Incidence of postoperative acute kidney injury in patients with chronic kidney disease undergoing minimally invasive valve surgery

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Background: We hypothesize that minimally invasive valve surgery in patients with chronic kidney disease (CKD) is superior to a conventional median sternotomy.

Methods: We retrospectively analyzed 1945 consecutive patients who underwent isolated valve surgery. Included were patients with CKD stages 2 to 5. In-hospital mortality, composite complication rates, and intensive care unit and total hospital lengths of stay of those who underwent a minimally invasive approach were compared with those who underwent a standard median sternotomy. Resource use was approximated based on intensive care unit and total hospital lengths of stay.

Results: There were 688 patients identified; 510 (74%) underwent minimally invasive surgery, and 178 (26%) underwent a median sternotomy. There was no significant difference in mortality. Minimally invasive surgery was associated with fewer composite complications (33.1% vs 49.4%; odds ratio, 0.5; $P \leq .001$), shorter intensive care unit (48 [interquartile range {IQR}, 33-74] hours vs 71 [IQR, 42-96] hours; $P < .01$), and hospital (8 [IQR, 6-9] days vs 10 [IQR, 8-15] days; $P < .001$) lengths of stay, and a lower incidence of acute kidney injury (8% vs 14.7%; odds ratio, 0.5; $P = .01$), compared with median sternotomy. In a multivariable analysis, minimally invasive surgery was associated with a 60% reduction in the risk of development of postoperative acute kidney injury.

Conclusions: In patients with CKD undergoing isolated valve surgery, minimally invasive valve surgery is associated with reduced postoperative complications and lower resource use. (J Thorac Cardiovasc Surg 2013;146:1488-93)

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According to data published by the National Institutes of Health, more than 10% of the US population is diagnosed with chronic kidney disease (CKD), and nearly 113,000 patients will progress to end-stage renal disease each year.[1] Cardiovascular disease is one of the leading causes of morbidity and mortality in this population, and the chronic inflammation, endothelial dysfunction, and metabolic disturbances seen in the progression of CKD have been strongly associated with the development of valvular heart disease.[2,3] Patients undergoing cardiac surgery have a 3.3-fold increased risk of developing acute kidney injury (AKI), with a 2.3-fold increased risk of requiring dialysis, and in the past decade, the associated mortality of AKI after cardiac surgery has increased from 30% to 47%.[4] In the setting of CKD, these effects are augmented, with an increased incidence of CKD progression and late-term mortality.[5]

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When compared with a median sternotomy approach, the reported benefits of minimally invasive valve surgery include decreased blood loss, reduced incidence of postoperative atrial fibrillation, shorter intensive care unit and hospital length of stays, and faster patient recovery.[6-11] These findings have also been reported in such high-risk groups as elderly patients, obese patients, and those undergoing reoperative valve surgery, leading to an increased acceptance of minimally invasive surgery as a viable option to the standard median sternotomy approach.[12-15] The purpose of our study was to analyze the impact of minimally invasive valve surgery on the incidence of postoperative AKI and postoperative complications in patients with stage 2 to 5 CKD. We analyzed the outcomes of patients who underwent valve surgery via a minimally invasive approach, and compared them with a cohort who underwent median sternotomy valve surgery.

METHODS

After obtaining approval from the Mount Sinai Medical Center Institutional Review Board, we retrospectively evaluated 1945 valve operations performed at our institution between January 1, 2005, and December 7, 2011, to identify patients with stage 2 to 5 CKD who underwent isolated mitral or aortic valve surgery. Excluded were patients who had concomitant coronary artery bypass graft surgery, surgery on another valve and/or ascending aorta, a history of cardiac surgery, infective endocarditis, emergency surgery, and stage 1 CKD. The estimated glomerular filtration rate (eGFR) was calculated using the modification of diet in renal

Abbreviations and Acronyms

AKI = acute kidney injury
CKD = chronic kidney disease
eGFR = estimated glomerular filtration rate
IQR = interquartile range
RIFLE = Risk, Injury, Failure, Loss, End-stage renal disease

disease equation: eGFR (mL/min per 1.73 m^2) = 186 × (serum creatinine)$^{-1.154}$ × (age)$^{-0.203}$ × (0.742 if female) × (1.21 if African American). Patients were grouped according to eGFR and the National Kidney Foundation stages for CKD, as follows: stage 1, 90 mL/min per m^2 or higher; stage 2, 60 to 89 mL/min per m^2; stage 3, 30 to 59 mL/min per m^2; stage 4, 15 to 29 mL/min per m^2; and stage 5, less than 15 mL/min per m^2 or patients undergoing dialysis.[16] The median sternotomy surgery was performed by 6 different surgeons, whereas the minimally invasive surgery was performed by a single surgeon.

All patients underwent left heart catheterization and echocardiography to evaluate their valvular lesions, and all operative reports and echocardiograms were reviewed. *Postoperative composite complications* were defined as the development of AKI, prolonged ventilation (>24 hours), reintubation, atrial fibrillation, deep wound infection, pneumonia, sepsis, bleeding requiring reexploration, stroke, or death. *In-hospital mortality* was defined as death at any time after the operation if the patient was not discharged from the hospital alive. The surgical technique time was evaluated by comparing the aortic crossclamp with the total cardiopulmonary bypass times. The definitions and variables selected were based on the Society of Thoracic Surgeons Database definitions. Postoperative AKI was further analyzed by the Risk, Injury, Failure, Loss, End-stage renal disease (RIFLE) classification system, proposed by the Acute Dialysis Quality Initiative group.[16] This classification divides the patients with AKI into 5 categories: (1) risk, GFR decrease of less than 25%, serum creatinine increase of 1.5 times, or urine production of less than 0.5 mL/kg per hour for 6 hours; (2) injury, GFR decrease of greater than 50% and doubling of creatinine or urine production by less than 0.5 mL/kg per hour for 12 hours; (3) failure, GFR decrease of greater than 75%, tripling of creatinine or creatinine increase greater than 355 μmol/L (with an increase of >44 μmol/L [>4 mg/dL]), or urine output lower than 0.3 mL/kg per hour for 24 hours; (4) loss, persistent AKI or complete loss of kidney function for more than 4 weeks; and (5) end-stage renal disease, need for renal replacement therapy for more than 3 months.

Technique for Minimally Invasive Valve Surgery

A femoral or axillary platform was used to establish cardiopulmonary bypass. The femoral/axillary artery was cannulated with a 15-19 Fr arterial cannula (Biomedicus; Medtronic, Minneapolis, Minn), and the femoral vein was cannulated with a 25 Fr venous cannula (Biomedicus). Transesophageal echocardiography was used to aid in the placement of the venous cannula in the superior vena cava.

For the mitral valve procedures, a 5- to 6-cm skin incision was made in the fourth to fifth intercostal space lateral to the anterior axillary line. The mitral valve was accessed through the Waterston groove, then through the atrial septum into the left atrium. Mitral valve repair or replacements were performed in the standard manner. For aortic valve procedures, a 5- to 6-cm right transverse skin incision was made 1 cm lateral to the sternum over the second to third intercostal space. In all aortic valve procedures, the second or third costochondral cartilage was transected to allow adequate exposure of the aorta and avoid fracturing the rib. At the completion of the operation, the rib was reattached to the sternum with a 1-cm metal plate (Synthes, West Chester, Pa), and a fiber wire was placed in a figure-of-eight manner. A left ventricular vent was inserted into the left ventricle via a purse string suture in the right superior pulmonary vein, and a retrograde cardioplegia cannula was inserted via the right atrial appendage using transesophageal echocardiographic guidance. A transverse aortotomy was performed to expose the aortic valve, and valve replacement was performed under direct vision using standard techniques.

For all procedures, cardiopulmonary bypass was initiated at 32°C to 36°C using a closed-membrane oxygenator and roller pump. Venous drainage was augmented with vacuum assistance, applying negative pressures of 30 to 70 mm Hg as needed to decompress the right side of the heart. Transincisional direct aortic crossclamping was performed using a flexible and retractable shaft crossclamp (Novare Surgical Systems, Cupertino, Calif). One dose of antegrade cold blood cardioplegia was given to establish electromechanical arrest of the heart. Thereafter, retrograde cold blood cardioplegia was given throughout the procedure at 20- to 25-minute intervals. If retrograde cardioplegia was not possible, a cardioplegia cannula was left in the ascending aorta, or direct cannulation of the coronary ostia was performed to deliver antegrade cardioplegia. Carbon dioxide was infused into the operative field during the entire procedure. Removal of air from the heart was performed with a venting needle in the root of the aorta and under transesophageal echocardiographic guidance. After discontinuing cardiopulmonary bypass and administering protamine, decannulation was performed. A single chest tube was left in the pleural space. For pain relief, all patients had an On-Q pain relief system inserted (I-Flow Corporation, Lake Forest, Calif). Two catheters were placed in the interspace to deliver 0.25% bupivacaine for 72 hours. The thoracotomy incision was closed in the routine manner.

Statistical Analyses

Patient demographics and operative data were expressed as the mean ± 1 SD, or median and interquartile range (IQR, or 25%-75%), as appropriate. Continuous variables with a normal distribution were compared using an independent Student *t* test and correlation coefficient, when appropriate, whereas variables that did not exhibit a normal distribution were compared using a Mann-Whitney *U* test. A χ^2, Pearson χ^2, or Fisher exact test was used to compare dichotomous variables, when appropriate. A univariable analysis was performed for baseline characteristics, surgical procedural variables, postoperative outcomes, and other known risk factors that could influence the clinical outcomes. The variables with $P \leq .2$ were included in a binary logistic regression analysis to determine their independent effects. The model was assessed by the Hosmer-Lemeshow goodness-of-fit test. All statistical analyses were performed with the assistance of a statistician using SPSS, version 17 (SPSS Inc, Chicago, Ill).

RESULTS

A total of 688 patients were identified. Of these patients, 510 had valve surgery via a minimally invasive approach, and 178 underwent a median sternotomy. The patients in the minimally invasive group were older (71.3 ± 11.6 vs 67.8 ± 12 years; $P = .001$), whereas those in the median sternotomy group had a higher body mass index (27.3 ± 4.8 vs 28.5 ± 5.8 kg/m^2; $P = .03$) and greater incidence of stage 5 CKD (4% vs 1%; $P = .008$). There were no other differences between the 2 groups regarding baseline characteristics (Table 1).

In the entire cohort of patients (excluding those with stage 5 CKD at baseline), 66 developed AKI and 608 did not. Those who developed AKI were significantly older, obese, had a greater incidence of median sternotomy, and had a higher baseline mean pulmonary artery

TABLE 1. Baseline characteristics of the minimally invasive versus median sternotomy groups

Variable	Minimally invasive (n = 510)	Median sternotomy (n = 178)	P value
Age, y	71.3 ± 11.6	67.8 ± 12	.001
Male sex	258 (51)	99 (56)	.21
Body mass index, kg/m^2	27.3 ± 4.8	28.5 ± 5.8	.03
African American race	24 (5)	7 (4)	.84
Diabetes mellitus	130 (26)	45 (25)	.99
Hypertension	393 (89)	151 (86)	.63
Previous myocardial infarction	95 (19)	26 (15)	.29
Chronic obstructive pulmonary disease	125 (25)	50 (30)	.26
Peripheral vascular disease	82 (16)	27 (15)	.86
Preoperative GFR	64.4 ± 16	63.9 ± 18	.53
Preoperative creatinine	1.16 ± 0.36	1.3 ± 0.29	.1
Stage 2 CKD (GFR, 60-89 mL/min per 1.73 m^2)	325 (64)	112 (63)	.95
Stage 3 CKD (GFR, 30-59 mL/min per 1.73 m^2)	167 (33)	57 (32)	.98
Stage 4 CKD (GFR, 15-29 mL/min per 1.73 m^2)	11 (2)	2 (1)	.26
Stage 5 CKD (GFR, <15 mL/min per 1.73 m^2)	7 (1)	7 (4)	.008
Ejection fraction, %*	58 (50-60)	55 (43-60)	.09
Pulmonary artery pressure, mm Hg	27 ± 9	28 ± 9	.58
Hematocrit, %	38.8 ± 4.8	39.4 ± 4.5	.1
Predicted risk for morbidity and mortality, %	19 ± 9	18 ± 10	.14
Predicted risk for acute renal failure, %	5 ± 4	4 ± 3	.16

Data are given as mean ± SD or number (%). *GFR*, Glomerular filtration rate; *CKD*, chronic kidney disease. *Data are given as median (interquartile range).

TABLE 2. Baseline characteristics in patients with postoperative acute kidney injury versus no acute kidney injury (based on 674 patients with CKD stages 2-4)

Variable	Acute kidney injury (n = 66)	No acute kidney injury (n = 608)	P value
Age, y	72 ± 11	70 ± 11	.03
Male sex	30 (45.4)	318 (52.5)	.41
Body mass index, kg/m^2	29 ± 5.5	27 ± 5.1	.04
African American	2 (3)	25 (4)	.49
Diabetes mellitus	22 (34)	147 (24)	.13
Hypertension	63 (96)	527 (87)	.06
Previous myocardial infarction	10 (15)	106 (17)	.8
Chronic obstructive pulmonary disease	17 (26.2)	153 (25.2)	.98
Peripheral vascular disease	8 (12)	99 (16)	.24
Preoperative GFR, mL/min per m^2	64.6 ± 17	65.5 ± 14.7	.63
Preoperative serum creatinine, mg/dL	1.12 ± 0.44	1.1 ± 0.3	.57
Stage 2 CKD (GFR, 60-89 mL/min per 1.73 m^2	40 (61)	397 (65)	.53
Stage 3 CKD (GFR, 30-59 mL/min per 1.73 m^2)	23 (34)	201 (33)	.87
Stage 4 CKD (GFR, 15-29 mL/min per 1.73 m^2)	3 (5)	10 (2)	.12
Ejection fraction, %*	55 (40-64)	58 (50-60)	.71
Pulmonary artery pressure, mm Hg	30.5 ± 9.5	27.1 ± 9.2	.003
Hematocrit, %	38.5 ± 2.9	39 ± 4.5	.47
Median sternotomy surgery	26 (40)	145 (24)	.009
Aortic crossclamp time, min	82 ± 33	78 ± 29	.26
Cardiopulmonary bypass time, min	113 ± 39	106 ± 35	.13

Data are given as mean ± SD or number (%) and are based on the Risk, Injury, Failure, Loss, End-stage renal disease (RIFLE) definition. Excluded in the analysis were patients with stage 5 CKD. *CKD*, Chronic kidney disease; *GFR*, glomerular filtration rate. *Data are given as median (interquartile range).

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pressure. However, the aortic crossclamp and cardiopulmonary bypass times did not differ between the 2 groups (Table 2).

The valve surgery consisted of 323 aortic valve replacements (236 [46%] minimally invasive and 87 [49%] median sternotomy; $P = .6$) and 365 mitral valve operations (274 [54%] minimally invasive and 91 [51%] median sternotomy; $P = .6$). Of the mitral valve operations, there were 110 (40%) versus 31 (34%) replacements ($P = .36$), and 164 (60%) versus 60 (66%) repairs ($P = .36$), in the minimally invasive versus median sternotomy groups, respectively. The mean aortic crossclamp time was 83 ± 27 versus 63 ± 30 minutes ($P < .001$), and the mean cardiopulmonary bypass time was 113 ± 32 versus 87 ± 38 minutes ($P < .001$), for the minimally invasive and the median sternotomy groups, respectively. The patients undergoing minimally invasive surgery had significantly less need for packed red blood cell and fresh-frozen plasma transfusions, when compared with those who had a median sternotomy. No difference was noted in the in-hospital mortality between the minimally invasive and the median sternotomy groups (1% vs 3%; $P = .17$). However, composite postoperative complications were significantly less in the minimally invasive group (33% vs 49%; $P < .001$), driven by a decreased incidence of AKI, atrial fibrillation, prolonged ventilation, reintubation, and sepsis. The intensive care unit and total hospital lengths of stay were 48 (IQR, 33-74) hours versus 71 (IQR, 42-96) hours ($P < .01$) and 8 (IQR, 6-9) days versus 10 (IQR, 8-15) days ($P < .001$) for the minimally invasive and the median sternotomy groups, respectively (Table 3, Figure 1).

Among the patients who developed postoperative AKI, when compared with those who did not develop AKI, there was a higher in-hospital mortality (8% vs 1%; $P < .001$), and composite postoperative complications (64% vs 34%; $P < .001$), with a significant increase in the incidence of pneumonia, need of reintubation, sepsis, deep wound infection, and prolonged ventilation (Table 4, Figure 2). Furthermore, the patients with postoperative AKI had a median intensive care unit length of stay of 116 (IQR, 60-317) hours versus 49 (IQR, 46-77) hours ($P < .001$) and a median total hospital length of stay of 14 (IQR, 10-18) days versus 8 (IQR, 6-10) days ($P < .001$).

TABLE 3. Operative and postoperative outcomes in patients undergoing minimally invasive versus median sternotomy valve surgery

Variable	Minimally invasive (n = 510)	Median sternotomy (n = 178)	*P* value
Aortic valve replacement, No.	236	87	.6
Aortic crossclamp time, min	84 ± 28	68 ± 33	<.001
Cardiopulmonary bypass time, min	111 ± 35	88 ± 24	<.001
Mitral valve replacement, No.	110	31	.36
Aortic crossclamp time, min	71 ± 28	67 ± 36	.4
Cardiopulmonary bypass time, min	100 ± 34	96 ± 43	.6
Mitral valve repair, No.	164	60	.36
Aortic crossclamp time, min	74 ± 30	53 ± 18	<.001
Cardiopulmonary bypass time, min	104 ± 37	77 ± 26	<.001
Transfusion of packed red blood cells, U*	2 (1-3)	4 (2-5)	<.001
Transfusion of fresh-frozen plasma, U*	0.2 (0-3)	2 (0-4)	<.001
Acute kidney injury (based on STS)	11 (2)	11 (7)	.01
Acute kidney injury (based on RIFLE)	40 (8)	25 (15)	.01
Stage 1 (risk)	26 (5)	13 (8)	.32
Stage 2 (injury)	11 (2)	9 (5)	.31
Stage 3 (failure)	3 (1)	3 (2)	.17
Dialysis	8 (2)	3 (2)	.99
In-hospital mortality	7 (1)	6 (3)	.17
Composite complications	169 (33)	88 (49)	<.001
Atrial fibrillation	95 (19)	48 (27)	.02
Pneumonia	22 (4)	7 (4)	.99
Reintubation	30 (6)	21 (13)	.004
Stroke	4 (1)	4 (2)	.24
Sepsis	8 (2)	10 (6)	.008
Wound infection	2 (0.4)	2 (1)	.59
Prolonged ventilation	86 (17)	50 (28)	.002
Bleeding requiring reoperation	12 (2)	5 (3)	.95
Postoperative creatinine (peak), mg/dL	1.28 ± 0.6	1.3 ± 0.6	.47
Intensive care unit length of stay, h*	48 (33-74)	71 (42-96)	<.01
Hospital length of stay, d*	8 (6-9)	10 (8-15)	<.001

Data are given as mean ± SD or number (%). *STS*, Society of Thoracic Surgeons; *RIFLE*, Risk, Injury, Failure, Loss, End-stage renal disease. *Data are given as median (interquartile range).

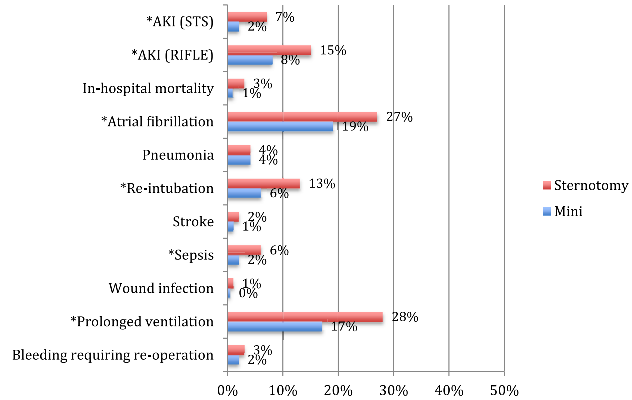

FIGURE 1. Postoperative outcomes in patients undergoing minimally invasive versus median sternotomy valve surgery. The *asterisk* denotes statistically significant differences between groups. *AKI*, Acute kidney injury; *STS*, Society of Thoracic Surgeons; *RIFLE*, Risk, Injury, Failure, Loss, End-stage renal disease; *Sternotomy*, median sternotomy; *Mini*, minimally invasive.

Multivariable analysis revealed that minimally invasive surgery was associated with a reduction in postoperative AKI, whereas mean pulmonary artery pressure, age older than 75 years, cardiopulmonary bypass time greater than 100 minutes, and postoperative sepsis were associated with an increased incidence of AKI (Table 5).

DISCUSSION

Because of an increased incidence of cardiovascular comorbidities and pathophysiological changes associated with chronic uremia, patients with CKD undergoing cardiac surgery have a significant risk of perioperative complications. Preoperative renal dysfunction has been an independent predictor of in-hospital mortality and poor late-term survival, with a nearly 5-fold increased mortality among patients undergoing valve surgery.[17-19] Furthermore, the development of AKI after cardiac surgery is associated with a significant increase in healthcare costs, with small increases in serum creatinine (>0.3 mg/dL) adding nearly $10,000 to the cost of hospitalization.[20] A minimally invasive approach to valve surgery has emerged as a safe and feasible alternative to standard median sternotomy surgery in such high-risk populations as elderly patients, obese patients, and those with a history of sternotomy.[12-15] Our hypothesis was that patients with CKD undergoing isolated valve surgery are at a high risk for perioperative morbidity and mortality and, thus, would benefit from a minimally invasive approach.

In the present study, despite significantly longer aortic crossclamp and cardiopulmonary bypass times in the minimally invasive group, we observed an overall 60% reduction in the risk of development of postoperative AKI. In the entire cohort, the predictors of AKI included an increased mean pulmonary artery pressure, an age of 75 years or older, a cardiopulmonary bypass time of greater than 100 minutes, and postoperative sepsis. The development of AKI was associated with an increased mortality, an increased incidence of infections, the need for reintubation, prolonged ventilation, and significantly longer intensive care unit and hospital lengths of stay. Therefore, minimally invasive valve surgery, by reducing the incidence of AKI, may have reduced the incidence of these complications, and shortened the intensive care unit and hospital lengths of stay.

The data comparing postoperative renal injury between less invasive valve surgery and standard median sternotomy surgery are limited. McCreath and colleagues[21] analyzed a total of 650 patients who underwent mitral valve surgery via

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TABLE 4. Postoperative outcomes in patients with acute kidney injury versus no acute kidney injury

Variable	Acute kidney injury (n = 66)	No acute kidney injury (n = 608)	P value
In-hospital mortality	5 (8)	7 (1)	<.001
Composite complications	42 (64)	204 (34)	<.001
Atrial fibrillation	16 (24)	123 (20)	.54
Pneumonia	13 (20)	15 (3)	<.001
Reintubation	5 (8)	7 (1)	<.001
Stroke	1 (2)	6 (1)	1
Sepsis	10 (15)	8 (1)	<.001
Wound infection	2 (3)	2 (0.3)	.04
Prolonged ventilation	31 (47)	94 (15)	<.001
Bleeding requiring reoperation	4 (6)	13 (2)	.12
Postoperative creatinine (peak), mg/dL	2.24 ± 1	1.17 ± 0.38	<.001
Intensive care unit length of stay, h*	116 (60-317)	49 (46-77)	<.001
Hospital length of stay, d*	14 (10-18)	8 (6-10)	<.001

Data are given as number (%) or mean ± SD. Excluded in the analysis were patients with stage 5 chronic kidney disease. *Data are given as median (interquartile range).

TABLE 5. Multivariable predictors of postoperative acute kidney injury (based on RIFLE criteria)

Variables	Odds Ratio	95% CI	P value
Minimally invasive valve surgery	0.4	0.19-0.88	.02
Mean pulmonary artery pressure	1.03	1.00-1.06	.03
Aged ≥75 y	1.9	1.05-2.07	.03
Cardiopulmonary bypass time >100 min	2.4	1.2-4.6	.007
Postoperative sepsis	6.8	1.9-23	.003

Chronic kidney disease stage, diabetes mellitus, hematocrit lower than 35%, units of packed red blood cells (transfusion), body mass index greater than 35 kg/m^2, and African American race were entered into the multivariable analysis, and were not statistically significant. *RIFLE*, Risk, Injury, Failure, Loss, End-stage renal disease; *CI*, confidence interval.

port access (n = 467) or median sternotomy (n = 183) and found a significant reduction in postoperative renal injury and a trend toward reduced major adverse events among the port-access group. Similar results were reported by Antonic and Gersak,[22] who compared 96 patients undergoing port-access mitral valve surgery with 102 patients undergoing a median sternotomy approach; they found that patients in the median sternotomy group had lower postoperative creatinine clearance and higher incidence of postoperative renal impairment. The present study validates the reported renoprotective benefits of a minimally invasive approach, and demonstrates the safety and feasibility of this technique in patients with CKD. We hypothesize that the renoprotective benefits of minimally invasive valve surgery in patients with CKD may be driven by 2 main factors. First, cardiac surgery is a powerful trigger of immune system activation, leading to the up-regulation of cellular immune factors and the development of systemic immune inflammatory syndrome, which increases the risk of renal injury and failure.[23] By avoiding the surgical trauma and morbidity associated with a median sternotomy, a minimally invasive approach allows for a reduction in postoperative inflammation and enhanced recovery, which may provide renoprotective effects in high-risk populations, such as patients with CKD. Second, because of structural and biochemical alterations that develop in stored erythrocytes, transfusion of packed red blood cells can lead to activation of the inflammatory cascade and impaired oxygen delivery in susceptible populations, which are known contributors of renal dysfunction.[24] In patients undergoing cardiac surgery, transfusion of packed red blood cells is associated with increased risk of postoperative complications, early and late mortality, and hospital length of stay and costs.[25] Therefore, it is plausible that, by decreasing the incidence of blood transfusions and bleeding complications with minimally invasive valve surgery, postoperative renal injury and its associated complications may be reduced. One of the postoperative complications that was significantly reduced with the minimally invasive approach was the incidence of atrial fibrillation. We hypothesize that this reduction in atrial fibrillation may also be because of the decreased trauma leading to a reduction in inflammation.[9] This reduction in the incidence of postoperative arrhythmias, along with the reduction in the perioperative morbidity and in the intensive care unit and hospital lengths of stays, likely leads to a reduction in resource use.

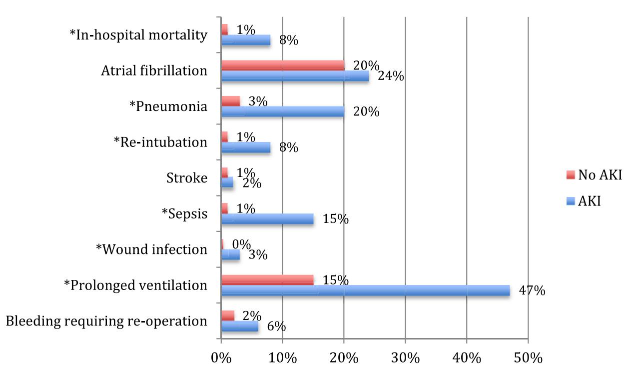

FIGURE 2. Postoperative outcomes in patients with acute kidney injury (*AKI*) versus no AKI. The *asterisk* denotes statistically significant differences between groups.

The main limitation of our study is that it is a retrospective, single-center study. The surgical approaches were performed by 2 different teams of surgeons, which introduces a potential uncontrollable confounder. Furthermore, all minimally invasive operations were performed by a single surgeon (J.L.). Finally, the comparison of the surgical techniques was limited to in-hospital outcomes.

In conclusion, our study demonstrates the safety and feasibility of minimally invasive valve surgery in patients with CKD, which is associated with decreased postoperative complications, faster recovery, and reduced resource use. This approach should be considered as an alternative to standard median sternotomy valve surgery in this high-risk population.

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