Bedside Tool for Predicting the Risk of Postoperative Dialysis in Patients Undergoing Cardiac Surgery

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***Background*—**Estimation of an individual patient's risk for postoperative dialysis can support informed clinical decision making and patient counseling.

***Methods and Results*—**To develop a simple bedside risk algorithm for estimating patients' probability for dialysis after cardiac surgery, we evaluated data of 449 524 patients undergoing coronary artery bypass grafting (CABG) and/or valve surgery and enrolled in >600 hospitals participating in the Society of Thoracic Surgeons National Database (2002–2004). Logistic regression was used to identify major predictors of postoperative dialysis. Model coefficients were then converted into an additive risk score and internally validated. The model also was validated in a second sample of 86 009 patients undergoing cardiac surgery from January to June 2005. Postoperative dialysis was needed in 6451 patients after cardiac surgery (1.4%), ranging from 1.1% for isolated CABG procedures to 5.1% for CABG plus mitral valve surgery. Multivariable analysis identified preoperative serum creatinine, age, race, type of surgery (CABG plus valve or valve only versus CABG only), diabetes, shock, New York Heart Association class, lung disease, recent myocardial infarction, and prior cardiovascular surgery to be associated with need for postoperative dialysis (*c* statistic=0.83). The risk score accurately differentiated patients' need for postoperative dialysis across a broad risk spectrum and performed well in patients undergoing isolated CABG, off-pump CABG, isolated aortic valve surgery, aortic valve surgery plus CABG, isolated mitral valve surgery, and mitral valve surgery plus CABG (*c* statistic=0.83, 0.85, 0.81, 0.75, 0.80, and 0.75, respectively).

***Conclusions*—**Our study identifies the major patient risk factors for postoperative dialysis after cardiac surgery. These risk factors have been converted into a simple, accurate bedside risk tool. This tool should facilitate improved clinician–patient discussions about risks of postoperative dialysis. **(*Circulation*. 2006;114:2208-2216.)**

Key Words: coronary disease ■ dialysis ■ risk factors ■ surgery ■ valves

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Cardiac surgery, including coronary artery bypass (CABG) and valve surgery, remains one of the most common surgical procedures, performed in an estimated 608 000 US patients annually.[1] The characteristics of those undergoing cardiac surgery have changed over time. Increasingly, those referred for surgical evaluation are elderly and have multiple comorbid conditions.[2,3] Although surgical outcomes also have improved over time,[3] these older, sicker patients remain at risk for postoperative complications.

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Postoperative renal failure requiring the initiation of dialysis ranks among patients' and physicians' most dreaded surgical complications. Postoperative renal failure has been shown to be associated with higher mortality, poor quality of life, and increased hospital length of stay and resource use.[4–8] However, <25% of patients with renal failure after cardiac surgery require dialysis.[4,6,8] Thus, a means of estimating a patient's individual risk for postoperative dialysis (a more important adverse event from patients' and physicians' standpoint than renal insufficiency) based on multiple preoperative clinical factors would facilitate informed clinical decision making and patient counseling. The small number of patients studied in prior investigations precluded them from providing any information on risk factors for postoperative dialysis in patients undergoing cardiac surgery.

The Society of Thoracic Surgeons (STS) National Cardiac Surgery Database provides an opportunity to study a national sample of patients undergoing cardiac surgery at a diverse cross section of US hospitals.[9–11] Using these data, we identified preoperative clinical variables and operative types associated with the need for postoperative dialysis after

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Received April 22, 2006; revision received August 21, 2006; accepted September 8, 2006.

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Circulation is available at http://www.circulationaha.org DOI: 10.1161/CIRCULATIONAHA.106.635573

CABG and/or valvular heart surgery. Using these identifiers, we sought to create an efficient bedside tool to estimate the need for dialysis after cardiac surgery. We then examined the degree to which this tool could estimate risk among diverse patient subgroups and among those undergoing different cardiac surgical procedures (including isolated CABG, isolated aortic valve or isolated mitral valve surgery, CABG plus aortic valve surgery, and CABG plus mitral valve surgery).

Methods

Study Sample and Data Collection

The STS National Cardiac Surgery Database

The formation, rationale, and methodology of the STS database have been published previously.[9–11] Briefly, this registry was initiated in 1986 to provide participants with their risk-adjusted outcomes compared with the national experience. Participants in the STS database receive individualized, semiannual, risk-adjusted surgery outcomes, along with direct comparisons with the aggregate database population. This information is used by member institutions as a part of their continuous quality improvement efforts to help design strategies to improve their outcomes. This dataset contains detailed clinical information on >2.5 million registered patients undergoing cardiac surgery from >600 academic, private, military, and Veterans Affairs hospitals from 50 US states and 5 Canadian provinces.

Patient Population

We analyzed data on patients undergoing CABG alone, mitral or aortic surgery alone, or the combination of CABG and aortic or mitral valve surgery. We limited our analysis to contemporary patients receiving surgery from July 1, 2002, through December 2004 at STS participant sites. In addition, given our primary purpose, patients who were on dialysis before their CABG were excluded.

Data Definitions

Operative mortality was defined as all deaths occurring during the hospital period in which the operation was performed and those deaths occurring after hospital discharge but within 30 days of the procedure. Morbidity was defined as the presence of any one of the following complications: permanent stroke, prolonged ventilation (>24 hours), reoperation for bleeding, or deep sternal wound infection. The STS database collects preoperative serum creatinine, defined as the last value measured before surgery. We estimated glomerular filtration rate (GFR) on the basis of the Modification of Diet in Renal Disease study formula as suggested by the National Kidney Foundation guidelines.[12] Remaining definitions of risk factors were as provided on the STS website (www.sts.org).

Statistical Analysis

Summary statistics are presented as frequency and percentage or median and interquartile range. The distributions of risk factors and outcomes for those who did and did not require dialysis were compared through χ^2 tests for categorical variables and Wilcoxon rank-sum tests for continuous variables. Records with missing values of serum creatinine, age, gender, and race were excluded from all consideration. Missing values of BSA were imputed to gender-specific median values, while missing values of ejection fraction were imputed to 50%. Missing values of the remaining risk factors and various outcomes were defaulted to their most common value.

Predictive Modeling

Logistic regression modeling was used to estimate risk of dialysis as a function of patient preoperative characteristics. Predictor variables were selected from a list of 24 candidate variables by performing backward selection with a significance criterion of $P=0.10$. Continuous variables were assumed to have a linear relationship (age, body surface area, left ventricular ejection fraction) or piecewise linear relationship (GFR) with the log odds of dialysis. Only 2 predictors were removed by backward elimination: congestive heart failure and smoking. The resulting model formed the basis for developing and evaluating a subsequent simpler model approximation and bedside risk scoring system.

Simplified Model Approximation

To reduce the number of variables, a parsimonious set of 10 predictor variables was identified that explained >90% of the variation in the predicted log odds of dialysis as estimated by the full model described above. These variables were chosen by selecting the 9 patient characteristics with the largest χ^2 statistics in the full logistic regression model, plus an indicator variable for type of surgery. To avoid complex calculations, GFR was eliminated at this stage and replaced by serum creatinine (a single linear term truncated at 4 mg/dL). The resulting set of variables was then entered into a multiple linear regression model in which

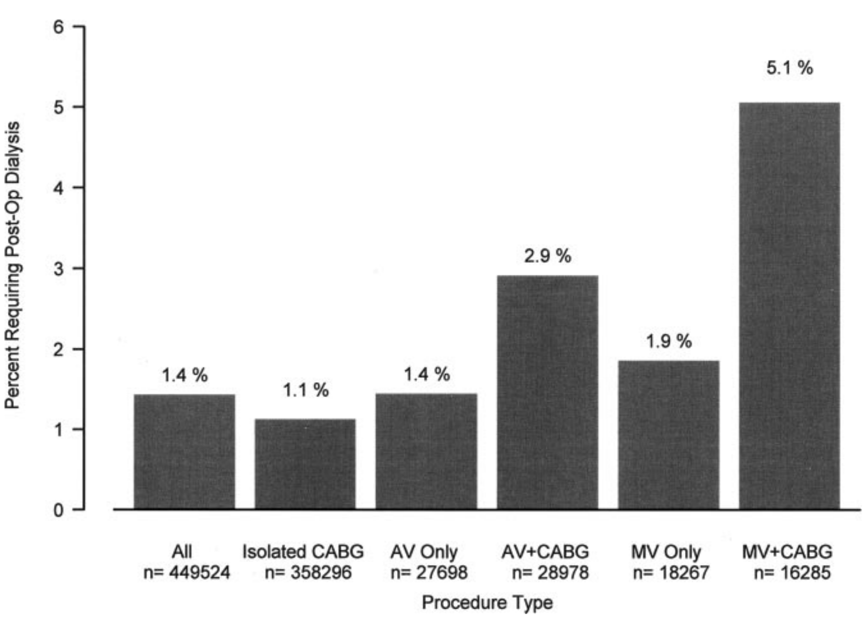

Figure 1. Postoperative dialysis frequency by procedure type. AV indicates aortic valve surgery; MV, mitral valve surgery.

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TABLE 1. Patient Characteristics

Characteristics	Overall	No Postoperative Dialysis	Postoperative Dialysis	*P*
Sample size, n (%)	449 524 (100)	443 073 (98.6)	6451 (1.4)	
Demographics				
Age, median (IQR), y	67 (58–74)	66 (58–74)	73 (65–79)	<0.0001
Female, %	30.4	30.2	39.5	<0.0001
White, %	88.1	88.1	85.0	<0.0001
BMI, median (IQR), m^2	28.2 (25.2–32.0)	28.2 (25.2–32.0)	28.4 (25.0–33.3)	<0.0001
BSA, median (IQR), m^2	2.0 (1.8–2.1)	2.0 (1.8, 2.1)	1.9 (1.8–2.1)	<0.0001
Medical history, %				
Hypertension	75.2	75.1	83.6	<0.0001
Diabetes	33.2	33.0	48.9	<0.0001
Current smoker	21.4	21.5	15.3	<0.0001
Obesity	11.3	11.3	15.8	<0.0001
Hypercholesterolemia	68.7	68.7	65.7	<0.0001
Chronic lung disease	19.6	19.5	31.1	<0.0001
Preoperative renal failure	4.2	3.8	27.6	<0.0001
Stroke	7.3	7.2	13.6	<0.0001
Infectious endocarditis	0.9	0.9	2.3	<0.0001
Immunosuppressive treatment	2.0	2.0	4.4	<0.0001
Peripheral vascular disease	14.6	14.5	25.9	<0.0001
Cerebrovascular disease	13.8	13.7	24.0	<0.0001
Preoperative cardiac status, %				
Prior CABG	6.0	5.9	12.7	<0.0001
Prior PCI	19.6	19.6	20.1	0.0863
Prior valve surgery	2.3	2.3	4.0	<0.0001
LVEF, median (IQR)	51	51	45	<0.0001
Mitral regurgitation	23.3	23.0	41.6	<0.0001
Left main disease >50%	22.9	22.8	26.7	<0.0001
Myocardial infarction <3 wk	22.9	22.7	36.6	<0.0001
Congestive heart failure	19.6	19.1	48.1	<0.0001
Cardiogenic shock	1.9	1.8	10.3	<0.0001
NYHA class IV	20.4	20.1	38.4	<0.0001
Preoperative IABP	6.5	6.4	17.0	<0.0001
Inotropic support	2.1	2.0	9.7	<0.0001
Operative details				
Surgery type				
CABG only, %	78.6	78.6	62.6	<0.0001
Aortic valve surgery only, %	6.2	6.2	6.2	0.8546
CABG plus aortic valve surgery, %	6.5	6.4	13.1	<0.0001
Mitral valve surgery only, %	4.1	4.1	5.3	<0.0001
CABG plus mitral valve surgery, %	3.6	3.5	12.8	<0.0001
Elective surgery, %	53.6	53.8	38.5	<0.0001
Urgent surgery, %	42.3	42.2	48.9	<0.0001
Emergent surgery, %	3.8	3.7	10.9	<0.0001
Emergent salvage surgery, %	0.3	0.2	1.6	<0.0001
Intraoperative IABP, %	2.1	1.9	11.8	<0.0001
Perfusion time, median >90th percentile, %	5.4	5.2	18.8	<0.0001
Cross-clamp time, median (IQR), min	69 (51–93)	69 (51–93)	85 (60–117)	<0.0001

IQR indicates interquartile range; BMI, body mass index; BSA, body surface area; PCI, percutaneous coronary intervention; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; and IABP, intra-aortic balloon pump.

the dependent variable was the predicted log odds of dialysis (as calculated by the full model described above). The regression equation that resulted from this process is an approximation of the full model.[13] The simplified model approximation was summarized by converting the regression coefficients to odds ratios. The accuracy of the simplified model approximation was assessed by computing the squared correlation between the predicted log odds based on the full model and the reduced model. We also calculated the average absolute deviation between the risk estimates obtained from the 2 different models.

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Bedside Tool

Regression coefficients from the simplified model approximation were then converted into whole integers to create a bedside risk prediction tool.[14] The reduction in accuracy that resulted from using whole-number regression coefficients was $<1\%$. For each possible risk score, the risk of dialysis was estimated by averaging the predicted values from the original full model among all patients having the same risk score. The heterogeneity of dialysis risk among patients having the same risk score was assessed by plotting the distribution of predicted risk within risk score subgroups.

Finally, the performance of the risk tool was tested in a different subset of patients meeting the inclusion criteria of the development sample. This validation sample consisted of 86 009 STS records dating from January 1, 2005, to June 30, 2005. Patients were divided into 10 approximately equal groups based on their predicted risks of dialysis as estimated by the bedside tool. The c index (also known as the area under the receiver-operating characteristics curve) was used to determine the ability of the model to discriminate between patients with and without the need for dialysis.[15] Model calibration was assessed by comparing observed versus predicted rates of dialysis across deciles of predicted risk and by the Hosmer-Lemeshow test statistics.[15] All analyses were performed with S-Plus 6 (Insightful Corp, Seattle, Wash) and SAS 8.1 (SAS Institute, Cary, NC) software.

The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results

Baseline Clinical Features and Outcomes of Patients With and Without the Need for Postoperative Dialysis After Cardiac Surgery

Of a total of 449 524 patients undergoing cardiac surgery in our study, postoperative dialysis was required in 6451 patients (1.4%). This ranged from 1.1% for the 358 296 patients undergoing isolated CABG procedures to 5.1% for the 16 285 patients requiring CABG plus mitral valve replacement (Figure 1). In the validation sample of 86 009 patients, 1372 individuals (1.6%) required postoperative dialysis.

Table 1 provides the preoperative characteristics of those requiring compared with those not requiring postoperative dialysis. The median age of patients needing postoperative dialysis was 7 years greater than those not requiring dialysis. Patients needing postoperative dialysis were 1.5- to 5.0-fold more likely to have comorbid preoperative conditions, including diabetes mellitus, chronic lung disease, peripheral or cerebrovascular disease, recent myocardial infarction, congestive heart failure, prior bypass or valve surgery, cardiopulmonary resuscitation, and cardiogenic shock (all $P<0.0001$). The incidence of postoperative dialysis also rose with increasing preoperative serum creatinine (and decreasing GFR) measurements (Figure 2). However, there was broad overlap in the preoperative creatinine levels among patients requiring compared with those not requiring postoperative dialysis (median serum creatinine levels, 1.8 versus 1.1 mg/dL, respectively; Figure 3).

Patients needing postoperative dialysis had worse in-hospital outcomes than those not (Table 2). Particularly, the in-hospital mortality was 18 times higher in those requiring postoperative dialysis (45%) than in those not needing postoperative dialysis (2.5%). Additionally, the overall median length of stay in the intensive care unit and postoperative hospital length of stay was increased by 11 and 13 days, respectively.

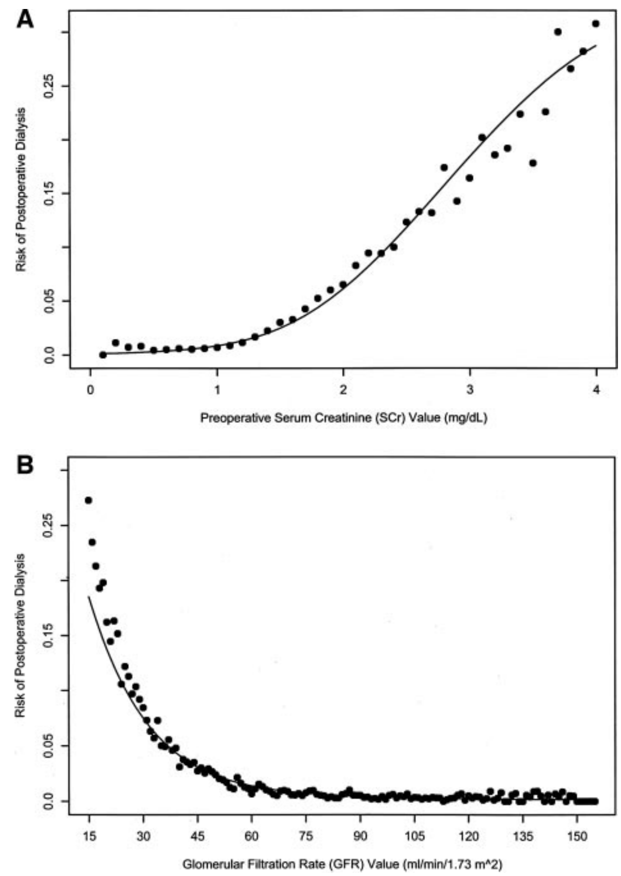

Figure 2. A, Risk of dialysis based on preoperative serum creatinine demonstrating a direct relationship between the preoperative serum creatinine and the need for postoperative dialysis. B, Similarly, the inverse relationship between preoperative GFR and the need for postoperative dialysis. Each data point represents >1 patient with same serum creatinine value.

Multivariable Analysis

The initial full model identified 22 factors independently associated with increased risk of postoperative dialysis (Table 3). This multivariable model showed excellent ability to discriminate between patients requiring and those not needing dialysis after cardiac surgery (c statistic=0.84). We then simplified the model as described above by limiting to only 10 variables. This simplified model retained much of its predictive power (c statistic=0.83; for patients in the development sample, the average absolute deviation between estimates calculated from the full and simplified models was 0.44%).

The simplified model coefficients were then converted into an additive risk score for easier use in routine practice (Figure 4). For patients in the development sample, the average absolute difference between estimates calculated from the full model compared with estimates based on the risk scores was 0.43%. Figure 5 demonstrates the ability of the risk scores to identify those with low, modest, and high risk for postoperative dialysis. Furthermore, this risk tool performed well when tested among patients undergoing isolated CABG (c statistic=0.83), off-pump CABG (c statistic=0.85), isolated aortic valve surgery (c statistic=0.81), aortic valve surgery plus CABG (c statistic=0.75), isolated mitral valve surgery (c statistic=0.80), and mitral valve surgery plus CABG (c statistic=0.75) in the test sample. Finally,

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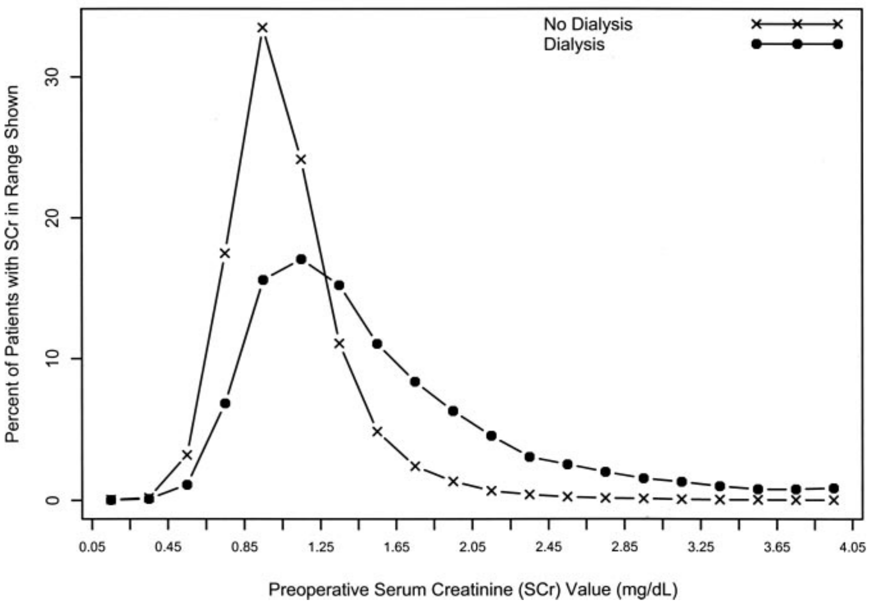

Figure 3. Distribution of preoperative serum creatinine in patients with and without postoperative renal failure requiring dialysis. The *y* axis represents the percent of patients in the 2 groups with creatinine values falling in the successive intervals of 0.20 mg/dL, starting from 0.05 on the *x* axis. Note the significant overlap in the serum creatinine values in the 2 groups.

when tested in a validation set, the bedside tool performed well not only in the overall validation sample (*c* statistic=0.83, Hosmer-Lemeshow χ^2 statistics=17.37, df=10, P=0.07 for lack of fit; Figure 6) but also among subsets of patients undergoing CABG, isolated valve surgery, or a combination of the two (*c* statistic range=0.74 to 0.83). Model calibration also was well preserved, with the Hosmer-Lemeshow statistic being nonsignificant for all groups except the CABG plus mitral valve surgery population (CABG plus mitral valve surgery was performed in few patients [3.6%] and had a limited number of event [6.0%] in the validation set).

Discussion

Physicians are increasingly being asked to counsel patients about their operative risk for complications after cardiac surgery. Postoperative renal failure requiring dialysis remains one of the most important complications equally feared by both physicians and patients. Rapid, accurate estimation of an individual patient's risk for this complication may facilitate clinical decision making and patient counseling. Having access to a national cardiac database, our study provides unique insights into the preoperative factors that portend increased risk of postoperative renal failure needing dialysis. We further developed and validated a simple bedside risk prediction tool that can be used to estimate accurately the probability of the need for postoperative dialysis for patients undergoing cardiac surgery.

Previous studies have demonstrated that a postoperative need to initiate renal dialysis occurs in 1.1% to 3.0% of cardiac surgery cohorts.[16–18] Importantly, these studies indicate that the minority of patients who require dialysis after cardiac surgery have significantly longer in-hospital length of stay and extremely high mortality, with 63% to 100% of patients dying before leaving the hospital.[1,16,17]

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TABLE 2. Outcomes

Complications	Overall	No Postoperative Dialysis	Postoperative Dialysis	Age-Adjusted Odds Ratio (95% Confidence Interval)	*P*
Sample size, n (%)	449 524 (100)	443 073 (98.6)	6451 (1.4)		
Permanent stroke, %	1.6	1.5	9.2	5.9 (5.4–6.5)	<0.0001
Prolong ventilation, %	9.2	8.2	75.1	30.5 (28.8–32.3)	<0.0001
Pneumonia, %	3.2	2.8	30.0	13.2 (12.5–14)	<0.0001
Cardiac tamponade, %	0.4	0.4	4.0	10.7 (9.4–12.3)	<0.0001
Reoperation for bleeding/tamponade, %	2.9	2.8	13.4	5.0 (4.6–5.3)	<0.0001
Deep sternal wound infection, %	0.4	0.4	4.0	10.7 (9.3–12.2)	<0.0001
Septicemia, %	1.2	0.9	23.3	30.5 (28.5–32.6)	<0.0001
Postoperative atrial fibrillation/flutter	21.7	21.3	45.7	2.6 (2.5–2.7)	0.0001
Multisystem organ failure	1.0	0.6	32.4	72.5 (67.9–77.4)	<0.0001
Length of ICU stay, median (IQR), d	1.33 (0.96–2.75)	1.29 (0.96–2.67)	12.42 (5.83–24.29)	NA	<0.0001
Postoperative length of stay, median (IQR), d	6.0 (4.0–8.0)	6.0 (4.0–7.0)	20.0 (11.0–33.0)	NA	<0.0001
Operative mortality, %	2.9	2.3	43.6	28.5 (27–30.1)	<0.0001

ICU indicates intensive care unit; IQR, interquartile range.

TABLE 3. Independent Correlates of the Need for Postoperative Dialysis After Cardiac Surgery Using Preoperative Serum Creatinine

	Full Model		Simplified Model Approximation	
Variables	OR	95% CI	OR	95% CI
GFR, mL/min per 1.73 m^2				
30 vs 90	9.85	8.89–10.90	. . .	. . .
45 vs 90	4.51	4.10–4.96	. . .	. . .
60 vs 90	2.07	1.85–2.31	. . .	. . .
Serum creatinine	. . .	. . .	4.62	4.34–4.92
Aortic valve surgery	1.45	1.24–1.69	1.44	1.29–1.60
Aortic valve surgery plus CABG	1.94	1.70–2.22	2.14	1.97–2.32
Mitral valve surgery	2.01	1.72–2.34	2.00	1.77–2.26
Mitral valve surgery plus CABG	2.57	2.29–2.88	3.12	2.87–3.39
Age (in 5-y increments starting at age <50 y)	1.14	1.13–1.16	1.23	1.21–1.24
Diabetes treated with insulin	1.86	1.74–2.00	2.17	2.03–2.33
Diabetes treated with oral agents	1.32	1.23–1.41	1.42	1.33–1.51
Chronic lung disease	1.45	1.37–1.54	1.57	1.49–1.66
Myocardial infarction in last 3 wk	1.36	1.28–1.45	1.44	1.36–1.53
Cardiogenic shock	1.92	1.71–2.16	2.36	2.10–2.64
NYHA class IV	1.41	1.33–1.49	1.49	1.41–1.58
Race (nonwhite vs white)	1.39	1.29–1.49	1.28	1.19–1.38
Prior CV surgery	1.55	1.44–1.67	1.63	1.51–1.75
Variables in the full model that were excluded from the simplified model approximation				
Female	0.83	0.77, 0.90	. . .	. . .
Peripheral or cerebrovascular disease	1.23	1.17, 1.30	. . .	. . .
Body surface area	0.78	0.62, 0.99	. . .	. . .
Left ventricular ejection fraction	0.99	0.99, 0.99	. . .	. . .
Emergent status, salvage/resuscitation vs elective/urgent	2.19	1.71, 2.81	. . .	. . .
Emergent status, emergent (no salvage) vs elective/urgent	1.7	1.53, 1.90	. . .	. . .
Triple-vessel disease	1.25	1.17, 1.34	. . .	. . .
Left main disease	1.12	1.06, 1.20	. . .	. . .
Prior percutaneous coronary interventions	1.64	1.34, 2.01	. . .	. . .
Hypertension	1.15	1.08, 1.24	. . .	. . .
Immunosuppressive treatment	1.4	1.23, 1.59	. . .	. . .
Aortic stenosis	1.24	1.09, 1.40	. . .	. . .
Mitral insufficiency	1.18	1.08, 1.30	. . .	. . .

OR indicates odds ratio; CI, confidence interval; NYHA, New York Heart Association; and CV, cardiovascular.

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Our contemporary data suggest that the need for dialysis after cardiac surgery in the community at large is on the lower side of prior estimates (1.4%) despite the fact that surgery is increasingly being performed on elderly high-risk patients. Nevertheless, when postoperative dialysis occurs, our study concurs with earlier finding that postoperative dialysis remains associated with significant morbidity and mortality.

The risks for postoperative dialysis are clearly related to preoperative kidney function (Figure 2). These results support and extend the work of others. One prior study of renal function and outcome suggested that patients with a serum creatinine level ≥2.6 mg/dL are at extreme risk for dialysis dependency after CABG[16] and that perhaps alternative options for coronary management should be strongly considered. In contrast, our data suggest that this relationship is continuous and that risk of postoperative dialysis parallels the increasing serum creatinine. However, as we show in Figure 3, preoperative serum creatinine alone is a relatively poor discriminator of those who will require dialysis. For example, although the average preoperative serum creatinine of those requiring postoperative dialysis is 1.6 mg/dL, up to three quarters of those with preoperative serum creatinine of 3.5 mg/dL will not require postoperative dialysis.

We also identified other important clinical factors beyond renal function that increased a patient's risk for postoperative dialysis. Advanced age and insulin-dependent diabetes have both been shown to be associated with glomerular sclerosis or disease, which increases the risk of renal failure in general and make subjects more susceptible to ischemic insults during cardiopulmonary bypass.[16,17,19] The unstable preoperative state among those with recent myocardial infarction, cardiogenic shock, and advanced functional class is more likely to be associated with reduced renal perfusion secondary to lower cardiac output, making these patients more vulnerable to renal damage during further reduction in flow during cardiopulmo-

Last Creatinine	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0 and higher	Score
Points (Creatinine * 10)	5	10	15	20	25	30	35	40	

Age	<55	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100+	Score
Points	0	1	2	3	4	5	6	7	8	9	10	

Surgery	CABG Only	AV Only	AV + CABG	MV Only	MV + CABG	Score
Points	0	2	5	4	7	

Diabetes	No Diabetes	Controlled Orally	Insulin Dependent	Score
Points	0	2	5	

MI Recent	No Recent MI	Within Last 3 weeks	Score
Points	0	3	

Race	White	Non-White	Score
Points	0	2	

Chronic Lung Disease	No	Yes	Score
Points	0	3	

Reoperation	No Prior CV Surgery	Prior CAB or Other CV Surgery	Score
Points	0	3	

NYHA Class	I,II,III	IV	Score
Points	0	3	

Cardiogenic Shock	No	Yes	Score
Points	0	7	

Total Score:

Total Score: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68+

Risk of Dialysis, %: 0, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.2, 0.2, 0.2, 0.2, 0.3, 0.3, 0.4, 0.4, 0.5, 0.6, 0.7, 0.9, 1.1, 1.3, 1.5, 1.8, 2.1, 2.5, 3, 3.4, 4, 4.7, 5.4, 6.2, 7.1, 8.1, 9.2, 10, 11, 13, 14, 15, 16, 18, 19, 19, 20, 20, 21, 22, 24, 25, 28, 31, 31, 33, 35, 40, 42, 44, 48, 55, 56, 59, 59, 59, 59, 70, 70, 80, 80, 85

Figure 4. Nomogram to predict postoperative renal dysfunction needing dialysis.

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nary bypass. The risk also appears to be surgery specific, with the highest risk posed by a combination of CABG with valve surgery, particularly mitral valve surgery (Figure 1). Similarly, repeat cardiac surgery also increases the risk. Valvular surgery, especially combined CABG and valve operations and repeat cardiac surgery, prolongs the on-pump time, increasing the likelihood of renal failure requiring dialysis in these patients. Chronic lung disease increases the liability of prolonged ventilation, leading to increased risk of pneumonia, sepsis, and multisystem organ failure, resulting in renal failure and dialysis. Finally, in general, nonwhites have increased risk of renal failure requiring dialysis.[20] Perhaps the perioperative milieu during cardiac surgery further accentuates this tendency in this at-risk population. Further investigations are needed to understand the pathophysiological mechanisms underlying this racial predilection for postoperative dialysis.

Our predictive models also benefited from being derived from a very large national patient sample. As a result, we were able to test and validate this simplified risk tool across a wide spectrum of patient population and operative procedures. Additionally, the large number of events of interest (postoperative dialysis) in the development (n=6451) and validation (n=1372) cohorts, the model fit in the validation set, and the excellent performance of the risk score in risk stratification and in different subgroups of patients undergoing CABG and/or valve surgery not only lend credence to the robustness of the model but also suggest a high predictive accuracy of the same.

Clinical Implications

Our findings have several clinical applications. It is estimated that 608 000 patients underwent open heart surgery in the United States in 2002.[1] Of these, on the basis of the findings of our study, ≈8500 patients would be expected to develop renal failure that required dialysis, and of these 8500, half would die. In addition, the 13 extra days spent on average in hospital after surgery by those requiring postoperative dialysis translate into an average of 110 500 patient-days in hospital, most of it in the intensive care unit. Thus, this complication after open heart surgery has tremendous implications in terms of cost for the already challenged healthcare industry. Identifying patients before cardiac surgery would allow the at-risk patients to receive treatment strategies to minimize the risk of postoperative renal failure in general and dialysis in particular to improve patient outcomes and to reduce the burden of healthcare cost. Potentially helpful strategies include avoiding nephrotoxic drugs, including aminoglycoside antibiotics and nonsteroidal antiinflammatory drugs before, during, and after surgery; avoiding prolonged cardiopulmonary bypass if needed by choosing to perform fewer anastomoses; or performing operations instituting significantly aggressive hypothermic regimen or off pump. Furthermore,

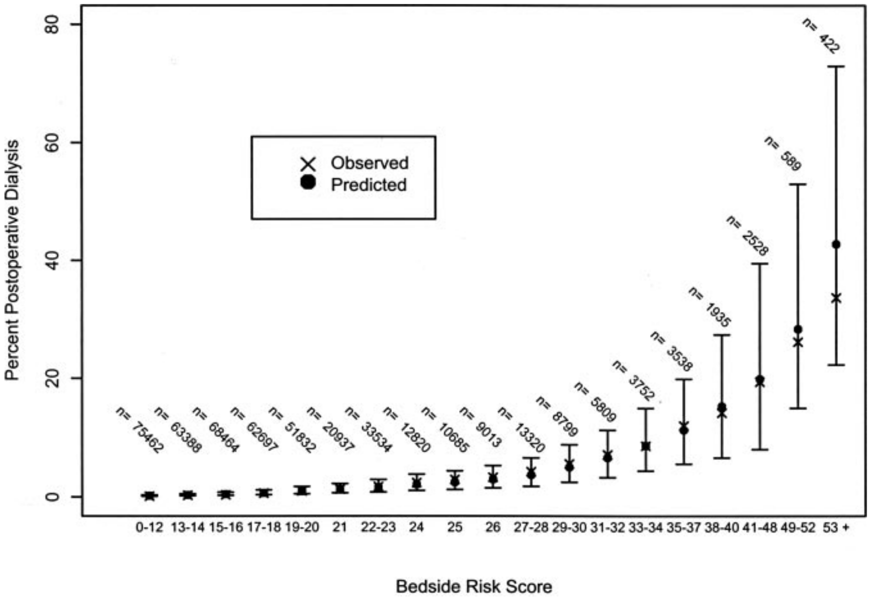

Figure 5. Risk score and incidence of renal failure requiring postoperative dialysis. Vertical bars extend from the 5th to the 95th percentiles of the distribution of predicted risk as calculated by the original full model.

optimizing the patient's hemodynamics and improving renal perfusion by using inotropes, closely monitoring fluid and renal status, and vigorously controlling blood glucose levels in the perioperative period also may help to minimize the incidence of this complication. In addition, identifying patients at high risk for postoperative renal failure requiring dialysis would enable communication of this risk to patients and family, allowing more comprehensive informed consent. Finally, our risk tool could be used for risk adjustment in clinical research and in observational studies for comparing the need for postoperative dialysis among diverse groups of patients undergoing cardiac surgery.

Study Limitations

Our study findings should be viewed in light of the limitations of this study. As is true in any observational study, we are unable to account for the influence of any unmeasured factors on the risk of postoperative dialysis. In particular, we did not have the details on the intraoperative and postoperative management of these patients. Thus, we are unable to determine whether surgical risk can be altered by optimizing perioperative care. Furthermore, although our findings suggest association of baseline factors with need for dialysis, a cause–effect relationship should not be inferred. Future studies evaluating mechanisms

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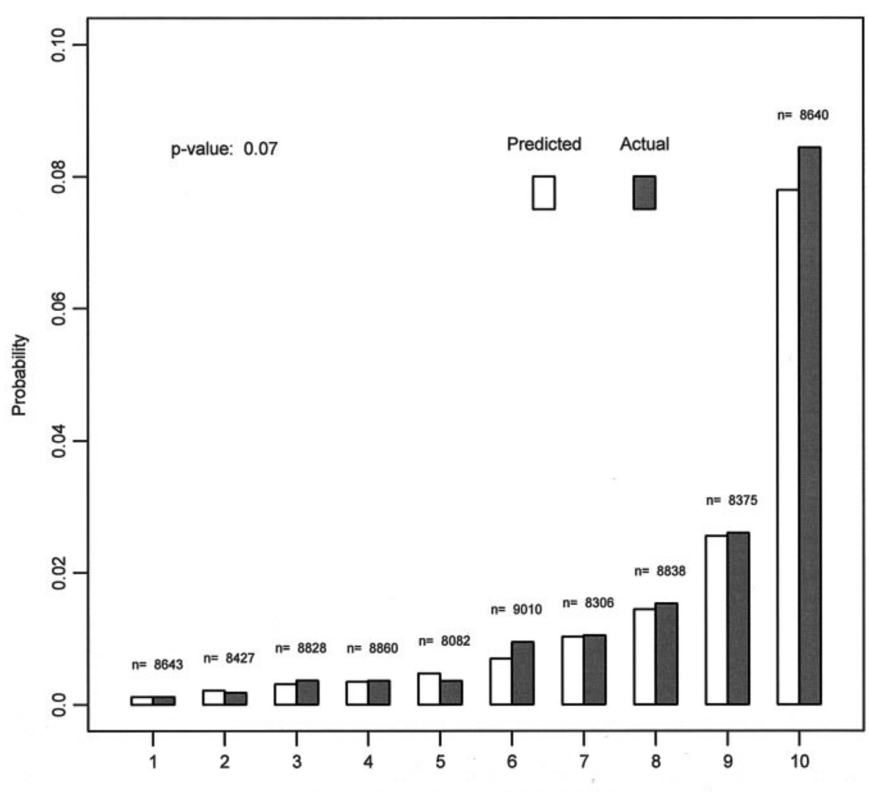

Figure 6. Calibration graphs. The *x* axis represents deciles of predicted risk based on the risk model; the *y* axis, the probability for the need for postoperative dialysis (Hosmer-Lemeshow χ^2 =17.37, *df*=10, *P*=0.07 for the lack of fit).

underlying these associations are in order. The current database allowed only for evaluation of short-term risk because we had no information on long-term outcomes. Finally, we did not have any data on the length of postoperative dialysis (temporary versus long term) and are unable to provide information on differences in outcomes between the 2 groups.

Conclusions

We conclude that the estimation of patient-specific risk of dialysis after cardiac surgery is feasible with the simplified additive risk tool developed in our study using routinely available preprocedural data. We believe that physicians will find this tool applicable and useful in routine clinical practice. However, future studies are needed to understand the mechanisms and pathophysiology of renal dysfunction requiring dialysis after cardiac surgery and to develop and evaluate clinical and therapeutic strategies that not only would help to minimize the risk of this complication but also would result in an improvement in the otherwise dismal morbidity and mortality rates observed among patients with this complication.

Source of Funding

This work was supported by the STS National Cardiac Surgery Database and Duke Clinical Research Institute.

Disclosures

None.

References

1. American Heart Association. *Heart Disease and Stroke Statistics: 2005 Update*. Dallas, Tex: American Heart Association; 2005.
2. Plume SK, O'Connor GT, Omstead EM. Changes in patients undergoing coronary artery bypass grafting: 1987–1990: update in 2000. *Ann Thorac Surg*. 2001;72:314–315.
3. Ferguson TB, Hamill PG, Peterson ED, DeLong ER, Glover FL. A decade of change: risk profiles and outcomes for isolated coronary artery bypass grafting procedures, 1990–1999: a report from the STS National Database Committee and the Duke Clinical Research Institute. *Ann Thorac Surg*. 2002;73:480–490.
4. Mangano CM, Diamondstone LS, Ramsay JG, Aggarwal A, Herskowitz A, Mangano DT, for the Multicenter Study of Perioperative Ischemia Research Group. Renal dysfunction after myocardial revascularization: risk factors, adverse outcomes, and hospital resource utilization. *Ann Intern Med*. 1998; 128:194–203.
5. Koning HM, Koning AJ, Defauw JJ. Optimal perfusion during extracorporeal circulation. *Scand J Thorac Cardiovasc Surg*. 1987;21:207–213.
6. Corwin HL, Sprague SM, DeLaria GA, Norusis MJ. Acute renal failure associated with cardiac operations: a case-control study. *J Thorac Cardiovasc Surg*. 1989;98:1107–1112.
7. Slogoff S, Reul GJ, Keats AS. Role of perfusion pressure and flow in major organ dysfunction after cardiopulmonary bypass. *Ann Thorac Surg*. 1990;50: 911–918.
8. Chertow GM, Levy EM, Hammermeister KE, Grover F, Daley J. Independent association between acute renal failure and mortality following cardiac surgery. *Am J Med*. 1998;104:343–348.
9. Edwards FH, Petersen ED, Coombs LP, DeLong ER, Jamieson WRE, Shroyer ALW, Grover FL. Prediction of operative mortality after valve replacement surgery. *J Am Coll Cardiol*. 2001;37:885–892.
10. Edwards FH, Clark RE, Schwartz M. Coronary artery bypass grafting: the Society of Thoracic Surgeons National Database experience. *Ann Thorac Surg*. 1994;57:12–19.
11. Clark RE. The STS Cardiac Surgery National Database: an update. *Ann Thorac Surg*. 1995;59:1376–1381.
12. Levey AS, Bosch JP, Lewis JB, Greene T, Rogers N, Roth D. A more accurate method to estimate glomerular filtration rate from serum creatinine: a new prediction equation: Modification of Diet in Renal Disease Study Group. *Ann Intern Med*. 1999;130:461–470.
13. Frank E Harrell. *Regression Modeling Strategies With Applications to Linear Models, Logistic Regression, and Survival Analysis*. New York, NY: Springer; 2001:98–101.
14. Sullivan LM, Massaro JM, D'Agostino RB Sr. Tutorial in biostatistics: presentation of multivariate data for clinical use: the Framingham study risk score functions. *Stat Med*. 2004;23:1631–1660.
15. Grunkemeier GL, Jin R. Receiver operating characteristic curve analysis of clinical risk models. *Ann Thorac Surg*. 2001;72:323–326.
16. Samuels LE, Sharma S, Morris RJ. Coronary artery bypass grafting in patients with chronic renal failure: a reappraisal. *J Card Surg*. 1996;11: 128–133.
17. Abel RM, Buckley MJ, Austen WG. Etiology, incidence, and prognosis of renal failure following cardiac operations. *J Thorac Cardiovasc Surg*. 1976; 71:323–333.
18. Chertow GM, Lazarus JM, Christiansen CL, Cook EF, Hammermeister KE, Grover F, Daley J. Preoperative renal risk stratification. *Circulation*. 1997; 95:878–884.
19. Beckman JA, Creager MA, Libby P. Diabetes and atherosclerosis: epidemiology, pathophysiology, and management. *JAMA*. 2002;287: 2570–2581.
20. Tell GS, Hylander B, Craven TE, Burkart J. Racial differences in the incidence of end-stage renal disease. *Ethn Health*. 1996;1:21–31.

CLINICAL PERSPECTIVE

Although cardiac surgical outcomes have improved over time, patients remain at risk for postoperative complications, including the need for postoperative dialysis. A means of easily estimating a patient's individual risk for postoperative dialysis based on multiple preoperative clinical factors at a patient's bedside would facilitate informed clinical decision making and patient counseling. A study of 449 524 cardiac surgery patients in the Society of Thoracic Surgeons National Adult Cardiac Database found that postoperative dialysis was required in 6451 patients (1.4%). Multivariable analysis identified preoperative serum creatinine, age, race, type of surgery (coronary artery bypass grafting plus valve or valve only versus CABG only), diabetes, shock, New York Heart Association class, lung disease, recent myocardial infarction, and prior cardiovascular surgery to be associated with need for postoperative dialysis (c statistic=0.83). This multivariable model was then converted into a simplified additive bedside risk prediction tool for making estimates of patient-specific risk of dialysis after cardiac surgery feasible using routinely available preprocedural data. When tested in a validation set, the bedside tool performed well in the validation sample (c statistic=0.83, Hosmer-Lemeshow χ^2 =17.37, df=10, P=0.07 for the lack of fit). We believe that physicians will find this tool applicable and useful in routine clinical practice.

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