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Role of Conventional Biomarkers versus Novel Biomarkers in Detecting Perioperative Acute Kidney Injury in Cardiac Surgery Patients

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ABSTRACT

Background: Acute kidney injury (AKI) following cardiac surgery with cardiopulmonary bypass (CPB) is relatively common and has serious implications for morbidity and mortality. This study aimed to compare the incidence, risk factors, and early detection of acute kidney injury in cardiac surgery patients involving CPB, using both conventional and novel biomarkers. **Patients and Methods:** A prospective, randomised, and clinical study was conducted after ethical approval and informed consent from sixty-four patients. Blood and urine samples were collected before and after anaesthesia. Serum creatinine (SCr), serum cystatin C (SCysC), and urine N-acetyl-β-D-glucosaminidase (uNAG) to indicate renal tubular damage were concurrently assayed. **Results:** The pre-to-post-op alterations between SCr (73.50 vs 72.50, p=0.166) and SCysC (51.69 vs 54.84, p=0.100) and the incidence of AKI by KDIGO and TRIBE were 9.4% and 18.8%, respectively. The statistically significant risk factors of postoperative AKI were high BMI, New York Heart Association (NYHA) Class > II, Left Ventricular Ejection Fraction (LVEF) < 35%, prolonged cardiopulmonary bypass time > 3 hrs, prolonged cross-clamp time, insulin-dependent diabetes, high baseline creatinine, and high Cleveland Risk Score. A binomial logistic regression was performed to ascertain the effects of the pre-op biochemical profile on the likelihood of AKI by SCr. The logistic regression model was statistically significant for SCysC. Increasing SCysC was associated with an increased likelihood of AKI by SCr. **Conclusions:** The incidences of acute kidney injury detected with SCysC were 18.8% compared to SCr of 9.4%, and a Kappa of 0.62 suggests moderate agreement between the SCr and SCysC AKI definitions. However, they could also result from non-renal influences on SCysC levels, such as inflammation due CPB or medication effects, highlighting both the strengths and limitations of this biomarker.

KEYWORDS: Acute kidney injury, Cardiac surgery, Serum creatinine, Serum cystatin C, Urine N-acetyl-β-D-glucosaminidase

INTRODUCTION

Acute kidney injury (AKI) is a recent nomenclature used for acute renal failure (ARF). In 1918, William McNider was the first to use the term AKI in the case of mercury poisoning. [1] However, in an acute dialysis quality initiative (ADQI) study, it became evident that AKI does not always progress to renal failure, as previously emphasised. Thus, AKI is indicative of the potential reversibility of an acute renal condition. [2] Perioperative AKI depicts a sudden and sustained decrease in baseline renal function during surgery or the instantaneous postoperative period. [3] This is associated with many perioperative events such as haemodynamic instability, cardiopulmonary bypass (CPB), mechanical ventilation, coagulopathy, transfusion-related injuries, anaemia, and sepsis. [4] The Society of Thoracic Surgeons defines AKI as a 3-fold increase in serum creatinine, creatinine more than 4 mg/dL, or initiation of dialysis after cardiac surgery. [5] Perioperative -AKI is also designated as surgery-associated AKI because it predominantly occurs among patients in surgical settings.

Hobson et al. reported that perioperative events remain the leading cause of AKI among hospitalised patients and vary between 18-47%. [6] Another meta-analysis observational study of cardiac surgery patients reported an AKI rate in coronary artery bypass graft (CABG) surgery (19.0%) compared to those who underwent valve surgery (27.5%). [7] The development of AKI is associated with worse

short- and long-term mortality and longer hospital length of stay. This was confirmed in a retrospective study of cardiac surgery patients that reported a mortality of 58.6% in patients requiring postoperative renal replacement therapy. [8]

Time-honoured kidney function tests are based on the increase in serum creatinine (SCr) and decrease in urine output (Uo) as validated by the Kidney Disease Improving Global Outcomes (KDIGO). [9] Cheruku et al. considered them insensitive pointers of acute changes in perioperative kidney function due to the obligatory delay between the onsets of AKI and its diagnosis. [10] Translational Research in Biomarker Endpoint (TRIBE) consortium, a multi-centre, prospective observational study focused on improving outcomes and safety in cardiac surgery by investigating novel biomarkers for the early detection of AKI. Nine North American sites participated in this study, both adults and children undergoing cardiac surgery were enrolled. Kidney injury biomarkers peaked earlier than serum creatinine and were associated with AKI in their population. [7, 10] Our study focused on the identification of novel biomarkers, serum cystatin C (SCysC), and urine N-acetyl- β-D- glucosaminidase (uNAG) and identified whether they rule out perioperative ARI earlier than traditional biomarkers SCr and Uo in this population.

SCysC is a 13-kDa non-glycosylated cysteine protease inhibitor constantly synthesised by all cells with a nucleus. It has evolved as an easily measurable filtration index of renal function in some clinical areas [11, 12], and unlike creatinine, it is less influenced by race, age, gender and muscle mass and also eliminated solely by glomerular filtration. Practically, cystatin C's half-life is one-third of SCr, enhancing its prompt passage in an equilibrated state compared to creatinine. [13]

uNAG is a lysosome-located enzyme in the proximal tubular epithelial cells, validated by some studies as a strong diagnostic index of AKI and an achingly sensitive pointer to renal tubular damage. [14] The primary benefits of utilising urinary uNAG relate to its ease of quantitation as well as the enhanced sensitivity. Increased concentration of renal directly correlates with the degree of tubular injury. [11]

Novel biomarkers can assist in detecting AKI as early as an hour after an injury. [11] These biomarkers indicate that their concentration in the operating theatre during surgery allows clinicians to identify patients at risk of developing clinically apparent postoperative AKI, predict outcomes, and tailor specific early therapies. Unfortunately, the literature is scarce regarding studies that have evaluated SCysC and uNAG compared to traditional markers in cardiac surgery involving CPB. Therefore, the present study provides clinical insights into the use of several novel biomarkers alongside conventional markers among patients undergoing elective cardiac surgery in which CPB was part of the surgical plan.

MATERIALS AND METHODS

Study Objective

The primary objective was to analyse the incidence of AKI associated with cardiac surgeries involving CPB in our patient population, using conventional and novel biomarkers. Secondary objectives were to identify the risk factors for AKI in this setting and to compare the time to AKI detection using conventional versus novel biomarkers.

Definitions and Clinical Outcomes

The primary outcome of interest was the incidence of AKI as detected by SCr and SCysC within 48 hours after cardiac surgeries involving CPB. The cumulative incidence of SCr and SCysC predicted post-surgical AKI was evaluated by the number of cases observed, denominated by the total number of AKI at-risk patients followed in 48 h x 100%. Recognition of SCr-detected AKI was based on the 2012 KDIGO consensus criteria as a relative increase in SCr level within 48h of renal insult evidenced by $\geq$50% or 0.3 mg/dL ($\geq$26.5 μmol/L) from the baseline. [9]

To predict SCysC AKI, the KDIGO practice guideline was used, employing a postoperative SCysC rise that is $\geq$25% from the preoperative baseline, as previously reported from the TRIBE study. [12, 13] The duration of kidney injury was adjusted from the period between the last normal SCr concentration to the first 48-hour postoperative period where the said elevations in the measured analytes were observed.

The intraoperative time to event of AKI was defined as the interval between the start of CPB and the occurrence of SCr and SCysC-detected AKI. [12] Furthermore, the presence of renal tubular cell injury was determined by a two-fold rise from baseline in the absolute concentrations of urine N-acetyl- β-D- glucosaminidase (uNAG), as previously reported by clinical chemistry and laboratory medicine. [14]

Study Objective

The primary objective was to study the incidence of AKI associated with cardiac surgeries involving CPB in this study population. Secondary objectives were to describe the risk factors of AKI with renal tubular damage and the time to an acute injury event using old and novel biomarkers.

Study Design

A prospective, randomised, and clinical study conducted between July 2023 and June 2024 in the Department of Anaesthesiology and Intensive Care after approval from the Ethical Clearance Committee on Human Research (Number: CAU/274/j/2023) SAMSRI, Lucknow, as per the Helsinki declaration and revised guidelines of 2013. Informed consent was obtained from sixty-four patients.

Inclusion Criteria for the study were the American Society of Anaesthesiologists (ASA) physical status (PS) III and IV male and female adults between 18-60 years scheduled for cardiac surgery under GA. Patients in whom cardiopulmonary bypass (CPB) was part of the surgical plan were approached for consent. Exclusion criteria were cardiac surgery in those below 18 or above 60 years, preoperative deranged kidney function or disease requiring dialysis, preoperative period requiring extracorporeal membrane oxygenation (ECMO), or patient refusal. For patients with multiple surgeries in a single hospitalisation, analyses were restricted to the first surgery.

Demographic data and baseline variables were recorded as well as risk factors used to calculate the Cleveland Risk Score (CRS) tool. [15] This included gender, type of surgery, heart failure (congestive heart failure symptoms defined as New York Heart Association class (NYHA) > II [16], left ventricular ejection fraction (LVEF < 35%), chronic obstructive pulmonary disease (COPD) on treatment, previous cardiac surgery, preoperative intra-aortic balloon pump requirement, insulin-dependent diabetes, and baseline serum creatinine concentration. [15] Baseline estimated glomerular filtration rate (via the Chronic Kidney Disease Epidemiology Collaboration equation) and Euro-score were also calculated. [15, 17] The eGFR was determined from the most recent preoperative SCr with a modified Cockcroft- Gault (C-G BSA) formula adjusted for the body surface area (1.73 m^2x GFR-Cockcroft- Gault); where the GFR -Cockcroft-Gault is in ml/min, and the body surface area is calculated in meters squared using the Dubois-Dubois equation. The Larsson formula for SCysC-based GFR was also used. Larsson formula: eGFR = 77.24 X cystatin C (mg/l)-1.2623. [18]

Biochemical Parameters

Blood (5 ml) and fresh urine samples (15 ml) were obtained at baseline (immediately following urinary catheter placement), on CPB (every 30 minutes), post-CPB period (immediately after off-CPB at the end of surgery) and then when the patients were transferred to the CCU at 4, 12, 24, and 48 hours after the surgery. Samples were subdivided into 2 ml aliquots and frozen for later analysis.

Determination of Sample Size

Variability in the study population and settings added to the AKI reporting patterns accounts for an estimated AKI prevalence of <1% to 66%. [6–8] A pilot study determined an AKI prevalence of 15% in our institution. Required sample size (n) = z^2pq/d^2, where z = z score corresponding to the 95% significance level, p = the estimated proportion = 1 minus p (as referenced in the previous study), and d = the tolerated margin of error. Therefore, z=1.96, p=0.15, q= (1-0.15), d=0.1. Substituting these values into the above equation: n = (1.96) ^{2}(0.15) (1 -0.15)/ $(0.1)^2$ = 48.98 Considering a 30% dropout rate = 30/100 $\times$ (48.98) = 14.69.

The required sample size (n'): [estimated: 48.98 + (dropout: 14.69)] = [63.67] = 64.

Determination of the Sampling Technique

The sampling technique was a simple random sampling technique to give each eligible participant an equal chance of enrolment. 64 participants who met the eligibility criteria were identified each weekday from the registry of the theatre manager's surgical caseloads, and patients were randomly selected using a computer-generated program till the sample size of 64 was reached.

Conduction of Anaesthesia

A. Pre-anaesthetic assessment and sample collection: On arrival at the preoperative holding unit, confirmation of the patient and proposed surgical procedure was done. Data collected included age, gender, and weight. The body mass index (BMI) of each patient was computed as BMI= weight (kg) / height (m^2). A BMI $\geq$30 kg/ m^2 was considered obese. As part of the routine pre-anaesthetic evaluation at the pre-operative area, baseline parameters such as non-invasive blood pressure (NIBP), mean arterial pressure (MAP), electrocardiogram (ECG), pulse oximetry-SpO_2, and pulse were recorded. An ultrasound machine recorded the inferior vena cava (IVC) diameter to calculate the vena cava collapsibility index to assess the hydration status of patients without invasive procedures and increasing patient management costs in a low-resource setting. The duration of preoperative fasting, indication for surgery, and the proposed surgical procedure were recorded. A 15 ml volume of voided urine specimen was collected in an appropriately labelled urine specimen container. A 16-G intravenous cannula was inserted in the right hand on the dorsum to collect five millilitres (5 ml) of a venous blood sample into plain sample glass tubes. Samples collected were immediately sent to the research laboratory. Dictated by the patient's hydration needs, an appropriate infusion was set up to run using the same venous line where a sample was collected.

B. Anaesthesia: Standard anaesthesia and surgery protocols were used as per the study protocol and hospital guidelines. For pre-medication tablet diazepam 10 mg (oral) was given on the night prior to surgery, and 5 mg in the morning prior to anaesthesia was administered. After arrival at the operation theatre (OT), monitoring of the electrocardiogram (3 leads) with automated ST segment analysis, non-invasive blood pressure, and pulse oximetry equipment was applied. General anaesthesia was induced while the patient breathed 100% O_2 by facemask, using a combination of fentanyl 2 mcg/kg, midazolam 100 mcg/kg, and a sleep dose of propofol (1–2 mg/kg). Endotracheal intubation was performed after administration of pancuronium bromide at a dose of 0.15 mg/kg, and mechanical ventilation to achieve normocarbia with end-tidal carbon dioxide ($EtCO_2$) monitoring was initiated. General anaesthesia was maintained with sevoflu-

rane using a low-flow technique (fresh gas flow of 1.5 L/min) using a circle system delivered by an anaesthesia machine. Fentanyl and pancuronium were repeated as per requirements. An 18-G, 9-cm intra-arterial cannula was introduced into the right femoral artery for monitoring the arterial pressure and obtaining arterial blood for analysis. In the right internal jugular vein, a central venous catheter triple lumen 7frx 20 cm was inserted. The temperature was recorded using a nasopharyngeal probe. All the patients were subject to mild hypothermia (32–35 °C). Blood pressure, heart rate, $EtCO_2$, end-tidal anaesthetic concentration (ETAC), arterial oxygen saturation, and temperature were recorded as per study protocols. Haemodynamic changes within the range of $\pm$20% of initial values were controlled using appropriate anaesthetic practice. At the end of the surgery, normothermia was maintained with a warming blanket, and warm airflow at 35–37 °C (Bair Hugger system) was used. After completion of the procedure, the patients were extubated as soon as the criteria were met in the cardiac care unit (CCU). Haemodynamic parameters, awakening conditions, and drug usage were recorded. Blood and fresh urine samples were obtained as per study protocol.

C. Postoperative Period: Monitoring vital signs as part of the general anaesthetic emergence standard operating protocol (SOP) in the immediate postoperative period was ensured and recorded until patients were transferred out of the post-anaesthesia care unit to their respective surgical wards. Blood and urine were sampled as per the study protocol. In addition, patients were monitored for any complications or dialysis needed within 48 hours after surgery.

Statistical Methods

Data were analysed using Statistical Package for Social Sciences (SPSS) 23.0; IBM, Armonk, NY. For continuous data, normality was checked using Shapiro-Wilk's test. Normally distributed data were presented as mean $\pm$ standard deviation (SD), percentage, and the significance of the difference of markers was evaluated between the presence and absence of AKI using paired t-tests. One-way repeated measures analysis of variance (repeated measures ANOVA) was used to test for the significance of differences between groups. Multiple comparisons were adjusted by using Bonferroni correction. Nonparametric data were presented as median (interquartile ranges) and the significance of differences of markers were evaluated using Wilcoxon signed rank tests with continuity correction. The level of agreement between the different AKI definitions using SCr and SCysC was evaluated using the Kappa-statistic. To determine potential factors associated with the presence of AKI, binomial logistic regression analysis was performed and a p-value < 0.05 was considered statistically significant.

RESULTS

In our study, 273 patients were assessed for the eligibility criteria, and 97 were found eligible for the study. The computer-generated program randomly selected 64 individuals for the study. There were no missing samples or attrition.

In our study, 12 (18.75%) patients developed AKI after surgery. There were no gross differences between the groups with and without AKI in terms of age, weight, gender, IVC diameter, Bubois BSA, CGBSA and Larsson eGFR. There was a statistically significant higher BMI in patients with AKI (p=0.008), as shown in Table 1.

Patients undergoing single valve (aortic) procedures had a lower incidence of AKI. New York Heart Association Class > II, low ejection fraction, prolonged cardiopulmonary bypass time, prolonged cross clamp time, insulin-dependent diabetes, baseline serum creatinine, and Cleveland Risk Score were all significantly associated with the development of AKI, as shown in Table 2.

The demographic and clinical characteristics potentially associated with AKI, based on SCysC, showed that female gender was associated with increased odds of AKI (OR = 1.71, 95% CI: 0.19–15.39, p = 0.632). Increasing age also showed elevated odds: 31–39 years (OR = 1.50, 95% CI: 0.19–12.15, p = 0.704); 40–49 years (OR = 3.60, 95% CI: 0.56–23.24, p = 0.178); 50–59 years (OR = 3.86, 95% CI: 0.53–28.24, p = 0.184); and >60 years (OR = 1.80, 95% CI: 0.13–24.16, p = 0.657). A general anaesthesia (GA) duration of $\geq$4 hours was associated with reduced odds of AKI (OR = 0.54, 95% CI: 0.14–2.79, p = 0.541), while intraoperative MAP $\geq$70 mmHg had an OR of 1.19 (95% CI: 0.23–6.31, p = 0.838), also statistically insignificant. Although variables such as female gender, age groups, obesity, fasting duration, intraoperative MAP, and GA duration were associated with changes in the odds of AKI, none reached statistical significance, as shown in $.

The demographic and clinical variables potentially associated with AKI based on SCr included increasing age 31–39 years: OR = 3.17, 95% CI (0.26–38.85), p = 0.367; 50–59 years: OR = 4.75, 95% CI (0.38–60.15), p = 0.229; >60 years: OR = 3.80, 95% CI (0.20–72.00), p = 0.374—and intraoperative MAP $\geq$70 mmHg (OR = 1.17, 95% CI (0.12–11.05), p = 0.891). Although these factors were associated with increased odds of AKI, the associations were not statistically significant, as shown in Table 3.

In Table 4, a Kappa of 0.62 indicates moderate agreement between the KDIGO (SCr-based) and TRIBE (SCysC-based) AKI definitions. The six SCysC only positive cases may reflect cystatin C's greater sensitivity to early or subclinical kidney injury.

Parameter	Study population (n=64)	No AKI(n=52) (mean ± SD)	AKI (n=12)	p-value
Age (yrs)	44.09 ± 13.46	42.83 ± 13.82	45.35 ± 12.94	0.627
Weight (kg)	71.92 ± 10.57	72.19 ± 10.41	71.64 ± 11.85	0.359
Height (cm)	156 ± 0.06	159 ± 0.07	152 ± 0.04	0.273
BMI (kg/m^2)	29.89 ± 3.89	28.52 ± 3.84	31.26 ± 3.95	0.008*
Gender (male : female) percentage %	8:56 (12.5% : 87.5%)	7:45 (13.46% : 86.54%)	1:11 (8.33% : 91.67%)	0.059
IVC diameter (mm)	20.83 ± 0.89	20.71 ± 0.82	20.94 ± 0.86	0.624
Bubois BSA	1.73 ± 0.15	1.74 ± 0.12	1.72 ± 0.11	0.827
CGBSA	114.56 ± 37.62	117.09 ± 36.42	112.03 ± 34.61	0.653
CGBasic	116.29 ± 32.58	118.63 ± 31.71	113.95 ± 32.48	0.495
Larsson eGFR	0.53 (0.41 - 0.62)	0.54 (0.43 - 0.57)	0.52 (0.41- 0.58)	0.538

Data are presented as means ± SD, ratio, and percentages. BSA- body surface area, CG- Cockcroft- Gault, cm-centimetre, DM- diabetes mellitus, GFR- glomerular filtration rate, IVC-inferior vena cava, kg- kilograms, mins- minutes, m-metre.

Table 1: Demographic and clinical characteristics of the study population

Type of Surgery	No AKI (n=52)	AKI (n=12)	P-value
Isolated CABG, n (%)	21 (40.38)	4 (33.32)	0.585
Single Valve, n (%)	15 (28.85)	1 (8.34)	0.043*
Single Valve + CABG, n (%)	7 (13.46)	3 (25)	0.316
More than 1 Valve, n (%)	5(9.62)	2 (16.67)	0.617
Other, n (%)	4(7.69)	2 (16.67)	0.752
Risk Factors/Comorbidities			
New York Heart Associate (NYHA) Class >II, n (%)	11 (21.15)	8 (66.67)	<0.001*
Left Ventricular Ejection Fraction (LVEF) <35%, n (%)	4 (7.69)	4 (33.34)	0.012*
Duration of CPB time in min	118 ± 41.47	193 ± 67.12	<0.017*
Duration of CC time in min	92 ± 35.29	113 ± 48.46	<0.021*
Pre-operative Intra-aortic Balloon Pump, n (%)	0 (0)	1 (8.33)	0.997
COPD, n (%)	8 (15.38)	1 (8.33)	0.251
Insulin Dependent Diabetes, n (%)	3 (5.76)	3 (25)	0.013*
Redo sternotomy, n (%)	14 (26.92)	2 (16.67)	0.289
Baseline Creatinine (mg/dl), mean ±SD	1.08 ± 0.41	1.28 ± 0.37	0.027*
Glomerular Filtration Rate ($ml/min/1.73m^2$), mean ± SD	74 ± 25	69 ± 21	0.219
Cleveland Risk Score, mean ± SD	3.6 ± 1.5	5.0 ± 1.4	0.001*
Euro-score (%), median (Interquartile range)	2.7 (1.4–5.9)	4.3 (3.2–8.6)	0.086

Comparisons were made using either a two-sample chi-square test or Fisher's exact test, as appropriate, for categorical variables and an independent samples t-test or Wilcoxon rank sum test as appropriate for continuous variables. CPB- cardiopulmonary bypass, CC- cross clamp, CABG = coronary artery bypass grafting; COPD = chronic obstructive pulmonary disease; SD = standard deviation.

Table 2: Type of surgeries and risk factors

Variables	AKI absent	AKI present	COR (95% CI)	
Sex SCysC				
Male: n (%)	7 (10.94)	1 (1.56)	1	
Female: n (%)	45 (70.32)	11 (17.18)	1.71 (0.19-15.39)	0.632
Age (yrs) SCysC				
<31: n (%)	18 (28.13)	2 (3.13)	1	
31-39: n (%)	12 (18.74)	2 (3.13)	1.50 (0.19-12.15)	0.704
40-49: n (%)	10 (15.63)	4 (6.25)	3.60 (0.56-23.24)	0.178
50-59: n (%)	7 (10.93)	3 (4.68)	3.86 (0.53-28.24)	0.184
≥60: n (%)	5 (7.82)	1 (1.56)	1.80 (0.13-24.16)	0.657
BMI SCysC				
Underweight: n (%)	2 (3.12)	0 (0.0)	na	
Normal: n (%)	13 (20.32)	2 (3.12)	1	
Overweight: n (%)	22 (34.38)	2 (3.12)	0.59 (0.07-4.71)	0.619
Obesity class 1: n (%)	11 (17.19)	7 (10.94)	4.14 (0.71-24.16)	0.115
Obesity class 2: n (%)	4 (6.25)	1 (1.56)	1.63 (0.12-22.98)	0.719
Fasting duration (hrs) SCysC				
≤8: n (%)	36 (56.26)	6 (9.37)	1	
>8: n (%)	16 (25)	6 (9.37)	2.25 (0.63-8.06)	0.213
Intra OP MAP SCysC				
<70: n (%)	10 (15.63)	2 (3.12)	1	
≥70: n (%)	42 (65.62)	10 (15.63)	1.19 (0.23-6.31)	0.838
Duration of GA SCysC				
<4 hr: n (%)	9 (14.06)	3 (4.68)	1	
≥4 hr: n (%)	43 (67.18)	9 (14.06)	0.54 (0.14-2.79)	0.541
Sex SCr				
Male: n (%)	8 (12.50)	0 (0.0)	na	na
Female: n (%)	50 (78.13)	6 (9.37)	1	
Age (yrs) SCr				
<31: n (%)	19 (29.68)	1 (1.56)	1	
31-39: n (%)	12 (18.75)	2 (3.13)	3.17 (0.26-38.85)	0.367
40-49: n (%)	14 (21.88)	0 (0.0)	na	na
50-59: n (%)	8 (12.50)	2 (3.13)	4.75 (0.38-60.15)	0.229
≥60: n (%)	5 (7.81)	1 (1.56)	3.80 (0.20-72.00)	0.374
BMI SCr				
Underweight: n (%)	2 (3.13)	0 (0.0)	na	na
Normal: n (%)	15 (23.44)	0 (0.0)	na	na
Overweight: n (%)	22 (34.37)	2 (3.13)	1	
Obesity class 1: n (%)	15 (23.44)	3 (4.68)	2.20 (0.33-14.79)	0.417
Obesity class 2: n (%)	4 (6.25)	1 (1.56)	2.75 (0.20-38.01)	0.450
Fasting duration (hrs) SCr				
≤8: n (%)	37 (57.81)	5 (7.81)	1	
>8: n (%)	21 (32.82)	1 (1.56)	0.35 (0.04-3.22)	0.356
Intra OP MAP SCr				
<70: n (%)	11 (17.19)	1 (1.56)	1	
≥70: n (%)	47 (73.44)	5 (7.81)	1.17 (0.12-11.05)	0.891
Duration of GA SCr				
<4 hr: n (%)	12 (18.75)	0 (0.0)	1	
≥4 hr: n (%)	46 (71.87)	6 (9.38)	na	na

Table 3: Demographic and clinical characteristics potentially associated with SCysC and SCr detected AKI

Data are presented as number (n), percentage (%) and crude odds ratio (COR). COR- crude odds ratio, CI- confidence interval, hr-hour, MAP- mean arterial pressure, GA- general anaesthesia.

Variables	TRIBE-(SCysC)-AKI Positive	TRIBE-(SCysC)-AKI Negative	Row Total
KDIGO- (SCr) AKI Positive	6	0	6
KDIGO- (SCr) AKI Negative	6	52	58
Column Total	12	52	64

*Observed agreement (Po): 0.906, Expected agreement (Pe): 0.754, Kappa (κ): 0.62, CI 95% for Kappa: (0.37 to 0.87)

Table 4: Contingency Table KDIGO (SCr) vs. TRIBE (SCysC)AKI

The pre-op to post-op alterations between SCr 73.50 (62.0-89.50) vs 72.50 (59.25-83.75), p=0.166 and SCysC 51.69 (47.50-62.90) vs 54.84 (51.70-61.82), p=0.100, which were statistically insignificant (Figure 1), the incidence of AKI by Creatinine and TRIBE Cystatin C were 9.4% and 18.8%, respectively. All patients with AKI by KDIGO were females whereas, for TRIBE, there were 11 (17.2%) and 1 (1.6%) females and males, respectively (Figure 2).

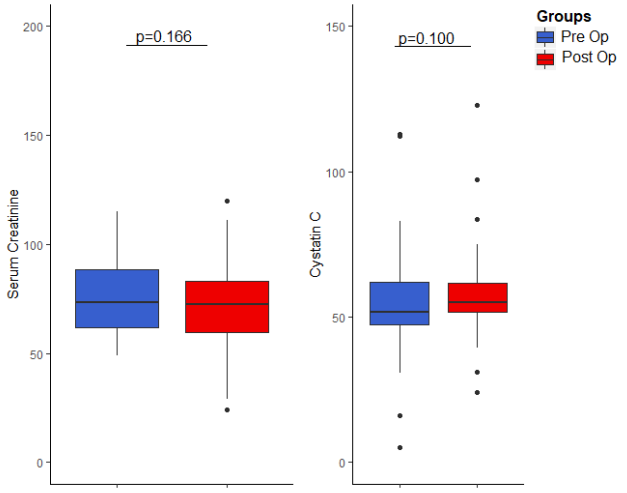

Figure 1: Comparison of serum creatinine and cystatin C between pre- and post-operation periods

As shown in Figure 3 a comparison of haemodynamic parameters between preoperative, intraoperative (after CPB), and immediate postoperative periods. The pre-op SBP was significantly higher compared to both intra-op SBP (134.60±18.63 vs 116.16±16.51 mmHg, p<0.0001) and post-op SBP (134.60±18.63 vs 120.24±15.31, p<0.0001). There was no statistically significant difference between intra-op and post-op SBP (p>0.05). Similar observations were made for diastolic blood pressure (DBP) and had similar results. The pre-op mean arterial pressure (MAP) was significantly higher compared to both intra-op MAP

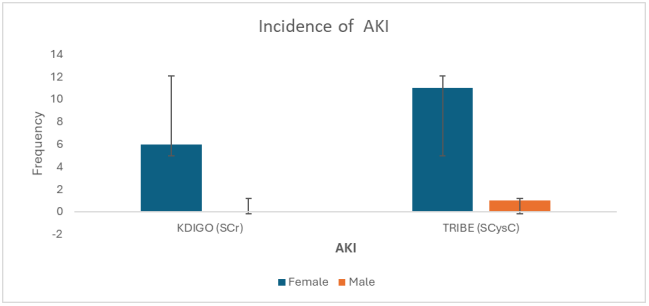

Figure 2: Incidence of serum creatinine (SCr) and serum cystatin C (SCysC) AKI

(98.04±6.83 vs 80.64±4.76 mmHg, p<0.0001) and post-op MAP (98.04±6.83 vs 93.12±5.62, p<0.0001) (Figure 3).

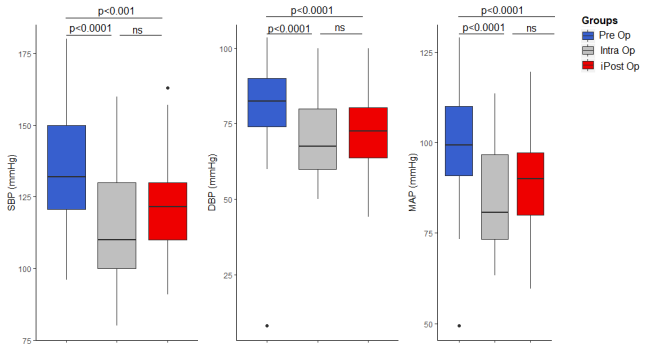

Figure 3: Comparison of haemodynamic parameters between preoperative, intraoperative after CPB and immediate postoperative periods

A binomial logistic regression was performed to ascertain the effects of the pre-op biochemical profile on the likelihood of AKI by SCysC. The logistic regression model was statistically significant for serum sodium levels; the model explained 11.9% of the variance in AKI development and correctly classified 81.3% of cases. Increasing pre-op sodium level was associated with reduced likelihood of AKI by SCysC, a unit rise in sodium level reduces the odds of AKI based on SCr by 15% (Table 5). A binomial logistic regression was performed to ascertain the effects of the pre-op biochemical profile on the likelihood of AKI by SCr. The logistic regression model was statistically significant for SCysC. The model explained 18.10% of the variance in AKI development and correctly classified 90.6% of cases. Increasing SCysC was associated with an increased likelihood of AKI by SCr. Specifically, a unit increase in SCysC increases the odds of AKI based on SCr by 4% (Table 5).

Urinary NAG activity among studied subjects was not significantly different between the pre-and post-op periods (8.21 (7.79-8.64) vs 8.48 (7.69-9.05), p=0.131) (Figure 4). NAG is a lysosome-located enzyme in the proximal tubular epithelial cells, which was not significant in this study.

Variables	B	SE	COR (95% CI)	p-value
SCr	0.02	0.02	1.02 (0.98-1.06)	0.317
Urea	-0.02	0.31	0.99 (0.54-1.82)	0.963
Uric acid	-0.01	0.01	0.99 (0.98-1.00)	0.153
Sodium	-0.17	0.08	0.85 (0.72-0.99)	0.033*
Potassium	0.67	0.46	1.95 (0.80-4.77)	0.141
ICA	0.82	1.35	2.28 (0.16-31.81)	0.541
Urine NAG	0.53	0.50	1.70 (0.64-4.50)	0.283
SCysC	0.04	0.02	1.04 (1.00-1.07)	0.032*
Urea	-0.61	0.5	0.55 (0.20-1.47)	0.230
Uric acid	0.01	0.01	1.01 (0.99-1.02)	0.089
Sodium	-0.14	0.1	0.87 (0.72-1.05)	0.143
Potassium	-0.42	0.62	0.66 (0.20-2.22)	0.502
ICA	-2.17	1.88	0.12 (0.003-4.55)	0.249
Urine NAG	0.05	0.63	1.06 (0.31-3.61)	0.931

*Nagelkerke R^2 was 0.119 with SCysC and 0.181 with SCr.

Table 5: Preoperative biochemical parameters potentially associated with SCysC and SCr-detected AKI

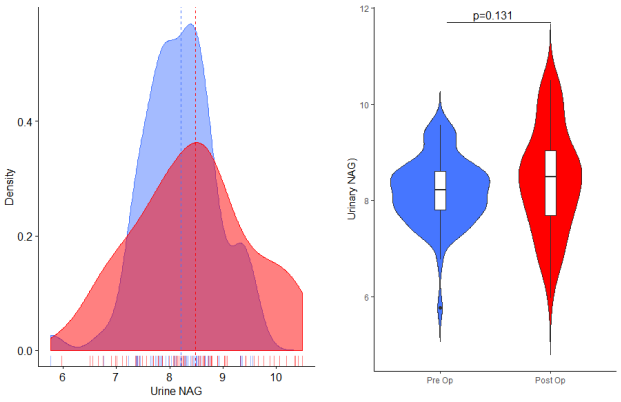

Figure 4: Assessment renal tubular cell injury by β-N-Acetyl-β-D-glucosaminidase

DISCUSSION

Approximately 2 million patients undergo on-pump cardiac surgery each year, and an estimated 20 to 30% develop acute kidney injury (AKI) [19], resulting in increased morbidity, mortality and hospital costs. [7, 20] The pathogenesis of AKI during cardiac surgery is multifactorial, with haemodynamic perturbations during and immediately after cardiopulmonary bypass (CPB) playing a significant role. [21]

In this study, the incidence of postoperative AKI was 9.4% based on the Kidney Disease Improving Global Outcomes (KDIGO) serum creatinine (SCr) criteria and 18.8% based on the Translational Research in Biomarker Endpoint (SCysC) criteria within the first 24 hours postoperatively. Despite this difference, there was no statistically significant change in the pre- to postoperative levels of SCr and SCysC.

Meta-analyses published between 2006 and 2024 report AKI incidences ranging from 10% to 40% (with an average of 22.1%) in cardiac surgery patients using SCr measurements by the ninth postoperative day. This is comparable to the pooled median incidence observed using SCysC in our study. [19] These findings suggest that SCysC may offer a more accurate and earlier assessment of renal function in the perioperative period.

The lower AKI detection rate using SCr (9.4%) compared to SCysC (18.8%) within 48 hours highlights SCr's limitation as a real-time marker. SCr levels typically rise only after more than 50% of renal function is lost, reflecting a delayed reduction in GFR. This lag usually 48 to 72 hours post-injury can delay diagnosis and timely intervention. [10, 22] In contrast, cystatin C, with a half-life approximately one-third that of creatinine, equilibrates more rapidly in plasma, offering a more immediate indication of renal function.

Emerging serum and urinary biomarkers, such as cystatin C, are gaining attention for their ability to detect structural renal injury earlier than traditional creatinine-based measures. [20–23] The higher AKI incidence detected by SCysC in this study likely reflects its favourable physiological characteristics a short half-life, complete metabolism after glomerular filtration, and a close correlation with both stable and fluctuating GFR. Moreover, SCysC levels are unaffected

by age, sex, muscle mass, or volume status. [24, 25] These features support its potential as a reliable, early diagnostic biomarker of GFR across a range of clinical settings.

Using investigational markers as predictors, the time points for the onset of intraoperative AKI were stratified by gender. From the Kaplan-Meier survival curve analysis, males did not have any intraoperative AKI onset by SCr. Contrarily, the onset of AKI for females increased with time; about 9.37% developed AKI. Additionally, the intraoperative onset of AKI as determined by SCysC among males and females was 1.56% and 17.18%. Nevertheless, there was no statistically significant difference between the two groups. Our findings are consistent with the study of Karkouti, suggesting that the female gender has a higher prevalence of AKI when undergoing cardiac surgery. [26]

Identifying patients with other risk factors for cardiac surgery–associated AKI may facilitate interventions to mitigate their risk throughout the perioperative period. Numerous studies have assessed clinical and surgical risk factors for cardiac surgery associated AKI. Still, to date, the variables identified for risk prediction are most accurate for predicting stage 3 AKI, which is renal failure associated with a 3-fold increase in serum creatinine or requiring renal replacement therapy. These models include the Cleveland Clinic score, the Mehta score, and the Simplified Renal Index. [15, 17, 20] In our study statistically significant risk factors for postoperative AKI include high BMI, New York Heart Association (NYHA) Class > II, Left Ventricular Ejection Fraction (LVEF) <35%, prolonged cardiopulmonary bypass time > 3 hrs, prolonged cross clamp time, insulin-dependent diabetes, high baseline creatinine, and high Cleveland Risk score. AKI was common among female patients undergoing cardiac surgery but was not statistically significant.

Patients with BMI $\geq$ 30 kg/m^2 had a significantly higher incidence of postoperative AKI, with obesity class I and II increasing the risk of AKI two- to fourfold. This is supported by multicenter and regional studies linking obesity to renal impairment. [27, 28] A study conducted in Ghana confirmed that higher BMI is associated with renal compromise. It is reasoned that obesity causes physiological disturbances that lead to glomerular impairment and pose a perioperative risk for AKI. [28] The influence of central fat deposition correlates with an increase in filtration fraction. However, recent reports also highlight a direct pathophysiological link between increased BMI and renal haemodynamic compromise through mechanisms that fail to balance elevations in glomerular filtration rate with renal plasma supply, resulting in an increased filtration fraction and subsequent glomerular hyperfiltration and hypertension. These adverse renal endpoints are reported among humans and observational species. [29]

CPB duration was significantly longer in the AKI group compared to the non-AKI group (193 vs. 118 minutes), highlighting its strong association with postoperative AKI. This is consistent with prior studies implicating prolonged CPB as a risk factor due to ischemia-reperfusion injury, non-pulsatile flow, and systemic inflammation. [17, 21, 24] However, it is important to note that the definition of ”prolonged” CPB varies widely across studies, with no universally accepted cutoff. Many investigations have dichotomised CPB duration at different thresholds, ranging from 90 minutes to over 180 minutes, which can complicate direct comparisons. Despite this heterogeneity, our findings align with those of Mangano and colleagues, who reported that a CPB time exceeding 3 hours (180 minutes) was an independent predictor of AKI in patients undergoing cardiac surgery. [30] Prolonged cross clamping time may liberate atheroemboli to the kidneys, further exacerbating ischemia and promoting inflammation. [21, 30] This reinforces the relevance of CPB duration and cross clamping time as a modifiable intraoperative factor and highlights the need for tailored strategies to minimise bypass and cross clamping time, particularly in high-risk patients.

There was a statistical difference between presurgical serum sodium levels and postoperative AKI. While all studied patients had normal presurgical serum sodium levels, the study showed that a unit increase in sodium level decreases the odds of SCr-determined postoperative AKI by 15% and correctly classifies 81.3% of cases. A historical South African study identified hypernatraemia as a significant risk for mortality among surgical patients. [31] These studies confirm the preventive, diagnostic, and prognostic role of sodium in subjects with AKI. This is based on the current understanding that renal haemodynamic control is closely linked to sodium homeostasis to maintain GFR within renal autoregulatory mechanisms. [31]

In an American study aiming to determine biomarker reference values among healthy individuals, a doubling of the absolute concentration of uNAG was reported as evidence of renal tubular damage. UNAG has relatively high sensitivity and specificity. [32] Urinary NAG activity among studied subjects was high in the post- to pre-op period [8.48 (7.69-9.05) vs. 8.21 (7.79-8.64)], p=0.131, but was not statistically significant in our study. The discordant reporting was due to the mixed type of cardiac surgical cases, different baseline characteristics, and study design adopted in each study.

The definition of cardiac surgery-associated AKI remains inconsistent across studies. We used the KDIGO creatinine-only criteria to allow comparison with prior research, though the full KDIGO definition includes both serum creatinine changes and prolonged oliguria. [9–11] We performed a sensitivity analysis that showed the biomarkers we tested were stronger predictors of the creatinine-only criteria than the full KDIGO definition for AKI. However, the prognostic value of oliguria is unclear due to confounding factors such as fluid shifts, diuretics such as mannitol, and anaesthesia-related effects. [21, 26, 33]

Our findings suggest that SCr, while widely used, may not be the optimal real-time marker for AKI during cardiac

surgery. Biomarkers such as SCysC, which respond earlier to renal injury, offer promising alternatives for timely detection and intervention.

CONCLUSION

The superior diagnostic utility of serum cystatin C relative to serum creatinine as a sensitive AKI biomarker was accentuated. A postoperative AKI incidence of 9.4% and 18.8% was reported for serum creatinine and serum cystatin C detected AKI, respectively. A kappa of 0.62 suggests moderate agreement, and the presence of six SCysC-only positive cases may reflect cystatin C's higher sensitivity to early or subclinical AKI. Demographic and clinical factors that predisposed patients to postoperative AKI were identified as high BMI, New York Heart Association (NYHA) Class >II, Left Ventricular Ejection Fraction (LVEF) <35%, prolonged cardiopulmonary bypass time > 3 hrs, prolonged cross clamp time, insulin-dependent diabetes, high baseline creatinine, and high Cleveland Risk Score. Furthermore, serum cystatin C and serum sodium were the preoperative biochemical parameters potentially associated with postoperative AKI.

LIMITATIONS

There are some limitations of this study, as this was a single-centre study; generalisation of its findings is inherently limited. The sample size was relatively small, restricting the ability to assess meaningful long-term outcomes. While intraoperative elevations in biomarkers were associated with AKI within 48 hours postoperatively, they did not correlate with the composite outcome of in-hospital mortality or elevated serum creatinine at discharge. Despite targeted screening for patients at increased risk of developing AKI, the overall incidence observed was low. This may be explained by the exclusion of patients undergoing urgent or emergent surgery, those with pre-existing kidney dysfunction or dialysis dependence, and individuals requiring extracorporeal membrane oxygenation (ECMO) in the preoperative period, as populations known to be at highest risk for AKI. These exclusion criteria may have introduced selection bias and reduced the applicability of our findings to the broader surgical population. Further study of the potential implications of elevated preoperative AKI biomarkers on perioperative surgical outcomes may be a worthwhile endeavour.

CONTRIBUTORSHIP STATEMENT

SS: Obtained ethics approval, data collection, analysis, protocol implementation, wrote the manuscript, and critical review of the manuscript.

DEM: Performed most surgeries, study design and did a critical review of the manuscript.

No AI-assisted technologies used in the writing process and all the authors have approved the final version to be published.

DISCLOSURES

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Confidentiality of Data: The authors declare that they have followed the protocols of their work centre on the publication of data from patients.

Protection of Human Subjects: The authors declare that the procedures followed were per the regulations of the relevant clinical research ethics committee and those of the Code of Ethics of the World Medical Association (Declaration of Helsinki as revised in 2024).

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REFERENCES

1. Makris K, Spanou L. Acute Kidney Injury: Definition, Pathophysiology and Clinical Phenotypes. Clinical Biochemist Reviews. 2016;37(2):85–98. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC5198510/.
2. Meersch M, Schmidt C, Zarbock A. Perioperative Acute Kidney Injury: An Under-Recognized Problem. Anesthesia & Analgesia. 2017;125(4):1223–1232. Available from: https://dx.doi.org/10.1213/ane.0000000000002369.
3. Goren O, Matot I. Perioperative acute kidney injury. British Journal of Anaesthesia. 2015;115(2):ii3–ii14. Available from: https://dx.doi.org/10.1093/bja/aev380.
4. Singh LC, Singh S, Deigheidy EM, Okyere I, Boateng NA. Effectiveness of bispectral index on clinical outcomes of beating heart off-pump coronary artery bypass grafting surgeries. Journal of Medical Society. 2025;39(1):71–79. Available from: https://dx.doi.org/10.4103/jms.jms_11_25.
5. Zarbock A, Koyner JL, Hoste EAJ, Kellum JA. Update on Perioperative Acute Kidney Injury. Anesthesia & Analgesia. 2018;127(5):1236–1245. Available from: https://dx.doi.org/10.1213/ane.0000000000003741.
6. Hobson C, Ruchi R, Bihorac A. Perioperative Acute Kidney Injury: Risk Factors and Predictive Strategies. Critical Care Clinics. 2017;33(2):379–396. Available from: https://doi.org/10.1016/j.ccc.2016.12.008.
7. Hu J, Chen R, Liu S, Yu X, Zou J, Ding X. Global Incidence and Outcomes of Adult Patients With Acute Kidney Injury After Cardiac Surgery: A Systematic Review and Meta-Analysis. Journal of Cardiothoracic and Vascular Anesthesia. 2016;30(1):82–89. Available from: https://dx.doi.org/10.1053/j.jvca.2015.06.017.

8. Wu B, Sun J, Liu S, Yu X, Zhu Y, Mao H et al. Relationship among Mortality of Patients with Acute Kidney Injury after Cardiac Surgery, Fluid Balance and Ultrafiltration of Renal Replacement Therapy: An Observational Study. Blood Purification. 2017;44(1):32–39. Available from: https://dx.doi.org/10.1159/000455063.

9. Khwaja A. KDIGO Clinical Practice Guidelines for Acute Kidney Injury. Nephron Clinical Practice. 2012;120(4):c179–c184. Available from: https://dx.doi.org/10.1159/000339789.

10. Cheruku SR, Raphael J, Neyra JA, Fox AA. Acute Kidney Injury after Cardiac Surgery: Prediction, Prevention, and Management. Anesthesiology. 2023;139(6):880–898. Available from: https://dx.doi.org/10.1097/aln.0000000000004734.

11. Andreucci M, Faga T, Pisani A, Perticone M, Michael A. The ischemic/nephrotoxic acute kidney injury and the use of renal biomarkers in clinical practice. European Journal of Internal Medicine. 2017;39:1–8. Available from: https://dx.doi.org/10.1016/j.ejim.2016.12.001.

12. Kuo G, Yang SY, Chuang SS, Fan PC, Chang CH, Hsiao YC et al. Using acute kidney injury severity and scoring systems to predict outcome in patients with burn injury. Journal of the Formosan Medical Association. 2016;115(12):1046–1052. Available from: https://dx.doi.org/10.1016/j.jfma.2016.10.012.

13. Teo SH, Endre ZH. Biomarkers in acute kidney injury (AKI). Best Practice & Research Clinical Anaesthesiology. 2017;31:331–344. Available from: https://dx.doi.org/10.1016/j.bpa.2017.10.003.

14. Singh S, Mahrous DE, Singh B, Rahman MMA, Bandoh I, Singh A. A Prospective Randomised Observational Study of Obstructed Total Anamalous Pulmonary Venous Connection (TAPVC) Repair Patients with Milrinone Versus Milrinone and Inhaled Nitric Oxide. Perspectives in Medical Research. 2024;12(2):61–69. Available from: https://www.pimr.org.in/2024-vol12-issue-2/1047799pimr120212-2024.php.

15. Thakar CV, Arrigain S, Worley S, Yared JP, Paganini EP. A Clinical Score to Predict Acute Renal Failure after Cardiac Surgery. Journal of the American Society of Nephrology. 2005;16(1):162–168. Available from: https://dx.doi.org/10.1681/asn.2004040331.

16. Nomenclature and Criteria for Diagnosis of Diseases of the Heart and Great Vessels. New York Heart Association. Criteria Committee; 1994. Available from: https://books.google.co.in/books/about/Nomenclature_and_Criteria_for_Diagnosis.html?id=Vs5qQgAACAAJ&redir_esc=y.

17. Roques F, Michel P, Goldstone AR. The logistic EuroSCORE. European Heart Journal. 2003;24(9):882–882. Available from: https://doi.org/10.1016/s0195-668x(02)00799-6.

18. Levey AS, Stevens LA, Schmid CH, Zhang YL, Castro AF, Feldman HI et al. A New Equation to Estimate Glomerular Filtration Rate. Annals of Internal Medicine. 2009;150(9):604–612. Available from: https://dx.doi.org/10.7326/0003-4819-150-9-200905050-00006.

19. Cheruku SR, Raphael J, Neyra JA, Fox AA. Acute Kidney Injury after Cardiac Surgery: Prediction, Prevention, and Management. Anesthesiology. 2023;139(6):880–898. Available from: https://dx.doi.org/10.1097/aln.0000000000004734.

20. Elmedany SM, Naga SS, Elsharkawy R, Mahrous RS, Elnaggar AI. Novel urinary biomarkers and the early detection of acute kidney injury after open cardiac surgeries. Journal of Critical Care. 2017;40:171–177. Available from: https://dx.doi.org/10.1016/j.jcrc.2017.03.029.

21. Singh S, Singh A, Rahman MMA, Mahrous DE, Singh LC. Is the combination of conventional ultrafiltration and modified ultrafiltration superior to modified ultrafiltration in pediatric open-heart surgery? Journal of Medical Society. 2023;37(3):159–166. Available from: https://dx.doi.org/10.4103/jms.jms_104_23.

22. Wang JJ, Chi NH, Huang TM, Connolly R, Chen LW, Chueh SCJ et al. Urinary biomarkers predict advanced acute kidney injury after cardiovascular surgery. Critical Care. 2018;22(1):1–13. Available from: https://dx.doi.org/10.1186/s13054-018-2035-8.

23. Hoste EAJ, Kellum JA, Selby NM, Zarbock A, Palevsky PM, Bagshaw SM et al. Global epidemiology and outcomes of acute kidney injury. Nature Reviews Nephrology. 2018;14(10):607–625. Available from: https://dx.doi.org/10.1038/s41581-018-0052-0.

24. Murty MSN, Sharma UK, Pandey VB, Kankare SB. Serum cystatin C as a marker of renal function in detection of early acute kidney injury. Indian Journal of Nephrology. 2013;23(3):180–183. Available from: https://doi.org/10.4103/0971-4065.111840.

25. Odutayo A, Cherney D. Cystatin C and acute changes in glomerular filtration rate. Clinical Nephrology. 2012;78(07):64–75. Available from: https://dx.doi.org/10.5414/cn107324.

26. Karkouti K, Wijeysundera DN, Yau TM, Callum JL, Cheng DC, Crowther M et al. Acute Kidney Injury After Cardiac Surgery. Circulation. 2009;119(4):495–502. Available from: https://dx.doi.org/10.1161/circulationaha.108.786913.

27. Mathis MR, Naik BI, Freundlich RE, Shanks AM, Heung M, Kim M et al. Preoperative Risk and the Association between Hypotension and Postoperative Acute Kidney Injury. Anesthesiology. 2020;132(3):461–475. Available from: https://dx.doi.org/10.1097/aln.0000000000003063.

28. Singh S, Rahman M, Deigheidy M, Singh A. Lignocaine Preconditioning for Protamine-Induced Pulmonary Vasoconstriction in Pediatric Cardiac Surgery. Revista da sociedade portuguesa de anestesiologia. 2024;33(4):191–199. Available from: https://revistas.rcaap.pt/anestesiologia/article/view/36837/27594.

29. Kwakernaak AJ, Toering TJ, Navis G. Body mass index and body fat distribution as renal risk factors: a focus on the role of renal haemodynamics. Nephrology Dialysis Transplantation. 2013;28(suppl 4):iv42–iv49. Available from: https://dx.doi.org/10.1093/ndt/gft331.

30. Axtell AL, Fiedler AG, Melnitchouk S, Da D, Villavicencio MA, Jassar AS et al. Correlation of cardiopulmonary bypass duration with acute renal failure after cardiac surgery. The Journal of Thoracic and Cardiovascular Surgery. 2019;159(1):170–178. Available from: https://doi.org/10.1016/j.jtcvs.2019.01.072.

31. Ramburuth M, Moodley Y, Gopalan PD. Preoperative serum sodium measurements and postoperative inpatient mortality: A case-control analysis of data from the South African Surgical Outcomes Study. South African Medical Journal. 2018;108(10):847–851. Available from: https://dx.doi.org/10.7196/samj.2018.v108i10.13178.

32. Biro E, Szegedi I, Kiss C, Olah AV, Dockrell M, Price RG et al. The role of urinary N-acetyl-β-D-glucosaminidase in early detection of acute kidney injury among pediatric patients with neoplastic disorders in a retrospective study. BMC Pediatrics. 2022;22(1):429. Available from: https://doi.org/10.1186/s12887-022-03416-w.

33. Pennemans V, Rigo JM, Faes C, Reynders C, Penders J, Swennen Q. Establishment of reference values for novel urinary biomarkers for renal damage in the healthy population: are age and gender an issue? Clinical Chemistry and Laboratory Medicine. 2013;51(9):1795–1802. Available from: https://dx.doi.org/10.1515/cclm-2013-0157.

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