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RESEARCH ARTICLE

Higher Body Mass Index and Prolonged Cardiopulmonary Bypass Time increase the Risk of Cardiac Surgery-associated Acute Kidney Injury

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Abstract:

Background:

Cardiac surgery is the second leading cause of Acute Kidney Injury in intensive care settings. The incidence of cardiac surgery-associated Acute Kidney Injury might be more than 30% in some cardiac surgery types. The associated factors for this complication are mostly ischemia-reperfusion injury, inflammation, hemolysis, and others. On the other hand, cardiac surgery-associated Acute Kidney Injury can be reduced and prevented.

Objective:

This study aims to investigate the incidence of cardiac surgery-associated Acute Kidney Injury among cardiac surgery patients and the most common predictors of this complication.

Methods:

This study adopted a retrospective quantitative design. A convenience sample of 151 adult patients with any type of on-pump open heart surgery from three major hospitals was included. Data were collected from electronic medical records and analyzed using binary logistic regression.

Results:

Two-thirds of the sample were males, 33.1% were overweight, and 55% underwent coronary artery bypass graft surgery. Cardiac surgery-associated Acute Kidney Injury occurred in 49 patients (32.5%) and was significantly associated with higher patients' body mass index (OR = 1.112, p-value = 0.006) and longer cardiopulmonary bypass time (OR = 1.015, p-value = 0.002).

Implications for Nursing:

Weight control and reduction of cardiopulmonary bypass time might decrease the incidence of cardiac surgery-associated acute kidney injury, morbidity, and mortality and improve resource utilization.

Conclusion:

Obesity and more prolonged cardiopulmonary bypass time increased the incidence of cardiac surgery-associated Acute Kidney Injury.

Keywords: Acute kidney injury, Renal failure, Cardiac surgery, Open heart, Cardiopulmonary bypass, On-pump.

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1. INTRODUCTION

Acute Kidney Injury (AKI) is an abrupt decline in kidney function, resulting in the retention of urea and other nitrogenous waste products and dysregulation of extracellular volume and electrolytes [1]. AKI is a clinical syndrome that complicates and worsens the outcomes in many hospitalized patients worldwide [2]. AKI is often associated with various complications (*i.e*., development of chronic kidney disease and cardiovascular morbidity) affecting the patient's quality of life [3]. The reported incidence of AKI varies widely among the existing literature; it ranges between 7% to 18% of hospitalized patients [4]. It causes complications among 50% to 60% of

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patients admitted to the intensive care unit (ICU) [5].

AKI is a common and severe complication after cardiac surgery, including Coronary Artery Bypass Graft Surgery (CABG), with an incidence range between 2% and 5%. In contrast, patients undergoing valvular or combined procedures show a higher incidence rate, as high as 30% [6]. The wide variation in AKI incidence is attributed to the differences in AKI definitions, the availability of scoring systems, and the differences in AKI etiological factors and AKI patients' characteristics [7, 8].

Cardiac Surgery-associated Acute Kidney Injury (CSA-AKI) occurs due to ischemia, contrast toxicity, inflammatory mediators, and other factors [9]. Severe postoperative CSA-AKI is an independent risk factor for mortality among cardiac patients [9]. While mortality after open-heart surgery with no CSA-AKI ranges between 1% and 8%, the odds of death increase more than fourfold following CSA-AKI [10]. The reported prevalence of CSA-AKI is up to 30% [4] and is independently associated with increased morbidity and mortality. Severe CSA-AKI that requires dialysis is usually uncommon in up to 4% of cardiacpatients [11]. Approximately 18% of patients undergoing cardiac surgery experience CSA-AKI, and about 2%–6% require hemodialysis [12].

A combination of several risk factors, including pre-operative, intraoperative, and postoperative, may contribute to the development of AKI following cardiac surgery [13]. Patient demographic characteristics such as older age and female sex were found to be positively associated with the risk of CSA-AKI [13]. Moreover, obesity, hyperlipidemia, pre-operative anemia, and comorbidities such as diabetes mellitus (DM), heart failure, chronic obstructive pulmonary disease (COPD), systemic arterial hypertension (HTN), and peripheral vascular disease are positively associated with variable degrees of CSA-AKI. Nephrotoxic medications or intravenous contrast may lead to tubular damage, with subsequent AKI.

Intraoperative factors associated with the development of CSA-AKI were also investigated. Patients who underwent valvular surgery with or without CABG were at a greater risk of developing AKI than those who underwent CABG alone [6]. Moreover, prolonged Cardiopulmonary Bypass (CPB), cross-clamp time, hemodilution during CPB, intraoperative red blood cell transfusion, use of inotropic or vasoconstrictor drugs, and the use of an intra-aortic balloon pump were found to be risk factors for CSA-AKI [8, 14].

Identifying CSA-AKI predictors can help healthcare providers identify patients at high risk of developing AKI after cardiac surgery and initiate early preventive and therapeutic strategies to reduce the risk of CSA-AKI and its adverse outcomes. Moreover, developing practical approaches to prevent CSA-AKI is necessary to minimize the transition of AKI to Chronic Kidney Disease (CKD) and End-stage Renal Disease (ESRD). Therefore, this study aimed to examine the incidence of CSA-AKI among cardiac-surgery patients and identify the most common predictors of CSA-AKI.

2. METHODS

2.1. Study Design

This study was conducted using a descriptive retrospective electronic record review for all adult patients who met the inclusion criteria between April and June 2022 to identify the predictors of CSA-AKI.

2.2. Sample and Sampling

A convenience sampling technique was used to recruit the sample for this study. Patients were included in the study if they: (1) aged 18 years or older, (2) went through on-pump cardiac surgery through sternotomy or thoracotomy including CABG, valve replacement or repair, CABG combined valve surgery, and aortic aneurysm surgery, (3) had at least one creatinine level readings within five days before the surgery and two creatinine level readings within 48 hours of the surgery; to make comparison and determine the incidence of CSA-AKI. Patients were excluded if they: (1) started with off-pump surgery and then converted to on-pump surgery, (2) with CKD or ESRD, (3) and were on pre-operative dialysis.

The estimated sample size was 150 participants using the G* power 3.1.9.7 software. Our assumptions included logistic regression as a major statistical test with an estimated odds ratio of 2.6 (based on 55% men and 45% women), an alpha of 0.05, two-tailed tests, a power of 0.80, and a medium effect size of (0.3).

2.2.1. Sites and Settings

According to the Ministry of Health (MOH), the healthcare system in Palestine consists of four major sectors: governmental (public) hospitals, Military Medical Services (MMS), teaching hospitals, and private hospitals. The accessible population of interest for this study was all eligible patients who underwent cardiac surgery in different health sectors, including governmental, private, and teaching hospitals. The MMS sector was excluded because cardiac surgery wasn’t available in its hospitals yet. After identifying all hospitals that contained open heart surgery units in Palestine, the researcher chose the three largest hospitals that do the largest number of open heart surgeries in a month in the governmental, private, and educational sectors. These three hospitals usually perform nearly 100 surgeries each month and cover the whole area of the country and sometimes the nearby countries.

The first hospital is a 250-bed capacity tertiary teaching hospital performing all types of cardiac surgery in Jerusalem. The second is a 330-bed private hospital located in Ramallah City. This hospital is a JCI accredited hospital with very high occupancy rates and performs all types of cardiac surgeries. The third one was a governmental hospital, one of the oldest hospitals in Hebron city. It has 257 beds and performs all types of cardiac surgery.

2.3. Data Collection Procedure

One coauthor reviewed the electronic medical systems for patients who underwent cardiac surgery and met the inclusion criteria. The medical files for each eligible patient were assessed and analyzed before and after cardiac surgery. Data were collected during the period between April and June 2022. The data included: (1) socio-demographic and clinical variables including age, sex, marital status, BMI, vital signs, comorbidities including DM and HTN, (2) pre-operative data including pre-operative serum creatinine (sCr) level, pre-operative c-reactive protein, type of surgery, and ejection fraction, (3) intraoperative data including length of surgery, intraoperative blood transfusion, CPB duration and mean arterial pressure during surgery, (4) postoperative data including postoperative sCr level, postoperative c-reactive protein, postoperative mean arterial pressure, and postoperative blood transfusion.

2.4. Measurement of Main Variables

This study defined (CSA-AKI) according to RIFLE (Risk, Injury, Failure, Loss of kidney function, and ESRD). RIFLE criteria are as follows: at least an increase in sCr ≥50% within 48 hours post-surgery and divided into three stages, "Risk; sCr ≥1.5 times baseline", "Injury; sCr ≥ 2 times baseline", and "Failure; sCr ≥ 3 times baseline". The two outcome criteria, L and E, were defined by the duration as the following: loss of kidney function, if there was a complete loss of kidney function, >4 weeks, and ESRD if there was a complete loss of kidney function >3 months [1, 15, 16]. It is worth noting that if the patients were at risk for CSA-AKI, they were not considered that they developed CSA-AKI. In this study, the normal range for sCr was from 0.7 to 1.20 milligrams per deciliter, although this can vary from lab to lab, between men and women, and by age [17].

2.5. Ethical Considerations

Before data collection, ethical approval was obtained from the Research and Ethics Committee/ Institutional Review Board (IRB) at Applied Science Private University (IRB #: Faculty 20-20-1-1). Other ethical approvals were obtained from the Ministry of Health in Palestine and the selected hospitals. The study was conducted based on the Helsinki Declaration of 1975.

2.6. Data Analysis

The Statistical Package for the Social Sciences (SPSS version 25 from IBM) was used to run descriptive and inferential statistics. Descriptive analyses (frequencies, percentages, mean, and standard deviation) were used to describe the sample demographic and the incidence of CSA-AKI after cardiac surgery. Frequencies and percentages were used to describe the categorical variables, whereas means and standard deviations were used to describe the continuous variables.

Logistic regression analysis was used to predict the influence of the independent variables on the occurrence of AKI post-cardiac surgery (AKI *vs*. No-AKI). The occurrence of AKI post-cardiac surgery (yes, no) was used as the dependent variable in this model. The independent variables were: age, sex, BMI, DM, HTN, pre-operative sCr and C-reactive protein level, CPB duration, blood transfusion, intraoperative mean arterial pressure, type, and length of surgery. A two-sided p-value of <.05 was considered statistically significant. The magnitude of the association was measured by odds ratios with confidence intervals of 95%.

Variables were entered in the logistic regression as independent variables: Block 1: Age, sex, BMI, history of HTN, and history of DM. Block 2: CBP time, surgery time and type, intra- and postoperative mean arterial pressure, and PRBCs transfusion. Block 3: pre-op sCr.

3. RESULTS

3.1. Demographic and Clinical Characteristics

Patients' socio-demographic and clinical characteristics are presented in Table **1**. Pre-operative and postoperative blood tests are shown in Table **2**. A total of 151 patients were included in this study. About two-thirds of the patients were males (66.9%), with about a third of them (32.5%) between 50 and 59 years old and more than a third of them (35.8%) between 170 and 179 cm in height. The percentages were more distributed in weight, with about one-fourth of patients (25.9%) between 70 and 79 kg in weight. According to BMI, one-third of the patients were overweight, and more than half (58.7%) had an average ejection fraction. Regarding medical history, about half of the patients (49.7%) had HTN, only 2.6% were diagnosed with COPD, and less than half (47%) had DM. Lastly, 19.9% of patients reported having a previous myocardial infarction, and 2.0% were diagnosed with heart failure.

Table 1. Demographic and clinical characteristics (N = 151).

Variable	n (%)	M ± SD
Sex Male Female	 101 (66.9) 50 (33.1)	56.67± 10.95
Age < 40 years 40 – 49 years 50 – 59 years 60 – 69 years 70+ years	 10 (6.6) 26 (17.2) 49 (32.5) 47 (31.1) 19 (12.6)	58.57 ± 10.94

(Table 1) contd.....

Variable	n (%)	M ± SD
BMI Underweight (<18.5) Normal weight (18.5 - 24.9) Overweight (25 - 29.9) Obese 1 (30 - 34.9) Obese 2 (35 - 39.9) Extreme obesity (40 and more)	 5 (3.3) 38 (25.2) 50 (33.1) 37 (24.5) 17 (11.3) 4 (2.6)	28.57 ± 5.69
EF Severe low (< 35%) Moderate low (35% – 44%) Mild low (45% - 54%) Normal EF (55% - 70%)	 1 (0.7) 7 (4.6) 55 (36.4) 88 (58.3)	51.91 ± 7.50
Comorbidities HTN COPD DM Old MI Heart failure	 75 (49.7) 4 (2.6) 71 (47.0) 30 (19.9) 3 (2.0)	-
Employment status Currently working Not working/retired	 101 (66.9) 50 (33.1)	-
Education High School BSc Others	 65 (43.0) 70 (46.4) 16 (10.6)	-
Marital status Single Married Divorced/ widowed	 20 (13.2) 125 (82.8) 6 (3.0)	-

Abbreviations: BMI: body mass index, Bsc: bachelor degree, EF: ejection fraction, HTN: history of hypertension, COPD: history of chronic obstructive pulmonary disease, DM: history of diabetes Mellitus, MI: myocardial infarction.

Table 2. Comparison between the (pre and post) operative lab values (N=151).

Variable	Preoperative		Postoperative		Chi-square p-value	Paired t P-value
	n (%)	M ± SD	*n (%)	M ± SD		
Hemoglobin Anemic (<13.5 g/dL) Normal (13.5 – 17.0 g/dL)	88 (58.7%) 52 (41.3%)	13.07 ± 1.77	125 (85.0%) 22 (15.0%)	11.75 ± 1.58	< .05	< .001
BUN Normal (6 – 20 mg/dL) High (> 20 mg/dL)	94 (66.2%) 48 (33.8%)	19.43 ± 8.76	103 (72.0%) 40 (28.0%)	18.28 ± 7.78	<.001	<.01
Creatinine	20 (13.2%) 102 (67.5%) 29 (19.2%)	0.95 ± 0.30	-	24-h post (1.02 ± 0.30) 48-h post (1.11 ± 0.45)	-	<.001 <.001
Low (< 0.7 mg/dL) Normal (0.7 – 1.2 mg/dL) High (> 1.2 mg/dL)			24-h post 12 (7.9%) 105 (69.5%) 34 (22.5%)	-	<.001	-
Creatinine Low (< 0.7 mg/dL) Normal (0.7 – 1.2 mg/dL) High (> 1.2 mg/dL)	20 (13.2%) 102 (67.5%) 29 (19.2%)	-	48-h post 17 (11.6%) 83 (56.5%) 47 (32.0%)	-	<.001	-
RBS Normal (74 – 110 mg/dL) High (> 110 mg/dL)	44 (31.6%) 95 (68.3%)	173.80±94.73	5 (3.5%) 146 (96.5%)	190.65±54.16	NS	NS
CRP Normal (0 – 5 mg/dL) High (> 5 mg/dL)	43 (52.4%) 39 (47.6%)	12.23 ± 23.22	16 (53.3%) 14 (46.7%)	34.31 ± 65.51	<.001	NS

Note: NS: Not significant, *: Numbers do not round to 151 because there were missing data.

Regarding (pre and post) operative blood tests, Table **2**. shows that more than half of the patients were anemic (58.7%), with a mean Hemoglobin of 13.07 g/dL; this percentage increased to 85% postoperatively, and the mean dropped to

11.75 g/dL. Two-thirds of them (66.2%) had normal BUN levels, and (67.5%) had normal pre-operative sCr levels, which fell to 56.5% of the patients after 48 hours of the surgery. More than two-thirds of the sample (68.3%) had high blood glucose levels.

Table **3**. presents data on performed surgeries. More than half of the open-heart surgeries were CABG (55%). Most CABG cases (88.7%) included taking the graft from saphenous and internal mammary arteries. The left anterior descending artery was the most common grafted artery considering that most patients had one or more grafts implanted. The mean number of implanted grafts for each CABG patient was 2.9, ranging from 1 to 4 grafts. Regarding valve surgeries, more than half of the patients (54.1%) had aortic valve surgery. The mean cardiopulmonary bypass time was 119.45 minutes (SD = 50.00 minutes. At the same time, the mean cross-clamp time was 75.39 minutes (SD = 33.06 minutes), ranging between 10 and 198 minutes. On the other hand, the mean total surgery time was 8.07 hours (SD = 1.51 hours), ranging between 6 and 10 hours.

Regarding other postoperative information, the mean amount of blood loss until the extubation was 411.33 ml (SD = 427.64 ml), ranging from 50 to 2,000 ml while,the meantime of intubation postoperatively was 8.35 hours till extubation (SD = 4.09 hours), ranging from 3 to 24 hours. Regarding postoperative blood transfusion, the mean transfused PRBC units were 1.72 units (SD = 0.87 unit), ranging from 1 to 4 units. The mean amount of fresh frozen plasma units transfused was 1.58 units (SD = 0.87 unit), ranging from 1 to 4 units, with a mean platelets units transfused of 5.26 units (SD = 2.1 units) ranging from 2 to 12 units and five units of mean cryoprecipitate (SD = 1.5 units) ranging from 2 to 8 units. Considering that some patients did not take any or some of the mentioned types of blood products, the detailed numbers are for patients who took the transfused units.

3.2. The Incidence of Postoperative CSA-AKI

Table **4** shows that the mean difference in creatinine level from the pre-operative to 24-hr postoperative phase is 0.06 mg/dL (SD = 0.19), ranging from a decrease of 0.55 mg/dL to an increase of 0.74 mg/dL. On the other hand, the mean difference in creatinine level from the pre-operative to 48-hr postoperative phase is 0.15 mg/dL (SD = 0.30), ranging from a decrease of 0.56 mg/dL to an increase of 1.4 mg/dL. In total, the incidence of CSA-AKI was 32.5% of the total sample.

3.2.1. The Most Common Predictors of CSA-AKI among Patients who Underwent Cardiac Surgery

Table **5** shows the results of the binary logistic regression test between patients' independent and dependent variables. Independent statistical significance factors correlated to AKI occurrence were BMI (p = 0.006) and CPB time (p = 0.002). Regarding BMI, the relationship was mildly positive (B = 0.106), with an increase in the possibility of having postoperative AKI by 11.2% (OR = 1.112) for each level of increase in BMI. Similarly, the relationship between CPB time and occurrence of postoperative AKI is mild and positive (B = 0.015), with an increase in the possibility of having AKI by 1.5% (OR = 1.015) for each minute increased in CPB time.

Table 3. Characteristics of surgeries performed (N = 151).

Variable	n (%)
Surgery type	
CABG	83 (55.0%)
AVR	21 (13.9%)
MVR	13 (8.6%)
Double-valve	11 (7.3%)
Other types	23 (25.2%)
Location of taken grafts	
Saphenous vein graft	9 (9.3%)
Internal mammary graft	2 (2.1%)
Both	86 (88.7%)
Grafts implanted	
LAD	90 (88.7%)
Cx	15 (9.9%)
PDA	42 (27.8%)
D1	31 (20.5%)
D2	18 (11.9%)
OM	18 (11.9%)
RCA	28 (18.5%)
Location of repaired/replaced valve	
Aortic valve	33 (54.1%)
Mitral valve	19 (31.1%)
Tricuspid valve	9 (14.8%)

Abbreviations: CABG: Coronary artery bypass graft, AVR: aortic valve replacement, MVR: mitral valve replacement, LAD: left anterior descending artery, Cx: circumflex artery, PDA: Patent Ductus Arteriosus, D: diagonal artery, OM: obtuse marginal artery, RCA: right coronary artery.

Table 4. Distribution of postoperative creatinine levels and cardiac surgery-associated AKI.

Variable	n (%)	M ± SD
Preoperative vs. 24-h postoperative Cr difference		
Less than 0.7 mg/dL	132 (88.0%)	
0.7 mg/dL or more	18 (12.0%)	0.06 ± 0.19
Preoperative vs. 48-hr postoperative Cr difference		
Less than 0.7 mg/dL	107 (72.8%)	
0.7 mg/dL or more	40 (27.2%)	0.15 ± 0.30
CSA-AKI		
Yes	49 (32.5%)	-
No	102 (67.5%)	

Abbreviation: CSA-AKI: Cardiac-surgery associated acute kidney injury.

Table 5. Independent predictors of CSA-AKI by Binary logistic regression.

Variable	B	Wald	p-value	OR	95% CI
BMI (Cont.)	0.106	7.573	0.006	1.112	1.031 – 1.198
CPB time (Cont.)	0.015	9.274	0.002	1.015	1.05 – 1.025

Note: B: Beta, OR: Odds ratio, CI: Confidence interval, CPB: cardio-pulmonary bypass time. Variables were entered in the logistic regression as independent variables: Block 1: Age, sex, BMI, history of HTN, and history of DM. Block 2: CBP time, surgery time, (intra- and post)-operative mean arterial pressure and PRBCs transfusion. Block 3: pre-op sCr.

4. DISCUSSION

This study aimed to examine the incidence of CSA-AKI among cardiacsurgery patients and identify the most common predictors of CSA-AKI. The main findings were that CSA-AKI occurred in 32.5% of the patients who underwent On-Pump Cardiac Surgery and that patients' higher BMI and prolonged CPB time were significantly associated with increased incidence of postoperative CSA-AKI.

4.1. Incidence of CSA-AKI

In this study, the incidence of AKI post-cardiac surgery was in 49 cases out of 151 (32.5%), which is similar to what was concluded by [18] and [19], who found that CSA-AKI happens in around 30% of patients after cardiac-surgeries. However, our result was higher than that of Thiele *et al*. [12], who reported an incidence of (18%). The differences and similarities in CSA-AKI incidence were highly dependent on AKI diagnostic criteria, as well as the selection criteria of the patients.

Kumar and Suneja [20] found that the incidence of CSA-AKI is higher among patients who undergo valve surgeries and even more significant for patients who undergo a combined cardiac surgery of CABG and valve replacement. Conversely, our study revealed no significant difference in postoperative AKI incidence according to surgery type. This difference can be related to the lack of control over surgery type regarding equality in the number of patients collected for each surgery type; in our study, 55% of the patients underwent CABG surgery.

The incidence of CSA-AKI is different in our study compared to previous studies, which can be attributed to several interpretations. For example, Ortega-Loubon, and Fernández-Molina [9] found that CSA-AKI occurred in 54 patients out of 435 Spanish patients (12.4%), which is much lower than the incidence in our study, and this can be because they conducted their study on a more extended period (2012 to 2016) and that they included CABG surgeries only. On the other hand, Kwon, Jung [21] found that the incidence of CSA-AKI is 40.5% among Korean patients, which is not far from our finding, even though they used similar criteria of selection as in the previous Spanish study (CABG patients only) and on an extended period (2007 to 2016). Still, they used the same retrospective design on 210 consecutive patients as in our study.

The incidence of CSA-AKI was 10.4% among 1395 patients who underwent cardiac surgery [22]. This percentage is lower than reported in the current study. This difference might be due to different factors: (1) the nature of the surgery since they included 90.4% CABG patients and 9.6% combined surgery. The current study included 55% of CABG patients. It was reported that combined surgeries increased the risk for CSA-AKI. (2) Li, Fan [22] classified the CPB time as a categorical variable of less than 207.5 and more than 207.5 minutes, while the current study used this variable as a continuous variable. (3) the mean BMI of the previous study was lower (25.90 ± 3.28) compared to the current study (28.57 ± 5.69). Higher levels of BMI are usually associated with an increased risk of CSA-AKI. (4) the difference in the criteria used to operationally define CSA-AKI. The current study used RIFLE criteria, the previous study used AKI Network criteria, and (5) the experience of the surgeons who did the surgery. The surgeons who did the operations in the previous study were experts in the field. Each surgeon had more than 15 years of experience after residency training and performed more than 100 cases using the specific technique, a factor we did not assess during the current study.

4.2. Significant Predictors of CSA-AKI

Body Mass Index (BMI): Our study found that BMI was significantly correlated with CSA-AKI incidence in a mild positive manner; a higher BMI was associated with a higher incidence of AKI. The explanation can be obesity-related glomerulopathy (ORG) [23]. ORG can describe obesity and its association with hypertension, glomerular hypertrophy, and glomerulosclerosis. It was also linked to more activation of renal artery stenosis. Since it was out of the scope of the study's aims, there was no investigation into the incidence of renal artery stenosis symptoms among different BMI classifications. Yue, Yan-meng [24] found the same correlation even with a lower BMI; of 24.79 ± 3.31, compared to the current study BMI of 28.57 ± 5.69. This might be due to a higher percentage of patients who are overweight (33.1%) and obese (24.5%) in the current study. Also, in a prospective observational study by Kanji *et al*. [25], BMI ≥25 was a 4.2 times higher risk of developing CSA-AKI than other patients.

Kwon, Jung [21] found a positive correlation between AKI development postoperatively according to body weight and body surface area (BSA). While this differs from our aims, it was not found to be the same in our study, as seen in a separate test (between weight and BSA and AKI, p-value > 0.05). A possible interpretation for this difference could be related to the fact that the investigation of the relationship between body weight and CSA-AKI is not adequate. This difference is because different weights can be found for similar patient' heights, which is why we aimed to investigate the relationship between 'patients' BMI and the incidence of CSA-AKI. Moreover, body weight may be used for postoperative assessment of weight gain related to fluid balance assessment. BMI reflects more on the calculated suitability between a patient's height and weight. In other words, relying on the mere association between weight, or BSA, only and the incidence of CSA-AKI is not adequate, and BMI should be adopted for this relationship.

Kumar, Bridget Zimmerman [26] found that the incidence of postoperative CSA-AKI was 39%, which is more than our findings (32.9%). The distribution of BMI categories in our study compared to theirs was as follows: 25.2% *vs*. 24% for BMI < 25, 33.1% *vs*. 30% for BMI = 25 – 30, 24.5% *vs*. 23% for BMI = 30 – 35, 11.3% *vs*. 12% for BMI = 35 – 40 and 2.6% *vs*. 11% for BMI > 40. This distribution indicated higher percentages of overweight and obese patients among participants of the previous study. The previous study found a significantly higher incidence of CSA-AKI in patients with BMI > 40, which is different than our investigation. The current study used binary logistic regression, and the independent variable of BMI was entered into the model as a continuous (scale) variable rather than the categorical classification of the previous study. In our study, we found that each 1 unit increase in a patient's BMI was associated with an increased risk of having postoperative CSA-AKI by 11.1%. On the other hand, the previous study aimed to find the BMI group significantly associated with the highest incidence of CSA-AKI. Moreover, this difference might be due to the definition used to define CSA-AKI. The current study used the RIFLE criteria, while the previous used the AKI Network criteria.

Cardiopulmonary Bypass (CPB): The mean CPB time in the current study was about two hours (119.45 ± 50.0 minutes), with a wide range of 31 to 370 minutes. This wide range could cause a significant correlation between CPB time and CSA-AKI. A rationale for the relationship between CPB and AKI is its ischemia-reperfusion effect and the systematic inflammatory response, which affects major organs, mainly kidneys [27]. Moreover, it has been demonstrated that the longer the CPB time is, the more oxidants and inflammatory mediators are released [28]. These interpretations are consistent with our findings regarding the significant mild positive correlation between CPB time and the incidence of postoperative CSA-AKI. In the current study, every minute increase in CPB time was significantly associated with a 1.5% risk of developing postoperative CSA-AKI. This association is consistent with previous studies [20, 29]. In a meta-analysis study, Kumar, and Suneja [20] found that CPB is associated with the development of CSA-AKI and happened in 6.06% of the investigated samples. The difference in these percentages might be due to the different definitions of CSA-AKI used by the investigators, in addition to differences in the sample sizes, types of operations, and the duration of the CPB time.

In a prospective observational study, Kanji, and Schulze [25] found no significant correlation between either CPB or aortic cross-clamp times and CSA-AKI incidence. However, higher levels of mean arterial pressure were protective, and lower flow was correlated with a higher incidence of AKI. On the other hand, we studied the relationship between CPB time and AKI and found a significant correlation. An explanation for these inconsistent results regarding the duration of CPB may be due to the difference in the criteria used to define CSA-AKI operationally and patient selection. Kanji, *et al*. [25] recruited more complicated and high-risk patients, using more sensitive criteria to define CSA-AKI. Still, we did not investigate the correlation with CPB flow or aortic cross-clamp time.

Schopka *et al*. [30] did not show a significant relationship between CPB and postoperative GFR. They used the decrease in GFR as a diagnostic criterion of AKI postoperatively. Furthermore, they made a comparison between on-pump and off-pump surgeries. When the AKI definition was used, there was no significant difference in AKI incidence between on-pump and off-pump patients. So the authors concluded no correlation between the use and time of CPB and the incidence of AKI postoperatively.

5. CLINICAL IMPLICATIONS

The main contribution of our study is to help healthcare providers identify patients at a high risk of developing AKI after cardiac surgery and initiate early preventive and therapeutic strategies to reduce the risk of CSA-AKI and its negative consequences. Therefore, reduction of body weight and CPB time might decrease the incidence of CSA-AKI and morbidity, improve health outcomes, and decrease cost. The difference in the criteria used to define CSA-AKI operationally is inconsistent, making it difficult to compare results between studies. Researchers and clinicians are encouraged to have a universally conceptual definition of AKI that might help identify patients with AKI post-cardiac surgery.

6. LIMITATIONS

The retrospective design presents a weakness regarding the availability of all data that might be needed to identify predictors of CSA-AKI. Studies with longer follow-up duration and investigation of AKI incidence in different groups according to their biomarkers and several clinical measurements are still warranted. The sampling technique used in this study was convenience sampling, which may limit the generalizability of our findings along with the small geographical area, Palestine.

CONCLUSION

AKI incidence in the postoperative stage of cardiac surgeries is a common complication. Previous literature found variations in the pre-, intra-, and postoperative predictors and incidence of CSA-AKI. The incidence of CSA-AKI was mainly correlated with higher BMI levels and longer intraoperative CPB time.

LIST OF ABBREVIATIONS

AKI	=	Acute Kidney Injury
ICU	=	Intensive Care Unit
CABG	=	Coronary Artery Bypass Graft Surgery
CSA-AKI	=	Cardiac Surgery-associated Acute Kidney Injury

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by Ethics Committee/ Institutional Review Board (IRB) at the Applied Science Private University (IRB #: Faculty 20-20-1-1). Other ethical approvals were obtained from the Ministry of Health in Palestine and the selected hospitals.

HUMAN AND ANIMAL RIGHTS

No animals were used for the studies. The study was conducted based on the Helsinki Declaration of 1975.

CONSENT FOR PUBLICATION

Informed consent was obtained.

STANDARDS OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIAL

All the data and supporting information is provided within the article.

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None.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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