On-pump versus off-pump coronary surgery outcomes in patients requiring dialysis: Perspectives from a single center and the United States experience

Jason Beckermann, MD, Joseph Van Camp, MD, Shuling Li, MS, Sharon K Wahl, RN, CNS, Allan Collins, MD, and Charles A Herzog, MD

Objective: Coronary artery bypass graft surgery carries increased risk for patients requiring dialysis compared with other groups. Little data exist comparing outcomes of on-pump and off-pump techniques in dialysis patients. This study compares outcomes of bypass grafting in dialysis patients with these two techniques at a single institution and in the United States Renal Data System (USRDS) database.

Methods: From March 1997 to April 2004, 37 patients requiring dialysis underwent bypass graft surgery at our institution. On-pump surgery was performed for 16 patients and off-pump surgery for 21. From January 1, 2001, to December 31, 2002, a total of 3922 patients in the USRDS underwent bypass graft surgery. On-pump surgery was performed for 3382 and off-pump surgery for 540. Comparisons were made between patients undergoing on-pump and off-pump bypass surgery with respect to demographics, risk factors, and outcomes. Univariate analysis, the Kaplan-Meier method, and a multivariate Cox model were used.

Results: Institutional analysis revealed similar patient demographics, risk factors, use of thoracic artery grafts, and number of distal anastomoses. Outcome analysis was significant for less postoperative atrial fibrillation with the off-pump technique: 37.5% on-pump and 4.8% off-pump ($P = .028$). USRDS data revealed all-cause survivals at 1 and 18 months of 87.5% and 59.5% for on-pump versus 88.3% and 61.9% for off-pump procedures ($P = .226$). In a comorbidity-adjusted Cox model, off-pump bypass grafting was associated with a 16% reduction in all-cause mortality ($P = .032$).

Conclusion: Off-pump bypass grafting is uncommon in patients in the United States who require dialysis. Off-pump bypass grafting provides a morbidity benefit and is associated with a lower risk of death.

Cardiac disease is the leading cause of death in patients requiring dialysis, accounting for greater than 40% of mortality.¹ Several studies have shown that dialysis patients have improved long-term outcomes when treated with coronary artery bypass grafting (CABG) compared with percutaneous procedures.²⁻⁵ Multiple studies evaluating on-pump CABG in dialysis patients have shown short-term mortality rates from 7.8% to 20%, which are considerably higher

From the Divisions of Cardiology and Nephrology, Department of Internal Medicine, Department of Surgery, Hennepin County Medical Center, United States Renal Data System-Cardiovascular Special Studies Center, Minneapolis Medical Research Foundation, University of Minnesota-Twin Cities, Minneapolis, Minn.

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Address for reprints: Joseph Van Camp, MD, Department of Surgery, Hennepin County Medical Center, 701 Park Ave, Minneapolis, MN 55415 (E-mail: joe.van.camp@co.hennepin.mn.us).

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Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
CPB	= cardiopulmonary bypass
ESRD	= end-stage renal disease
ICD	= International Classification of Disease
USRDS	= United States Renal Data System

than typical reports of 2% to 3% in patients not receiving dialysis.⁶⁻¹¹ Recent trials have evaluated off-pump CABG as a technique to decrease morbidity and mortality in high-risk patient populations.^{12,13} Off-pump CABG in patients requiring dialysis has been evaluated in several small retrospective studies and has shown decreased blood loss, reductions in ventilator and intensive care unit times, less need for postoperative dialysis, and lower costs.¹²⁻¹⁶ Our cardiac surgical program is characterized by a low-volume, high-risk population. Approximately 11% of our CABG patients have end-stage renal disease (ESRD) compared with an average of 1% in The Society of Thoracic Surgeons national database. In an attempt to optimize outcomes, we have adopted off-pump CABG as our procedure of choice for appropriate candidates. In this article we report our experience with this approach and the nationwide results from the United States Renal Data System (USRDS) database for dialysis patients undergoing CABG.

Methods

From May 1997 to April 2004, 37 patients requiring dialysis underwent primary CABG at Hennepin County Medical Center, Minneapolis, Minnesota. Of these patients, 16 (43.6%) were operated on with an on-pump technique and 21 (56.4%), off-pump. Before the year 2000, all procedures were performed on-pump. Beginning in 2000 an aggressive approach to off-pump surgery was initiated. Since that time 21 of 24 CABG operations for patients requiring dialysis have been performed with off-pump technique. Three have been performed on-pump for the following indications: a mycotic aneurysm of the circumflex artery at the site of a percutaneously placed stent, a circumflex artery located deep in the myocardium, and one procedure done by an visiting surgeon who does not perform off-pump CABG surgery. All operations were performed through a median sternotomy. Patients undergoing combined procedures or reoperations were not included. This study was reviewed and approved by the Human Subject Research Committee of the Hennepin County Medical Center Institutional Review Board.

Operative Technique

On-pump CABG. Heparin was given to achieve an activated clotting time of 480 seconds. Cardiopulmonary bypass (CPB) was established between the ascending aorta and right atrium. A coronary sinus catheter was placed for retrograde perfusion during cardioplegia. Cold blood cardioplegia was accomplished with antegrade delivery through the aortic root and retrograde delivery

through the coronary sinus. CPB was carried out under mild hypothermia (32°C). Heparin was reversed with protamine at the completion of the anastomoses.

Off-pump CABG. Heparin was given to achieve an activated clotting time greater than 300 seconds. Deep pericardial stitches were placed to manipulate the heart and expose the coronary arteries. An Octopus coronary stabilizer, (Medtronic, Inc, Minneapolis, Minn) was used. Distal anastomoses were performed first. Proximal anastomoses were then completed with a side clamp applied the ascending aorta. Heparin was reversed with protamine after completion of the anastomoses.

Retrospective review of our institutional cardiac surgery database maintained since January 1997 was performed. These data are prospectively collected in The Society of Thoracic Surgeons format and submitted as part of the national database program. (Lummedex, Seattle, Wash) The database was reviewed for demographics, preoperative risk factors, intraoperative data, and postoperative outcomes. Statistical analysis of categorical variables was performed by the Pearson χ^2 test or the Fisher exact test. Continuous variables were analyzed with the 2-sample *t* test. Statistical analysis was performed with SAS version 8 (SAS Institute, Inc, Cary, NC).

USRDS Data

Data were retrospectively collected from the USRDS, which contains information on 1.5 million patients with ESRD. This database includes all patients requiring dialysis in the United States.¹⁷ Most data sets used by USRDS are provided by the Centers for Medicare and Medicare Services. Administrative data come from Medicare claims, parts A (hospitalization) and B (physician/provider). The accuracy of these data has been previously validated.¹⁸

The present study was a retrospective analysis of dialysis patients undergoing CABG surgery after initiation of renal replacement therapy. Eligible patients had received renal replacement therapy for 90 days or more. Exclusion criteria included a history of CABG or valve surgery after initiation of dialysis or concomitant valve surgery during CABG.

Patients were identified from the USRDS by International Classification of Disease codes (ICD-9-CM) for CABG surgery (code 36.1) between January 1, 2001, and December 31, 2002. Surgery performed without CPB was recognized by off-pump CPT code 00566. Patients receiving internal thoracic artery grafts were identified by ICD-9-CM codes 36.15 and 36.16. Data evaluated for patient characteristics and survival data were obtained from Medicare claims. Patient characteristics evaluated included age, gender, race, ESRD etiology, prior ESRD time, comorbidities identified before hospitalization, and internal thoracic artery graft use.

Patients were followed up from the date of CABG surgery to the earliest of death, transplant, loss to follow-up, or March 31, 2003. Patients' baseline characteristics with on-pump and off-pump CABG surgery were compared by χ^2 square tests. Long-term survival was estimated by the Kaplan-Meier method, and survival of subgroups was compared by the log-rank test. The effect of off-pump CABG surgery on outcomes was estimated by the Cox proportional hazards model, with adjustment for patient characteristics. Statistical analysis was performed with SAS version 8.

TABLE 1. Baseline patient characteristics in the cardiac surgical program

	On-pump (n = 16)		Off-pump (n = 21)		P value*
	No.	% (70% CI)	No.	% (70% CI)	
Age (y), mean (SD)	16	59 (10.6)	21	62 (9.99)	.430
Gender					.729
Male	9	56.3 (40.4, 71.1)	13	61.9 (48.2, 74.2)	
Female	7	43.7 (28.9, 59.6)	8	38.1 (25.8, 51.8)	
Race					.231
White	11	68.6 (52.7, 81.8)	9	42.9 (30.1, 56.5)	
African American	1	6.2 (1.0, 19.6)	5	23.8 (13.7, 37.1)	
Other	4	25 (13.2, 40.9)	7	33.3 (21.6, 47.0)	
ESRD etiology					.865
Diabetes	11	68.6 (52.7, 81.8)	16	76.2 (62.9, 86.3)	
HTN	3	18.8 (8.5, 34.1)	2	9.5 (3.3, 21.1)	
Other	2	12.5 (4.3, 27.1)	3	14.3 (6.4, 26.6)	
Comorbidity					
PVD	6	37.5 (23.4, 53.6)	9	42.9 (30.1, 56.5)	.742
HTN	14	87.5 (72.9, 95.7)	21	100 (91.4, 100)	.096
CVA	1	6.2 (1.0, 19.6)	4	19.0 (10.0, 31.9)	.259
COPD	0	0	1	4.8 (0.8, 15.2)	.376
MI	12	75 (59.2, 86.8)	11	52.4 (39.0, 65.5)	.16
EF <40%	9	56.3 (40.4, 71.1)	6	28.6 (17.6, 42.1)	.089
Other cardiac	4	25.0 (13.2, 40.9)	5	23.8 (13.7, 37.1)	.933
ITA graft	14	87.5 (72.9, 95.7)	20	95 (84.8, 99.2)	.393
Distal anastomosis, mean (SD)		3.25 (1.0)		3.33 (0.73)	.771

CHF, Congestive heart failure; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; EF, ejection fraction; ESRD, end-stage renal disease; HTN, hypertension; ITA, internal thoracic artery; MI, myocardial infarction; PVD, peripheral vascular disease; SD, standard deviation. *Using a 2-sample *t* test for continuous variables and the Pearson's χ^2 test or Fisher exact test for categorical variables.

Results

Review of institutional results showed that patients undergoing on-pump and off-pump CABG surgery were similar in terms of age, gender, race, and ESRD etiology (Table 1). Comorbidities evaluated included hypertension, previous cerebrovascular accident, peripheral vascular

disease, chronic obstructive pulmonary disease, previous myocardial infarction, and ejection fraction of 40% or less (Table 1). Patients were similar with regard to these comorbidities. An internal thoracic artery graft was used in 14 of 16 (87.5%) on-pump operations and 20 of 21 (95%) off-pump, *P* = .39. Mean number of distal anas-

TABLE 2. Complications and length of stay in the cardiac surgical program

	On-pump (n = 16)		Off-pump (n = 21)		P value*
	N	% (70% CI)	N	% (70% CI)	
Reoperative bleeding	0	0	0	0	NA
Perioperative MI	3	18.8 (8.5, 34.1)	0	0	.072
Infected leg wound	2	12.5 (4.3, 27.1)	3	14.3 (6.4, 26.6)	>.999
Sepsis	3	18.8 (8.5, 34.1)	1	4.8 (0.8, 15.2)	.296
CVA	1	6.3 (1.0, 19.6)	1	4.8 (0.8, 15.2)	>.999
Prolonged mechanical ventilation	6	37.5 (23.4, 53.6)	4	19.0 (10.0, 31.9)	.274
Pneumonia	3	18.8 (8.5, 34.1)	1	4.8 (0.8, 15.2)	.296
Other GI complications	2	12.5 (4.3, 27.1)	0	0	.180
Atrial fibrillation	6	37.5 (23.4, 53.6)	1	4.8 (0.8, 15.2)	.029
Death	2	12.5 (4.3, 27.1)	1	4.8 (0.8, 15.2)	.568
Hospital LOS (d), mean (SD)		10.31 (6.37)		10.23 (6.16)	.972

CI, Confidence interval; CVA, cerebrovascular accident; MI, myocardial infarction; GI, gastrointestinal; LOS, length of stay; NA, not applicable; SD, standard deviation. *Using 2-sample *t* test for continuous variable and the Fisher exact test for categorical variables.

TABLE 3. Baseline patient characteristics, USRDS data

	All (n = 3922) 100	On-pump (n = 3382) 86.2	Off-pump (n = 540) 13.8	P value*
Age (y)				<.0001
<45	6.0	6.1	5.4	
45-64	42.6	43.8	34.8	
65-74	35.0	34.7	37.2	
≥75	16.4	15.4	22.6	
Gender				.5598
Male	60.0	59.8	61.1	
Female	40.0	40.2	38.9	
Race				.0713
White	65.5	64.8	69.6	
African American	28.5	29.2	24.4	
Other	6.0	6.0	5.9	
Prior ESRD time (y)				.8151
<1	23.7	23.5	25.2	
1-<2	21.2	21.2	21.1	
2-<5	37.1	37.1	36.7	
≥5	18.0	18.2	17.0	
ESRD etiology				.3079
Diabetes	56.5	56.8	54.8	
HTN	24.4	24.5	23.7	
Other	19.1	18.9	21.5	
Comorbidity				
ASHD	53.8	54.0	52.6	.5363
Cancer	8.5	8.0	11.3	.0109
Cardiac (other)	31.4	31.1	33.7	.2220
CHF	32.2	31.9	34.1	.3096
COPD	15.6	15.3	17.4	.2070
CVA/TIA	12.9	12.2	16.7	.0043
Gallbladder	3.9	3.8	4.8	.2376
GI bleeding	10.8	10.5	12.8	.1181
Liver disease	1.6	1.7	0.9	.2031
PVD	27.0	26.5	30.0	.0910
ITA graft				
Yes	73.3	72.8	76.5	.0723

ASHD, Atherosclerotic heart disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; ESRD, end-stage renal disease; GI, gastrointestinal; HTN, hypertension; ITA, internal thoracic artery; PVD, peripheral vascular disease; TIA, transient ischemic attack; USRDS, United States Renal Data System. All numbers given in percentage. *Using the χ^2 test.

tomoses was 3.25 in the on-pump group and 3.33 in the off-pump group, $P = .77$. Outcomes were similar in terms of bleeding requiring reoperation, perioperative myocardial infarction, leg infections, perioperative sepsis, pneumonia, cerebrovascular accident, prolonged ventilator support, gastrointestinal complications, mortality, and hospital length of stay (Table 2). Patients undergoing off-pump surgery had a lower incidence of new-onset atrial fibrillation, 1 of 21 (4.8%) versus 6 of 16 (37.5%), $P = .03$.

Figure 1. Kaplan-Meier survival estimates of time to all-cause mortality. The numbers below the x-axis indicate the number of event-free patients under observation at 0, 6, 12, 18, and 24 months. $P = 0.2263$ for comparison of patients with to those without CPB by log-rank test.

USRDS

A total of 3922 dialysis patients who underwent CABG surgery were evaluated. Of these patients, 3382 (86%) had their operation performed on-pump and 540 (14%) off-pump. The mean follow-up time is 10.8 months (SD 7.9) for the on-pump group and 10.4 months (SD 7.4) for the off-pump group, $P = .2598$. Comparison of demographics revealed that patients undergoing on-pump CABG tended to be younger, with 49.9% being less than 65 years old versus 40.2% in the off-pump group, $P < .0001$. The off-pump group also had more patients with a prior malignancy (11.3% vs 8.0%; $P = .01$) and a higher incidence of prior cerebrovascular accident or transient ischemic attack (16.7% vs 12.2%; $P = .004$). Patients in both groups were similar in terms of gender, race, duration of ESRD, ESRD etiology, and other comorbidities (Table 3). Internal thoracic artery grafts were used in 72.8% of on-pump versus 76.5% of off-pump CABG operations, $P = .072$. USRDS data revealed all-cause survivals at 1 and 18 months of 87.5% and 59.5% for on-pump versus 88.3% and 61.9% for off-pump operations, $P = .226$ (Figure 1). In-hospital death occurred in 12.0% of patients undergoing on-pump procedures and 10.9% off-pump, $P = .471$. Patients in the off-pump CABG group were older and had a greater number of comorbidities. To adjust for baseline differences in demographics and comorbidities between patients in the off-pump and on-pump groups, a multivariate Cox proportional hazards model was used. The estimated hazard ratio using a Cox model for off-pump CABG as a predictor of all-cause death was 0.84 (0.72, 0.99), $P = .032$ (Table 4). Other independent risk factors

TABLE 4. Results of Cox proportional hazards model of all-cause mortality in patients undergoing off-pump or on-pump CABG, USRDS data

	Hazard ratio (95% CI)	P value
Off-pump CABG surgery	0.84 (0.72, 0.99)	.0325
Age (y)		
<45	0.89 (0.68, 1.16)	.387
65-74	1.39 (1.23, 1.58)	<.0001
≥75	1.87 (1.60, 2.18)	<.0001
Gender		
Female	1.19 (1.07, 1.33)	.0017
Race		
African American	0.99 (0.87, 1.12)	.8457
Other	1.01 (0.80, 1.27)	.9533
Prior ESRD time (y)		
1-<2	0.95 (0.80, 1.13)	.5395
2-<5	1.30 (1.13, 1.51)	.0004
5+	1.41 (1.18, 1.69)	.0001
ESRD etiology		
Diabetes	1.36 (1.17, 1.59)	<.0001
HTN	1.23 (1.04, 1.46)	.0141
Comorbidity		
ASHD	1.01 (0.89, 1.14)	.8657
Cancer	1.03 (0.86, 1.23)	.764
Cardiac (other)	1.17 (1.04, 1.32)	.0096
CHF	1.04 (0.92, 1.17)	.5648
COPD	1.45 (1.27, 1.66)	<.0001
CVA/TIA	1.21 (1.05, 1.40)	.0082
Gallbladder	1.26 (1.00, 1.59)	.0522
GI bleeding	1.04 (0.89, 1.22)	.6235
Liver disease	1.76 (1.24, 2.52)	.0018
PVD	1.28 (1.14, 1.44)	<.0001
ITA graft		
Yes	0.86 (0.77, 0.97)	.0133

ASHD, Atherosclerotic heart disease; CABG, coronary artery bypass grafting; CHF, congestive heart failure; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; ESRD, end-stage renal failure; GI, gastrointestinal; HTN, hypertension; ITA, internal thoracic artery; PVD, peripheral vascular disease; TIA, transient ischemic attack; USRDS, United States Renal Data System. The reference group has the following characteristics: CABG surgery performed with cardiopulmonary bypass; age between 45 and 64 years; male gender; white race; prior ESRD duration less than 1 year; other ESRD etiology; no comorbid conditions; no ITA graft.

for all-cause death using this model included age greater than 65 years, female gender, ESRD duration greater than 2 years, diabetes, hypertension, other cardiac disease, chronic obstructive pulmonary disease, cerebrovascular accident/transient ischemic attack, liver disease, peripheral vascular disease, and not using an internal thoracic artery graft (Table 4).

Discussion

The merits of on-pump versus off-pump CABG surgery have been a source of considerable debate in recent years.

Potential benefits of off-pump surgery include less postoperative cognitive impairment,¹⁹ a lower incidence of renal failure,²⁰ less blood loss, less prolonged mechanical ventilation, shorter intensive care unit and hospital stays, and lower mortality in high-risk groups.²¹⁻²³

One concern regarding off-pump surgery has been adequacy of revascularization owing to the difficulty of exposing the circumflex artery and its branches with this technique.²⁴ A fairly consistent pattern of fewer distal anastomoses being performed with the off-pump technique is present in the existing literature. This is somewhat concerning given the 26% reduction in mortality that has been shown with complete versus incomplete revascularization after CABG surgery.²⁵ Advances in technology for cardiac stabilization and increased experience with positioning have allowed surgeons to overcome some of these challenges. A recent randomized study including 200 patients showed similar rates of complete revascularization for CABG with on-pump and off-pump techniques when performed by an experienced surgeon.²¹ In our experience, we performed a similar number of anastomoses in cases with and without the pump.

Several studies have addressed the question of whether certain high-risk populations would benefit more from off-pump CABG surgery. Theoretically, this idea is appealing in dialysis patients, in whom smaller volume shifts associated with reduced production of inflammatory mediators may be particularly beneficial. A number of small retrospective series have recently addressed this possibility. Papadimitriou and associates¹⁴ reviewed 34 dialysis patients undergoing CABG, 15 of whom had off-pump procedures. They showed less blood loss, lower catabolic rates, and less frequent postoperative dialysis in off-pump patients. Tashiro and colleagues¹⁵ performed 26 CABG operations on dialysis patients, with 15 completed off-pump. Their results included decreased ventilator time, shorter intensive care unit time, and lower cost. A series of 40 hemodialysis patients operated on by Hirose and coworkers¹⁶ included 16 patients having off-pump operations. They found less blood loss, a lower overall complication rate, shorter intubation times, shorter intensive care unit stays, and less frequent postoperative dialysis in patients undergoing off-pump surgery. The primary benefit of off-pump CABG in our institutional series of 21 off-pump procedures was a lower incidence of postoperative atrial fibrillation when compared with 16 patients undergoing on-pump CABG. Although all of these small series showed significant decreases in morbidity with the off-pump technique, none was able to independently show a survival benefit.

Using USRDS data allowed us to evaluate outcomes for a large volume of dialysis patients from many different institutions who received CABG. When a Cox model was applied to adjust for independent risk factors, off-pump

CABG was associated with a 16% reduction in risk of all-cause death.

The primary limitations of our study include its retrospective nature, a short follow-up time, and the possible impact of selection bias for choice of procedure.

Although the majority of CABG operations for dialysis patients are performed with CPB, USRDS data would suggest that a survival benefit exists for patients undergoing off-pump CABG. In addition multiple institutional reports including our own data indicate that the off-pump technique provides a significant reduction in the morbidity associated with CABG.

The USRDS data also suggest that surgeons may already be risk stratifying high-risk patients to off-pump CABG. In addition, the data suggest that the internal thoracic artery may be underused in these patients. All of these areas show room for improving the long-term outcome of dialysis patients undergoing CABG.²⁶

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