)	574 (83.43%)	770 (84.90%)	0.030
Aspirin	174 (79.45%)	520 (75.58%)	694 (76.51%)	0.272

ACEI: angiotensin-converting enzyme inhibitors; AKI: acute kidney injury; ARB: angiotensin receptor blocker; BMI: Body mass index; eGFR: estimated glomerular filtration rate; LVEF: left ventricular ejection fraction; MI: myocardial infarction; NYHA: New York Heart Association.

Table 2 Univariate analysis of intra-opertative and post-operative risk factors for the development of AKI in derivation cohort.

Clinical variables	AKI (*n* = 219)	Non-AKI (*n* = 688)	Global cohort (*n* = 907)	*P*-value
Intraoperative				
Operation time, min	234.02 ± 60.30	228.25 ± 65.52	229.64 ± 64.31	0.248
Cardiopulmonary bypass	40 (18.26%)	114 (16.57%)	154 (16.98%)	0.605
Emergency surgery	5 (2.28%)	21 (3.05 %)	26 (2.87%)	0.649
Graft number	2.96 ± 0.87	3.10 ± 0.79	3.07 ± 0.81	0.033
Postoperative				
Intubation time, min	36.98 ± 21.65	22.44 ± 17.51	25.95 ± 19.66	0.000
Intubation time > 24 h	74 (33.79%)	132 (19.109%)	206 (22.71%)	0.000
Length of ICU stay, h	53.65 ± 49.90	38.22 ± 26.37	42.17 ± 34.18	0.000
Use of IABP	55 (25.11%)	62 (9.01%)	117 (12.90%)	0.000
Use of ECMO	7 (3.20%)	1 (0.15%)	8 (0.88%)	0.000
RBC transfusion	53 (24.20%)	71 (10.32%)	124 (14.00%)	0.000
Dopamine	217 (99.08%)	683 (99.27%)	900 (99.23%)	0.635
Adrenaline	114 (52.05%)	190 (27.61%)	304 (33.51%)	0.000
Norepinephrine	105 (47.94%)	289 (41.34%)	391 (43.11%)	0.137
Pituitrin	32 (14.61%)	38 (5.52%)	70 (7.72%)	0.000
LCOS	20 (9.13%)	24 (3.49%)	97 (4.85%)	0.002
Pneumonia	23 (10.50%)	43 (6.25%)	66 (7.28%)	0.051
Reoperation for bleeding	17 (7.76%)	5 (0.73%)	22 (2.43%)	0.000
Stroke	2 (0.91%)	0 (0%)	2 (0.22%)	0.058
Postoperative AF	26 (11.87%)	46 (6.69%)	72 (7.94%)	0.021
Serious infection	13 (5.94%)	6 (0.87%)	19 (2.09%)	0.000
In-hospital mortality	10 (4.57%)	0 (0%)	10 (1.10%)	0.000

AF: atrial fibrillation; AKI: acute kidney injury; ICU: intensive care unit; IABP: intra-aortic balloon pump; ECMO: extracorporeal membrane oxygenation; RBC: red blood cell; LCOS: low cardiac output syndrome.

Table 3 Multivariate analysis of risk factors associated with AKI after CABG.

Risk factors	β-coefficient	OR	95%CI	*P*-value
Preoperative				
Age ≥ 70 yrs	0.524	1.688	1.092−2.610	0.019
BMI ≥ 25 kg/m^2	0.431	1.539	1.077−2.197	0.018
eGFR ≤ 60 mL/min per 1.73 m^2	0.776	2.173	1.190−3.966	0.012
EF ≤ 45%	0.673	1.961	1.011−3.803	0.046
Statins	0.593	1.809	1.046−3.129	0.034
Intraoperative				
Adrenaline	0.634	1.885	1.273−2.789	0.002
RBC transfusion	0.514	1.671	1.035−2.700	0.036
Postoperative				
Use of IABP	0.695	2.003	1.206−3.327	0.007
LCOS	1.037	2.820	1.775−4.481	0.000
Reoperation for bleeding	1.513	4.538	1.311−15.710	0.017

AKI: acute kidney injury; BMI: body mass index; CABG: coronary artery bypass grafting; EF: ejection fractions; eGFR: estimated glomerular filtration rate; IABP: intra-aortic balloon pump; LCOS: low cardiac output syndrome; RBC: red blood cell.

Table 4 Factor scoring for predicting of AKI development.

Risk factors	Points
Preoperative	
Age, yrs	
≤ 40	0
40–49	1
50–59	2
60–69	3
70–79	4
≥ 80	5
BMI ≥ 25 kg/m^2	2
eGFR ≤ 60 mL/min per 1.73 m^2	2
LVEF ≤ 45%	3
Intraoperative and postoperative	
Statins	2
Adrenaline	3
RBC transfusion	2
Use of IABP	3
LCOS	4
Reoperation for bleeding	6

AKI: acute kidney injury; BMI: body mass index; eGFR: estimated glomerular filtration rate; IABP: intra-aortic balloon pump; LVEF: Intensive care unit; RBC: red blood cell; LCOS: low cardiac output syndrome.

um of 0 to a maximum of 32 points with three risk categories. The AKI frequencies were as follows: 0–8 points (15.9%), 9–17 points (36.5%) and ≥ 18 points (90.4%). Table 5 illustrated the frequency of AKI at each score level in the generation cohort. The AKI frequencies in the validation cohort were as follows: 0–8 points (13.0%), 9–17 points (34.9%) and ≥18 points (90%), which was similar to the generation cohort.

Score Validation

The area under the ROC curve (AUC) for the generation cohort was 0.730 (95% CI: 0.691–0.768) (Figure 1), which was similar to that for the validation cohort (0.735; 95% CI: 0.655–0.815). The Hosmer–Lemeshow goodness-of-fit statistic P-value was 0.807 for the generation cohort and 0.372 for the validation cohort.

Table 5 AKI risk according to risk categories.

Points	AKI	Total	AKI categories (%)
0–8	95	598	15.9
9–17	105	288	36.5
≥ 18	18	21	90.4

AKI: acute kidney injury.

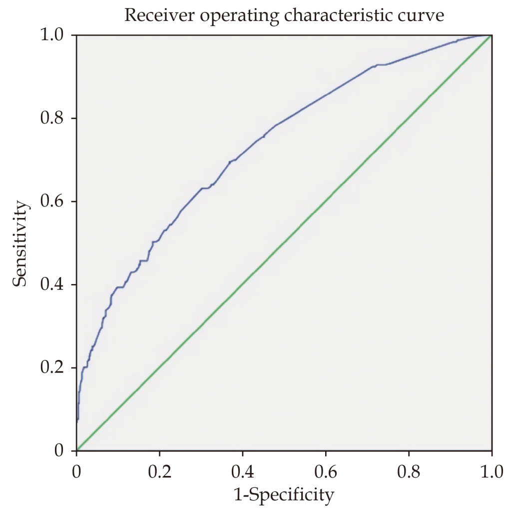

Figure 1 Receiver operating characteristic curve for the generation cohort.

DISCUSSION

The incidence of CSA-AKI is a major cause of acute kidney injury, and the occurrence of CSA-AKI is closely related to poor prognosis such as long-term death and end-stage renal failure.[3,5,6] CABG is an effective treatment for coronary heart disease, and greatly improves the quality of life and prognosis of patients.[10] The incidence of AKI post-CABG surgery in our study was 24.17%, which was consistent with the literature reports ranging from 5% to 52.7%.[1,11] Only 0.53% of patients needed dialysis, possible because the preoperative cardiac function and various biochemical indicators were generally normal in the study population, there were fewer emergency operations, less ventilator support time of after surgery, and most operations were performed without CPB.

Brown, *et al.*,[9] reported that age, sex, white blood cell count > 12,000, prior CABG, congestive heart failure, peripheral vascular disease, diabetes, hypertension, and preoperative IABP were independent risk factors for postoperative AKI. Kristovic, *et al.*[12] revealed that older age, atrial fibrillation, NYHA class III or IV heart failure, previous cardiac surgery, higher preoperative SCr and endocarditis increased the incidence of AKI. Palomba *et al.*,[3] identified age > 60 years, diabetes requiring insulin, eGFR < 60 mL/min per 1.73m^2, LVEF < 40%, CPB time > 140 min, and aortic cross clamp time > 100 min as for CSA-AKI. In our study, we identified ten risk factors namely, age ≥ 70 years, body mass index (BMI) ≥ 25 kg/m^2, eGFR ≤ 60 mL/min per 1.73 m^2, LVEF ≤ 45%, use of statins before operation, RBC transfusion, use of adrenaline, IABP implantation, postoperative LCOS, and reoperation for bleeding, and most of these predictors were reported in previous research.

The majority of patients undergoing CABG surgery were middle-aged or elderly patients. According to a report from the UK's Fifth National Heart Surgery Database, before 2003, the average mortality of cardiac surgery increased by 5.7% and the proportion of patients aged > 75 years increased by 8%.[13] At present, some studies have shown that advanced age is an independent risk factor for AKI after CABG.[14] The average age in this study was 62.43 ± 8.55 years, and 19.33% of patients were older than 70 years. Patients in the AKI group were older, suggesting that advanced age increased the risk of CSA-AKI. Sex was not an independent predictor for CSA-AKI in many previous researches, which was consistent with our study although the male patients accounted for more than 70% in the whole group.

Many studies have revealed that obesity is related to coronary heart disease, diabetes, stroke and other diseases, which would increase the mortality of patients and the incidence of complications after CABG.[15,16] Our study also suggested that high BMI was a predictor for AKI. However, there is still controversy about whether statins can reduce the risk of CAS-AKI. Liakopoulos, *et al.*,[17] found that the preoperative use of statins can reduce postoperative mortality, risk of atrial fibrillation and stroke, but cannot reduce the risk of myocardial infarction and AKI. Billings, *et al.*,[18] found that the incidence of AKI in patients who used statins early after surgery was lower than that of patients who stopped statins, which was similar to the results of our study suggesting that statins can reduce the occurrence of postoperative AKI.

Cardiac and kidney function in CAD patients might be mutually influenced, and decreased heart function before surgery might induce AKI. The use of CPB and LCOS after cardiac surgery can also cause renal insufficiency. Therefore, haemodynamic stability during the perioperative period was crucial to reduce the risk of AKI. IABP cannot induce AKI directly, and IABP is mostly used in patients with poor heart function before surgery or LCOS after surgery. It can reflect the inadequate perfusion of organs when LCOS occurs. Our study suggested that both the use of IABP and LCOS were independent risk factors for AKI. Red blood cells and plasma transfusion might increase the risk of AKI after cardiac surgery.[19] Red blood cells have poor oxygen-carrying capacity, and stored red blood cells are more easily deformed and may block smaller capillaries. Furthermore circulating free iron content easily increases AKI. Kaekouti, *et al.*,[20] suggested that the decision of preoperative blood transfusion to increase haematocrit should be very careful. Reoperation for bleeding accompanied by extensive RBC transfusion further increased the risk of CSA-AKI, but it was still an important choice for the patients with a high risk of bleeding.

CPB can produce series of inflammatory factors and cause tissue damage. Long-time support of CPB can increase haemolysis and the release of free haemoglobin, and damage the kidney function by releasing iron as an endogenous toxin. CPB was considered as the main risk factor for CSA-AKI, and OPCABG could reduce stroke and renal function injury,[21] but some studies found no significant difference in AKI between OPCABG and on-pump CABG surgery.[22] We found that the use of CPB did not apparently increase the risk of AKI, which might be related to the improvement in CPB technology and the small sample size of the on-pump group.

Decreased basic renal function might lead to CSA-AKI.[3] A high level of SCr increases the mortality of patients, and the more serious the degree of AKI is, the higher the mortality.[23] Even if, the renal function is slightly impaired, the risk of adverse events increases significantly.[2] Coca, *et al.*,[24] found that accompanied by increases in creatinine of 10%–24%, 25%–49% and ≥ 50%, and the corresponding 30-day postoperative mortality risks (RRs) was 1.8, 3.0 and 6.9, respectively. According to the KDIGO standard of AKI, we could further assess the severity and prognosis of AKI accurately. Most studies have shown that eGFR < 60 mL/min per 1.73 m^2 was the threshold for predicting postoperative adverse events.[25] In our study, the in-hospital mortality rates for non-AKI, and AKI stages 1, 2, and 3 were 0, 2.4%, 10.0% and 22.2%, respectively. A preoperative eGFR < 60 mL/min per 1.73 m^2 significantly increased the incidence of CSA-AKI compared with non-AKI patients by 1.12-fold. In addition, AKI imposed heavy medical and economic burdens.[26] The overall hospitalization cost of the AKI group was much higher than that of the non-AKI group (10 678 ± 643 vs. 4 748 ± 162 $). Therefore, active prevention of the occurrence of AKI not only improves prognosis, but also reduces medical costs.

The mortality of AKI-D patients was 35%–85%, which was 10–50 fold higher than that of non-AKI patients,[4,6] and in our study it was 50%. All the 15 deaths were combined with AKI. Although AKI did not cause death directly, different degrees of renal impairment could indicate the existence of other organ dysfunction. For AKI patients without insufficient volume or LCOS, if the response to diuretics was poor, the early use of bedside CRRT might reduce postoperative mortality or other complications.[27] Additionally, AKI after surgery might also affect the long-term prognosis and reduce the long-term survival rate of patients.[2] The United States, Canada, Singapore, Brazil and other countries have already developed warning systems for AKI scores after cardiac surgery,[3,5,6] and in China the risk factors of CSA-AKI have been analyzed.[28] However, few predictive scores have focus on CABG patients and most studies have paid more attention to preoperative risk characteristics.[5,29] This study therefore established a predictive scoring system that was suitable for Chinese adult CABG patients and included both preoperative and perioperative risk factors, which were helpful for assessing patient prognosis.

Limitation

There are also some limitations that should be mentioned. First, our study was retrospective and the data collection was dependent on medical records. Second, the sample size was limited and all included patients were from the same hospital, so the efficiency of this model should be prospectively validated by other centers or regional registries. Third, our study investigated only short-term outcomes during hospitalization, and the long-term prognosis needs to be observed.

Conclusions

The pathogenesis of CSA-AKI is complicated and it is still difficult to predict the risk factors of AKI precisely. The present study is attempted to create a scoring system to predict AKI after CABG in an Asian population. Only when clinicians accurately discover potential predictors for AKI in time and intervene as soon as possible, can they minimize the occurrence of AKI after cardiac surgery.

Ethics Approval and Consent to Participate

The study was approved by the Institutional Review Board and Ethics Committee of Beijing Anzhen Hospital(2010043X) and informed consent was taken from all individual participants.The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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COMPETING INTERESTS

None

AUTHORS CONTRIBUTIONS

Ran DONG and Yang LI were responsible for the design, supervision of the study, and revision of the manuscript. Yang LI drafted the manuscript. Zhu-Hui HUANG and Xue-Jian HOU designed a statistical plan. Shi-Jun XU and Tao-Shuai LIU participated in the revision of the manuscript and the coordination of the study. Xiao-Yu Xu and Peng-Yun YAN participated in data acquisition. All authors read and agreed to the final manuscript.

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