Predialysis coronary revascularization and postdialysis mortality

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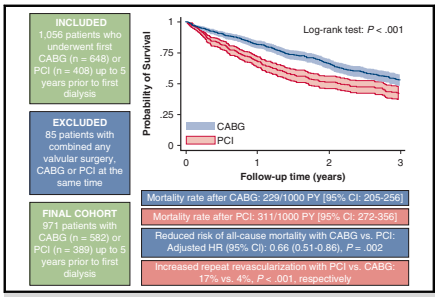
ABSTRACT

Objectives: Coronary artery bypass grafting (CABG) is associated with better survival than percutaneous coronary intervention (PCI) in patients with mild-to-moderate chronic kidney disease (CKD) and end-stage renal disease (ESRD). However, the optimal strategy for coronary artery revascularization in patients with advanced CKD who transition to ESRD is unclear.

Methods: We examined a contemporary national cohort of 971 US veterans with incident ESRD who underwent first CABG or PCI up to 5 years before dialysis initiation. We examined the association of a history of CABG versus PCI with all-cause mortality following transition to dialysis using Cox proportional hazards models adjusted for time between procedure and dialysis initiation, sociodemographics, comorbidities, and medications.

Results: In total, 582 patients underwent CABG and 389 patients underwent PCI. The mean age was 64 ± 8 years, 99% of patients were male, 79% were white, 19% were African American, and 84% had diabetes. The all-cause post-dialysis mortality rates after CABG and PCI were 229 per 1000 patient-years (95% confidence interval [CI], 205-256) and 311 per 1000 patient years (95% CI, 272-356), respectively. Compared with PCI, patients who underwent CABG had 34% lower risk of death (multivariable adjusted hazard ratio, 0.66; 95% CI, 0.51-0.86, $P = .002$) after initiation of dialysis. Results were similar in all subgroups of patients stratified by age, race, type of intervention, presence/absence of myocardial infarction, congestive heart failure, and diabetes.

Conclusions: CABG in patients with advanced CKD was associated lower risk of death after initiation of dialysis compared with PCI. (J Thorac Cardiovasc Surg 2019;157:976-83)



Retrospective cohort study design and main outcomes.

Central Message

An optimal strategy for coronary revascularization in CKD patients who transition to ESRD is proposed. Pre-ESRD coronary revascularization history with CABG vs PCI had a 34% lower risk of post-ESRD death.

Perspective

Decisions about optimal strategy need to balance the risks and benefits of CABG vs PCI in patients with CKD.

See Commentary on page 984.

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Abbreviations and Acronyms

ACEI = angiotensin-converting enzyme inhibitor
ARB = angiotensin receptor blocker
BMI = body mass index
CABG = coronary artery bypass grafting
CI = confidence interval
CKD = chronic kidney disease
eGFR = estimated glomerular filtration rate
ESRD = end-stage renal disease
HR = hazard ratio
PCI = percutaneous coronary intervention
VA = Veterans Affairs

Scanning this QR code will take you to the article title page to access supplementary information.

Patients with chronic kidney disease (CKD) are at increased risk of cardiovascular diseases and related mortality.[1-3] In the advanced stages of CKD, cardiovascular disease–related mortality rates are much greater than in earliest stages of CKD and in non-CKD populations.[1-3] Invasive interventions such as coronary artery bypass grafting (CABG) and percutaneous coronary interventions (PCI) are commonly and successfully used to treat coronary artery disease, but in advanced CKD, patients may be an at increased risk of adverse events from these interventions, which may directly impact on their outcomes after transitioning to end-stage renal disease (ESRD).[4-8] Physicians should make critical decisions about the optimal strategy of coronary revascularization in this vulnerable group of population with coronary artery disease, balancing their putative benefits with the potential complications associated with the procedures.[9-12] Despite advances in coronary revascularization, using second-generation drug-eluting stents with radial artery access in PCI and technological developments of CABG surgery, the postrevascularization complications and mortality rate remaining high, especially in the CKD population.[13-18]

Previous randomized controlled trials compared the effects of PCI versus CABG in patients with coronary artery disease but typically excluded patients with advanced CKD because of increased risk of major complications (eg, bleeding, acute kidney injury, or short-term risk of death).[19-22] Consequently, results from such clinical trials cannot be extrapolated to patients with advanced CKD, in whom the risk–benefit ratio of the 2 procedures may be shifted because of their different effects on outcomes such as acute kidney injury. Previous retrospective studies in large cohorts reported that compared with PCI, CABG is associated with better survival in mild-to-moderate CKD, in ESRD, and in patients with diabetes.[23-26] However, the optimal strategy for coronary artery revascularization in patients with advanced CKD is unclear. To address this knowledge gap, we aimed to study post-ESRD all-cause mortality associated with history of CABG versus PCI performed in patients with advanced CKD before transitioning to ESRD, using a large nationally representative cohort of US veterans with incident ESRD who underwent a first CABG or PCI up to 5 years before dialysis initiation. We hypothesized that CABG would be associated with reduced mortality compared with PCI in this population.

METHODS

Study Population

We studied longitudinal data from the Transition of Care in Chronic Kidney Disease study, a historical cohort study examining US veterans with incident ESRD transitioning to dialysis from October 1, 2007, through March 31, 2014.[27,28] A total of 85,505 US veterans were identified from the US Renal Data System[29] as a source population. The algorithm for the cohort definition is shown in Figure 1. Patients who did not receive CABG or PCI up to 5 years before first dialysis initiation were excluded. For the present study, 1056 patients who underwent PCI or CABG up to 5 years before ESRD (defined as the date of first maintenance dialysis service) were included. Patients receiving both CABG and PCI during the same hospitalization and patients undergoing concomitant ventricular reconstruction or pericardial or valve surgery were excluded. The final study population consisted of 971 patients, of whom 582 underwent CABG and 389 underwent PCI.

Exposures and Covariates

A history of CABG surgery and PCI procedure types were determined from *International Classification of Diseases, 9th Revision, Clinical Modification* procedure codes and Current Procedural Terminology procedure codes in the Veterans Affairs (VA) Inpatient or Outpatient Medical SAS Datasets and categorized according to the Clinical Classifications Software procedural classification system (Table E1). Based on Current Procedural Terminology and *International Classification of Diseases, 9th Revision, Clinical Modification* secondary codes, revascularizations were stratified as single-vessel or multivessel procedures. Information about baseline age, race, sex, marital status, per capita income, and body mass index (BMI) was obtained from national VA research data files, as previously described.[9,30] Information about comorbidities (diabetes, hypertension, ischemic heart disease, myocardial infarction, cerebrovascular disease, congestive heart failure, peripheral vascular disease, atrial fibrillation, chronic pulmonary disease, connective tissue disease, paraplegia and hemiplegia, hyperlipidemia, liver disease, peptic ulcer disease, depression, dementia, malignancy, and anemia) within 6 months before the studied coronary artery revascularization procedure was extracted from VA Inpatient and Outpatient Medical SAS Datasets and from the Centers for Medicare & Medicaid Services datasets using diagnostic and procedure codes.[31] The Charlson Comorbidity Index score was calculated using the Deyo modification for administrative datasets, without including kidney disease.[32] Medication use (angiotensin-converting enzyme inhibitor and angiotensin receptor blocker [ACEIs/ARBs], β-blockers, α-blockers, statins, calcium channel blockers, thiazide diuretics, loop

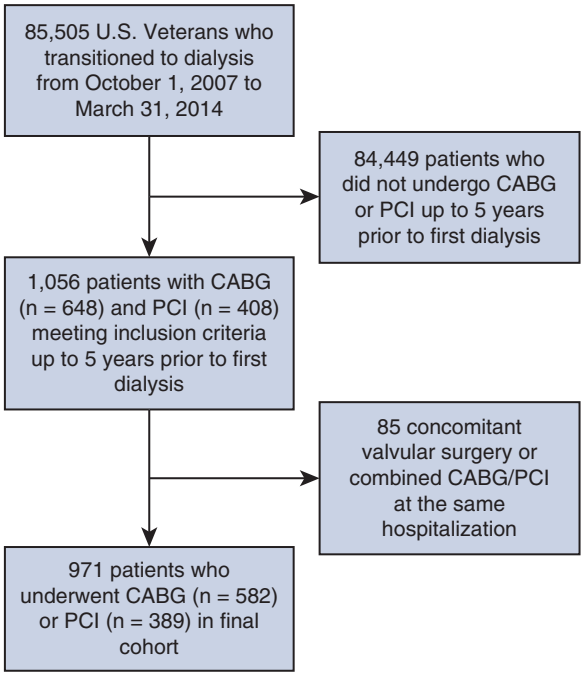


FIGURE 1. Flow chart of the patients' selection. *CABG*, Coronary artery bypass grafting; *PCI*, percutaneous coronary intervention.

diuretics, potassium-sparing diuretics, anticoagulants, thrombolytics, aspirin, digitalis, antianginals, vasodilators, antidiabetic agents, and radiocontrast material) was determined from VA pharmacy dispensation records in the 6 months before coronary artery revascularization.[33]

Blood hemoglobin and serum albumin levels were obtained from VA research databases as previously described,[9,30] and their baseline values were defined as the average of each covariate during the 6-month period preceding CABG or PCI. Estimated glomerular filtration rate (eGFR) was calculated by the Chronic Kidney Disease Epidemiology Collaboration equation.[34,35] Time to ESRD was defined as the period between the day of coronary revascularization and the first day of dialysis initiation.

Outcome Assessment

The primary outcome of interest was all-cause mortality after dialysis therapy initiation. All-cause mortality data, censoring events, and associated dates were obtained from VA and US Renal Data System data sources.[29] The start of the follow-up period was the date of dialysis therapy initiation, and patients were followed up until death or other censoring events, including kidney transplantation, loss of follow-up, or March 31, 2014.

Statistical Analysis

Data are summarized as percentages for categorical variables and as mean ± standard deviation or median (quartile 1-3), as appropriate. Categorical variables were compared using χ^2 tests. Continuous variables were compared using *t* tests, Mann–Whitney *U* tests, or analysis of variance, as appropriate.

The association of a history of CABG versus PCI with all-cause mortality was estimated using the Kaplan–Meier method and Cox proportional hazards models. Models were incrementally adjusted for the following potential confounders based on theoretical considerations and their availability in this study: model 1: adjusted for time between procedure and ESRD initiation; model 2: additionally adjusted for demographics (age, sex, race/ethnicity, marital status and income); model 3: additionally adjusted for comorbidities (diabetes, malignancy, liver diseases, hypertension, ischemic heart disease, congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic pulmonary disease, connective tissue disease, peptic ulcer disease, anemia, atrial fibrillation, depression, and hyperlipidemia), eGFR, and BMI; model 4: additionally adjusted for medications (anticoagulants, thrombolytic, aspirin, digitalis, beta-blockers, alpha-blockers, calcium channel blockers, antianginals, statins, vasodilators, thiazide diuretics, loop diuretics, potassium-sparing diuretics, ACEIs/ARBs, radiocontrast and antidiabetics), procedure type (single- vs multivessel); and model 5: additionally adjusted for baseline blood hemoglobin, serum albumin, and systolic and diastolic blood pressure.

In total, 891 (92%) patients had complete data for analysis in model 4. In model 5, an additional 420 cases (43% of cohort) had missing variables. Therefore, we regarded model 4 as our main multivariable adjusted model without replacing missing data, but, due to the relatively high proportion of missingness (43%) in model 5, missing covariates were imputed using multiple imputations.[27]

We conducted several sensitivity analyses to evaluate the robustness of our main findings. The association of a history of CABG and PCI with post ESRD mortality also were examined in subgroups of patients stratified by age (<65 or ≥65 years), race (African-Americans or others), type of intervention (single-vessel or multivessel), and presence/absence of myocardial infarction, congestive heart failure, and diabetes. Potential interactions were formally tested by including relevant interaction terms. We also examined the multivariable adjusted (model 4) association of a history of CABG versus PCI with all-cause mortality in cohorts of patients who underwent these procedures up to 1 and up to 2 years before dialysis initiation as well as separately in the subgroup of patients who underwent multivessel intervention. In addition, the association of a history of CABG versus PCI with all-cause mortality was evaluated after 1:1 propensity score matching in the subgroup of patients who underwent multivessel intervention.

P values are 2-sided and reported as significant at <.05 for all analyses. All analyses were conducted using STATA MP, Version 15 (STATA Corporation, College Station, Tex). The study was approved by the institutional review boards of the Memphis and Long Beach VA Medical Centers, with exemption from informed consent.

RESULTS

Baseline Characteristics

Patients' baseline characteristics in the overall cohort and stratified by type of coronary artery revascularization are presented in Table 1. The overall mean ± standard deviation age at baseline was 64 ± 8 years; 99% of patients were male, 19% were African American, and 84% had diabetes. Patients who underwent PCI (compared with CABG) had a greater prevalence of hypertension and chronic pulmonary disease and a lower prevalence of diabetes. Patients who underwent CABG were more likely to use statins, anticoagulants, antidiabetics, aspirin, and antianginals and less likely to use ACEIs/ARBs. In the PCI group compared with CABG group, 73% versus 12% of patients received single-vessel and 29% versus 88% of patients received multivessel treatments, respectively ($P < .001$). The eGFR at the time of procedure and the time to ESRD transition were similar in the PCI and CABG groups, but patients who underwent CABG had significantly lower levels of blood hemoglobin and serum albumin. BMI and systolic and diastolic blood pressure did not differ between the PCI and CABG groups. Patients who underwent PCI

TABLE 1. Baseline characteristics of patients

	All (n = 971)	PCI (n = 389)	CABG (n = 582)	*P* value
Demographics				
Age, y	64 ± 8	65 ± 9	64 ± 8	.115
Sex (male), n (%)	959 (99)	384 (99)	575 (99)	.909
Race, n (%)				.576
White	725 (74)	292 (75)	433 (74)	
African-American	180 (19)	76 (20)	104 (18)	
Native American and Asian	17 (2)	5 (1)	12 (2)	
Unknown	49 (5)	16 (4)	33 (6)	
Ethnicity (Hispanic), n (%)	73 (8)	23 (6)	50 (9)	.121
Marital status, n (%)				.002
Married	480 (49)	216 (55)	264 (45)	
Single	86 (9)	22 (6)	64 (11)	
Divorced	318 (33)	115 (30)	203 (35)	
Widowed	87 (9)	36 (9)	51 (9)	
Income, $	20,225 (10,620-35,028)	22,788 (11,000-36,276)	18,741 (10,488-33,876)	.207
Comorbidities at time of procedure				
Diabetes, n (%)	773 (80)	294 (76)	479 (82)	.011
Hypertension, n (%)	883 (91)	368 (95)	515 (88)	.001
Myocardial infraction, n (%)	322 (33)	119 (31)	203 (35)	.164
Cerebrovascular disease, n (%)	297 (31)	108 (28)	189 (32)	.119
Congestive heart failure, n (%)	416 (43)	172 (44)	244 (42)	.480
Peripheral vascular disease, n (%)	346 (36)	130 (33)	216 (37)	.239
Atrial fibrillation, n (%)	65 (7)	35 (9)	30 (5)	.019
Chronic pulmonary disease, n (%)	334 (34)	154 (40)	180 (31)	.005
Connective tissue disease, n (%)	24 (3)	14 (4)	10 (2)	.064
Paraplegia and hemiplegia, n (%)	23 (2)	10 (3)	13 (2)	.735
Hyperlipidemia, n (%)	750 (77)	303 (78)	447 (77)	.692
Liver disease, n (%)	32 (3)	13 (3)	19 (3)	.947
Peptic ulcer disease, n (%)	32 (3)	13 (3)	19 (3)	.947
Depression, n (%)	230 (24)	100 (26)	130 (22)	.226
Dementia, n (%)	8 (0.8)	7 (2)	1 (0.2)	.006
Malignancy, n (%)	123 (13)	56 (14)	67 (12)	.186
Anemia, n (%)	317 (33)	134 (34)	183 (31)	.328
Charlson Comorbidity Index	4 (2-5)	4 (2-5)	4 (2-5)	.675
Vital parameters at time of procedure				
Body mass index, kg/m^2	29.9 ± 5.7	30.1 ± 6.0	29.8 ± 5.6	.322
Systolic BP, mm Hg	144 ± 16	144 ± 17	144 ± 16	.675
Diastolic BP, mm Hg	75 ± 10	75 ± 11	75 ± 10	.605
Laboratory parameters at time of procedure				
Blood hemoglobin, g/dL	11.6 ± 1.7	11.9 ± 1.8	11.4 ± 1.5	<.001
Serum albumin, g/dL	3.43 ± 0.58	3.56 ± 0.59	3.35 ± 0.56	<.001
eGFR, mL/min/1.73 m^2	34 (21-53)	33 (20-51)	34 (22-53)	.159
Medications at time of procedure				
ACEIs/ARBs, n (%)	741 (24)	106 (27)	458 (21)	.033
β-blockers, n (%)	858 (88)	335 (86)	523 (90)	.075
α-blockers, n (%)	266 (27)	121 (31)	145 (25)	.034
Calcium channel blockers, n (%)	616 (63)	240 (62)	376 (65)	.356
Statins, n (%)	831 (86)	320 (82)	511 (88)	.016
Thiazide diuretics, n (%)	284 (29)	112 (29)	172 (30)	.798
Loop diuretics, n (%)	609 (63)	245 (63)	364 (63)	.890
Potassium-sparing diuretics, n (%)	86 (9)	39 (10)	47 (8)	.295
Anticoagulants, n (%)	376 (39)	135 (35)	241 (41)	.036
Thrombolytics, n (%)	5 (0.5)	0	5 (0.8)	.067
Aspirin, n (%)	712 (73)	252 (65)	460 (79)	<.001

(Continued)

TABLE 1. Continued

	All (n = 971)	PCI (n = 389)	CABG (n = 582)	*P* value
Digitalis, n (%)	46 (5)	23 (6)	23 (4)	.159
Antianginals, n (%)	611 (63)	205 (53)	406 (70)	<.001
Vasodilators, n (%)	320 (33)	128 (33)	192 (33)	.978
Antidiabetics, n (%)	699 (72)	223 (57)	476 (82)	<.001
Radiocontrast, n (%)	5 (0.5)	2 (0.5)	3 (0.5)	.998
No. of diseased vessels				<.001
Single vessel, n (%)	348 (36)	277 (71)	71 (12)	
Multivessel, n (%)	621 (64)	112 (29)	509 (88)	
Repeat revascularization, n (%)	94 (10)	68 (17)	26 (4)	<.001
Repeated CABG, n (%)	26 (3)	18 (5)	8 (1)	
Repeated PCI, n (%)	68 (7)	50 (13)	18 (3)	
Time to ESRD, d	775 (228-1251)	769 (222-1252)	781 (240-1250)	.709

Data are presented as mean ± SD, median and quartile 1-3, and number of observation and percentage as appropriate. *PCI*, Percutaneous coronary intervention; *CABG*, coronary artery bypass grafting; *BP*, blood pressure; *eGFR*, estimated glomerular filtration rate; *ACEI*, angiotensin-converting enzyme inhibitor; *ARB*, angiotensin receptor blocker; *ESRD*, end-stage renal disease.

compared with CABG had significantly greater incidence of repeat revascularization (17% vs 4%, $P < .001$; Table 1).

All-Cause Mortality

During the median 1.5-year (617 (quartile 1-3: 289-1155) days) follow-up period after dialysis initiation, there were 523 deaths (54%) in the overall cohort. The crude mortality rate in patients who underwent CABG and PCI were 229/1000 patient-years (95% confidence interval [CI], 205-256] and 311 per 1000 patient-years (95% CI, 272-356), respectively. In Kaplan–Meier survival analysis (Figure 2), the survival probability was lower in patients who underwent PCI ($P < .001$).

Table 2 and Table E2 show the association of a history of CABG (vs PCI) with all-cause mortality after initiation of dialysis in different models of multivariable Cox regression. In model 1, patients who underwent CABG had a 26% lower risk of death (hazard ratio [HR], 0.74; 95% CI, 0.62-0.88, $P = .001$) after initiation of dialysis, which remained similar after multivariable adjustments (HR, 0.66; 95% CI, 0.51-0.86, $P = .002$). Qualitatively similar results were observed after multiple imputations for model 5 (HR, 0.64; 95% CI, 0.50-0.83, $P = .001$). The results also remained similar in the cohort of patients who underwent a first coronary revascularization 1 or 2 years before the dialysis initiation (HR, 0.42; 95% CI, 0.25-0.68, $P = .001$ and HR, 0.46; 95% CI, 0.31-0.66, $P < .001$, respectively, Table E3).

CABG was associated with better survival compared with PCI in all other subgroups (Figure 3). A statistically significant interaction was present for congestive heart failure, with stronger associations of reduced mortality in patients who underwent CABG in the presence of congestive heart failure. CABG was also associated with better survival compared with PCI in the subgroup of patients who underwent multivessel treatment (Table E4), even after propensity score matching (Table E5 and Figure E1).

DISCUSSION

In this large nationally representative cohort of US veterans with incident ESRD, we found that pre-ESRD history of coronary artery revascularization with CABG was associated with a 26% lower risk of death after initiation of dialysis compared with PCI. After adjustment for potential cofounders such as demographics, comorbidities, baseline eGFR, BMI, medications, and number of treated vessels, CABG remained associated with 34% lower risk of death (Graphical Abstract).

Several randomized clinical trials compared short-term and long-term outcomes after CABG versus PCI in patients with left main, equivalent to left main, or multivessel coronary artery disease.[19,23,26,36-39] Some of the clinical trials demonstrated that the rates of death and myocardial infarction were similar between the PCI and CABG groups[36] and implementation of PCI with drug-eluting stents was noninferior to CABG regarding major adverse cardiac and cerebrovascular events,[37,39] even after 5 years follow-up[19]; however, PCI was associated with increased rate of repeat revascularization.[36] In contrast to these clinical trials, CABG had significantly reduced rates of death and myocardial infarction, but with a greater rate of stroke, in patients with diabetes[26] and those with mild-to-moderate CKD in the same cohort.[38] However, these randomized trials did not include patients with advanced CKD; hence, more generalizable results for the CKD population come from retrospective cohorts.

The results from retrospective studies in large cohorts involving patients with CKD were contradictory.[13,14,40-43] A few studies reported similar advantages of PCI versus CABG regarding postprocedural mortality,[13,42] whereas another few studies demonstrated significantly lower rates

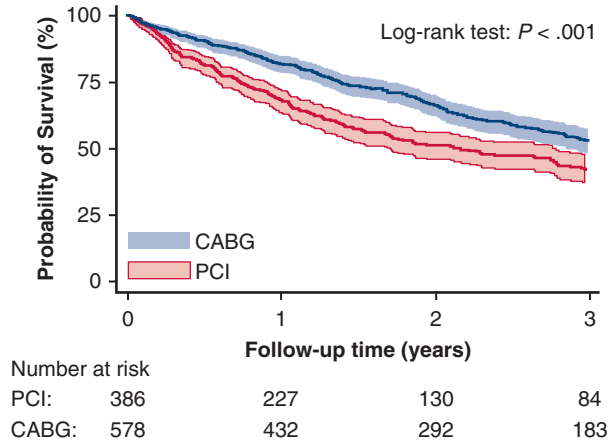


FIGURE 2. Probability of survival in the CABG and PCI group in the entire cohort. *CABG*, Coronary artery bypass grafting; *PCI*, percutaneous coronary intervention.

of death and major adverse cardiac and cerebrovascular events associated with CABG compared with PCI.[14,21,40] Such diverse results of outcomes might be due to investigation of various cohorts consisting of data from different revascularization eras and a different proportion of CKD stages, with a minority of severe CKD.

The results of our study, regarding reduced long-term mortality associated with a history of CABG compared with PCI, were comparable with the main results of FREEDOM (Future Revascularization Evaluation in Patients with Diabetes Mellitus: Optimal Management of Multivessel Disease) trial[38] and some retrospective cohort studies.[14,21,40] However, we examined patients with moderate and advanced CKD, whereas the previous cohort studies included variable proportions of patients with mild-to-moderate CKD. The aforementioned cohort studies compared the outcomes of CABG versus PCI in CKD investigated patients with multivessel coronary artery disease. There is a lack of knowledge regarding the ideal intervention strategy in patients with advanced CKD who have single-vessel coronary artery disease. In the general population with single-vessel coronary artery disease, PCI is considered the optimal revascularization strategy,[44] but the risk–benefit ratio may be altered in patients with advanced CKD, who have increased risk of bleeding, fluid overload, acute kidney injury, infections, and other complications.[45] Various risk scores can aid in decision-making about the optimal revascularization strategy in an individual patient,[46-48] but these scores haven't been validated for patients with advanced CKD. In our study, CABG was associated with reduced risk of death compared with PCI in all subgroups, including subgroup of patients with single and multivessel treatments. Results were similar in the subgroup of patients who underwent multivessel intervention.

TABLE 2. Association between post-ESRD all-cause mortality and type of revascularization (CABG vs PCI [reference]) using Cox proportional hazards models

Models	Patients/events	HR (95% CI)	*P* Value
Model 1	964/523	0.74 (0.62-0.88)	.001
Model 2	915/498	0.72 (0.60-0.86)	<.001
Model 3	893/481	0.65 (0.53-0.80)	<.001
Model 4	891/480	0.66 (0.51-0.86)	.002

Data are presented as odd ratio (95% CI) unless otherwise specified. Models are as follows: model 1: adjusted for time between procedure and ESRD initiation; model 2: additionally adjusted for demographics (age, sex, race/ethnicity, marital status, and income); model 3: additionally adjusted for comorbidities (diabetes, malignancy, liver diseases, hypertension, ischemic heart disease, congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic pulmonary disease, connective tissue disease, peptic ulcer disease, anemia, atrial fibrillation, depression, and hyperlipidemia), eGFR, and BMI; and model 4: additionally adjusted for medications (anticoagulants, thrombolytic, aspirin, digitalis, beta-blockers, alpha-blockers, CCBs, antianginals, statins, vasodilators, thiazide diuretics, loop diuretics, potassium-sparing diuretics, ACEIs/ARBs, radiocontrast, and antidiabetics) and procedure type (single- vs multivessel). *HR*, Hazard ratio; *CI*, confidence interval.

Cardiovascular disease is one of the major causes of early post-ESRD mortality along with infections.[29,49,50] Sudden cardiac death, heart failure, and myocardial infarction are the most frequent cause of cardiovascular mortality during first 5 years after dialysis initiation.[29,51] The mechanisms underlying the greater long-term mortality associated with PCI compared with CABG are not clear. Possible mechanisms include neointimal cell proliferation of the stented vessel and vascular remodeling, which could lead to progression of atherosclerosis and restenosis after PCI.[52] Furthermore, these mechanisms could worsen in patients with ESRD due to malnutrition, inflammation, and atherosclerosis.[53]

The strengths of this study include its large size, its nationally representative nature, and the examination of patients with advanced CKD. Our study also has limitations that deserve to be mentioned. First, because this was a retrospective observational study, we were unable to collect information on severity and complexity of coronary artery lesions that were used to decide the type of revascularization procedure and its urgent (most likely in PCI) versus elective (most likely in CABG) nature. Therefore, only associations, but not cause–effect relationships, can be established in this study. Second, most of our patients were male US veterans; hence, the results may not be generalizable to women or other patient populations, in particular those outside the United States. Third, because of the observational nature of our study, adjusted analyses were limited to preprocedural (preoperative) confounders measured and available in our cohort, and therefore our study may be limited by potential residual confounding from unmeasured intraoperative and postoperative confounders, such as radiocontrast material type and volume, baseline left ventricle ejection fraction, proteinuria, and others. Differences in outcomes may be affected by indication bias, as the decision to perform CABG versus PCI may have been motivated by

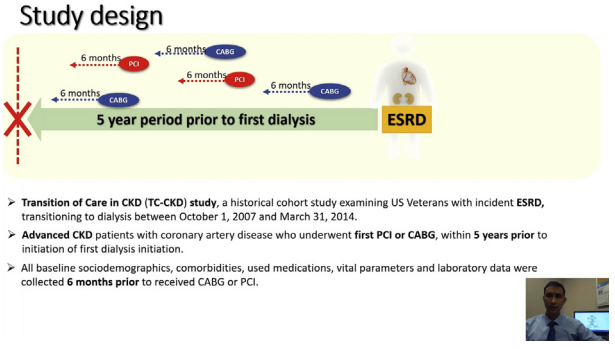
SUBGROUPS	Patients/ Events	Event rate %	UNADJUSTED Hazard Ratio and 95% Confidence Interval	*P* value for Interaction	ADJUSTED Hazard Ratio and 95% Confidence Interval	*P* value for Interaction
All patients	971/523	54	0.74 (0.62-0.88)		0.66 (0.51-0.86)	
Age				.455		.344
<65 years	575/286	50	0.80 (0.63-1.01)		0.75 (0.53-1.06)	
≥65 years	389/237	61	0.69 (0.53-0.89)		0.53 (0.33-0.83)	
Race				.455		.609
African-American	180/76	42	0.82 (0.51-1.31)		0.50 (0.20-1.25)	
Others	718/415	58	0.71 (0.59-0.87)		0.66 (0.49-0.88)	
Treated vessels				.185		.112
Single	345/193	56	0.87 (0.61-1.22)		0.68 (0.45-1.04)	
Multi	617/329	53	0.62 (0.47-0.82)		0.53 (0.37-0.75)	
Myocardial Infarction				.717		.928
Yes	320/182	57	0.71 (0.52-0.96)		0.84 (0.48-1.47)	
No	644/341	53	0.75 (0.60-0.93)		0.59 (0.43-0.81)	
Congestive Heart Failure				.010		.035
Yes	413/232	56	0.54 (0.41-0.71)		0.52 (0.34-0.79)	
No	551/291	53	0.90 (0.71-1.38)		0.65 (0.45-0.92)	
Diabetes Mellitus				.368		.219
Yes	770/412	54	0.71 (0.58-0.86)		0.57 (0.42-0.76)	
No	194/111	57	0.85 (0.58-1.24)		0.56 (0.24-1.33)	

FIGURE 3. Association between post-ESRD all-cause mortality and type of revascularization (CABG vs PCI [reference]) using Cox proportional hazards models in selected subgroups. *CABG*, Coronary artery bypass grafting; *PCI*, percutaneous coronary intervention.

unmeasured factors in individual patients. Finally, our data were derived from a cohort of patients with incident ESRD; hence, we could not include information from patients undergoing revascularization procedures with advanced CKD but who died before dialysis or did not initiate dialysis for other reasons. However, to minimize this bias, we provided sensitivity analyses by examining patients who underwent coronary revascularization close to the dialysis start date (within up to 1 and up to 2 years), and the results remained similar.

CONCLUSIONS

In conclusion, CABG in patients with advanced CKD was associated with 34% lower risk of death after initiation of dialysis compared with PCI. Decisions about the optimal revascularization strategy need to balance short-term and long-term risks and benefits of CABG versus PCI in patients with advanced CKD (Video 1).



VIDEO 1. Dr Gaipov discusses the background and relevance of the study. Video available at: https://www.jtcvs.org/article/S0022-5223(18)32502-9/fulltext.

Conflict of Interest Statement

K.K.Z. received personal fees from Abbott, Abbvie, Alexion, and Astra-Zeneca. M.Z.M. received personal/consultant fees from Merck and Abbvie. All other authors have nothing to disclose with regard to commercial support.

C.P.K. and K.K.Z. are employees of the Department of Veterans affairs. Opinions expressed in this paper are those of the authors' and do not necessarily represent the opinion of the Department of Veterans Affairs. The results of this paper have not been published previously in whole or part.

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Key Words: all-cause mortality, coronary artery bypass grafting, percutaneous coronary interventions, chronic kidney disease, end-stage renal disease

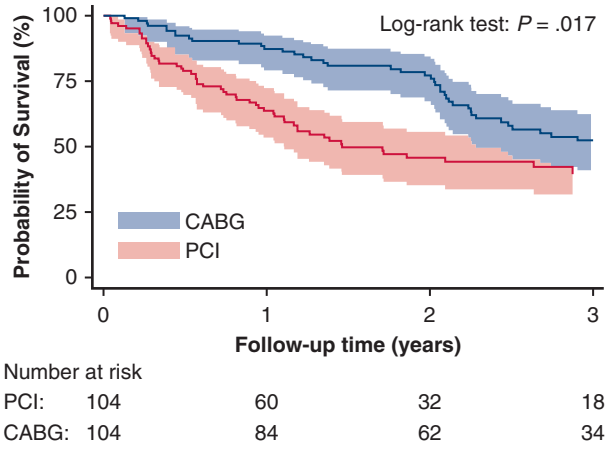

FIGURE E1. Probability of survival in the CABG and PCI groups with multivessel intervention after propensity score matching. *CABG*, Coronary artery bypass grafting; *PCI*, percutaneous coronary intervention.

TABLE E1. CPT procedural and ICD-9 surgery codes

CABG	PCI
CPT procedure codes for CABG	CPT procedure codes for PCI
33510 – Coronary artery bypass, vein only; single coronary venous graft	92973 – Coronary Therapeutic Services and Procedures
33511 – Coronary artery bypass, vein only; 2 coronary venous grafts	92980 – Stenting, (92981 - Stenting, additional vessel)
33512 – Coronary artery bypass, vein only; 3 coronary venous graft	92982 – Angioplasty (92984 - Angioplasty, additional vessel)
33513 – Coronary artery bypass, vein only; 4 coronary venous grafts	92985 – Percutaneous transluminal coronary atherectomy
33514 – Coronary artery bypass, vein only; 5 coronary venous grafts	92995 – Atherectomy (92996 - Atherectomy, additional vessel)
33516 – Coronary artery bypass, vein only; 6 or more coronary venous graft	92920 – Balloon angioplasty
33517 – Coronary artery bypass, using venous graft(s) and arterial graft(s); single vein graft	92924 – Atherectomy
33518 – Coronary artery bypass, using venous graft(s) and arterial graft(s); 2 venous grafts	92928 – Stenting
33519 – Coronary artery bypass, using venous graft(s) and arterial graft(s); 3 venous grafts	92933 – Atherectomy with stenting
33521 – Coronary artery bypass, using venous graft(s) and arterial graft(s); 4 venous grafts	92941 – PCI of acute total/subtotal lesion
33522 –- Coronary artery bypass, using venous graft(s) and arterial graft(s); 5 venous grafts	92943 – PCI of chronic total occlusion
33523 – Coronary artery bypass, using venous graft(s) and arterial graft(s); 6 or more venous grafts	ICD-9-CM surgery codes for PCI
33530 – Combined Arterial-Venous Grafting for Coronary Bypass	00.66 – Percutaneous transluminal coronary angioplasty or coronary atherectomy
33533 – Coronary artery bypass, using arterial graft(s); single arterial graft	36.0 – Removal of Coronary Artery Obstruction and Insertion of Stent(s)
33534 – Coronary artery bypass, using arterial graft(s); 2 coronary arterial graft	36.01 – Single-vessel percutaneous transluminal coronary angioplasty or coronary atherectomy without thrombolytic agent
33535 – Coronary artery bypass, using arterial graft(s); 3 coronary arterial graft	36.02 – Single-vessel percutaneous transluminal coronary angioplasty or coronary atherectomy with thrombolytic agent
33536 – Coronary artery bypass, using arterial graft(s); 4 or more coronary arterial graft	36.05 – Multiple-vessel percutaneous transluminal coronary angioplasty or coronary atherectomy
33572 – Coronary Endarterectomy Procedures	36.06 – Insertion of Non-Drug-Eluting Coronary Artery Stent(s)
ICD-9-CM surgery codes for CABG	36.07 – Insertion of Drug-Eluting Coronary Artery Stent(s)
36.10 – Aortocoronary Bypass for Heart Revascularization, Not Otherwise Specified	36.09 – Other Removal of Coronary Artery Obstruction
36.11 – Aortocoronary Bypass of One Coronary Artery	00.40 – Procedure on single vessel (secondary code)
36.12 – Aortocoronary Bypass of Two Coronary Arteries	00.41 – Procedure on two vessels (secondary code)
36.13 – Aortocoronary Bypass of Three Coronary Arteries	00.42 – Procedure on three vessels (secondary code)
36.14 – Aortocoronary Bypass of Four or More Coronary Arteries	00.43 – Procedure on four or more vessels (secondary code)
36.15 – Single Internal Mammary-Coronary Artery Bypass	00.45 – Insertion of one vascular stent (secondary code)
36.16 – Double Internal Mammary-Coronary Artery Bypass	00.46 – Insertion of two vascular stents (secondary code)
36.17 – Abdominal-Coronary Artery Bypass	00.47 – Insertion of three vascular stents (secondary code)
36.19 – Other Bypass Anastomosis for Heart Revascularization	00.48 – Insertion of four or more vascular stents (secondary code)

CABG, Coronary artery bypass grafting; *PCI*, percutaneous coronary intervention; *CPT*, current procedural terminology; *ICD-9-CM*, *International Classification of Diseases, Ninth Revision, Clinical Modification*.

TABLE E2. Complete adjusted Cox proportional hazard models (STATA output) evaluating association between post-ESRD all-cause mortality and type of revascularization

Model 1

No. of subjects = 964
No. of failures = 523
Time at risk = 2033.675565
Log likelihood = −3187.5586

Number of obs = 964
LR χ^2 (2) = 14.73
Prob > χ^2 = 0.0006

_t	Hazard ratio	Standard error	z	*P* >|z|	95% confidence inteval	
CABG (PCI ref)	0.7414783	0.0662199	–3.35	.001	0.622414	0.8833189
Time to ESRD	1.000146	0.0000805	1.81	.070	0.999988	1.000303

Model 2

No. of subjects = 915
No. of failures = 498
Time at risk = 1911.227926
Log likelihood = −2977.8877

Number of obs = 915
LR chi2(10) = 68.99
Prob > χ^2 = 0.0000

_t	Hazard ratio	Standard error	z	*P* > |z|	95% confidence interval	
CABG (PCI ref)	0.7160332	0.0664397	–3.60	.000	0.5969685	0.8588453
Time to ESRD	1.000261	0.0000837	3.12	.002	1.000097	1.000425
Race_African-Am	0.5691123	0.071976	–4.46	.000	0.4441666	0.7292057
Race_others	0.879551	0.3382598	–0.33	.739	0.4139081	1.869038
Sex_female	0.5704547	0.2877776	–1.11	.266	0.212234	1.533301
Age	1.028224	0.0059122	4.84	.000	1.016702	1.039877
Marital_single	1.023306	0.1759549	0.13	.893	0.730539	1.4334
Marital_divorced	1.061564	0.1106945	0.57	.567	0.8653407	1.302282
Marital_widowed	1.134877	0.1732279	0.83	.407	0.8414359	1.530652
Income	1	9.66e-07	0.28	.779	0.9999984	1.000002

Model 3

No. of subjects = 893
No. of failures = 481
Time at risk = 1874.759754
Log likelihood = −2831.5718

Number of obs = 893
LR χ^2 (30) = 136.06
Prob > χ^2 = 0.0000

_t	Hazard ratio	Standard error	z	*P* > M	95% confidence interval	
CABG (PCI ref)	0.6509751	0.066776	–4.18	.000	0.5324139	0.7959382
Time to ESRD	1.000191	0.0000966	1.98	.048	1.000002	1.00038
Race_African-Am	0.5238392	0.0691761	–4.90	.000	0.4043819	0.6785851
Race_others	0.8165122	0.3436967	–0.48	.630	0.3578196	1.863208
Sex_female	0.6495655	0.3314899	–0.85	.398	0.2389093	1.76609
Age	1.027756	0.0068284	4.12	.000	1.01446	1.041227
Marital_single	1.093802	0.1946803	0.50	.614	0.7716812	1.550386
Marital_divorced	1.051067	0.1149988	0.46	.649	0.8482014	1.302451
Marital widowed	1.127265	0.1779769	0.76	.448	0.8272468	1.536091
Income	1	1.03e-06	0.16	.870	0.9999982	1.000002
Myocardial infarction	1.091731	0.1144263	0.84	.402	0.8889957	1.3407
Congestive heart failure	1.214857	0.1233258	1.92	.055	0.9956702	1.482294
Peripheral vascular disease	1.165184	0.1174573	1.52	.129	0.9562876	1.419713
	1.085647	0.1128758	0.79	.429	0.8855	1.331034
Cerebrovascular disease	1.456675	0.7633727	0.72	.473	0.5215421	4.068517

(Continued)

TABLE E2. Continued

_t	Hazard ratio	Standard error	z	*P* > M	95% confidence interval	
Dementia	1.067431	0.1111536	0.63	.531	0.8703675	1.309113
Chronic pulmonary disease	.6588231	0.2155919	–1.28	.202	0.3469153	1.251164
Connective tissue disease	0.5948436	0.1561601	–1.98	.048	0.3555845	0.9950909
Peptic ulcer disease	2.125083	1.037116	1.54	.122	0.8165059	5.530855
AIDS/HIV	1.318167	0.162887	2.24	.025	1.034634	1.6794
Liver_disease	1.062783	0.194696	0.33	.740	0.7421796	1.521879
Malignancy	1.446563	0.1940624	2.75	.006	1.112104	1.88161
Anemia	0.9818625	0.1088198	–0.17	.869	0.7901545	1.220083
Atrial fibrillation	1.613503	0.2796404	2.76	.006	1.148803	2.266176
Depression	0.9804514	0.1151847	–0.17	.867	0.7787998	1.234316
Hyperlipidemia	1.325837	0.1627238	2.30	.022	1.042365	1.6864
Hypertension	0.7145937	0.1186453	–2.02	.043	0.5160985	0.9894316
Ischemic heart disease	0.9600305	0.1275502	–0.31	.759	0.7399355	1.245593
BMI	0.9777187	0.0086736	–2.54	.011	0.9608657	0.9948672
eGFR	1.009281	0.0023098	4.04	.000	1.004764	1.013818
Model 4						
No. of subjects = 893					Number of obs = 893	
No. of failures = 481					LR $\chi^2(46)$ = 147.76	
Time at risk = 1874.759754					Prob > χ^2 = 0.0000	
Log likelihood = –2825.7231						
_t	Hazard ratio	Standard error	z	*P* > |z|	95% confidence interval	
CABG (PCI ref)	0.6375721	0.0684449	–4.19	.000	0.5165957	0.7868788
Time to ESRD	1.000158	0.0001038	1.52	.128	0.9999544	1.000361
Race_African-Am	0.5398305	0.0738526	–4.51	.000	0.4128641	0.7058423
Race_others	0.8428893	0.3590652	–0.40	.688	0.3657331	1.94257
Sex_female	0.6984896	0.3606936	–0.69	.487	0.2538676	1.921819
Age	1.028686	0.0070715	4.11	.000	1.014919	1.04264
Marital_single	1.041356	0.1896596	0.22	.824	0.7287392	1.488081
Marital_divorced	1.021924	0.113965	0.19	.846	0.8212821	1.271582
Marital_widowed	1.122028	0.1792137	0.72	.471	0.8204402	1.534476
Income	1	1.00e-06	0.15	.883	0.9999982	1.000002
Myocardial infarction	1.143135	0.1256792	1.22	.224	0.9215406	1.418015
Congenital heart failure	1.255467	0.1384223	2.06	.039	1.011476	1.558315
Peripheral vascular disease	1.166234	0.1194715	1.50	.133	0.9540844	1.425557
Cerebrovascular disease	1.08494	0.1158217	0.76	.445	0.8801087	1.337441
Dementia	1.461129	0.7796359	0.71	.477	0.513453	4.157924
Chronic pulmonary disease	1.089397	0.1158518	0.81	.421	0.8844335	1.341859
Connective tissue disease	0.6902939	0.229029	–1.12	.264	0.3602619	1.322665
Peptic ulcer disease	0.5653374	0.1518267	–2.12	.034	0.3339716	0.9569868
AIDS/HIV	2.065751	1.04883	1.43	.153	0.7636655	5.587953
Liver_disease	1.342649	0.1866441	2.12	.034	1.022434	1.763151
	1.09896	0.2049967	0.51	.613	0.762432	1.584026
Malignancy	1.384775	0.1892996	2.38	.017	1.059301	1.810252
Anemia	0.9964353	0.1144021	–0.03	.975	0.7956489	1.247891
Atrial fibrillation	1.62185	0.2878718	2.72	.006	1.145317	2.296654

(Continued)

TABLE E2. Continued

_t	Hazard ratio	Standard error	z	$P > \|z\|$	95% confidence interval	
Depression	0.9891169	0.117943	–0.09	.927	0.7829783	1.249527
Hyperlipidemia	1.376285	0.1765778	2.49	.013	1.070284	1.769774
Hypertension	0.7186856	0.1218245	–0.95	.051	0.5155273	1.001904
Ischemic heart disease	0.9090606	0.1310846	–0.66	.508	0.6852537	1.205964
BMI	0.9807048	0.0087683	–2.18	.029	0.963669	0.9980418
eGFR	1.008641	0.002508	3.46	.001	1.003737	1.013568
Anticoagulants	0.8590826	0.1024546	–1.27	.203	0.6800177	1.085299
Thrombolytics	1.721869	1.060342	0.88	.378	0.515018	5.756754
Aspirin	1.011148	0.1285439	0.09	.931	0.7881422	1.297255
Digitalis	1.239423	0.2477217	1.07	.283	0.8377054	1.833783
Betablockers	0.9981035	0.1675265	–0.01	.991	0.7182999	1.386901
Alpha-blockers	0.8782665	0.0975522	–1.17	.243	0.7064482	1.091873
Ca_chan_blockers	1.056736	0.1109094	0.53	.599	0.8602586	1.298088
Antianginals	1.17349	0.1314483	1.43	.153	0.9421759	1.461593
Statins	0.9825247	0.1409892	–0.12	.902	0.7416495	1.301632
Vasodilators	1.010731	0.1214586	0.09	.929	0.7986329	1.279156
Thiazides	0.8384454	0.089459	–1.65	.099	0.6802284	1.033463
Loop-diuretics	0.8907888	0.1039961	–0.99	.322	0.7085986	1.119823
K_sparing_diuret	0.8359263	0.1478496	–1.01	.311	0.5910397	1.182277
RAAS_Inh	0.9424705	0.1135198	–0.49	.623	0.7442883	1.193423
Insulin	1.033784	0.1291894	0.27	.790	0.8092025	1.320694
Treated_vessels	1.036528	0.1065456	0.35	.727	0.8473938	1.267876

CABG, Coronary artery bypass grafting; *PCI*, percutaneous coronary intervention; *ESRD*, end-stage renal disease; *BMI*, body mass index; *eGFR*, estimated glomerular filtration rate; *RAAS*, renin angiotensin aldosterone system inhibitors.

TABLE E3. Association between post-ESRD all-cause mortality and type of revascularization (CABG vs PCI [reference]) using multivariable Cox proportional hazards model (final model 4 from original analysis) in a cohort of patients with revascularization performed up to 2 years and up to 1 year before the first dialysis

Cohort years	Patients/events	HR (95% CI)	*P* Value
Two years	421/217	0.46 (0.31-0.69)	<.001
One year	272/133	0.42 (0.25-0.68)	.001

ESRD, End-stage renal disease; *CABG*, coronary artery bypass grafting; *PCI*, percutaneous coronary interventions; *HR*, hazard ratio; *CI*, confidence interval.

TABLE E4. Association between post-ESRD all-cause mortality and type of revascularization (CABG vs PCI [reference]) using multivariable Cox proportional hazards model (final model 4 from original analysis) in a cohort of patients with multivessel intervention

Cohort type	Patients/events	HR (95% CI)	*P* Value
Multivessel	571/302	0.53 (0.37-0.75)	<.001

HR, Hazard ratio; *CI*, confidence interval.

TABLE E5. Association between post-ESRD all-cause mortality and type of revascularization (CABG vs PCI [reference]) using multivariable Cox proportional regression analysis in a PSM cohort of patients with multivessel intervention

PSM 1:1	Patients/events	HR (95% CI)	*P* Value
Multivessel	208/115	0.64 (0.44-0.93)	.018

ESRD, End-stage renal disease; *CABG*, coronary artery bypass grafting; *PCI*, percutaneous coronary intervention; *PSM*, propensity score-matched; *HR*, hazard ratio; *CI*, confidence interval.