Mitral Valve Surgery and Acute Renal Injury: Port Access Versus Median Sternotomy

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Background. **Many outcomes and complications of minimally invasive and conventional cardiac surgery await comparison. Patients undergoing mitral valve surgery commonly sustain renal injury. Using peak postoperative fractional change of serum creatinine as a marker of renal injury, we tested the hypothesis that mitral valve surgery with port access minithoracotomy (Port) and conventional surgery with a median sternotomy (MS) incision are associated with different degrees of acute renal injury.**

Methods. **We evaluated data from all isolated mitral valve operations by a single surgeon between 1990 and 2000 (MS = 90, Port = 227). We also performed a secondary analysis of mitral valve surgeries performed by both MS and Port approaches in a concurrent period from 1996 to 2002 (MS = 93, Port = 240). Univariable and multivariable tests were used to determine the association of surgical technique with peak postoperative creatinine (Cr_{max}Post) and peak postoperative fractional change in creatinine (%ΔCr); p less than 0.05 was considered significant.**

Results. **In our analysis that accounted for the date of surgery, we observed a highly significant independent association between surgical approach and %ΔCr, indicating a greater risk of acute renal injury in the MS group (F value 13.33; $p = 0.0003$). Similar findings were noted in the secondary (time-concurrent) analysis of %ΔCr (F value 12.65; $p = 0.0176$).**

Conclusions. **We present retrospective evidence of reduced acute renal injury associated with the port access technique in mitral valve surgery patients. Our findings suggest that a port access minithoracotomy approach to mitral valve surgery may be preferable to conventional methods for patients with high renal risk.**

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The development of acute renal dysfunction after cardiac surgery is associated with marked increases in morbidity, mortality, and cost. The incidence of this postoperative complication exceeds 7% and renal replacement therapy is necessary in 1% to 2% of patients [1–3]. Despite advances in dialytic technology mortality for patients requiring dialysis after cardiac surgery is greater than 60% [1, 2]. Even minor kidney injury reflected by a serum creatinine rise that never exceeds the normal range is linked to adverse outcomes [4]. In the absence of effective pharmacologic interventions to prevent or treat acute renal injury [5] it is vital to minimize the risk of sustaining kidney damage during cardiac surgery; prevention is better than a cure.

Minimally invasive cardiac surgery has been variably defined as the avoidance of median sternotomy, cardiopulmonary bypass, or manipulation of the ascending aorta [6]. Although outcomes from several case series of minimally invasive procedures have been reported [7, 8], many of the risks and potential benefits of these procedures have not been rigorously compared with equivalent conventional techniques. Minimally invasive cardiopulmonary bypass systems such as the EndoCPB or EndoDirect Systems (Heartport, Redwood City, CA) permit surgical access to the heart through a minithoracotomy incision, or "port," and have been adopted by some surgeons to facilitate a less invasive approach to mitral valve surgery. Patients undergoing mitral valve surgery are particularly susceptible to kidney damage [2]. However, the association of the port access technique with acute perioperative renal injury has not been previously investigated. Therefore we tested the hypothesis that mitral valve surgery with port access minithoracotomy and conventional surgery with a median sternotomy incision are associated with different degrees of acute renal injury.

Patients and Methods

Patient Selection

After Institutional Review Board (Duke University Medical Center) approval (IRB Registry 2179-00-12R0ER, approved December 14, 2000), all consecutive adult patients who underwent isolated mitral valve surgery by a single surgeon (DDG) at Duke University Medical Center between March 1990 and October 2000 were identified. In order to form a time-concurrent group, we also identified all patients who underwent isolated mitral valve surgery

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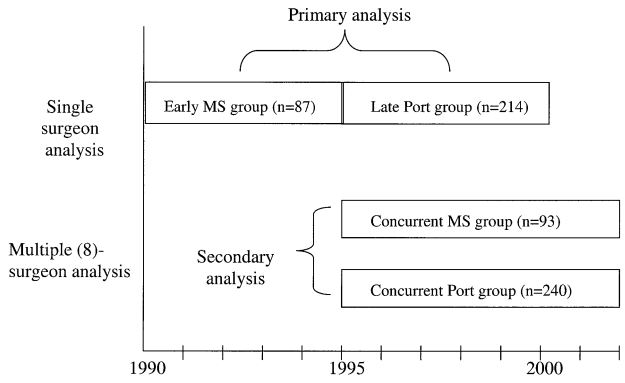

Fig 1. Temporal description of patient selection for the primary (single-surgeon) and secondary (time-concurrent) analyses. MS = *median sternotomy.*

from May 1996 to March 2002. A temporal description of selection of patient cohorts is shown in Figure 1. Patients undergoing combined procedures (eg, double valve replacement) or those procedures in which an external aortic cross-clamp was required during a port access approach were excluded from data collection. Patients who required perioperative renal replacement therapy or who died within the first 2 postoperative days were also excluded as their serum creatinine values did not accurately reflect the degree of renal injury. Demographic data collection included previously described perioperative variables associated with the development of acute renal dysfunction [1, 3]. These variables were gathered for each subject from a retrospective chart review including age, sex, race, weight, presence of peripheral vascular disease, diabetes mellitus, congestive heart failure, chronic obstructive pulmonary disease, carotid bruit, preoperative serum creatinine 133 μmol/L or greater ($\geq$1.5 mg/dL), hematocrit, and left ventricular ejection fraction. Data pertaining to cardiopulmonary bypass (CPB) and aortic occlusion duration, use of inotropic agents at the time of admission to the cardiac intensive care unit, and intraoperative use of an intraaortic balloon pump (IABP) insertion in the operating room was obtained from automated anesthesia records using the ARKIVE Information Management System (Arkive IMS, San Diego, CA). The date of surgery was also recorded for each patient. Outcome data were available from the prospectively gathered Duke Quality Measurement and Management Initiative (QMMI) database and included in-hospital death, stroke, infection, and length of hospital stay.

Renal Function Assessment

Preoperative (CrPre) and daily postoperative serum creatinine (CrPost) values were measured until hospital discharge as per institutional protocol. Serum creatinine was measured using a dry slide enzymatic reflectance technique (Vitros 950; Johnson and Johnson, New Brunswick, NJ) with a normal range of 44 to 133 μmol/L (0.5 to 1.5 mg/dL). Preoperative creatinine was obtained within 1 week before surgery and defined as the value recorded closest to but not on the day of surgery. The peak postoperative creatinine ($Cr_{max}Post$) value was the highest of the daily in-hospital postoperative creatinine values. Preoperative to peak postoperative change in serum creatinine was defined as the difference between the CrPre and $Cr_{max}Post$ expressed as an absolute value (ΔCr) or as a percentage of CrPre ($\%\Delta Cr$). The peak fractional change in serum creatinine for each postoperative day was defined as the difference between the CrPre and CrPost for that day expressed as a percentage of CrPre ($\%\Delta Cr_{daily}$). Creatinine clearance (CrCl) values were derived from CrPre and $Cr_{max}Post$ values using the Cockroft-Gault equation [9].

Anesthesia and Surgery

Anesthesia was managed per the attending anesthesiologist's preference. Use of agents with potential renal effects (eg, intravenous dopamine, antifibrinolytic agents) was not regulated. Antifibrinolytic agent usage changed during the study period. Administration of ε-aminocaproic acid went from being uncommon to routine during 1992 (10 g intravenous bolus pre-CPB, then 1 g/h $\times$ 5 hours) [10]. Aprotinin (high-dose regimen) was generally used for revision surgery after 1995.

The CPB circuit was primed with mannitol (50 g of 20% solution), crystalloid solution (0.9% normal saline) and packed red blood cells to achieve a hematocrit of 0.18 or higher during CPB. Extracorporeal perfusion was maintained using a nonpulsatile flow of 2 to 2.4 $L \cdot min^{-1} \cdot m^{-2}$. Since 1990 the Cobe CML Duo flatsheet membrane oxygenator (Cobe Laboratories, Lakewood, CO) was used in most cases. Some surgeries were performed using the Terumo Capiox hollow fiber membrane oxygenator (Terumo Cardiovascular Systems, Ann Arbor, MI). The arterial carbon dioxide tension was main-

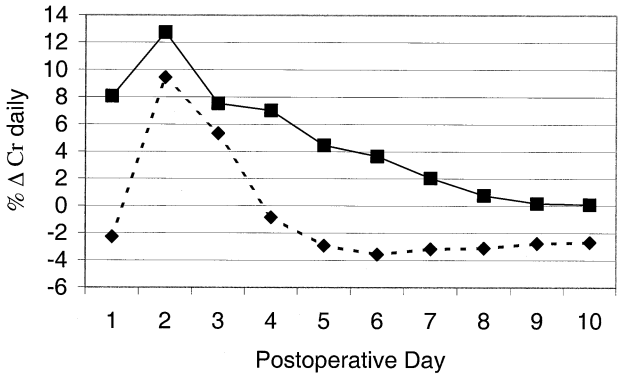

Fig 2. Daily postoperative fractional change in serum creatinine (Cr) after mitral valve surgery. Data are population-averaged mean values. The day of peak fractional change in creatinine ($\%\Delta Cr$) varies among patients. $\%\Delta Cr_{daily}$ = daily postoperative fractional *change in serum creatinine; MS* (squares; *n = 87) = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp; Port* (diamonds; *n = 214) = mitral valve surgery through a minithoracotomy incision employing fibrillatory arrest or an endovascular balloon catheter for aortic occlusion.*

tained throughout CPB at 35 to 40 mm Hg (uncorrected for temperature), with the arterial oxygen tension maintained at 150 to 250 mm Hg. Mean arterial pressure was maintained between 50 and 70 mm Hg during CPB using intravenous phenylephrine or sodium nitroprusside as required. Although antegrade and retrograde blood cardioplegia delivered between 6°C and 8°C was the myocardial protection strategy of choice, cardiac fibrillation without aortic occlusion was employed at the discretion of the surgeon. An arterial line filter (Pall Medical, Ann Arbor, MI) was used in the circuit throughout the duration of CPB. Target inflow temperature during CPB was 28°C and patients were actively rewarmed to a nasopharyngeal temperature of 36.5°C before discontinuation of CPB. Except during the period of heparin anticoagulation, shed blood was not reinfused. Postoperative mediastinal shed blood was discarded. Intraoperative cell salvage was used only for redo procedures where a cell saver was used and all salvaged blood was washed before reinfusion. The average crystalloid fluids administered in the first 24 hours postoperatively was 1,000 to 1,500 mL lactated Ringer's solution and 500 to 1,000 mL hetastarch solution.

Identification of Patient Groups

During a 3-month period ending August 1996 the surgeon's approach to the mitral valve changed from a median sternotomy incision and ascending aorta cannulation (patient group MS) to a right anterolateral thoracotomy (7 cm) incision and the use of a minimally invasive CPB system (EndoCPB System) with femoral artery cannulation (patient group PortFem). This port access approach employs an endovascular balloon catheter advanced from the femoral artery to occlude the ascending aorta in the place of an external aortic cross-clamp. From July 1998 onward the port access arterial cannulation site was changed to the ascending aorta (patient group PortA). If endovascular balloon catheter aortic occlusion was contraindicated (eg, aortic ectasia) in port access patients an external aortic cross-clamp was used at the discretion of the surgeon; these procedures were excluded from analysis.

For the secondary time-concurrent analysis, patients operated on by the median sternotomy approach were identified as the MS group and those operated on by the port access approach were identified as the Port group.

Statistical Analysis

Univariable comparisons of demographic and renal function data were made using Student's t tests for continuous variables and χ^2 or Fisher's exact tests for categorical variables. PortFem and PortA groups were separately analyzed using an analysis of variance test and combined (Port) for comparison with the MS group. Peak fractional change in creatinine (%ΔCr) was selected as the primary outcome in this study as this marker has been shown to be a reliable indicator of acute renal injury [11]. The association of Port and MS with %ΔCr was then examined by using multivariable linear regression analyses. First we performed a full-model analysis in which we included all the demographic, comorbidity, and intraoperative data. To follow up this analysis we implemented a stepwise selection so that the final model includes only variables that are significantly ($p < 0.10$) associated with the outcome (%ΔCr).

A second analysis of covariance was then performed to identify similar associations with Cr_{max}Post. Because of the potential for non-normal distribution of Cr_{max}Post values, and to assess generalizability and robustness of results, this analysis was then repeated on ranked data. This approach was used for both, the primary and secondary (time-concurrent) analyses. Additional data analysis included graphic, temporal display of 10-day postoperative serum creatinine patterns between Port and MS groups. Missing postdischarge serum creatinine values from postoperative days 4 to 10 were imputed to equal the final in-hospital serum creatinine value. A p value less than 0.05 was considered significant. All statistical analyses were performed using the SAS statistical software version 8.0 (SAS Institute, Cary, NC)

Results

Primary Analysis

A total of 333 patients met the defined selection criteria. Demographic and renal function data were collected for all PortFem (n = 81), PortA (n = 146), and MS (n = 90) patients during this study. Sixteen patients were excluded from the study for the following reasons: Port patients requiring the use of an external aortic cross-clamp (n = 9); incomplete data (MS n = 1); and patients requiring perioperative renal replacement therapy (Port n = 4, MS n = 2). The incidence of new-onset postoperative dialysis in the Port and MS groups was similar (2.1 versus 2.8%; $p = 0.75$). Univariable analysis of demographic data demonstrated no significant differences between PortFem and PortA groups. Therefore, a combined Port group was used for further comparison with the MS group.

Demographic variables were broadly similar in the Port and MS groups (Table 1). However, some differences were noted including several known renal risk factors that were more common in the MS patients (ie, African-American ethnicity, congestive heart failure, chronic obstructive pulmonary disease, preoperative serum creatinine 133 μmol/L or greater (≥1.5 mg/dL), low preoperative hematocrit and aortic occlusion time).

Preoperative serum creatinine and estimated creatinine clearance were similar between patient groups. However, postoperative markers of renal function were significantly different between Port and MS patients with regard to Cr_{max}Post (104.3 ± 36.3 versus 127.2 ± 84.0 μmol/L; $p = 0.02$), ΔCr (15.4 ± 25.3 versus 33.6 ± 67.8 μmol/L; $p = 0.02$), and %ΔCr (18.5 ± 28.8 versus 35.4% ± 58.3%; $p = 0.01$; Table 2). Figure 2 illustrates the population-averaged $\%\Delta Cr_{daily}$ for the MS and Port groups over the 10 days after surgery (Fig 2).

The primary multivariable analysis that accounted for significant demographic covariates in the univariate

Table 1. Patient Demographics

Variable	Port (n = 214)	MS (n = 87)	*p* Value
Age (years)	57.4 (13.9)	57.2 (14.8)	0.91
Female (%)	42.5	32.6	0.11
African-American ethnicity (%)	10.3	20.7	0.02
Weight (kg)	73.1 (15.3)	73.2 (15.6)	0.95
PVD (%)	6.5	7.0	0.89
DM (%)	7.9	8.1	0.96
CHF (%)	83.1	93.1	0.02
COPD (%)	8.9	20.9	0.004
Carotid bruit (%)	1.9	3.5	0.40
CrPre ≥133 μmol/L (%)	4.2	11.5	0.02
Preoperative hematocrit (%)	39.5 (5.8)	37.4 (6.1)	0.007
Ejection fraction (%)	53.4 (11.9)	56.3 (12.6)	0.06
Repair/replacement (%/%)	59.8/40.2	48.3/51.7	0.07
Revision surgery (%)	11.2	16.1	0.25
CPB duration (min)	181.2 (50.7)	170.9 (82.4)	0.28
Aortic occlusion duration (min)	119.2 (48.9)	103.5 (33.8)	0.003
Vfib (no aortic occlusion) (%)	13.6	5.8	0.05
Postoperative inotropes (%)	28.2	29.2	0.86
IABP (%)	0	1.2	0.29

Univariable comparisons are presented. Numbers are mean values or percentages; values in parentheses represent SD.

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; CPB = cardiopulmonary bypass; CrPre = preoperative serum creatinine; DM = diabetes mellitus; IABP = postbypass insertion of intraaortic balloon pump; inotropes = use of dopamine (≥5 μg/kg/min) or epinephrine (>0.03 μg/kg/min) at the time of admission to the cardiac intensive care unit; MS = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp; Port = mitral valve surgery through a minithoracotomy incision employing fibrillatory arrest or an endovascular balloon catheter for aortic occlusion; PVD = peripheral vascular disease; Vfib = fibrillatory arrest technique instead of aortic occlusion.

analysis demonstrated a highly significant association between surgical approach and %ΔCr (F value = 13.33; $p = 0.0003$), indicating a greater risk of acute renal injury with MS surgery. Notably, the date of surgery was not a significant predictor of %ΔCr ($p = 0.45$). A similar multivariable analysis for $Cr_{max}Post$, also controlling for the differences between groups in demographic variables, again indicated that MS surgery was associated with a greater renal injury (F value = 12.72; $p = 0.0004$). Association of previously recognized renal risk factors (CPB duration and CrPre) [1] with %ΔCr and $Cr_{max}Post$ were also confirmed (Table 3). An assessment of ranked data revealed comparable results.

We also analyzed the data looking at the differences in creatinine values between fibrillated (n = 35) and nonfibrillated patients (n = 281) in our primary groups of patients (Table 4). Patients who were fibrillated during surgery had a lower but statistically insignificant difference in peak postoperative creatinine ($Cr_{max}Post$: 106.1 μmol/L versus 123.8 μmol/L; $p = 0.21$); fibrillated patients also showed a lower %ΔCr that also did not reach significance (16.6% versus 26.8%; $p = 0.23$). When this variable (fibrillated) was tested in the multivariable model, it was not significantly associated with %ΔCr ($p = 0.41$), or $Cr_{max}Post$ ($p = 0.38$).

Table 2. Renal Function Assessment

Variable	Port (n = 214)	MS (n = 87)	*p* Value
CrPre (μmol/L)	88.8 (25.4)	93.5 (37.3)	0.28
$Cr_{max}Post$ (μmol/L)	104.3 (36.3)	127.2 (84.0)	0.02
ΔCr (μmol/L)	15.4 (25.3)	33.6 (67.8)	0.02
%ΔCr (%)	18.5 (28.8)	35.4 (58.3)	0.01
CrClPre (mL/min)	81.7 (30.4)	79.1 (28.9)	0.50
CrClPost (mL/min)	71.3 (28.0)	65.0 (30.2)	0.09

Univariable comparisons are presented. Numbers are mean values or percentages; values in parentheses represent SD.

Δ = change; ΔCr = $Cr_{max}Post$ − CrPre; %ΔCr = peak postoperative fractional change of serum creatinine; CrClPre = preoperative creatinine clearance; CrClPost = lowest postoperative creatinine clearance; $Cr_{max}Post$ = peak postoperative serum creatinine; CrPre = preoperative serum creatinine; Port = mitral valve surgery through a minithoracotomy incision employing fibrillatory arrest or an endovascular balloon catheter for aortic occlusion; MS = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp.

We additionally analyzed data on the 9 patients who had external aortic cross clamps placed. These were all Port patients. These external clamp patients (n = 9) were compared with other Port patients (n = 227) and also with all other patients (n = 316) in the study population (Table 5). All nine patients who had external clamps placed had higher peak postoperative creatinine and %ΔCr compared with other patients. However, neither value reached statistical significance.

Secondary Analysis

A total of 333 patients underwent isolated mitral valve surgery between May 1996 and March 2002. Eight surgeons performed 93 median sternotomy surgeries and 240 port access procedures for mitral valve repair/

Table 3. Multivariable Analyses of Renal Function Markers in Mitral Valve Surgery

	F Value	*p* Value
%ΔCr		
MS	13.33	0.0003
CPB duration	10.99	0.001
$Cr_{max}Post$		
MS	12.72	0.0004
CrPre	12.31	0.0005

Only variables (see Table 1) that were significant covariates ($p < 0.05$) were included in the final statistical models. Analysis repeated on ranked data demonstrated similar results.

%ΔCr = preoperative to peak postoperative fractional change of serum creatinine; CPB = cardiopulmonary bypass; $Cr_{max}Post$ = peak postoperative serum creatinine; CrPre = preoperative serum creatinine; MS = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp.

Table 4. Univariate Comparison of Serum Creatinine Values Between Fibrillated (n = 35) and Nonfibrillated Patients (n = 281)

Variable	Fibrillated	Nonfibrillated	*p* Value
CrPre (μmol/L)	97.2 (44.2)	97.2 (70.7)	0.98
Cr_{max}Post (μmol/L)	106.1 (53.0)	123.8 (106.1)	0.21
%ΔCr (%)	16.6 (47)	26.8 (48)	0.23

Numbers are mean values or percentages; values in parentheses represent SD.

Δ = change; %ΔCr = peak postoperative fractional change of serum creatinine; Cr_{max}Post = peak postoperative serum creatinine; CrPre = preoperative serum creatinine.

replacement during this period. Demographics for these groups are shown in Tables 6 and 7. As in the primary analysis there were some differences between groups with regard to some demographic variables (African-American ethnicity, chronic obstructive pulmonary disease, CrPre >133 μmol/L, preoperative hematocrit, ejection fraction, repair/replacement ratio, CPB duration and packed red cells transfusion. Although MS patients received more transfusions than Port patients (0.7 versus 1.11; $p = 0.02$), this variable was not independently associated with %ΔCr in the multivariable analysis (see Tables 6 and 7).

In the stepwise multivariable analysis of factors associated with %ΔCr in this time-concurrent dataset (Table 8), there was a significant association between MS surgery and %ΔCr (F value 12.65; $p = 0.0176$) after accounting for preoperative differences between groups. Other covariates that were significantly associated with %ΔCr in this analysis were CrPre (F value −4.73; $p = 0.046$) and preoperative hematocrit (F value −0.83; $p = 0.018$).

A graphic description of unadjusted %ΔCr values for the primary (single-surgeon) and secondary (time-concurrent) patient groups is shown in Figure 3. These values were not statistically analyzed for differences.

Comment

We present retrospective evidence suggesting that port access mitral valve surgery is associated with less perioperative acute renal injury than conventional techniques. In the absence of prospective randomized trials this is the first comparison of perioperative organ injury between unselected patient cohorts undergoing mitral valve surgery by port access and traditional surgical techniques. In addition we have confirmed the association of previously known perioperative variables with the development of acute renal injury after mitral valve surgery. The technical feasibility of port access mitral valve surgery has been well established but our data suggesting that this surgical approach is associated with reduced renal risk relative to traditional techniques requires prospective validation.

Although complications for minimally invasive mitral valve surgery have been previously reported [7, 8], specific organ injury has not been compared with traditional techniques [12, 13]. The minimally invasive technique has been previously reported to be "safe" in patients with renal dysfunction [14, 15] However, none of these studies looked specifically at the application of the technique in equivalent mitral valve surgery patients. Outcome data are also limited to reports of small case series [16, 17] or the Port-Access International Registry (PAIR) and reported results relating to adverse renal outcomes are inconsistent [7, 8]. Although the first PAIR study [7] reported a 0.5% renal failure rate in port access mitral valve surgery, a recent Internet-based update of the registry reports a 2.7% renal failure rate in the same updated population (unpublished data accessed from the Heartport-supported [Heartport, Redwood City, CA] World Wide Web site at http://www.heartport.com/webpage _templates/PAIR2000.pdf). Our study is the first comparative report of the association between two different surgical techniques of mitral valve surgery and perioperative renal injury.

Although we believe that the findings of this report are important, there are limitations inherent to our study design. Our study tests a hypothesis on retrospectively collected data and does not have the rigorous controls of a randomized clinical trial. However, serum creatinine values for this study were obtained from the computerized Duke University Medical Center Information Systems and individual patient charts with a yield close to 100%. Other data were gathered from the prospectively gathered quality assurance QMMI database. The study involved patients enrolled over a 10-year period during which major changes occurred in patient management for mitral valve disorders. Prosthetic valve technology, indications for valve repair, anesthetic and medical management, and other factors involved in treatment of mitral valve disease have changed during this time

Table 5. Univariate Comparison Between 9 Patients Who Had External Aortic Cross-Clamps Placed Versus Other Port Patients and Versus All Other Patients in Study Population

Variable	External Clamp (n = 9)	Other Port (n = 227)	*p* Value	All Patients (n = 316)	*p* Value
CrPre (μmol/L)	106.1 (2.52)	97.2 (61.9)	0.4	97.2 (70.7)	0.6
Cr_{max}Post (μmol/L)	176.4 (194.5)	106.1 (61.9)	0.29	123.8 (97.2)	0.4
%ΔCr (%)	62.1 (112.1)	20.0 (37.1)	0.29	24.6 (44.5)	0.3

Numbers are mean values or percentages; values in parentheses represent SD.

Δ = change; %ΔCr = peak postoperative fractional change of serum creatinine; Cr_{max}Post = peak postoperative serum creatinine; CrPre = preoperative serum creatinine.

Table 6. Demographics in the Time-Concurrent Patient Cohort

Variable	Port (n = 240)	MS (n = 93)	*p* Value
Age (years)	57.5 (14.4)	57.1 (15.9)	0.81
Female (%)	51.2	58.2	0.25
African-American ethnicity (%)	9.6	21.4	0.003
Weight (kg)	74.3 (14.9)	75.9 (18.3)	0.45
PVD (%)	7.1	5.1	0.50
DM (%)	11.0	9.0	0.60
CHF (%)	79.5	80.6	0.82
COPD (%)	8.7	19.4	0.006
Carotid bruit (%)	1.7	5.1	0.07
CrPre ≥133 μmol/L (%)	5.0	19.4	0.001
Preoperative hematocrit (%)	39.4 (6.7)	37.5 (7.2)	0.02
Ejection fraction (%)	52.1 (12.5)	59.9 (12.6)	0.03
Postoperative inotropes (%)	22.1	28.6	0.22
Repair/replacement (%/%)	64.2/35.8	35.8/64.2	0.001
CPB duration (min)	183.2 (54.4)	171.6 (59.9)	0.04
Aortic occlusion duration (min)	119.2 (61.5)	109.2 (52.1)	0.20
IABP (%)	0	1.2	0.32
RBC units within 48 hours	0.7 (1.5)	1.1 (1.7)	0.02
Postoperative cardiac output (L/min)[a]	5.6 (4.8)	5.6 (0.5)	0.93

Univariable comparisons are presented. Numbers are mean values or percentages, values in parentheses represent SD.

[a] N = 178.

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; CPB = cardiopulmonary bypass; CrPre = preoperative serum creatine; DM = diabetes mellitus; IABP = postbypass insertion of intraaortic balloon pump; inotropes = use of dopamine (≥5 μg/kg/min) or epinephrine (>0.03 μg/kg/min) at the time of admission to the cardiac intensive care unit; MS = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp; Port = mitral valve surgery through a minithoracotomy incision employing fibrillatory arrest or an endovascular balloon catheter for aortic occlusion; PVD = peripheral vascular disease; RBC = packed red blood cells.

period. Patient referral and selection patterns in our cohort have also varied over time, as highlighted by the difference in demographic data between Port and MS groups. However, multivariable analysis including demographic factors and controlling for the date of surgery should account for the differences in known renal risk factors and minimize any potential bias. Among port access patients the cardiopulmonary bypass technique altered during the study period and the arterial cannulation site changed from the femoral artery to the ascending aorta. Despite the change in technique separate analysis of PortA and PortFem patients failed to reveal any significant differences and therefore they were combined for comparison with the MS patients. Our study examined a consecutive series of patients undergoing isolated mitral valve surgery performed by a single surgeon at a single institution during a period when surgical technique changed. The transition from one technique to the other was gradual; 21 patients in the MS group underwent surgery after the introduction of minimally invasive technology. Although ineligibility for port access surgery may have contributed to higher renal risk for these patients (eg, peripheral vascular disease would contraindicate PortFem surgery), peripheral vascular disease was accounted for in the multivariable analysis.

The selection of a creatinine-based marker (%ΔCr) as an indicator of acute renal injury was based on the strength of the association of this marker with mortality and other adverse outcomes after cardiac surgery [18]. Peak postoperative creatinine is also independently linked with adverse outcome [11]. As a consequence, we performed a secondary analysis of this variable (Table 3). Although %ΔCr and Cr_{max}Post were selected as good markers of renal filtration function [11, 18] they do not address the numerous other homeostatic roles of the kidney including osmolality, electrolyte and acid-base regulation and production and release of enzymes and hormones. History of nonsteroidal antiinflammatory drugs (NSAID) use was not included in our statistical models. However, routine NSAID administration was introduced in 1998 and was commonly used for Port patients during the first 48 hours after surgery. Any unmeasured bias attributable to NSAID-related nephrotoxicity would be expected to increase renal injury in the Port group, diminishing the effect we observed. Another difference in aortic occlusion times between groups demonstrated a trend toward significantly longer times in the Port group (Table 1). However, this factor was accounted for in the multivariable analysis but was not found to be significantly associated with either marker of renal function. Moreover, any adverse renal effect of longer aortic occlusion times in the port access patients would have decreased the difference in creatinine-derived variables we observed in our analyses. Although our report provides the first comparison of renal injury in a large number of patients undergoing equivalent mitral valve surgery using minimally invasive and traditional meth-

Table 7. Renal Demographics in the Time-Concurrent Patient Cohort

	Port (n = 240)	MS (n = 93)	*p* Value
CrPre (μmol/L)	90.1 (29.1)	99.0 (53.5)	0.04
Cr_{max}Post (μmol/L)	106.8 (51.4)	128.94 (82.1)	0.01
ΔCr (μmol/L)	16.7 (47.1)	29.97 (76.9)	0.33
%ΔCr (%)	19.9 (36.5)	33.58 (56.4)	0.08
CrClPre (mL/min)	83.0 (30.0)	76.21 (29.5)	0.67
CrClPost (mL/min)	72.7 (28.3)	63.54 (30.3)	0.15
Postoperative dialysis (%)	1.1	1.6	0.76

Univariable comparisons are presented. Numbers are mean values or percentages; values in parentheses represent SD.

Δ = change; ΔCr = Cr_{max}Post − CrPre; %ΔCr = peak postoperative fractional change of serum creatinine; CrClPre = preoperative creatinine clearance; CrClPost = lowest postoperative creatinine clearance; Cr_{max}Post = peak postoperative serum creatinine; CrPre = preoperative serum creatinine; Port = mitral valve surgery through a minithoracotomy incision employing fibrillatory arrest or an endovascular balloon catheter for aortic occlusion; MS = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp.

Table 8. Multivariable Analysis of Factors Associated With %ΔCr in the Time-Concurrent Patient Cohort

Variable	Parameter Estimate	Standard Error	*p* Value
Intercept	70.50	14.71	<0.0001
MS surgery	12.65	5.30	0.0176
CrPre (μmol/L)	−4.73	2.36	0.0465
Preoperative hematocrit (%)	−0.83	0.35	0.0182

%ΔG = peak postoperative fractional charge of serum creatinine; CrPre = preoperative serum creatinine; MS = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp.

ods the data are retrospective and reflect a decade of practice. Although it would be ideal, it is unlikely that a randomized trial will be performed to confirm our findings.

The results of our study are novel and prompt speculation as to a possible mechanistic interpretation. The major differences between the MS and Port procedures relate to the location and size of incision and the method of aortic occlusion. Other studies have failed to demonstrate any major differences in outcome between sternotomy and minithoracotomy incisions [19, 20]. The method of aortic occlusion represents an important difference between the MS and Port techniques. It has been proposed that aortic manipulation increases embolization of ascending aorta atheroma; extensive evidence supports the relationship of ascending aortic arteriosclerosis and atheroemboli with postcardiac surgery complications including acute renal injury [21–23]. A mechanistic rationale that could explain the findings of our study is that different rates of atheroemboli-related complications, including acute renal injury, result from differences between the two methods of aortic occlusion. Port patients who had external aortic clamps (n = 9) demonstrated markedly greater Cr_{max}Post and %ΔCr values compared with other Port and MS patients (Table 5). However, neither value reached statistical significance. Since there were only 9 patients in this external clamp group, this finding may be considered only suggestive of greater renal dysfunction in Port patients who had an external clamp placed. The higher creatinine values in this group of 9 patients are consistent with our theory that aortic manipulation from cross-clamp versus endo-balloon occlusion may increase atheroembolic injury in the kidneys. Endovascular balloon occlusion may cause less aortic wall distortion than external cross-clamping [24]. However, balloon migration may probably also be associated with detachment of atheroemboli. The original rationale for use of the port access approach to mitral valve surgery was to safely achieve surgical goals with reduced pain, accelerated recovery, and improved cosmesis [7, 16]. Our observation of reduced perioperative renal injury with the port access technique suggests that this technique may be beneficial in patients at high risk for postoperative renal dysfunction. It is also interesting to note that there has been no major change in the degree of perioperative renal injury as represented by %ΔCr in the MS group of patients whether operated during the period from 1990 to 1996 (primary cohort) or from 1996 to 2002 (secondary cohort; see Fig 3). This probably indicates that the procedure as a whole has consistently posed a risk of renal injury over time rather than increasing patient morbidity.

In summary, we present retrospective evidence that port access mitral valve surgery is associated with less acute renal injury than conventional techniques. A trend toward reduced major adverse outcomes was also observed. Our findings suggest that a port access approach to mitral valve surgery may be indicated for patients at high risk of perioperative acute renal dysfunction.

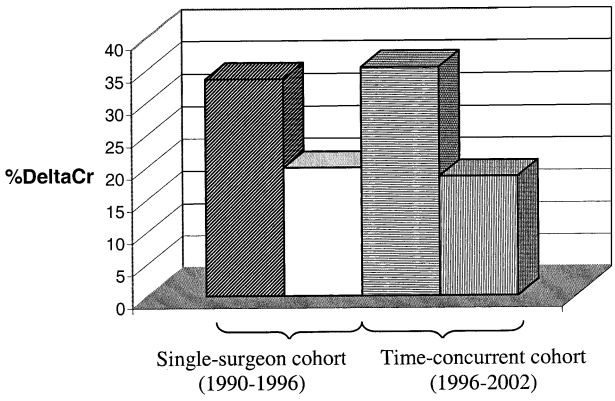

Fig 3. Unadjusted %DeltaCr values for MS and Port groups of patients from the primary (single-surgeon) and secondary (time-concurrent) analyses. Diagonally shaded bar = *MS 1990–1996 (n = 87);* open bar = *Port 1996–2000 (n = 214);* horizontally shaded bar = *MS 1996–2002 (n = 93);* vertically shaded bar = *Port 1996–2002.* (%DeltaCr = *peak postoperative fractional change in creatinine; MS = mitral valve surgery through a median sternotomy incision employing fibrillatory arrest or an external aortic cross-clamp; Port = mitral valve surgery through a minithoracotomy incision employing fibrillatory arrest or an endovascular balloon catheter for aortic occlusion.)*

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