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Original Article

Frequency of Early Acute Kidney Injury After On-Pump Coronary Artery Bypass Grafting: A Comparison Between Minimally Invasive and Conventional Median Sternotomy

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ABSTRACT

Background: Acute kidney injury is a frequent complication of cardiac surgery and may be influenced by patient characteristics, cardiopulmonary bypass, perioperative hemodynamics, and operative factors. Objective: To compare the frequency and severity of early AKI after on-pump CABG performed through minimally invasive anterior minithoracotomy and conventional median sternotomy. Methods: This comparative observational study included 150 patients undergoing elective on-pump CABG at two centers, with 75 patients in each surgical group. Serum creatinine was assessed preoperatively and at 24, 48, and 72 hours; eGFR, urea, BUN, and urine output were also evaluated. AKI was classified according to KDIGO criteria. Continuous and categorical outcomes were compared between groups, and crude effect estimates were calculated for AKI. Results: AKI occurred in 10/75 (13.3%) minimally invasive patients and 36/75 (48.0%) conventional patients ($p<0.001$), corresponding to a crude RR of 3.60 (95% CI 1.93–6.71) and OR of 6.00 (95% CI 2.68–13.42) for conventional surgery. KDIGO stages 2–3 occurred in 4.0% versus 17.3%. At 48 hours, creatinine was 1.26±0.58 versus 1.92±1.15 mg/dL, while eGFR was 67.67±22.68 versus 48.59±24.14 mL/min/1.73 m^2. The 48-hour creatinine increase was also smaller after minimally invasive CABG (0.26±0.52 vs 0.76±1.02 mg/dL; $p<0.001$). Conclusion: Minimally invasive CABG was associated with less early postoperative renal dysfunction; however, baseline renal differences and the observational design limit causal interpretation. Keywords: acute kidney injury, coronary artery bypass grafting, minimally invasive cardiac surgery, median sternotomy, cardiopulmonary bypass, KDIGO, renal function.

INTRODUCTION

Coronary artery bypass grafting (CABG) remains an established revascularization strategy for selected patients with complex or multivessel coronary artery disease, particularly when the expected anatomical and clinical benefits of surgical revascularization outweigh those of percutaneous treatment (1). Despite substantial advances in surgical technique, anesthesia, myocardial protection, cardiopulmonary bypass (CPB), and perioperative care, postoperative organ dysfunction continues to influence morbidity and recovery after cardiac surgery. Acute kidney injury (AKI) is among the most clinically important complications following cardiac surgery. Cardiac surgery-associated AKI (CSA-AKI) encompasses a spectrum from relatively small postoperative increases in serum creatinine to severe renal dysfunction requiring kidney replacement therapy. Its occurrence has been associated with longer intensive-care and hospital stays, higher healthcare utilization, and worse short- and long-term outcomes (2,3). The risk reflects the interaction of preoperative susceptibility, intraoperative hemodynamic and perfusion disturbances, systemic inflammation, ischemia-reperfusion injury, hemolysis, oxidative stress, microembolization, and postoperative exposures (3,4).

The Kidney Disease: Improving Global Outcomes (KDIGO) framework defines AKI according to changes in serum creatinine and urine output and stratifies severity into stages 1, 2, and 3 (5). This standardized definition is particularly relevant to cardiac surgery because postoperative renal dysfunction may evolve during the first several days after CPB, while serum creatinine itself can lag behind the underlying renal insult. Even apparently transient postoperative AKI is clinically important because greater AKI severity has been associated with poorer subsequent renal and clinical outcomes (2,6). CPB may contribute to renal dysfunction through several interrelated mechanisms. Exposure of blood to extracorporeal surfaces promotes inflammatory and coagulation activation, while non-pulsatile flow, hemodilution, changes in perfusion pressure, hypothermia, hemolysis, and altered renal oxygen delivery may increase susceptibility to tubular and microcirculatory injury (3,4,7). Consequently, contemporary renal-protection strategies in cardiac surgery emphasize preservation of adequate perfusion and oxygen delivery, avoidance of excessive hemodilution and nephrotoxic exposure, and close perioperative surveillance of kidney function (8,9). The operative access used for CABG may represent an additional component of perioperative physiological stress. Conventional CABG through a full median sternotomy provides broad operative exposure but entails extensive disruption of the anterior chest wall. Minimally invasive CABG performed through an anterior minithoracotomy reduces the extent of surgical access while allowing coronary revascularization in appropriately selected patients. Contemporary comparative evidence suggests that minimally invasive approaches can achieve acceptable perioperative outcomes and shorter postoperative recovery in selected populations; however, renal outcomes have been less consistently investigated than conventional endpoints such as ventilation duration, bleeding, wound morbidity, and length of hospital stay (10).

Recent evidence directly examining renal function after minimally invasive total coronary revascularization versus full sternotomy CABG has demonstrated that minimally invasive surgery does not necessarily increase renal complications despite potentially longer CPB and cross-clamp times, while the available comparative literature remains limited and heterogeneous with respect to operative techniques, baseline renal risk, AKI definitions, and outcome-assessment intervals (10). This heterogeneity is important because baseline renal function, CPB characteristics, perfusion management, and perioperative hemodynamics may substantially influence postoperative kidney outcomes independently of surgical access (8,9). Against this background, the present study compared early renal outcomes after elective on-pump CABG performed through minimally invasive anterior minithoracotomy and conventional median sternotomy. The primary objective was to compare the frequency and severity of early AKI during the first 48–72 postoperative hours between the two surgical approaches. Secondary objectives were to compare serial serum creatinine, estimated glomerular filtration rate (eGFR), serum urea, blood urea nitrogen (BUN), and urine-output-related renal outcomes. Because the surgical approaches were compared observationally rather than through randomized allocation, the findings were interpreted as associations rather than evidence of a causal effect of operative access.

MATERIALS AND METHODS

A comparative observational study was conducted among patients undergoing elective on-pump coronary artery bypass grafting at Umar Hospital & Cardiac Center and Gulab Devi Chest Hospital. The analyzed sample comprised 150 patients, including 75 who underwent minimally invasive CABG through an anterior minithoracotomy and 75 who underwent conventional CABG through median sternotomy. Patients were categorized for analysis according to the surgical approach received. The study compared early postoperative renal outcomes between these two operative groups. Demographic and preoperative clinical variables included age, sex, body mass index (BMI) category, diabetes mellitus, hypertension, chronic kidney disease (CKD), smoking status, baseline serum creatinine, baseline eGFR, left ventricular ejection fraction (LVEF), and preoperative hemoglobin concentration. These variables were evaluated to characterize the two surgical groups and identify potential baseline differences relevant to postoperative renal risk. Because preoperative renal function is an important determinant of CSA-AKI, baseline serum creatinine and eGFR were considered particularly important when interpreting postoperative differences between groups (2,6).

Renal function was assessed using serum creatinine, eGFR, serum urea, BUN, and urine output. Serum creatinine was documented preoperatively and at 24, 48, and 72 hours after CABG. Early AKI was classified according to the

KDIGO framework, which defines AKI by an increase in serum creatinine of at least 0.3 mg/dL within 48 hours, an increase to at least 1.5 times baseline within the defined diagnostic interval, or qualifying reduction in urine output, and grades severity as stages 1, 2, and 3 (5). The stage distribution was evaluated in addition to the binary occurrence of any AKI. Postoperative eGFR, serum urea, BUN, and urine-output status were assessed during the same early postoperative period as indicators of renal function. The principal exposure was surgical approach, categorized as minimally invasive anterior minithoracotomy or conventional median sternotomy. The principal outcome was occurrence of early AKI, while AKI stage and postoperative renal biochemical parameters represented secondary outcomes. Because changes in serum creatinine may be influenced by preoperative renal status and perioperative fluid balance, both absolute postoperative creatinine measurements and change from baseline were considered in the comparative evaluation. Contemporary cardiac-surgery recommendations emphasize that creatinine and urine-output surveillance should be interpreted alongside baseline renal risk and perioperative perfusion factors (8,9). Data were analyzed using IBM SPSS Statistics version 27. Continuous variables were summarized as mean ± standard deviation (SD), and categorical variables as frequency and percentage. Between-group comparisons of continuous variables were performed using independent-samples t-tests when parametric assumptions were applicable and Mann–Whitney U tests for non-normally distributed variables, as specified in the original analytical framework. Categorical variables were evaluated using Pearson's chi-square test or Fisher's exact test when expected cell frequencies were small. For variables represented by mutually exclusive categories, including age, BMI, LVEF category, and AKI stage, an overall contingency-table test was used rather than separate hypothesis tests for individual categories.

To improve clinical interpretability of the reported aggregate results, between-group mean differences and 95% confidence intervals (CIs) were calculated from the reported group means, SDs, and sample sizes where sufficient information was available. For the primary binary AKI comparison, crude odds ratio (OR), relative risk (RR), absolute risk difference, and corresponding 95% CIs were calculated directly from the reported 2×2 group counts. Crude ORs with 95% CIs were similarly derived for risk-factor comparisons when all required cell counts were available. These effect estimates were treated as unadjusted associations and not as independent causal effects. Statistical significance was defined as a two-sided p-value ≤0.05. Ethical approval for the study was obtained from the research committee of the University of Lahore, and informed consent was obtained from the participating patients.

RESULTS

A total of 150 patients were included, with 75 patients in the minimally invasive CABG group and 75 in the conventional median sternotomy group. Overall, 133 participants (88.7%) were male, 119 (79.3%) were older than 50 years, 148 (98.7%) had hypertension, 43 (28.7%) had diabetes mellitus, 40 (26.7%) were smokers, and 14 (9.3%) had CKD.

Table 1. Baseline Demographic and Clinical Characteristics

Variable	Minimally invasive (n=75), n (%)	Conventional (n=75), n (%)	p-value
Sex			1.000
Male	67 (89.3)	66 (88.0)	
Female	8 (10.7)	9 (12.0)	
Diabetes mellitus	23 (30.7)	20 (26.7)	0.718
Hypertension	75 (100.0)	73 (97.3)	0.497*
Chronic kidney disease	5 (6.7)	9 (12.0)	0.400
Smoking	18 (24.0)	22 (29.3)	0.580
Age category			0.360
20–30 years	2 (2.7)	0 (0.0)	
31–50 years	14 (18.7)	15 (20.0)	
>50 years	59 (78.7)	60 (80.0)	
BMI category			0.302
Normal	13 (17.3)	20 (26.7)	
Overweight	40 (53.3)	32 (42.7)	
Other reported BMI category†	22 (29.3)	23 (30.7)	
LVEF category			0.614
≥55%†	23 (30.7)	19 (25.3)	
41–54%	39 (52.0)	45 (60.0)	
<40%	13 (17.3)	11 (14.7)	

*Fisher's exact test. Other p-values are overall Pearson chi-square comparisons where applicable. †Count derived deterministically from the group total after subtracting the explicitly reported categories; the source manuscript did not provide the category label for the remaining BMI participants. The ≥55% LVEF count was similarly derived from the complete group denominator.

The two groups were broadly similar for sex, diabetes, hypertension, CKD, smoking, age distribution, BMI distribution, and LVEF category. Importantly, use of a single overall comparison for multi-category variables showed no statistically significant baseline differences in age distribution (p=0.360), BMI distribution (p=0.302), or LVEF category (p=0.614), replacing the fragmented category-specific testing in the original table. Baseline quantitative renal variables were not fully balanced between the groups. Mean serum creatinine was significantly lower in the minimally invasive group, whereas mean eGFR was significantly higher. LVEF and preoperative hemoglobin did not differ significantly.

Table 2. Baseline Quantitative Renal and Cardiac Variables

Variable	Minimally invasive, mean ± SD	Conventional, mean ± SD	Mean difference (95% CI)‡	p-value
Serum creatinine, mg/dL	1.00 ± 0.25	1.16 ± 0.37	−0.16 (−0.26 to −0.06)	0.002
eGFR, mL/min/1.73 m^2	80.37 ± 21.75	71.04 ± 24.08	9.33 (1.93 to 16.74)	0.013
LVEF, %	50.80 ± 9.70	49.39 ± 8.40	1.41 (−1.52 to 4.34)	0.344
Preoperative hemoglobin, g/dL	13.50 ± 1.40	13.19 ± 1.50	0.31 (−0.16 to 0.78)	0.200

‡Mean difference calculated as minimally invasive minus conventional from the reported means, SDs, and n=75 per group.

These baseline differences were clinically important for interpretation of subsequent renal outcomes. The minimally invasive group entered surgery with a mean creatinine 0.16 mg/dL lower and mean eGFR 9.33 mL/min/1.73 m^2 higher than the conventional group. Consequently, postoperative between-group differences were interpreted alongside the change-from-baseline measurements rather than as evidence attributable solely to surgical approach. Postoperatively, renal biochemical measurements consistently favored the minimally invasive group. At 24 hours, serum creatinine was 1.12±0.28 mg/dL after minimally invasive CABG and 1.38±0.42 mg/dL after conventional sternotomy. The difference increased at 48 hours, with mean creatinine values of 1.26±0.58 and 1.92±1.15 mg/dL, respectively, and remained apparent at 72 hours.

Table 3. Early Postoperative Renal Parameters

Parameter	Minimally invasive, mean ± SD	Conventional, mean ± SD	Mean difference (95% CI)‡	p-value
Creatinine at 24 h, mg/dL	1.12 ± 0.28	1.38 ± 0.42	−0.26 (−0.38 to −0.15)	<0.001
Creatinine at 48 h, mg/dL	1.26 ± 0.58	1.92 ± 1.15	−0.66 (−0.96 to −0.37)	<0.001
Creatinine at 72 h, mg/dL	1.21 ± 0.56	1.83 ± 1.07	−0.62 (−0.90 to −0.34)	<0.001
Δ creatinine at 48 h, mg/dL	0.26 ± 0.52	0.76 ± 1.02	−0.50 (−0.76 to −0.24)	<0.001
Creatinine ratio at 48 h	1.28 ± 0.55	1.69 ± 1.03	−0.41 (−0.68 to −0.14)	<0.001
eGFR at 48 h, mL/min/1.73 m^2	67.67 ± 22.68	48.59 ± 24.14	19.08 (11.52 to 26.64)	<0.001
Urea at 48 h, mg/dL	43.25 ± 13.72	49.43 ± 16.51	−6.18 (−11.08 to −1.28)	0.014
BUN at 48 h, mg/dL	20.21 ± 6.41	23.10 ± 7.72	−2.89 (−5.18 to −0.60)	0.014

‡Difference calculated as minimally invasive minus conventional from the reported aggregate data.

The change-from-baseline analysis strengthened the interpretation beyond the simple postoperative comparison. At 48 hours, the mean increase in creatinine was 0.26±0.52 mg/dL following minimally invasive CABG compared with 0.76±1.02 mg/dL following conventional sternotomy, corresponding to a between-group difference of −0.50 mg/dL (95% CI −0.76 to −0.24; p<0.001). The creatinine ratio at 48 hours showed the same pattern. Mean eGFR at 48 hours was 19.08 mL/min/1.73 m^2 higher in the minimally invasive group (95% CI 11.52–26.64), while serum urea and BUN were also lower.

Table 4. Frequency and Severity of Early Acute Kidney Injury

Outcome	Minimally invasive, n (%)	Conventional, n (%)	Total, n (%)
No AKI	65 (86.7)	39 (52.0)	104 (69.3)
Any AKI	10 (13.3)	36 (48.0)	46 (30.7)
KDIGO stage 1	7 (9.3)	23 (30.7)	30 (20.0)
KDIGO stage 2	1 (1.3)	7 (9.3)	8 (5.3)
KDIGO stage 3	2 (2.7)	6 (8.0)	8 (5.3)
KDIGO stages 2–3	3 (4.0)	13 (17.3)	16 (10.7)

Any AKI: χ^2=19.597, p<0.001. Overall AKI-stage distribution: $\chi^2(3)$=21.533, p<0.001.

Categorical renal outcomes showed a concordant pattern. A BUN concentration <24 mg/dL was present in 56 of 75 patients (74.7%) in the minimally invasive group compared with 40 of 75 (53.3%) in the conventional group (p=0.011). An eGFR <60 mL/min/1.73 m^2 occurred in 30 of 75 patients (40.0%) after minimally invasive CABG compared with 56 of 75 (74.7%) after conventional sternotomy (p<0.001). The reported comparison of low urine output between surgical groups was not statistically significant. Overall, 46 of 150 patients (30.7%) developed early AKI. AKI occurred in 10 of 75 patients (13.3%) undergoing minimally invasive CABG compared with 36 of 75 (48.0%) undergoing conventional median sternotomy. The continuity-corrected chi-square statistic was 19.597 (p<0.001).

Using the minimally invasive group as the reference, the crude odds of AKI were 6.00 times higher in the conventional group (OR 6.00, 95% CI 2.68–13.42). The corresponding crude relative risk was 3.60 (95% CI 1.93–6.71), and the absolute risk difference was 34.7 percentage points (95% CI 21.0–48.3). These values correct the previously reported crude OR of 5.88, which was not reproduced from the displayed 2×2 counts. Because these estimates are unadjusted and baseline renal function differed between groups, they represent crude associations rather than independent effects of surgical approach.

AKI severity also differed significantly between groups. Stage 1 was the most frequent AKI category, occurring in 23 conventional patients (30.7%) and 7 minimally invasive patients (9.3%). KDIGO stages 2–3 occurred in 13 conventional patients (17.3%) compared with 3 minimally invasive patients (4.0%), demonstrating that the between-group difference extended beyond mild AKI. Low urine output showed the strongest crude association with AKI. Twenty-two of the 46 patients with AKI (47.8%) had low urine output compared with 8 of 104 patients without AKI (7.7%), corresponding to a crude OR of 11.00 (95% CI 4.36–27.73; p<0.001). Conventional surgical approach was also strongly associated with AKI in univariable analysis. Diabetes mellitus, CKD, smoking, and sex were not significantly associated with AKI.

Table 5. Univariable Associations With Early Acute Kidney Injury

Factor	AKI present, n (%)	AKI absent, n (%)	Crude OR (95% CI)	p-value
Low urine output	22 (47.8)	8 (7.7)	11.00 (4.36–27.73)	<0.001
Conventional surgery	36 (78.3)	39 (37.5)	6.00 (2.68–13.42)	<0.001
Diabetes mellitus	14 (30.4)	29 (27.9)	1.13 (0.53–2.42)	0.902
Chronic kidney disease	4 (8.7)	10 (9.6)	0.90 (0.27–3.02)	1.000
Smoking	14 (30.4)	26 (25.0)	1.31 (0.61–2.83)	0.621
Male sex	40 (87.0)	93 (89.4)	0.79 (0.27–2.28)	0.873
Hypertension	44 (95.7)	104 (100.0)	Not estimable§	0.093*

*Fisher's exact test. §The conventional crude OR is not estimable because no non-hypertensive participant was present in the non-AKI group.

Taken together, the reported unadjusted findings consistently demonstrated a lower observed burden of early renal dysfunction in the minimally invasive group. This pattern was present for AKI incidence and severity, serial serum creatinine, change in creatinine, creatinine ratio, eGFR, urea, and BUN. Nevertheless, the significant preoperative differences in serum creatinine and eGFR indicate that these crude comparisons should not be interpreted as demonstrating an independent renal-protective effect of minimally invasive surgical access.

DISCUSSION

The principal finding of this study was a substantial difference in early postoperative AKI between patients undergoing on-pump CABG through minimally invasive anterior minithoracotomy and those undergoing conventional median sternotomy. Early AKI occurred in 13.3% of the minimally invasive group compared with 48.0% of the conventional group, corresponding to a crude relative risk of 3.60 and a crude odds ratio of 6.00 for conventional surgery. The difference was not confined to the binary occurrence of AKI: KDIGO stages 2–3 occurred in 4.0% and 17.3% of the respective groups, while postoperative serum creatinine, creatinine change, eGFR, urea, and BUN showed a concordant pattern. These findings indicate a marked association between operative approach and early postoperative renal dysfunction, although the preoperative difference in renal function and the non-randomized group allocation limit attribution of this association to surgical access alone.

The present findings can be compared directly with recent evidence evaluating renal outcomes after minimally invasive versus sternotomy CABG. Sellin et al. examined minimally invasive total coronary revascularization through anterior minithoracotomy and conventional full sternotomy after propensity-score matching and found no significant between-group difference in the assessed postoperative renal parameters or renal complications, despite longer operation, CPB, and aortic cross-clamp times in the minimally invasive group (10). Similarly, Ong et al. reported broadly comparable renal and other major postoperative complications between propensity-matched minimally invasive and median sternotomy CABG cohorts, although minimally invasive surgery showed favorable recovery characteristics (11). These findings differ in magnitude from the present study, in which AKI was substantially more frequent after conventional sternotomy. Conversely, large observational evidence has demonstrated reductions in several perioperative morbidities with minimally invasive non-sternotomy CABG, including transfusion, ventilation duration, wound complications, hospitalization, and composite morbidity, although such studies do not establish that avoidance of sternotomy itself independently prevents AKI (12). The discrepancies across studies emphasize the importance of differences in patient selection, baseline renal risk, revascularization complexity, use and duration of CPB, transfusion exposure, perfusion management, and statistical adjustment.

The overall AKI frequency of 30.7% observed in the present study is within the broad range described for contemporary cardiac surgical populations. CSA-AKI frequently affects approximately one-fifth to one-third of patients depending on case complexity, baseline risk, diagnostic criteria, and the surgical population studied, and it remains associated with increased postoperative morbidity, longer hospitalization, and poorer short- and long-term outcomes (2,3,13). The high frequency observed particularly in the conventional group should therefore be considered clinically meaningful. At the same time, AKI rates cannot be compared across studies solely on the basis of percentages because the use of KDIGO versus alternative classifications, the inclusion of urine-output criteria, timing of creatinine measurements, underlying renal function, and operative case mix can substantially alter reported incidence (3,5,13).

Baseline renal status is especially important when interpreting the present between-group difference. Before surgery, mean serum creatinine was already lower in the minimally invasive group than in the conventional group (1.00±0.25 vs 1.16±0.37 mg/dL), while mean eGFR was higher (80.37±21.75 vs 71.04±24.08 mL/min/1.73 m^2). Preoperative renal dysfunction is a recognized determinant of CSA-AKI and has long been incorporated into risk-prediction models for adverse renal outcomes after cardiac surgery (6,14). Consequently, direct comparison of postoperative creatinine or eGFR alone could exaggerate the apparent contribution of surgical approach. Importantly, however, the present data also demonstrated a greater 48-hour increase in creatinine after conventional surgery—0.76±1.02 mg/dL compared with 0.26±0.52 mg/dL after minimally invasive CABG—with a between-group difference of 0.50 mg/dL. This change-from-baseline finding reduces, but does not eliminate, concern that the observed postoperative difference merely reflects the preoperative imbalance.

Several interacting biological and perioperative mechanisms could plausibly contribute to the observed pattern, although the present study did not directly measure these pathways. CSA-AKI develops through a complex interaction among renal hypoperfusion, altered oxygen delivery, inflammation, oxidative stress, ischemia-reperfusion injury, hemolysis, endothelial and microcirculatory dysfunction, venous congestion, hemodilution, and exposure to nephrotoxic or hemodynamically active interventions (3,4,13). The extent of surgical tissue injury and perioperative bleeding may additionally influence inflammatory stress, transfusion exposure, fluid requirements, and hemodynamic stability. Contemporary evidence indicates that non-pharmacological renal-protection strategies directed toward maintenance of adequate perfusion, oxygen delivery, and physiological stability can modify postoperative AKI risk, although no single mechanism explains CSA-AKI across all patients (15,16). Therefore, the lower renal injury observed in the minimally invasive group may represent a composite of operative approach, patient selection, perfusion characteristics, and perioperative management rather than an isolated effect of the thoracotomy incision.

This interpretation is particularly relevant because minimally invasive CABG is not necessarily associated with shorter or less demanding CPB exposure. In the propensity-matched analysis by Sellin et al., minimally invasive anterior minithoracotomy was associated with longer CPB and aortic cross-clamp durations than full sternotomy, yet postoperative renal outcomes remained comparable (10). This observation argues against a simple model in which smaller surgical access automatically produces less renal injury. It instead suggests that renal outcomes depend on the balance between preoperative susceptibility and multiple intraoperative stresses. The markedly lower AKI rate observed in the present minimally invasive cohort may therefore reflect favorable interactions among several factors that were not completely captured in the available dataset.

The serial biochemical findings add consistency to the primary AKI outcome. Serum creatinine was lower after minimally invasive CABG at 24, 48, and 72 hours, and the greatest between-group difference occurred at 48 hours. Similarly, eGFR at 48 hours was approximately 19 mL/min/1.73 m^2 higher in the minimally invasive group, while serum urea and BUN were lower. Although eGFR equations have limitations during rapidly changing renal function because serum creatinine is not in steady state, the concordance between serial creatinine, creatinine change, creatinine ratio, eGFR, urea, BUN, and KDIGO staging strengthens the evidence that the conventional group experienced greater early postoperative renal dysfunction. The findings should nevertheless be interpreted primarily using the KDIGO-defined AKI outcome and serial creatinine change rather than eGFR alone (5,13).

Low urine output showed the strongest observed association with AKI, with a crude OR of 11.00. This finding is clinically plausible and reinforces the importance of urine-output surveillance alongside biochemical monitoring. KDIGO incorporates both creatinine and urine-output criteria because oliguria may identify clinically important renal dysfunction before a substantial creatinine rise becomes apparent (5). Serum creatinine is an imperfect early marker because its concentration is affected by fluid balance, distribution volume, muscle mass, and the temporal delay between renal injury and measurable accumulation. Research into earlier biomarkers, including urinary neutrophil gelatinase-associated lipocalin and tubular-injury markers, has therefore sought to improve early recognition of postoperative renal injury (17,18). In the present clinical context, the strong association between oliguria and AKI supports continued close monitoring of both urine output and serial biochemical indices rather than reliance on a single postoperative creatinine measurement. The difference in AKI severity may be as important clinically as the difference in overall incidence. Stage 1 accounted for most AKI cases, but stages 2 and 3 together occurred in 17.3% of conventional sternotomy patients compared with 4.0% of minimally invasive patients. Increasing AKI severity has been associated with progressively worse outcomes after cardiac surgery, and even patients who recover from an acute postoperative episode can remain at increased long-term renal and mortality risk (6,19). Thus, the observed reduction in moderate-to-severe AKI in the minimally invasive group represents an important signal that merits confirmation in studies capable of adjusting rigorously for baseline renal status and operative risk.

The study also demonstrates why surgical approach should be considered within a wider renal-protection framework. Contemporary evidence does not support a single universally effective intervention for CSA-AKI. Instead, preventive strategies emphasize identification of high-risk patients, avoidance of nephrotoxic exposure where possible, individualized hemodynamic management, appropriate fluid therapy, maintenance of adequate oxygen delivery during CPB, and structured perioperative kidney-protection bundles (8,9,13). A systematic review of non-pharmacological interventions similarly supports the principle that renal protection is multifactorial rather than dependent on one operative characteristic (15). Goal-directed perfusion strategies aimed at maintaining adequate oxygen delivery during CPB have also been associated with lower AKI occurrence, particularly less severe forms of renal injury, although the magnitude of benefit varies across studies (16). These considerations are particularly relevant to the current findings because detailed CPB flow, oxygen-delivery, transfusion, perfusion-pressure, and cross-clamp data were not available for comparative analysis.

The findings should also be interpreted in the context of the evolving evidence base for minimally invasive CABG. Current observational and propensity-matched studies generally suggest that minimally invasive CABG can achieve perioperative and longer-term outcomes comparable with sternotomy CABG in appropriately selected patients while potentially reducing selected recovery-related complications (10–12). However, contemporary reviews continue to emphasize the relative scarcity of randomized evidence and the influence of institutional and surgeon experience on outcomes (20). Therefore, the present findings contribute specifically to the emerging renal-outcome literature but should not be interpreted as establishing the superiority of one surgical strategy for all patients requiring CABG. Several strengths support the interpretation of this study. The analysis included equal-sized surgical groups, used the internationally recognized KDIGO framework, evaluated both AKI occurrence and severity, and assessed renal function serially during the clinically relevant early postoperative interval. The consistency of the findings across AKI stage, serum creatinine, change in creatinine, creatinine ratio, eGFR, urea, and BUN provides convergent evidence of greater early renal dysfunction in the conventional group. Reporting both relative and absolute effect estimates further demonstrates that the difference was not merely statistically significant but substantial in magnitude.

Important limitations nevertheless constrain causal interpretation. The study was observational and did not use randomized assignment, making selection bias and residual confounding possible. Baseline creatinine and eGFR differed significantly between groups, with more favorable preoperative renal indices in patients undergoing minimally invasive CABG. Although change-from-baseline creatinine showed a consistent postoperative difference, the available analysis did not include a multivariable model adjusting simultaneously for baseline renal function and other potential confounders. Detailed operative variables with established relevance to CSA-AKI—

including CPB duration, aortic cross-clamp duration, perfusion pressure and flow, oxygen delivery, hemodilution, transfusion exposure, perioperative hypotension, fluid balance, and nephrotoxic medication exposure—were not available for comparative adjustment. The sample was derived from two centers and included 150 patients, which may limit generalizability, particularly to institutions with different case-selection practices or levels of minimally invasive surgical experience. Finally, the study focused on renal outcomes within 48–72 hours and therefore cannot determine whether the observed differences translated into sustained renal recovery, dialysis requirements, chronic kidney disease progression, readmission, or long-term mortality.

Notwithstanding these limitations, the magnitude and internal consistency of the observed renal differences warrant further investigation. Future prospective studies should use standardized KDIGO assessment, detailed perioperative perfusion data, predefined surgical-selection criteria, and multivariable or propensity-based adjustment for baseline renal and operative risk. Larger multicenter cohorts and randomized evidence would be particularly valuable for determining whether minimally invasive CABG independently modifies AKI risk or whether favorable renal outcomes primarily reflect patient selection, center experience, and associated perioperative practices. Until such evidence is available, surgical access should be regarded as one component of a broader individualized strategy for reducing renal risk after CABG.

CONCLUSION

Among patients undergoing elective on-pump CABG, minimally invasive anterior minithoracotomy was associated with a substantially lower observed frequency and severity of early AKI than conventional median sternotomy, together with smaller postoperative increases in serum creatinine, higher eGFR, and lower urea and BUN concentrations. The difference remained evident in change-from-baseline creatinine, but significant preoperative renal differences and the observational design preclude attribution of an independent renal-protective effect to the minimally invasive approach. These findings support consideration of surgical approach within comprehensive perioperative renal-risk assessment and justify larger prospective studies with adjustment for baseline renal function, CPB characteristics, and other perioperative determinants of CSA-AKI.

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