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Cardiac Surgery Associated Acute Kidney Injury, Incidence, and Predictors. Prospective Observational Single Center Study

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Abstract

Acute kidney injury (AKI) is a condition characterized by a sudden decline in kidney function, leading to accumulation of waste products and fluids in the body. It is a common and serious complication in patients with cardiovascular diseases, and it is associated with increased morbidity and mortality.

Aim: In this study, we explore the relationship between cardiac issues and the development of AKI, as well as strategies for its prevention and management. The primary aim of this study is to examine the incidence and risk factors for the AKI in patients admitted to the cardiac intensive care unit/CICU), as well as the impact of AKI on patient outcomes.

Methods: We conducted prospective observational single center study. 292 consecutive patients admitted to ICU after open heart surgery by sternotomy were included. Patients were monitored in ICU for frequency of AKI, perioperative risk factors, cardiac surgery-associated acute kidney injury (CSA-AKI) and their impact on patients' outcome.

Results: After admission to the intensive care unit, 33 patients (11.3%) developed CSA-AKI in the postoperative period. According to the analysis, male gender (p=0.03), decreased GFR (p=0.02) as well as high EuroSCORE II (p=0.013), hemoglobin level before surgery (p = 0.002) and the presence of diabetes and chronic kidney disease (p=0.03) were independent predictors of AKI after open-heart surgery. In patients who developed AKI, the duration of artificial lung ventilation was increased (21.3 vs 9.9 hours p = 0.001) and the duration of stay in the intensive care unit (4.3 vs. 1.9 days, P = 0.02).

Conclusion: Patients often have AKI after heart surgery. EuroSCORE II, gender, diabetes, time of cardiopulmonary bypass and chronic kidney disease are independent predictors of AKI development. The appearance of AKI is due to an unfavorable outcome of events. The appearance of acute kidney injury is associated with adverse consequences.

Keywords: acute kidney injury, cardiac surgery, predictors of AKI, postoperative period, complications.

Introduction

Kidney injuries that occur following heart surgeries are referred as cardiac surgery associated acute kidney injuries (CSA-AKI) [1]. AKI is a frequent sequela after heart surgery, with the incidence reaching up to 30% and potentially serious negative consequences for a patient [2].

Understanding the risk factors and subsequent early CSA-AKI management is crucial for improving patient care and reducing the burden of this complication.

In this document, we will explore the etiology, clinical implications, diagnostic criteria, and management strategies for CSA-AKI. By gaining deeper understanding of this condition, healthcare providers can work towards implementing evidence-based practices to mitigate the risk and impact of CSA-AKI [3, 4].

CSA-AKI is a common complication among cardiac surgery patients, leading to longer ICU stays [5]. Despite advancements in surgical methodologies and perioperative care, postoperative incidence of AKI remains relatively high. CSA-AKI is a multifactorial condition that involves a complex interplay of patient comorbidities, perioperative factors, and postoperative management [6]. The etiology of AKI in this setting is often linked to the use of cardiopulmonary bypass, ischemia-reperfusion injury, and exposure to nephrotoxic agents [2]. Understanding these underlying mechanisms is paramount to develop effective preventive strategies and optimize patient care. CSA-AKI slows down cardiac surgery patients' recovery in up to 30% of cases [7].

In addition to the immediate clinical implications, CSA-AKI is linked to increased probability of occurrence of chronic kidney disease (CKD), cardiovascular events, and mortality. Addressing the diagnostic challenges and implementing timely management interventions is essential to minimize the impact of AKI on patient morbidity and mortality [3, 8]. Therefore, it is crucial for healthcare providers to have a comprehensive understanding of the risk factors, pathophysiology, diagnostic criteria, and management strategies for cardiac surgery patients [9].

Current work targets to study the prevalence of CSA-AKI in the immediate setting and to assess the perioperative risk factors for CSA-AKI after heart surgery and their association with subsequent morbidities and mortalities.

Material and methods

During a prospective observational study, data was gathered from patients in the ICU department at the National Research Cardiac Surgery Center from October 2023 to January 2024. All included patients received treatment based on the standard of care protocol. Consent for conducting the study was received from the local bioethics panel of NRCSC (N 01-74/2021 dated 10/06/20).

ICU patients older than 18 years who have undergone open heart surgery and were diagnosed with AKI in the postoperative period (within 48 hours, according to "Kidney disease: Improving global outcomes" criteria) were included in the investigation. The participants with the previously present end-stage renal failure undergoing dialysis were excluded from the study.

All consecutive patients who were admitted to the ICU after undergoing open heart surgery via sternotomy were enrolled in the investigation. The patients were followed to define the incidence of AKI, possible postoperative risks for CSA-AKI, as well as their impact on outcomes in the ICU.

Demographic data and the initial clinical preoperative parameters of the patients are shown in Table 1. CKD was determined based on the presence of an estimated glomerular filtration rate (eGFR) lower than 60 ml/min/1.73 m^2 as calculated using the CKD-EPI formulation.

The study observed the length of mechanical ventilation, the length of stay in the ICU, frailty, delirium, re-intubation, dialysis, and ICU mortality. The initial outcome was to estimate the incidence of CSA-AKI. Secondary objectives included

Table 1 Demographic data and the initial clinical preoperative parameters of the patients

Total population (%)	N(%)	AKI	No AKI	P value
	292	33(11.3%)	259 (88.7%)	
Baseline pre-operative characteristics				
Gender, female	90 (30.82)	10 (30.3%)	80 (30.9)	0.54
Gender, male	202 (69.2)	23 (69.7%)	179 (69.1)	0.03
Age (year)	62.8 (22-79)	69 (31–74)	65.1 (21–79)	0.57
BMI (kg/m2)	26.7 (23.1 32.6)	27.64 (25.6-30.5)	27.68 (22.5-30.7)	0.62
EuroScore II (%)	1.7 (1.09-2.9)	2.54 (1.52–4.4)	1.5 (0.94–2.4)	0.03
Hb (gr/dL)	13.9 (9.6-15)	11.4 (7.6–12.3)	12.2 (9.5–14.0)	0.23
WBC (×103/µL)	10.3(7.9-13.1)	11.4 (8.9–13.7)	10.5 (7.5–12.8)	0.63
Creatinine (mg/dL)	1.03 (0.8-1.4)	1.19 (0.9–1.4)	0.9 (0.8–1.1)	0.12
eGFR (mL/min/1.73 m2)	79.1 (60.2-89.9)	59.3 (52.3-84.2)	81.3 (63.1-90.8)	0.02
concomitant diseases				
hypertension	165(65.5)	27(16.36)	138(83.64)	0.04
CKD	50 (17.12)	22 (44%)	28 (56%)	0.04
diabetes type II	155(53.1)	23(14.83)	132(85.16)	0.03
ischemic Stroke	26(8.9)	12(46.15)	14(53.85)	0.27
Intraoperative characteristics				
Duration of CPB (min)	123 (80-184)	137 (112–184)	101 (80–132)	0.01
Aortic cross-clamp time (min)	81 (56-125)	93 (59–125)	69 (56–104)	0.02
Structure of surgeries				
CABG	167	7	160	0.63
Heart valve repair	**82**	**13**	**69**	**0.67**
Aortic valve replacement	20	5	15	0.74
Mitral valve replacement	18	2	16	0.21
Tricuspid valve replacement	17	2	15	0.3
Mixed valve replacement	27	4	23	0.07
LVAD	14	4	10	0.12
Bentall de Bono	15	3	12	0.63
Aortic arch debranshing	3	2	1	0.55
Supracoronary aortic arch replacement	8	2	6	0.17
Heart transplant	3	2	1	
Post-operative characteristics				
Duration of mechanical ventilation (hours)	12.5±3.5	21.3±6.43	9.9±5.15	0.001
LOS ICU days	2.69±3.15	4.3 ±3.6	1.9 ±2.9	0.02
Re-intubation, n (%)	11	9.00	2	0.027
Fluid balance 24 h post-surgery (mL)	712±154	1563±582	312± 205	0.001
VIS max	5.14±3.12	16.27±3.9	6.6±3.1	0.022
Mortality rate	14 (4.79%)	8 (57.15%)	6 (42.85%)	

AKI: Acute kidney injury; BMI: Body mass index, Hb: Hemoglobin, WBC: White blood cells; sCr: Serum creatinine, HTN: Hypertension; CKD: Chronic kidney disease defined as eGFR ≤ 60 mL/min/173m2; PAD: Peripheral artery disease; CPB: Cardiopulmonary bypass, ICU: Intensive care unit. VIS – vasopressor inotropic score. All continuous variables are presented as median (interquartile range) and categorical variables as absolute values (%). Statistical significance was set at P value less than 0.05.

guidelines, Table 2. and The Cleveland Clinic Scale is best suited for the diagnosis of CK-AKI requiring dialysis (Table 3). Baseline serum creatinine was measured 72 hours before surgery and monitored for 48 hours in the ICU after surgery.

Statistics

Data analysis involved using IBM SPSS Statistics version 26 software and R statistical software. Data following gaussian pattern of distribution was interpreted as means and their standard deviations, while non-normal data was summarized using medians and interquartile ranges. Categorical variables were represented as absolute and relative frequencies. The methods used for data analysis included univariate and multiple logistic regression models to determine the association between AKI development and risk factors.

Table 2 Serum creatinine level and urine output

Stage	Serum creatinine level	Urine output
1	Increase of ≥0.3 mg/dl (≥26.5 μmol/l) within 48 h or increase of 1.5–1.9-fold over baseline within 7 days	< 0.5 ml/kg/h for 6 to 12 h
2	Increase of 2.0–2.9-fold over baseline	< 0.5 ml/kg/h for 12 h
3	Increase of 3.0-fold over baseline, increase of ≥4.0 mg/dl (≥353.6 μmol/l), initiation of renal replacement therapy, or a GFR decrease < 35 ml/min/ 1.73 m^2 for patients < 18	< 0.3 ml/kg/h for 24 h or anuria for 12 h

KDIGO: Kidney Disease Improving Global Outcomes; AKI: acute kidney injury; GFR: glomerular filtration rate.

Table 3 Risk factors assessment

Risk factor	Score
Female Sex	1
Chronic heart failure	1
LVEF< 35%	1
Preoperative use of an intra-aortic balloon counterpulsor	2
COPD	1
Diabetes type1	1
heart surgery in anamnesis	1
Emergency intervention	2
Isolated valve surgery	1
CABG+valve surgery	2
Another cardiac surgery	2
Creatinin level before surgery less than 106 mcmol/l	2
Creatinine level before surgery more than 186 mcmol/l	5

assessing perioperative AKI risk factors and their association with clinical outcomes.

In our work, we analyzed the frequency of AKI occurrence and identified risk factors associated with open heart surgery that could impact ICU management and outcomes. Our findings revealed that AKI is a frequent consequence following cardiac surgery. The EuroSCORE II score, presence of type 2 diabetes, prior CKD, and leukocyte level in blood samples were independent parameters for AKI occurrence. AKI was linked to adverse sequences including length of mechanical ventilation, LOS, frequency of hemodialysis, re-intubation, delirium, and mortality.

CSA-AKI diagnosis was performed in accordance with the "Kidney disease: Improving global outcomes" (KDIGO)

Results

Clinical characteristics

Our study involved 292 patients, with a higher proportion being male (66.4%). According to KDIGO, 12.25% of the patients developed postoperative AKI. The demographic and clinical perioperative data for all patients are presented in Table 1. We performed various types of open-heart surgeries during the study, including heart transplants. Patients who acquired AKI were generally older and had a higher incidence of CKD, elevated values of EuroSCORE II. They also exhibited lower diastolic and mean blood pressure, along with an increased need for vasopressors and inotropes upon admission to the ICU compared to patients without AKI. Additionally, the patients with AKI had longer extracorporeal circulation and cross-clamping times during surgery, as well as an extended duration of general anesthesia and sedatives in the ICU, compared to patients without AKI.

The study revealed that certain parameters were linked to the development of CSA-AKI. These risk factors comprised a high EuroSCORE II value and a history of CKD.

The statistical analysis identified several significant predictors of AKI in the preoperative period. This included gender, with a male prevalence of 69.7% (p value = 0.03), a high EuroSCORE II value (95% CI: 2.54 vs 1.5, p = 0.003), GFR levels before surgery (95% CI: 59.1 vs 81.3, p = 0.02) and a history of CKD with an incidence rate of 66 % (p = 0.04) before surgery. Additionally, non-compensated arterial hypertension (p = 0.04) and type II diabetes were found to be independent predictive parameters for AKI.

The multifactorial analysis identified as well intraoperative parameters that may predict CSA-AKI, such as the duration of cardiopulmonary bypass (CPB) time (137 vs 101 minutes; p=0.01) and cross-clamp time (93 vs 69 minutes; p = 0.02).

AKI also has a negative impact on postoperative recovery in the ICU. Patients with AKI experienced significantly longer LOS in the ICU compared to those without AKI (4.3 vs 1.9 days, p = 0.02). There were also higher incidents of reintubation among patients with AKI and a substantial fluid retention leading to more than 1500 ml over 24 hours in the ICU (p = 0.001). The use of vasopressors and inotropic drugs, particularly when VIS max score was above 16 on the first day, showed a prominent association with the occurrence of AKI and adverse clinical outcomes such as prolonged mechanical ventilation, dialysis needs, and increased mortality rates for these patients.

AKI following cardiac surgery is associated with several negative clinical outcomes. These include longer durations of mechanical ventilation and higher LOS in the ICU, repeated intubation, and the need for dialysis.

Discussion

In our study, we found an increased occurrence of AKI in patients who had heart surgery. Our major results revealed that the severity score of the preoperative assessment, CKD, and diabetes were independent parameters of AKI development. Additionally, CSA-AKI incidence was strongly linked to unfavorable outcomes. Patients who developed post-surgery AKI experienced longer mechanical ventilation and intensive care unit stays, higher rates of repeated intubation, dialysis requirement and mortality. These findings emphasize the importance of identifying high-risk patients and implementing strategies to prevent or mitigate the occurrence of AKI during postoperative period after cardiac procedure [2].

Current work results align with previous reports that have shown a moderate to high degree of AKI occurrence, as indicated by various definitions. Over time, numerous definitions were implemented to recognize and grade AKI disease. The criteria for classifying risk, injury, insufficiency, loss, and end-stage kidney disease were implemented in 2004; few years later there was a revision proposed by the Acute Kidney Injury Network group; finally, at the KDIGO workshop in 2012 a conjunction of RIFLE and AKIN suggestions were proposed.

The overall occurrence extent of AKI during postsurgical period comprised around 22.3%, determined applying RIFLE, AKIN or KDIGO definitions which shows similarity with our findings based on KDIGO criteria. Notably, studies using different criteria showed variations in the reported incidence rates - studies using KDIGO reported an incidence rate of 24.2%, while those using RIFLE or AKIN reported rates of approximately 18.9% and 28% respectively [10, 11].

Prolonged CPB duration, longer sedation therapy, and mechanical ventilation emerged as the primary intraoperative risk factors for CSA-AKI. Our study confirmed these associations through one-dimensional analysis but not with multivariate analysis. The mechanisms by which CPB launches AKI is comprehensive and not fully researched, including non-pulsating perfusion leading to renal ischemia [12], inflammation from CPB pump as well as the circuit resulting in free radicals assembly with consequent complement activation [13], as well as intravascular hemolysis causing damage to the renal tubules [14]. The link between extended CPB duration and the occurrence of CSA-AKI highlights the importance of optimizing intraoperative practices to reduce the incidence of this complication [2]. Optimizing intraoperative practices, such as minimizing CPB duration, sedation therapy, and mechanical ventilation, is crucial for reducing the risk of developing CSA-AKI in postoperative period.

Future works are required to fully decipher the pathophysiological scenario involved and to validate the potential biomarkers for routine use in different patient populations undergoing heart surgery [15].

In our work, we observed a tendency for an association between CSA-AKI and CPB length, as demonstrated by prior studies. A recent meta-analysis involving 2,157 patients during cardiac postoperative period, indicated that a higher CPB length is linked to a higher risk of developing CSA-AKI [16].

Conclusion

In conclusion, patients who have undergone open-heart surgery often experience postoperative CSA-AKI. EuroSCORE II, male gender, a history of diabetes, and CPB time are identified as independent risk factors for AKI occurrence in the postoperative period. Furthermore, the AKI incidence after surgery was found to be linked to the following negative outcomes such as extended mechanical ventilation, LOS, and higher rates of re-intubation.

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