Effect of preoperative non–dialysis-dependent renal dysfunction on isolated aortic and mitral valve surgery: A propensity score analysis

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Objective: Our objective was to examine whether preoperative non–dialysis-dependent renal dysfunction is associated with operative mortality or morbidity in isolated valve surgery.

Methods: We reviewed consecutive patients undergoing isolated aortic (n = 2132) or mitral valve (n = 1664) surgery, between 1996 and 2009. Preoperative renal dysfunction was defined as preoperative estimated glomerular filtration rate < 60 mL/min without dialysis. Propensity score 1:1 matched samples were created, one for aortic (n = 626) and one for mitral (n = 526) valve surgery.

Results: The mean age was 70 ± 9 and 65 ± 10 years for the aortic and mitral groups, respectively. In the aortic cohort, patients with preoperative renal dysfunction had greater need for inotropes (39% vs 29%; *P* = .009), length of intensive care unit stay (27 vs 25 hours; *P* = .006), and duration of mechanical ventilation (8.2 vs 6.6 hours; *P* < .001). Operative mortality was 3.2% in the group with preoperative renal dysfunction and 2.2% in the group without preoperative renal dysfunction (*P* = .5). In the mitral cohort, patients with preoperative renal dysfunction had greater need for inotropes (47% vs 36%; *P* = .013), length of intensive care unit stay (40 vs 26 hours; *P* = .01), and duration of mechanical ventilation (7.2 vs 6.5 hours; *P* = .004). Operative mortality was 0% and 2.7% in the groups without and with preoperative renal dysfunction, respectively (*P* = .015).

Conclusions: Preoperative renal dysfunction is associated with higher morbidity in both cohorts, and patients undergoing mitral valve surgery also experienced higher mortality. The impact of non–dialysis-dependent preoperative renal dysfunction appears to be more pronounced in patients undergoing mitral valve surgery, potentially owing to their relative intolerance to volume overload. (*J Thorac Cardiovasc Surg* 2011;142:155-61)

Chronic kidney disease is a significant public health problem whose prevalence is progressively increasing in the world, particularly in developed countries.^{1,2} Chronic kidney disease is a widely known risk factor for the development and progression of cardiovascular diseases and currently affects approximately 2 million Canadians, which accounts for 6% of the total population in Canada.³⁻⁵ As a consequence, preoperative renal dysfunction (PRD) is prevalent in patients undergoing cardiovascular surgery. In a recent multicenter Canadian cohort study, approximately 30% of the patients undergoing cardiovascular surgery had an estimated preoperative glomerular filtration rate (GFR) less than 60 mL/min.⁶

The implications of kidney failure with chronic renal replacement therapy (chronic kidney disease stage 5) on cardiovascular surgical outcomes are widely known.⁷⁻¹⁰ Also,

the influence of the preoperative renal function on the development of postoperative acute renal failure and on operative mortality (OM) after cardiac surgery has been documented.¹⁰ In addition, multiple studies have shown increased mortality and morbidity in patients undergoing coronary artery bypass graft (CABG) surgery with non–dialysis-dependent chronic renal failure.¹¹⁻¹⁴ PRD has also been found to be a significant predictor of late mortality in CABG surgery.¹⁵ However, in isolated valve surgery, the association between PRD and mortality and morbidity has not been as well defined. We also hypothesized that the impact of PRD may be different in patients undergoing aortic valve surgery (AVS), primarily for pressure overload physiology, versus mitral valve surgery (MVS) for predominantly volume overload pathology.

METHODS

Ethical Requirements and Study Setting

The University of Toronto Research Ethics Board approved this study, and given the observational study design, an individual patient consent was waived. The study setting is the Toronto General Hospital in Toronto, Ontario, Canada.

Study Design and Participants

From a cohort of patients who underwent cardiac surgery at the Toronto General Hospital between 1996 and 2009, we reviewed consecutive patients undergoing isolated aortic (AVS: n = 2132) or mitral valve (MVS: n = 1664) surgery. All data were prospectively collected by a full-time

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Disclosures: Authors have nothing to disclose with regard to commercial support. Received for publication July 7, 2010; revisions received Oct 26, 2010; accepted for publication Dec 6, 2010; available ahead of print Jan 31, 2011.

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0022-5223/\$36.00

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doi:10.1016/j.jtcvs.2010.12.005

Abbreviations and Acronyms

AVS	= aortic valve surgery
BSA	= body surface area
CABG	= coronary artery bypass graft
GFR	= glomerular filtration rate
IQR	= interquartile range
LCOS	= low cardiac output syndrome
MVS	= mitral valve surgery
OM	= operative mortality
PRD	= preoperative renal dysfunction

professional research team. The quality of the data was assessed by random interrogation and the final edition stored in a computerized database after external validation.

PRD Classification

PRD was defined as preoperative estimated GFR less than 60 mL/min without the need for dialysis using the Cockcroft–Gault formula.⁹ The selection of this formula was based on its worldwide use and extensive temporal and external validation since its publication in 1976. In addition, the discrimination ability for OM after cardiovascular surgery using the Cockcroft–Gault formula has been reported as similar in comparison with a new method, the Modification of Diet in Renal Disease equation.^{9,16}

Covariables

The following preoperative variables were included: sex, age, body surface area (BSA), family history of cardiac disease, and associated comorbidities including, diabetes mellitus, hypertension, hyperlipidemia, chronic obstructive pulmonary disease, previous stroke or transitory ischemic attack, peripheral vascular disease, carotid disease, previous cardiac operations, previous CABG surgery, active endocarditis, previous or active endocarditis, New York Heart Association functional class, angina, urgent or emergency surgery, congestive heart failure, left ventricular ejection fraction, smoking, preoperative myocardial infarction, and pre-existing atrial fibrillation. Clinical variables were defined using standard operational definitions.^{6,10,11,13}

The following intraoperative variables were collected: cardiopulmonary bypass time, aortic crossclamp time, valvular replacement, valvular repair, annular enlargement in AVS, or annular reconstruction in MVS.

Outcomes

The primary outcome was OM and was defined as any death during the index hospital admission or during the first 30 postoperative days. The following secondary outcome variables were collected: reoperation for any cause, perioperative myocardial infarction, low cardiac output syndrome (LCOS), perioperative stroke, renal failure (defined as need for renal replacement therapy), sternal wound infection, sepsis, pulmonary complication, atrial fibrillation, use of intra-aortic balloon pump, use of inotropes, length of mechanical ventilation, length of stay in the intensive care unit, and postoperative length of stay.

Statistical Analysis

Categorical variables are reported as number and percentages. Continuous variables are expressed as mean and standard deviation or median and interquartile range (IQR). All statistical analyses were performed with the SAS 9.1 software (SAS Institute, Inc, Cary, NC). Statistical analysis was performed using the χ^2 test or Fisher exact test for categorical variables and *t* tests or Kruskal–Wallis equality-of-populations rank test

for continuous variables where appropriate. Propensity score 1:1 matched samples were created independently; one for AVS and one for MVS. The propensity score methodology was in accordance with Rosenbaum and associates^{17,18} and the current state of the art literature.^{19–21} Technical aspects are presented in [Appendices 1–3](#).

Considering the quality of the database and the minimal percentage of missing data (data not reported), no multiple imputation techniques were considered. Also, no adjustment for multiplicity was considered in the analyses. Finally, all the analyses were performed independently for the AVS and MVS matched sample groups.

RESULTS**Characteristics of the Propensity Score–Matched Samples**

The match selected 626 and 526 patients in the AVS and MVS samples who were well matched with a mean age of 70 ± 9 and 65 ± 10 years, respectively. The clinical characteristics of the matched samples are presented in [Tables 1](#) (AVS) and [2](#) (MVS). As expected with the propensity score matching technique, there were no significant differences between the PRD and non-PRD patients in either cohort of valve surgery. The only exception was the BSA, which was smaller in the PRD groups (AVS: 1.75 ± 0.21 vs 1.94 ± 0.20 m², $P < .001$; MVS: 1.70 ± 0.19 vs 1.88 ± 0.23 m², $P < .001$) of both cohorts. The type of valvular lesion and operative techniques were not statistically different between groups in either cohort ([Appendix 4](#)). The type of valvular lesion in both samples is presented in [Appendix 4](#). Finally, the perioperative and outcome variables for AVS and MVS are presented in [Tables 3 and 4](#), respectively.

Primary Outcomes of the Propensity-Matched Samples

In the AVS cohort, OM was similar (2.2% vs 3.2%; $P = .5$) in the non-PRD and PRD groups. In contrast, in the MVS cohort OM was lower in the non-PRD group (0% vs 2.7%; $P = .015$) ([Figure 1](#)). The timing and causes of OM in the MVS cohort are presented in [Appendix 5](#).

Secondary Outcomes in the AVS Group

In the AVS group, patients with PRD had greater need for inotropes (39% vs 29%; $P = .009$), duration of mechanical ventilation (8 hours [IQR = 9 hours] vs 7 hours [IQR = 5 hours]; $P < .001$) and length of intensive care unit stay (27 hours [IQR = 46 hours] vs 25 hours [IQR = 27 hours]; $P = .006$). There were no significant differences between groups in need for reoperation, perioperative myocardial infarction, LCOS, perioperative stroke, renal failure, sternal wound infection, sepsis, pulmonary complication, atrial fibrillation, use of intra-aortic balloon pump, and postoperative length of stay ([Table 3](#)).

Secondary Outcomes in the MVS Group

In the MVS group, patients with PRD had greater need for inotropes (47% vs 36%; $P = .013$), duration of

TABLE 1. Clinical characteristics of the matched aortic valve surgery groups (n = 313/group)

Variable	Non-PRD		PRD		P value
Male sex	56.9%	178	53.0%	166	.335‡
Age (y): mean (SD)	70.5 (8.26)		70.4 (9.39)		.910*
BSA (m ²): mean (SD)	1.94 (0.20)		1.75 (0.21)		<.001*†‡
Family history	38.5%	120	33.0%	103	.156‡
NYHA III or IV	71.6%	224	70.0%	219	.593‡
CHF	51.1%	160	49.8%	156	.749‡
Angina	1.3%	4	1.3%	4	1.0§
Urgent/emergency	4.5%	14	6.1%	19	.789‡
Redo CABG	6.1%	19	3.5%	11	.134‡
Any redo	16.0%	50	13.7%	43	.432‡
COPD	5.1%	16	7.0%	22	.315‡
LVEF < 40%	11.8%	37	16.9%	53	.168‡
Diabetes	13.4%	42	13.4%	42	1.0‡
Hypertension	49.8%	156	49.8%	156	1.0‡
Hyperlipidemia	42.2%	132	39.6%	124	.516‡
PVD	8.9%	28	8.3%	26	.776‡
Active endocarditis	1.9%	6	3.2%	10	.391‡
Any endocarditis	5.8%	18	5.1%	16	.724‡
Preop. MI	1.6%	5	1.3%	4	.737§
Stroke/TIA	9.6%	30	8.9%	28	.783‡
AF	9.3%	29	8.9%	28	.890‡

PRD, Preoperative renal dysfunction; SD, standard deviation; BSA, body surface area; NYHA, New York Heart Association; CHF, congestive heart failure; Redo CABG, previous coronary artery bypass graft surgery; Any redo, previous cardiac surgery; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction; PVD, peripheral vascular disease; Preop. MI, preoperative myocardial infarction; TIA, transitory ischemic attack; AF, atrial fibrillation. *Two-sample *t* test. †*P* < .05. ‡ χ^2 test. §Fisher exact test.

mechanical ventilation (7 hours [IQR = 7 hours] vs 6 hours [IQR = 5 hours]; *P* = .004), and length of intensive care unit stay (40 hours [IQR = 47 hours] vs 26 hours [IQR = 27 hours]; *P* = .011). As in the AVS cohort, there were no significant differences between groups in need for reoperation, perioperative myocardial infarction, LCOS, perioperative stroke, renal failure, sternal wound infection, sepsis, pulmonary complication, atrial fibrillation, use of intra-aortic balloon pump, or postoperative length of stay (Table 4).

DISCUSSION

In patients undergoing isolated valve surgery, we identified PRD to be associated with perioperative mortality after MVS but not AVS. However, the presence of PRD led to clinically significant morbidity in both cohorts.

Anderson and coworkers²² in 2000 reported mild renal insufficiency as an independent risk factor for adverse outcomes after cardiac valve surgery. Their sample, which included 834 patients undergoing valvular surgery with or without concomitant CABG from 14 Veterans' Affairs Medical Centers between 1992 and 1996, was stratified as normal renal function (serum creatinine < 1.5 mg/dL, n = 637), mild-to-moderate renal failure (serum creatinine between 1.5 and 3.0 mg/dL, n = 183), and advanced renal failure (serum creatinine > 3.0 mg/dL, n = 14). In a multi-

TABLE 2. Clinical characteristics of the matched mitral valve surgery groups (n = 263/group)

Variable	Non-PRD		PRD		P value
Male sex	39.9%	105	39.2%	103	.858‡
Age (y): mean (SD)	64.6 (9.83)		64.4 (11.05)		.878*
BSA (m ²): mean (SD)	1.88 (0.23)		1.70 (0.19)		<.001*†‡
Family history	40.1%	105	34.0%	89	.148‡
NYHA III or IV	70.0%	184	71.5%	188	.702‡
CHF	65.0%	171	62.4%	164	.526‡
Angina	6.1%	16	7.6%	20	.499‡
Urgent/emergency	2.3%	6	4.2%	11	.218‡
Redo CABG	4.2%	11	3.4%	9	.648‡
Any redo	16.7%	44	20.2%	53	.312‡
COPD	4.2%	11	3.4%	9	.649‡
LVEF < 40%	6.5%	17	9.1%	24	.255‡
Diabetes	11.4%	30	8.0%	21	.185‡
Hypertension	38.0%	100	32.7%	86	.202‡
Hyperlipidemia	29.7%	78	26.2%	69	.382‡
PVD	2.3%	6	2.3%	6	1.0‡
Active endocarditis	2.7%	7	4.9%	13	.171‡
Any endocarditis	8.0%	21	9.9%	26	.445‡
Preop MI	0.8%	2	0.8%	2	1.0§
Stroke/TIA	8.8%	23	12.2%	32	.200‡
AF	35.0%	92	33.5%	88	.713‡

PRD, Preoperative renal dysfunction; SD, standard deviation; BSA, body surface area; NYHA, New York Heart Association; CHF, congestive heart failure; Redo CABG, previous coronary artery bypass graft surgery; Any redo, previous cardiac surgery; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction; PVD, peripheral vascular disease; Preop MI, preoperative myocardial infarction; TIA, transitory ischemic attack; AF, Atrial fibrillation. *Two-sample *t* test. †*P* < .05. ‡ χ^2 test. §Fisher exact test.

variable logistic regression model, mild-to-moderate renal failure was associated with OM (*P* = .001) and postoperative morbidity. However, only 73 patients in their study displayed mild-to-moderate renal failure. In addition to a highly selected population of veterans, they did not independently examine the effects of renal function on AVS and MVS.

Abramov and associates²³ in 2003 reported preoperative renal dysfunction as an independent predictor of mortality and morbidity in a sample of 2214 patients, predominately isolated CABG (82%) with only 5% and 4% undergoing AVS and MVS, respectively. Preoperative creatinine clearance less than 0.84 mL · s⁻¹ · m⁻² was correlated with an exponential increase in a composite outcome of perioperative mortality, myocardial infarction, LCOS, and cerebrovascular accident. Again, their study had a very small sample of valve patients and did not report the results of AVS and MVS separately. Our study focuses selectively on isolated valve surgery and, with a relatively larger sample size, we were able to demonstrate a clear difference between aortic and mitral populations. Owing to the fact that we intentionally excluded patients requiring preoperative renal replacement therapy, we did not stratify patients according to the severity of renal dysfunction as per Anderson,²² Filsoufi,²⁴ and their associates. Similar to our results

TABLE 3. Perioperative data in the matched aortic valve surgery groups

Variable	Non-PRD (n = 313)	PRD (n = 313)	P value
CPB time (min): mean (SD)	101 (40.1)	96 (35.1)	.100*
Crossclamp time (min): mean (SD)	77 (32.5)	73 (27.5)	.092*
Aortic valve replacement: n (%)	290 (92.7%)	297 (94.9%)	.247‡
Aortic annulus enlargement: n (%)	62 (19.8%)	50 (16.0%)	.204‡
Reoperation: n (%)	28 (8.9%)	35 (11.2%)	.352‡
Postoperative bleeding: n (%)	22 (7.0%)	25 (8.0%)	.649‡
Postoperative tamponade: n (%)	3 (1.0%)	5 (1.6%)	.725
Mortality: n (%)	7 (2.2%)	10 (3.2%)	.461‡
Ventilation time (h): median (IQR)	6.6 (5.0)	8.2 (9.4)	<.001†§
LICU (h): median (IQR)	24.8 (26.9)	27.4 (46.1)	.006†§
Postoperative stay (d): median (IQR)	7 (4)	8 (5)	.163§
LCOS: n (%)	7 (2.2)	10 (3.2)	.457
Myocardial Infarction: n (%)	3 (1.0%)	3 (1.0%)	1.0
Sternal wound infection: n (%)	6 (1.9%)	3 (1.0%)	.505
Sepsis: n (%)	3 (1.0%)	5 (1.6%)	.725
Stroke (%)	8 (2.6%)	7 (2.2%)	.794‡
Pulmonary complication: n (%)	29 (9.3%)	39 (12.5%)	.199‡
Renal failure: n (%)	3 (1.0%)	7 (2.2%)	.340
Atrial fibrillation: n (%)	112 (35.8%)	95 (30.4%)	.149‡
IABP: n (%)	4 (1.3%)	7 (2.2%)	.545
Use of inotropes: n (%)	91 (29.1%)	122 (39.0%)	.009†‡

PRD, Preoperative renal dysfunction; CPB, cardiopulmonary bypass; SD, standard deviation; IQR, interquartile range; LICU, length of intensive care unit stay; LCOS, low cardiac output syndrome; IABP, intra-aortic balloon pump. *Two-sample *t* test. †*P* < .05. ‡ χ^2 test. §Kruskal–Wallis equality-of-populations rank test. ||Fisher exact test.

in AVS, Ibáñez and coworkers²⁵ reported in a sample of 681 valvular patients with or without concomitant CABG, no difference in OM between patients with (n = 207) or without (n = 474) PRD (3.4% vs 2.3%; *P* = .43). The main finding of their study was that PRD patients had a higher incidence of reoperation (6.8% vs 2.3%; *P* < .001), red blood cell transfusions, longer ventilation time, and hospital stay. Unfortunately, their study had a severe demographic imbalance between groups and they did not use a propensity score analysis to adjust risk. We did not investigate total transfusion requirements, but we also found differences in ventilation time and postoperative length of stay.

Howell and associates²⁶ reported that mild renal dysfunction, defined as an estimated GFR less than 60/mL per 1.73 m², was a predictor of early and late mortality. These authors stratified renal risk according to estimated GFR and found renal dysfunction in 74% of their 7621 patient cohort. Their sample included 1756 (23% of the entire surgical cohort) patients with valve surgery. The in-hospital mortality was 3.2% and directly correlated to the degree of renal dysfunction. Multivariate analysis demonstrated a stronger correlation in patients undergoing isolated CABG (odds ratio = 12.2), but a mortality effect persisted in patients undergoing valvular surgery. Unfortunately, this

TABLE 4. Perioperative data in the matched mitral valve surgery groups

Variable	Non-PRD n = 263	PRD n = 263	P value
CPB time (min): mean (SD)	89.3 (38.4)	92 (37.1)	.497*
Crossclamp time (min): mean (SD)	68 (29.5)	70 (34.9)	.379*
Mitral valve replacement: n (%)	127 (48.3%)	148 (55.3%)	.067‡
Mitral annulus reconstruction: n (%)	9 (3.4%)	15 (5.7%)	.206‡
Reoperation: n (%)	14 (5.3%)	17 (6.5%)	.579‡
Postoperative bleeding: n (%)	8 (3.0%)	14 (5.3%)	.191‡
Postoperative tamponade: n (%)	2 (0.8%)	3 (1.1%)	1.0
Mortality: n (%)	0 (0%)	7 (2.7%)	.015†
Ventilation time (h): median (IQR)	6.5 (5.4)	7.2 (6.6)	.004†§
LICU (h): median (IQR)	26.2 (26.5)	39.8 (47.3)	.011†§
Postoperative stay (d): median (IQR)	7 (5)	8 (4)	.310§
LCOS: n (%)	3 (1.1)	9 (3.4)	.141
Myocardial infarction: n (%)	2 (0.8%)	2 (0.8%)	1.0
Sternal wound infection: n (%)	1 (0.4%)	1 (0.4%)	1.0
Sepsis: n (%)	2 (0.8%)	4 (1.5%)	.686
Stroke: n (%)	1 (0.4%)	6 (2.3%)	.123
Pulmonary complication: n (%)	24 (9.1%)	32 (12.2%)	.258‡
Renal failure: n (%)	1 (0.4%)	6 (2.3%)	.061
Atrial fibrillation: n (%)	67 (26.3%)	71 (27.0%)	.844‡
IABP: n (%)	2 (0.8%)	6 (2.3%)	.285
Use of inotropes: n (%)	95 (36.1%)	123 (46.8%)	.013†‡

PRD, Preoperative renal dysfunction; CPB, cardiopulmonary bypass; SD, standard deviation; IQR, interquartile range; LICU, length of intensive care unit stay; LCOS, low cardiac output syndrome; IABP, intra-aortic balloon pump. *Two-sample *t* test. †*P* < .05. ‡ χ^2 test. §Kruskal–Wallis equality-of-populations rank test. ||Fisher exact test.

large study did not analyze the differential effect of renal dysfunction in patients undergoing AVS versus MVS. Our results show a clear difference between AVS and MVS, with PRD predicting mortality only in the MVS group. Also, the magnitude of the effect in MVS in our study (odds ratio = 10.4) is greater than Howell and colleagues²⁶ observed even in their group with the most severe renal dysfunction undergoing isolated valve surgery (odds ratio = 6.97).

Similarly, Diez and colleagues²⁷ reported mild renal dysfunction, defined as an estimated GFR less than 60/mL per 1.73 m², as a predictor of in-hospital mortality. Their sample included 994 patients with isolated or combined valve and CABG surgery. However, isolated aortic valve or mitral valve replacement represented only 307 and 115 patients, respectively. Estimated GFR predicted mortality and postoperative acute renal failure; however, the independent association based on valve site was not reported. Therefore, a direct comparison with our results is not possible.

Interestingly, our study failed to demonstrate a correlation of PRD and postoperative renal failure, defined as the need for renal replacement therapy. Likely, this is due to the fact that only 17 patients (AVS, n = 10; MVS,

FIGURE 1. Operative mortality in the mitral valve surgery and aortic valve surgery propensity score matched samples. AVS, Aortic valve surgery; MVS, mitral valve surgery; PRD, perioperative renal dysfunction (non-dialysis dependent); non-PRD, no perioperative renal dysfunction.

n = 7) in the entire cohort required dialysis. The differential effect of PRD on AVS and MVS was a surprising finding and, to our knowledge, has not been previously described. We hypothesize that patients undergoing MVS are less tolerant of postoperative fluid retention owing to their volume overload physiology and thus suffer to a greater proportion from a similar degree of renal dysfunction. Alternatively, patients undergoing AVS were more likely to suffer from aortic stenosis and thus their renal dysfunction may comprise a more “prerenal” component than those patients undergoing MVS. However, our data do not support any association between type of valve disease, as a surrogate of intracardiac pressure or volume overload physiology, and outcomes in this study (data not provided). In summary, our results are in agreement with previous reports in this area but definitely expand and clarify the relationship between PRD and OM in isolated valve surgery. The novel aspects of our study include the use of propensity score matching to balance demographic differences and the consideration of the intrinsic differences between aortic and mitral valve disease.

There are several limitations to our study. First, despite the use of a standard propensity matched sampling technique, the distribution of BSA is unequal. However, the BSA distributions are unlikely to explain the results, particularly in MVS, where the concept of prosthesis–patient mismatch is less established.^{28,29} Second, more aggressive diuretic therapy may be necessary in advanced cases of valve disease, which can exacerbate PRD. Despite the use of propensity scores, we were unable to document actual diuretic therapy in each patient. Third, our estimation of GFR was performed with the Cockcroft–Gault formula and not with more recent equations such as the Modification of Diet in Renal Disease, which is the basis

for the current chronic kidney disease classification. However, all equations for estimation of GFR are by definition only an approximation of the real physiologic GFR. Fourth, we did not explore as covariates the use of aprotinin, colloids, or blood products. Fifth, we did not differentiate between acute and chronic valvular disease, nor did we assess the chronicity of PRD. However, surgery was performed in an urgent or emergency fashion in less than 7% of these cases. Therefore, the vast majority of these patients had chronic valvular disease. Sixth, the PRD MVS group has a relatively higher proportion of mitral valve replacement than did the non-PRD MVS group, which is not statistically significant. Considering that we did not performed statistical adjustment for multiple analysis, we do not believe this is a statistical type I error and consequently not a real bias. Seventh, the time between preoperative angiography and the determination of estimated GFR was also variable, but is likely equally distributed among all groups. Finally, the number of events for our main outcome, OM, is small and therefore the generalizability of our conclusions may be limited.

CONCLUSIONS

In conclusion, our results demonstrate that PRD is associated with OM in MVS but not in AVS. In addition, PRD is associated with clinically significant morbidity in patients undergoing MVS, with a smaller impact in AVS.

This is the first study to distinguish the effects of PRD between AVS and MVS. We concede that this is an observational study, limited to perioperative outcomes. The potential differential effects of PRD on long-term clinical outcomes should be investigated in a similar manner. We hypothesize that renal function may improve after AVS for aortic stenosis, but may worsen after MVS for valvular insufficiency.

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APPENDIX 1. Propensity Score Methodology

Propensity scores were constructed using the SAS PROC LOGISTIC for the multivariate logistic regression. Balancing properties of both propensity score models were optimal. Propensity score 1:1 matched samples were created independently; one for AVS and one for MVS using the SAS GREEDY 5 → 1 Digit Match Macro developed by Lori Parsons.¹⁷⁻²¹

Variables Included in the AVS Propensity Score:

1. Age
2. Left ventricular grade
3. Timing of the operation
4. New York Heart Association class
5. Diabetes mellitus
6. Hypertension
7. Hyperlipidemia
8. Preoperative myocardial infarction
9. Preoperative stroke
10. Peripheral vascular disease
11. Shock
12. Sex

13. Endocarditis
14. Any redo
15. Angina
16. Congestive heart failure

Variables Included in the MVS Propensity Score:

1. Age
2. Left ventricular grade
3. Timing of the operation
4. New York Heart Association class
5. Diabetes mellitus
6. Hypertension
7. Hyperlipidemia
8. Preoperative myocardial infarction
9. Preoperative stroke
10. Peripheral vascular disease
11. Shock
12. Sex
13. Endocarditis
14. Any redo
15. Angina
16. Congestive heart failure

APPENDIX 2. Mirrored histogram of distribution of the propensity scores for unmatched and matched aortic valve surgery samples. *AVS*, Aortic valve surgery; *PRD*, perioperative renal dysfunction (non-dialysis dependent); *non-PRD*, no perioperative renal dysfunction.

APPENDIX 3. Mirrored histogram of distribution of the propensity scores for unmatched and matched mitral valve surgery samples. *MVS*, mitral valve surgery; *PRD*, perioperative renal dysfunction (non-dialysis dependent); *non-PRD*, no perioperative renal dysfunction.

APPENDIX 4. Type of valvular lesion

Variable	Non-PRD		PRD		<i>P</i> value
Aortic valve surgery					
Valve disease		n		n	.515*
Stenosis	61.7%	192	59.9%	185	
Regurgitation	19.9%	62	24.3%	75	
Mixed	17.0%	53	15.2%	47	
None	1.3%	4	0.7%	2	
Mitral valve surgery					
Valve disease		n		n	.873*
Stenosis	10.5%	27	9.7%	25	
Regurgitation	77.0%	198	75.7%	196	
Mixed	12.1%	31	14.3%	37	
None	0.4%	1	0.4%	1	

PRD, Preoperative renal dysfunction. *Fisher exact test.

APPENDIX 5. Clinical data in patients with perioperative death from the matched mitral valve surgery groups by patient

Patient	PRD status	Age (y)	Year	CHD	MVR	MAR	Redo	Time to death (mo)	Cause of death
1	Yes	23	1996	No	Yes	Yes	No	3	Sepsis (IE)
2	Yes	65	1998	No	Yes	No	Yes	172	MOF
3	Yes	65	1999	No	Yes	No	Yes	3	MOF
4	Yes	47	2001	No	Yes	No	No	0	OR death
5	Yes	73	2001	No	Yes	Yes	Yes	21	CVA
6	Yes	71	2005	No	Yes	Yes	No	0	OR death
7	Yes	34	2009	Yes	No	No	No	2	Heart/renal failure

PRD, Preoperative renal dysfunction; *CHD*, congenital heart disease; *MVR*, mitral valve replacement; *MAR*, mitral annulus reconstruction; *IE*, infective endocarditis; *MOF*, multiorgan failure; *OR*, operating room; *CVA*, cerebrovascular accident.