Technical appendix to "The Effect of Insurance in the First Three Months of Hemodialysis on Vascular Access"

APPENDIX A: Technical Specifications

Data Sources

Data came from the United States Renal Data System (USRDS), a registry with claims data for all patients with Medicare Parts A and B and ESKD. We used the CMS Medical Evidence Report (Form CMS-2728) to identify dialysis modality, vascular access, insurance coverage, pre-ESKD nephrology care, demographics, and comorbid conditions at dialysis onset. We obtained longitudinal insurance, treatment, and vascular access information from Medicare enrollment data and claims. Medicare claims have included the type of vascular access used at the end of each month since July 2010. We linked patient zip codes to the 2010 Census and 2012 American Community Survey and obtained dialysis facility-level data from annual facility surveys.

Identification of Vascular Access on Dialysis Claims

We used modifier codes on dialysis claims to identify the type of vascular access. The modifier code V5 indicated the use of a central venous catheter, V6 indicated the use of an arteriovenous graft, and V7 indicated the use of an arteriovenous fistula for that month of dialysis.[1]

Identification of Hospitalizations due to Vascular Access Infections

To identify hospitalizations due to infected vascular access, we first isolated acute hospitalizations from Medicare inpatient claims. Individual claims do not constitute acute admissions for two reasons. First, the United States Renal Data System (USRDS) inpatient claims file also contains admissions to inpatient rehabilitation and long-term care hospitals. Second, transfers between hospitals are billed as separate claims and thus need to be grouped

into a single admission. Therefore, we used a previously described algorithm to isolate acute inpatient stays and to group transfers into single admissions.[2]

We then identified the acute admissions that involved vascular access infections and those that involved any infection. To identify vascular access infections, we took the array of diagnosis codes (ICD-9 or International Classification of Diseases 9) and identified admissions with a diagnosis code that matched one of the codes in **Table S1**. For admissions that involved any infection, we matched diagnosis codes with the list in **Table S2**.

Table S1: Diagnosis Codes Corresponding to Center Venous Catheter Infections

ICD-9 Diagnosis Codes	
996.62	Infection and Inflammatory Reaction due to other Vascular Device, Implant, or Graft
999.31	Other and unspecified infection due to central venous catheter
999.32	Bloodstream infection due to central venous catheter
999.33	Local infection due to central venous catheter

Abbreviations: ICD-9 = International Classification of Diseases

Table S2: Diagnosis Codes Corresponding to Any Infection

ICD-9 Diagnosis Codes
001–134, 136, 254.1
320–325, 382–382.4, 383.0-383.2, 386.33, 386.35, 388.60
421–421.1, 422.0, 422.92–422.93, 460–466, 475–476.0, 478.21–478.24, 478.29, 480–489
510–511.1, 513, 519.01, 522.5, 522.7, 527.3, 528.3, 566–567.9, 569.5, 572–572.1, 573.1–573.3, 575.10–575.12, 576.1, 590–590.9, 595–595.4, 597–597.89, 598.0, 599.0
601–601.9, 604–604.9, 607.1, 607.2, 608.0, 608.4, 611.0, 614–616.1, 616.3–616.4, 616.8, 670, 675, 680–686.9
706.0, 711–711.9, 728.0, 728.86, 729.39, 729.4, 730–730.3, 730.8–730.9, 790.7–790.8
995.9, 996.60–996.69, 997.62, 998.5, 999.3

Abbreviations: ICD-9 = International Classification of Diseases

Calculation of Relative Risks

Odds ratios from logistic regression can be difficult to interpret, since the corresponding relative risk is dependent on the baseline event rate. To make these estimates more tangible, we calculated the predicted probability that each patient used an arteriovenous (AV) fistula or graft at the end of month four under the scenarios that the patient had insurance or was uninsured. The point estimate for the average relative risk, then, is the average of the quotient of these predicted probabilities. To obtain 95% confidence intervals, we used a non-parametric bootstrap. We describe our method to compute bootstrapped 95% confidence intervals on multiple imputation data later in this Appendix.

More formally, we specified the following logistic regression model:

$$Y_i|\beta_0 + X_{insurance,i}\beta_{insurance} + X_{covariates,i}\beta_{covariates} + \varepsilon_i$$

Here, we defined the outcome (Y_i) as the outcome that patient i was using an AV fistula or graft at the end of month four. We modeled Y_i using a Bernoulli distribution and a logit link function. In this model, $X_{insurance,i}$ is a binary exposure variable that indicates if patient i has insurance (1 if patient i has Medicare or Medicaid depending on the cohort and 0 if patient i is uninsured), $X_{covariates,i}$ is a vector of all other covariates, $\beta_{insurance}$ and $\beta_{covariates}$ are the respective coefficients from the regression, β_0 is the intercept, and ε_i is the randomly distributed error term for patient i. We defined the estimated coefficients from this model as $\hat{\beta}_0$, $\hat{\beta}_{insurance}$, and $\hat{\beta}_{covariates}$.

For each patient in the cohort, we calculated the predicted probability that the patient used AV fistula or graft at the end of month four under the scenarios that the patient had insurance ($\hat{Y}_{i,insurnace}$) or was uninsured ($\hat{Y}_{i,uninsured}$). In other words, for each patient i:

$$\hat{Y}_{i,insurnace} = logit^{-1}\left(\hat{\beta}_0 + \hat{\beta}_{insurance} + X_{covariates,i}\hat{\beta}_{covariates}\right)$$

$$\hat{Y}_{i,uninsured} = logit^{-1}\left(\hat{\beta}_0 + X_{covariates,i}\hat{\beta}_{covariates}\right)$$

For a patient i, we defined the adjusted relative risk of using an AV fistula or graft at month 4 when patient i has insurance *versus* no insurance:

$$RR_i = \frac{\hat{Y}_{i,insurnace}}{\hat{Y}_{i,uninsured}}$$

and the average relative risk of patients with insurance versus those without insurance is:

$$\overline{RR} = \frac{1}{N}\sum_{i=1}^{N} RR_i$$

Estimating the Probability of AVF/AVG Use by Month 13

Using logistic regression to estimate the probability of AVF or AVG use by month 13 would have introduced bias due to the high mortality rate in this population. To account for censoring, we employed a 2-step estimation procedure to obtain predicted probabilities. First, for each patient, we obtained the predicted probabilities of using a dialysis catheter at month 4, under the scenarios that the patient had insurance or was uninsured:

$$\widehat{\Pr}(catheter\ at\ month\ 4|insured) = 1 - \hat{Y}_{i,insurnace}$$

$$\widehat{\Pr}(catheter\ at\ month\ 4|uninsured) = 1 - \hat{Y}_{i,uninsured}$$

Next, we took patients still using a catheter at month 4 and estimated a parameterized survival model assuming an exponential survival function to determine the rate of switching from a catheter to an AVF or AVG, censoring for death. These regression estimates allowed us to estimate the probability of using a catheter at month 12 for each patient, *conditional* on using a catheter at month 4, for the scenarios that the patient had insurance or was uninsured:

$$\hat{Z}_{i,insurance} = \Pr(catheter\ at\ month\ 12|catheter\ at\ month\ 4, insured)$$

$$\hat{Z}_{i,uninsured} = \Pr(catheter\ at\ month\ 12|catheter\ at\ month\ 4, uninsured)$$

Using Baye's rule, we then estimated the unconditional probability of using an AVF or AVG by month 12, for the scenarios that the patient had insurance or was insured:

$$\widehat{W}_{i,insurance} = \Pr(AVF/AVG\ by\ month\ 12|insured) = 1 - \Pr(catheter\ at\ month\ 12|insured)$$

$$= 1 - \Pr(catheter\ at\ month\ 12|catheter\ at\ month\ 4, insured)$$

$$* \Pr(catheter\ at\ month\ 4|insured) = 1 - \hat{Z}_{i,insurance} * \left(1 - \hat{Y}_{i,insurance}\right)$$

$$\widehat{W}_{i,uninsured} = \Pr(AVF/AVG\ by\ month\ 12|uninsured)$$

$$= 1 - \Pr(catheter\ at\ month\ 12|uninsured)$$

$$= 1 - \Pr(catheter\ at\ month\ 12|catheter\ at\ month\ 4, uninsured)$$

$$* \Pr(catheter\ at\ month\ 4|uninsured) = 1 - \hat{Z}_{i,uninsured} * \left(1 - \hat{Y}_{i,uninsured}\right)$$

The average relative risk for using an AVF or AVG by month 12 is then:

$$\overline{RR}_{month13} = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{W}_{i,insurance}}{\widehat{W}_{i,uninsured}}$$

Multiple Imputation

Because we had high numbers of missing values for body mass index (BMI), hemoglobin, and albumin, we used multiple imputation for these covariates. Since all missing covariates were categorical variables, we imputed these variables using chained equations and a multinomial logistic regression model with the augmented-regression approach suggested by White *et al*. to avoid bias from perfect prediction of categorical variables.[3–5] For each statistic, we calculated the point estimate and 95% confidence interval using Rubin's rules.[6] Since these rules do not apply for bootstrapped confidence intervals, we used a different process to perform statistical inference on relative risks, which we describe below. We used a total of 10 imputations for each missing variable.

Statistical Inference using Bootstrap Confidence Intervals

We used non-parametric bootstrap 95% confidence intervals to assess if the relative risks were statistically significant. Schomaker and Heumann suggest that in order to obtain the

correct standard errors we should first draw $b = 1, \ldots, B$ bootstrap samples from the original dataset *with* missing values, then perform $m_b = 1, \ldots, M_B$ imputations on each of the B bootstrapped datasets.[7] The sampling-imputation process yields *B x* M_B bootstrapped-imputed datasets, and we can calculate a relative risk for each of these datasets: RR_{b,m_b}. To find confidence intervals, we first compute $RR_b = \frac{1}{M_B}\sum_{m_b} RR_{b,m_b}$, which is the mean of the "imputed" relative risks for each of the B bootstrapped datasets. We then take the 2.5% and 97.5% quantiles of RR_b. (Of note, we could simply take the 2.5% and 97.5% quantiles of all estimates RR_{b,m_b} for all b and m_b. Schomaker and Heumann suggest that this approach yields confidence intervals that are too wide). We again chose a total of ten imputations for each of the bootstrapped datasets (M_B = 10) and drew B = 250 bootstrapped samples.

Additional Analyses and Sensitivity Analyses

It is possible that for some patients AVFs or (to a lesser extent) AVGs were not ready for use by the end of the fourth dialysis month, due to delayed maturation or healing. To investigate this possibility, we performed the following sensitivity analyses:

1) We modeled the likelihood of using an AVF or AVG by the end of the sixth dialysis month using a multivariable logistic regression. This is in contrast to our primary analysis, which examined the likelihood of using an AVF or AVG by the end of the fourth dialysis month.
2) We restricted our study population to patients receiving hemodialysis through a central venous catheter at the end of the fourth dialysis month, and we examined the time to switching from a central venous catheter to an AVF or AVG using a competing risks model. In our primary analysis, we used a traditional Cox regression.

We also performed the following additional analyses to test model specifications:

3) We included patients with nephrology care prior to developing ESKD and incorporated an indicator for whether a patient received such care.
4) We repeated all primary analyses using a complete case analysis.

None of our results changed materially in these sensitivity analyses (**Table S11**):

APPENDIX B: Supplemental Tables

In **Tables S3-S10**, we show the regression coefficients from the primary analyses and analyses of hospitalization involving vascular access infection. We then show results from secondary study aims and sensitivity analyses in **Table S11**.

Table S3: Logistic Regression Coefficients, Modeling Arteriovenous Fistula or Graft Use at Month 4, Medicare *versus* No Insurance, Multiple Imputation Analysis

Covariate	OR	95% CI	P-Value
Intercept	0.07	(0.03, 0.15)	***
Insurance			
No insurance		Reference	
Medicare	2.00	(1.26, 3.16)	**
Dual Eligible	1.13	(0.93, 1.38)	
Age	0.83	(0.47, 1.47)	
Age^2	1.63	(0.37, 7.26)	
Sex			
Female	0.69	(0.58, 0.80)	***
Male		Reference	
Race			
White		Reference	
Black	1.39	(1.15, 1.69)	***
Other	1.58	(1.09, 2.28)	*
Ethnicity			
Hispanic	1.34	(1.05, 1.71)	*
Employed	0.75	(0.50, 1.12)	
BMI (kg/m^2)			
< 18.5	0.96	(0.62, 1.47)	
18.5 to < 30		Reference	
30 to < 40	1.05	(0.88, 1.25)	
≥ 40	0.98	(0.74, 1.28)	

Albumin (g/dL)			
< 2.5	0.65	(0.49, 0.87)	**
2.5 to < 3	0.91	(0.71, 1.16)	
3 to < 3.5	0.88	(0.70, 1.12)	
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	1.05	(0.82, 1.33)	
8 to < 9	1.03	(0.84, 1.25)	
9 to < 11		Reference	
≥ 11	1.00	(0.78, 1.28)	
Comorbidities			
Coronary Artery Disease	1.03	(0.84, 1.27)	
Congestive Heart Failure	0.92	(0.77, 1.09)	
Cancer	0.82	(0.61, 1.10)	
Hypertension	0.96	(0.76, 1.22)	
Chronic Obstructive Pulmonary Disease	0.81	(0.63, 1.04)	
Diabetes Mellitus	1.17	(0.99, 1.39)	
Peripheral Vascular Disease	0.82	(0.65, 1.04)	
Prior Cerebrovascular Accident	1.47	(1.17, 1.84)	**
Drug Dependence	1.05	(0.65, 1.71)	
Smoker	1.14	(0.85, 1.53)	
Patient institutionalized	0.85	(0.64, 1.13)	
Needs Assistance with ADLs and/or Inability to Transfer	0.81	(0.64, 1.03)	
Facility Characteristics			
Large Dialysis Organization	1.09	(0.91, 1.31)	
Facility is for-profit	0.90	(0.67, 1.22)	
Facility is hospital-based	1.22	(0.83, 1.78)	
Total Facility Patients per Year			
0 to 50	1.25	(1.01, 1.53)	*
51 to 100		Reference	
101 to 150	1.09	(0.89, 1.33)	
> 150	0.88	(0.69, 1.13)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	1.05	(0.89, 1.23)	
Residence Characteristics			

Urban	1.12	(0.94, 1.33)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	0.92	(0.74, 1.13)	
≥ 25%	0.88	(0.68, 1.14)	
% Less than High school Education in Zipcode			
< 15%		Reference	
15% to <30%	1.19	(0.97, 1.46)	
≥ 30%	1.44	(1.05, 1.97)	*
Year of Dialysis Start			
2010		Reference	
2011	1.01	(0.79, 1.29)	
2012	1.04	(0.81, 1.33)	
2013	1.34	(1.01, 1.79)	*
Season of Dialysis Start			
Winter		Reference	
Spring	1.29	(1.04, 1.59)	*
Summer	0.99	(0.80, 1.22)	
Fall	1.07	(0.85, 1.35)	

*** p < 0.001
** p < 0.01
* p < 0.05

Note: Includes robust standard errors.

Table S4: Logistic Regression Coefficients, Modeling Arteriovenous Fistula or Graft Use at Month 4, Medicaid *versus* No Insurance, Multiple Imputation Analysis

Covariate	OR	95% CI	P-Value
Intercept	0.07	(0.04, 0.10)	***
Insurance			
No insurance		Reference	
Medicaid	1.27	(1.13, 1.43)	***
Age	0.90	(0.75, 1.09)	
Age^2	0.98	(0.94, 1.03)	
Sex			
Female	0.78	(0.69, 0.88)	***
Male		Reference	
Race			
White		Reference	
Black	1.17	(1.01, 1.35)	*
Other	1.44	(1.12, 1.85)	**
Ethnicity			
Hispanic	1.13	(0.95, 1.33)	
Employed	0.73	(0.61, 0.88)	***
BMI (kg/m^2)			
< 18.5	0.83	(0.58, 1.19)	
18.5 to < 30		Reference	
30 to < 40	0.98	(0.86, 1.11)	
≥ 40	0.99	(0.82, 1.19)	
Albumin (g/dL)			
< 2.5	0.76	(0.63, 0.93)	**
2.5 to < 3	0.91	(0.76, 1.09)	
3 to < 3.5	0.86	(0.73, 1.02)	
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	0.99	(0.84, 1.16)	
8 to < 9	1.14	(0.97, 1.33)	

9 to < 11		Reference	
≥ 11	1.07	(0.90, 1.29)	
Comorbidities			
Coronary Artery Disease	1.00	(0.80, 1.24)	
Congestive Heart Failure	1.07	(0.93, 1.23)	
Cancer	0.48	(0.29, 0.79)	**
Hypertension	1.22	(1.01, 1.47)	*
Chronic Obstructive Pulmonary Disease	1.05	(0.80, 1.38)	
Diabetes Mellitus	0.94	(0.83, 1.07)	
Peripheral Vascular Disease	1.23	(0.97, 1.54)	
Prior Cerebrovascular Accident	1.15	(0.90, 1.46)	
Drug Dependence	0.95	(0.75, 1.20)	
Smoker	1.10	(0.92, 1.32)	
Patient institutionalized	0.73	(0.49, 1.07)	
Needs Assistance with ADLs and/or Inability to Transfer	0.95	(0.75, 1.21)	
Facility Characteristics			
Large Dialysis Organization	1.27	(1.11, 1.46)	***
Facility is for-profit	0.90	(0.73, 1.11)	
Facility is hospital-based	1.22	(0.93, 1.61)	
Total Facility Patients per Year			
0 to 50	1.00	(0.85, 1.18)	
51 to 100		Reference	
101 to 150	0.89	(0.77, 1.03)	
> 150	0.95	(0.80, 1.12)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	0.97	(0.86, 1.09)	
Residence Characteristics			
Urban	1.00	(0.87, 1.14)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	1.00	(0.86, 1.16)	
≥ 25%	0.86	(0.72, 1.04)	
% Less than High school Education in Zipcode			
< 15%		Reference	

15% to <30%	1.05	(0.90, 1.21)	
≥ 30%	1.21	(0.99, 1.50)	
Year of Dialysis Start			
2010		Reference	
2011	1.18	(0.98, 1.42)	
2012	1.20	(0.99, 1.44)	
2013	1.41	(1.14, 1.74)	**
Season of Dialysis Start			
Winter		Reference	
Spring	1.24	(1.06, 1.44)	**
Summer	1.00	(0.85, 1.17)	
Fall	0.98	(0.83, 1.16)	

*** p < 0.001
** p < 0.01
* p < 0.05

Note: Includes robust standard errors.

Table S5: Cox Regression Coefficients, Modeling Time to Arteriovenous Fistula or Graft Use, Medicare *versus* No Insurance, Multiple Imputation Analysis

Covariate	HR	95% CI	P-Value
Insurance			
No insurance		Reference	
Medicare	1.14	(0.94, 1.39)	
Dual Eligible	1.03	(0.93, 1.14)	
Age	0.91	(0.69, 1.20)	
Age^2	1.54	(0.82, 2.89)	
Sex			
Female	0.91	(0.84, 0.98)	*
Male		Reference	
Race			
White		Reference	
Black	1.10	(1.00, 1.22)	
Other	1.41	(1.18, 1.68)	***
Ethnicity			
Hispanic	1.27	(1.13, 1.44)	***
Employed	1.13	(0.95, 1.33)	
BMI (kg/m^2)			
< 18.5	0.82	(0.65, 1.04)	
18.5 to < 30		Reference	
30 to < 40	0.94	(0.86, 1.03)	
≥ 40	0.99	(0.87, 1.12)	
Albumin (g/dL)			
< 2.5	0.81	(0.71, 0.94)	**
2.5 to < 3	0.87	(0.76, 0.99)	*
3 to < 3.5	0.88	(0.77, 1.00)	
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	0.94	(0.83, 1.06)	
8 to < 9	0.92	(0.83, 1.02)	

9 to < 11		Reference	
≥ 11	0.90	(0.79, 1.02)	
Comorbidities			
Coronary Artery Disease	0.92	(0.83, 1.02)	
Congestive Heart Failure	0.94	(0.86, 1.02)	
Cancer	0.85	(0.73, 0.99)	*
Hypertension	1.12	(0.99, 1.26)	
Chronic Obstructive Pulmonary Disease	0.94	(0.83, 1.05)	
Diabetes Mellitus	1.08	(1.00, 1.18)	
Peripheral Vascular Disease	1.07	(0.95, 1.20)	
Prior Cerebrovascular Accident	0.99	(0.87, 1.12)	
Drug Dependence	0.85	(0.65, 1.11)	
Smoker	1.08	(0.93, 1.24)	
Patient institutionalized	0.85	(0.73, 0.98)	*
Needs Assistance with ADLs and/or Inability to Transfer	0.81	(0.71, 0.91)	***
Facility Characteristics			
Large Dialysis Organization	1.30	(1.19, 1.43)	***
Facility is for-profit	0.85	(0.73, 0.99)	*
Facility is hospital-based	0.91	(0.74, 1.12)	
Total Facility Patients per Year			
0 to 50	1.08	(0.98, 1.20)	
51 to 100		Reference	
101 to 150	1.02	(0.92, 1.12)	
> 150	0.89	(0.79, 1.01)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	1.02	(0.94, 1.10)	
Residence Characteristics			
Urban	1.00	(0.92, 1.09)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	1.08	(0.98, 1.19)	
≥ 25%	1.03	(0.91, 1.17)	
% Less than High school Education in Zipcode			
< 15%		Reference	
15% to <30%	0.96	(0.87, 1.06)	

≥ 30%	1.07	(0.92, 1.25)	
Year of Dialysis Start			
2010		Reference	
2011	1.13	(1.00, 1.26)	*
2012	1.16	(1.03, 1.31)	*
2013	1.16	(0.99, 1.37)	
Season of Dialysis Start			
Winter		Reference	
Spring	1.02	(0.91, 1.14)	
Summer	1.00	(0.90, 1.11)	
Fall	1.08	(0.97, 1.20)	

*** p < 0.001
** p < 0.01
* p < 0.05

Table S6: Cox Regression Coefficients, Modeling Time to Arteriovenous Fistula or Graft Use, Medicaid *versus* No Insurance, Multiple Imputation Analysis

Covariate	HR	95% CI	P-Value
Insurance			
No insurance		Reference	
Medicaid	1.00	(0.95, 1.05)	
Age	0.90	(0.83, 0.97)	**
Age^2	0.97	(0.96, 0.99)	**
Sex			
Female	0.83	(0.79, 0.87)	***
Male		Reference	
Race			
White		Reference	
Black	1.01	(0.95, 1.08)	
Other	1.22	(1.09, 1.36)	***
Ethnicity			
Hispanic	1.12	(1.05, 1.20)	**
Employed	0.99	(0.93, 1.06)	
BMI (kg/m^2)			
< 18.5	0.91	(0.78, 1.07)	
18.5 to < 30		Reference	
30 to < 40	0.97	(0.92, 1.02)	
≥ 40	1.04	(0.97, 1.13)	
Albumin (g/dL)			
< 2.5	0.90	(0.83, 0.98)	*
2.5 to < 3	0.94	(0.87, 1.02)	
3 to < 3.5	0.95	(0.88, 1.02)	
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	1.01	(0.95, 1.08)	
8 to < 9	0.99	(0.93, 1.06)	
9 to < 11		Reference	
≥ 11	0.98	(0.90, 1.06)	

Comorbidities			
Coronary Artery Disease	0.99	(0.90, 1.10)	
Congestive Heart Failure	0.94	(0.89, 1.00)	
Cancer	0.74	(0.62, 0.88)	***
Hypertension	1.15	(1.07, 1.24)	***
Chronic Obstructive Pulmonary Disease	1.06	(0.94, 1.19)	
Diabetes Mellitus	0.99	(0.94, 1.05)	
Peripheral Vascular Disease	0.92	(0.83, 1.03)	
Prior Cerebrovascular Accident	0.96	(0.86, 1.07)	
Drug Dependence	0.97	(0.88, 1.07)	
Smoker	1.03	(0.95, 1.11)	
Patient institutionalized	0.89	(0.76, 1.04)	
Needs Assistance with ADLs and/or Inability to Transfer	0.84	(0.75, 0.93)	***
Facility Characteristics			
Large Dialysis Organization	1.22	(1.15, 1.29)	***
Facility is for-profit	0.96	(0.88, 1.05)	
Facility is hospital-based	0.96	(0.85, 1.09)	
Total Facility Patients per Year			
0 to 50	0.99	(0.93, 1.06)	
51 to 100		Reference	
101 to 150	0.96	(0.91, 1.02)	
> 150	0.96	(0.90, 1.03)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	1.04	(0.99, 1.09)	
Residence Characteristics			
Urban	0.95	(0.89, 1.00)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	1.03	(0.97, 1.10)	
≥ 25%	1.01	(0.94, 1.09)	
% Less than High school Education in Zipcode			
< 15%		Reference	
15% to <30%	1.01	(0.95, 1.07)	
≥ 30%	1.02	(0.93, 1.12)	

Year of Dialysis Start		
2010		Reference
2011	1.04	(0.97, 1.12)
2012	1.07	(0.99, 1.15)
2013	1.09	(0.99, 1.20)
Season of Dialysis Start		
Winter		Reference
Spring	1.04	(0.98, 1.11)
Summer	1.03	(0.97, 1.11)
Fall	1.00	(0.93, 1.07)

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$

Table S7: Cox Regression Coefficients, Modeling Time to First Hospitalization Involving Vascular Access Infection, Medicare *versus* No Insurance, Multiple Imputation Analysis

Covariate	HR	95% CI	P-Value
Insurance			
No insurance		Reference	
Medicare	0.61	(0.37, 1.00)	*
Dual Eligible	1.05	(0.85, 1.29)	
Age	2.55	(1.37, 4.74)	**
Age^2	0.64	(0.12, 3.27)	
Sex			
Female	1.19	(1.00, 1.42)	
Male		Reference	
Race			
White		Reference	
Black	0.98	(0.79, 1.21)	
Other	0.82	(0.52, 1.31)	
Ethnicity			
Hispanic	0.84	(0.62, 1.15)	
Employed	0.79	(1.32, 0.48)	
BMI (kg/m^2)			
< 18.5	0.51	(0.28, 0.95)	*
18.5 to < 30		Reference	
30 to < 40	1.02	(0.83, 1.24)	
≥ 40	1.33	(1.03, 1.72)	*
Albumin (g/dL)			
< 2.5	1.39	(1.06, 1.83)	*
2.5 to < 3	1.14	(0.84, 1.54)	
3 to < 3.5	1.30	(0.98, 1.72)	
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	0.91	(0.70, 1.18)	
8 to < 9	1.11	(0.90, 1.37)	

9 to < 11		Reference	
≥ 11	0.88	(0.65, 1.18)	
Comorbidities			
Coronary Artery Disease	1.12	(0.90, 1.39)	
Congestive Heart Failure	1.06	(0.87, 1.28)	
Cancer	0.90	(0.65, 1.24)	
Hypertension	0.85	(0.66, 1.09)	
Chronic Obstructive Pulmonary Disease	1.29	(1.03, 1.63)	*
Diabetes Mellitus	0.98	(0.81, 1.18)	
Peripheral Vascular Disease	0.87	(0.67, 1.12)	
Prior Stroke	1.19	(0.93, 1.51)	
Drug Dependence	0.62	(0.30, 1.28)	
Smoker	0.84	(0.59, 1.19)	
Patient institutionalized	1.63	(1.25, 2.13)	***
Needs Assistance with ADLs and/or Inability to Transfer	1.09	(0.85, 1.40)	
Facility Characteristics			
Large Dialysis Organization	0.97	(0.79, 1.18)	
Facility is for-profit	1.39	(0.96, 2.01)	
Facility is hospital-based	1.09	(0.70, 1.72)	
Total Facility Patients per Year			
0 to 50	1.01	(0.80, 1.27)	
51 to 100		Reference	
101 to 150	0.99	(0.79, 1.24)	
> 150	1.18	(0.91, 1.54)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	0.82	(0.98, 0.69)	*
Residence Characteristics			
Urban	1.08	(1.32, 0.89)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	1.10	(0.87, 1.40)	
≥ 25%	1.13	(0.85, 1.51)	
% Less than High school Education in Zipcode			
< 15%		Reference	
15% to <30%	1.07	(0.85, 1.35)	

≥ 30%	0.95	(0.67, 1.36)	
Year of Dialysis Start			
2010		Reference	
2011	0.82	(0.65, 1.05)	
2012	0.77	(0.60, 0.98)	*
2013	0.68	(0.48, 0.97)	*
Season of Dialysis Start			
Winter		Reference	
Spring	0.82	(0.63, 1.05)	
Summer	1.06	(0.84, 1.33)	
Fall	0.93	(0.73, 1.18)	

*** p < 0.001
** p < 0.01
* p < 0.05

Table S8: Cox Regression Coefficients, Modeling Time to First Hospitalization for Involving Vascular Access Infection, Medicaid *versus* No Insurance, Multiple Imputation Analysis

Covariate	HR	95% CI	P-Value
Insurance			
No insurance		Reference	
Medicaid	1.11	(0.99, 1.23)	
Age	0.83	(0.78, 0.89)	***
Age^2	0.98	(0.94, 1.02)	
Sex			
Female	1.12	(1.00, 1.25)	*
Male		Reference	
Race			
White		Reference	
Black	1.00	(0.88, 1.15)	
Other	0.82	(0.62, 1.10)	
Ethnicity			
Hispanic	0.99	(0.84, 1.18)	
Employed	0.90	(0.76, 1.07)	
BMI (kg/m^2)			
< 18.5	0.66	(0.44, 0.98)	*
18.5 to < 30		Reference	
30 to < 40	1.21	(1.07, 1.37)	**
≥ 40	1.30	(1.10, 1.54)	**
Albumin (g/dL)			
< 2.5	1.33	(1.12, 1.59)	**
2.5 to < 3	0.96	(0.79, 1.18)	
3 to < 3.5	1.00	(0.83, 1.21)	
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	1.11	(0.95, 1.29)	
8 to < 9	1.07	(0.92, 1.25)	
9 to < 11		Reference	
≥ 11	1.01	(0.83, 1.22)	

Comorbidities			
Coronary Artery Disease	1.08	(0.88, 1.32)	
Congestive Heart Failure	1.03	(0.90, 1.18)	
Cancer	1.17	(0.82, 1.66)	
Hypertension	1.12	(0.94, 1.33)	
Chronic Obstructive Pulmonary Disease	0.98	(0.76, 1.26)	
Diabetes Mellitus	1.06	(0.94, 1.20)	
Peripheral Vascular Disease	1.18	(0.96, 1.45)	
Prior Stroke	1.07	(0.85, 1.35)	
Drug Dependence	1.41	(1.16, 1.72)	***
Smoker	1.04	(0.88, 1.23)	
Patient institutionalized	1.06	(0.78, 1.44)	
Needs Assistance with ADLs and/or Inability to Transfer	1.11	(0.90, 1.37)	
Facility Characteristics			
Large Dialysis Organization	0.99	(0.87, 1.12)	
Facility is for-profit	1.27	(1.03, 1.58)	*
Facility is hospital-based	1.23	(0.94, 1.61)	
Total Facility Patients per Year			
0 to 50	0.83	(0.70, 0.97)	*
51 to 100		Reference	
101 to 150	0.88	(0.77, 1.01)	
> 150	0.94	(0.81, 1.09)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	0.99	(0.89, 1.10)	
Residence Characteristics			
Urban	0.98	(0.86, 1.12)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	1.07	(0.92, 1.25)	
≥ 25%	1.19	(0.99, 1.42)	
% Less than High school Education in Zipcode			
< 15%		Reference	
15% to <30%	1.00	(0.86, 1.15)	
≥ 30%	1.01	(0.82, 1.25)	

Year of Dialysis Start			
2010		Reference	
2011	0.96	(0.82, 1.12)	
2012	0.84	(0.72, 0.99)	*
2013	0.74	(0.60, 0.92)	**
Season of Dialysis Start			
Winter		Reference	
Spring	0.92	(0.79, 1.06)	
Summer	0.88	(0.75, 1.02)	
Fall	0.86	(0.74, 1.00)	*

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$

Table S9: Cox Regression Coefficients, Modeling Time to First Hospitalization Involving Any Infection, Medicare *versus* No Insurance, Multiple Imputation Analysis

Covariate	HR	95% CI	P-Value
Insurance			
No insurance		Reference	
Medicare	0.93	(0.71, 1.22)	
Dual Eligible	1.06	(0.94, 1.18)	
Age	1.63	(1.18, 2.25)	**
Age^2	0.70	(0.29, 1.71)	
Sex			
Female	1.15	(1.05, 1.27)	**
Male		Reference	
Race			
White		Reference	
Black	0.84	(0.75, 0.94)	**
Other	0.70	(0.54, 0.91)	**
Ethnicity			
Hispanic	0.85	(0.72, 0.99)	*
Employed	0.81	(0.63, 1.06)	
BMI (kg/m^2)			
< 18.5	1.01	(0.79, 1.29)	
18.5 to < 30		Reference	
30 to < 40	0.97	(0.87, 1.08)	
≥ 40	1.03	(0.89, 1.20)	
Albumin (g/dL)			
< 2.5	1.38	(1.18, 1.62)	***
2.5 to < 3	1.16	(0.99, 1.36)	
3 to < 3.5	1.10	(0.92, 1.31)	
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	0.91	(0.79, 1.06)	
8 to < 9	1.01	(0.89, 1.14)	

9 to < 11		Reference	
≥ 11	0.94	(0.82, 1.09)	
Comorbidities			
Coronary Artery Disease	1.01	(0.89, 1.13)	
Congestive Heart Failure	1.11	(1.01, 1.23)	*
Cancer	1.23	(1.06, 1.43)	**
Hypertension	0.94	(0.81, 1.08)	
Chronic Obstructive Pulmonary Disease	1.36	(1.20, 1.54)	***
Diabetes Mellitus	1.09	(0.98, 1.20)	
Peripheral Vascular Disease	1.07	(0.94, 1.22)	
Prior Stroke	1.23	(1.08, 1.41)	**
Drug Dependence	1.17	(0.86, 1.58)	
Smoker	0.93	(0.78, 1.11)	
Patient institutionalized	1.32	(1.14, 1.53)	***
Needs Assistance with ADLs and/or Inability to Transfer	1.24	(1.09, 1.42)	**
Facility Characteristics			
Large Dialysis Organization	0.98	(0.88, 1.09)	
Facility is for-profit	0.98	(0.82, 1.17)	
Facility is hospital-based	0.95	(0.76, 1.20)	
Total Facility Patients per Year			
0 to 50	0.89	(0.78, 1.01)	
51 to 100		Reference	
101 to 150	0.97	(0.86, 1.10)	
> 150	1.07	(0.93, 1.24)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	0.95	(0.87, 1.05)	
Residence Characteristics			
Urban	1.11	(1.00, 1.23)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	1.05	(0.93, 1.19)	
≥ 25%	1.11	(0.95, 1.29)	
% Less than High school Education in Zipcode			
< 15%		Reference	
15% to <30%	1.02	(0.90, 1.15)	

≥ 30%	0.90	(0.74, 1.08)
Year of Dialysis Start		
2010		Reference
2011	0.97	(0.84, 1.11)
2012	1.01	(0.88, 1.16)
2013	0.89	(0.74, 1.08)
Season of Dialysis Start		
Winter		Reference
Spring	1.04	(0.91, 1.18)
Summer	1.08	(0.95, 1.22)
Fall	1.01	(0.88, 1.15)

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$

Table S10: Cox Regression Coefficients, Modeling Time to First Hospitalization Involving Any Infection, Medicaid *versus* No Insurance, Multiple Imputation Analysis

Covariate	HR	95% CI	P-Value
Insurance			
No insurance		Reference	
Medicaid	1.21	(1.13, 1.30)	***
Age	0.94	(0.90, 0.97)	***
Age^2	0.99	(0.97, 1.02)	
Sex			
Female	1.26	(1.18, 1.36)	***
Male		Reference	
Race			
White		Reference	
Black	0.88	(0.81, 0.96)	**
Other	0.74	(0.62, 0.88)	***
Ethnicity			
Hispanic	0.81	(0.73, 0.90)	***
Employed	0.86	(0.77, 0.97)	*
BMI (kg/m^2)			
< 18.5	0.91	(0.74, 1.12)	
18.5 to < 30		Reference	
30 to < 40	0.95	(0.87, 1.03)	
≥ 40	0.95	(0.85, 1.07)	
Albumin (g/dL)			
< 2.5	1.68	(1.49, 1.89)	***
2.5 to < 3	1.25	(1.10, 1.41)	***
3 to < 3.5	1.14	(1.01, 1.28)	*
≥ 3.5		Reference	
Hemoglobin category (g/dL)			
< 8	0.95	(0.86, 1.05)	
8 to < 9	0.98	(0.89, 1.08)	
9 to < 11		Reference	
≥ 11	0.96	(0.85, 1.07)	

Comorbidities			
Coronary Artery Disease	1.06	(0.93, 1.20)	
Congestive Heart Failure	1.11	(1.02, 1.20)	*
Cancer	1.45	(1.19, 1.77)	***
Hypertension	0.91	(0.82, 1.00)	
Chronic Obstructive Pulmonary Disease	1.22	(1.06, 1.42)	**
Diabetes Mellitus	1.18	(1.09, 1.28)	***
Peripheral Vascular Disease	1.25	(1.10, 1.42)	***
Prior Stroke	1.11	(0.97, 1.28)	
Drug Dependence	1.54	(1.36, 1.75)	***
Smoker	0.99	(0.89, 1.10)	
Patient institutionalized	1.08	(0.90, 1.30)	
Needs Assistance with ADLs and/or Inability to Transfer	1.24	(1.09, 1.41)	**
Facility Characteristics			
Large Dialysis Organization	0.97	(0.90, 1.06)	
Facility is for-profit	1.09	(0.96, 1.24)	
Facility is hospital-based	1.12	(0.95, 1.33)	
Total Facility Patients per Year			
0 to 50	0.92	(0.83, 1.02)	
51 to 100		Reference	
101 to 150	0.93	(0.85, 1.01)	
> 150	0.96	(0.87, 1.06)	
Full Time Patient to Nurse/Tech Ratio			
< 7		Reference	
≥ 7	0.98	(0.91, 1.05)	
Residence Characteristics			
Urban	1.05	(0.97, 1.14)	
% Poverty in Zipcode			
< 15%		Reference	
15% to <25%	1.06	(0.96, 1.16)	
≥ 25%	1.12	(1.00, 1.25)	
% Less than High school Education in Zipcode			
< 15%		Reference	
15% to <30%	0.98	(0.90, 1.07)	
≥ 30%	0.98	(0.86, 1.12)	

Year of Dialysis Start			
2010		Reference	
2011	0.95	(0.86, 1.05)	
2012	0.94	(0.85, 1.04)	
2013	0.79	(0.69, 0.90)	***
Season of Dialysis Start			
Winter		Reference	
Spring	0.96	(0.87, 1.06)	
Summer	0.97	(0.88, 1.07)	
Fall	0.97	(0.88, 1.07)	

*** p < 0.001
** p < 0.01
* p < 0.05

Table S11: Results of Secondary and Sensitivity Analyses

	Medicare			Medicaid		
Sensitivity Analyses	**RR or HR**	**95% CI**	**p-value**	**RR or HR**	**95% CI**	**p-value**
RR of AVF/AVG at month 4						
Main Analysis	1.63	1.14, 2.43	< 0.001	1.23	1.12, 1.38	< 0.001
Complete Case Analysis	1.75	1.08, 2.78	0.024	1.19	1.06, 1.36	< 0.001
RR by month 6	1.54	1.10, 2.18	0.013	1.24	1.13, 1.35	< 0.001
Including pre-ESKD nephrology care	1.84	1.38, 2.53	< 0.001	1.50	1.39, 1.61	< 0.001
Time to switching to AVF/AVG after month 4						
Main Analysis	1.17	0.97, 1.42	0.11	1.01	0.96, 1.06	0.73
Complete Case Analysis	1.09	0.86, 1.37	0.49	1.00	0.94, 1.06	0.97
Competing Risks Model	1.11	0.92, 1.35	0.27	0.99	0.94, 1.04	0.79
Including pre-ESKD nephrology care	1.12	0.97, 1.29	0.12	1.01	0.97, 1.06	0.60
RR of AVF/AVG at month 13						
Main Analysis	1.11	1.01, 1.22	0.040	1.01	1.00, 1.04	0.20
Complete Case Analysis	1.07	0.96, 1.20	0.23	1.01	0.99, 1.03	0.52
Including pre-ESKD nephrology care	1.14	1.06, 1.21	< 0.001	1.05	1.03, 1.07	< 0.001

Abbreviations: RR = relative risks. HR = hazard ratio, AVF = arteriovenous fistula, AVG = arteriovenous graft, ESKD = end-stage kidney disease

APPENDIX REFERENCES

1. Noridian Healthcare Solutions. Modifers. (2018). Available at: https://med.noridianmedicare.com/web/jfa/topics/modifiers. (Accessed: 28th July 2018)
2. Lin, E., Kurella Tamura, M., Montez-Rath, M. E. & Chertow, G. M. Re-evaluation of re-hospitalization and rehabilitation in renal research. *Hemodial. Int.* **21,** 422–429 (2017).
3. Azur, M. J., Stuart, E. A., Frangakis, C. & Leaf, P. J. Multiple Imputation by Chained Equations: What is it and how does it work? *Int. J. Methods Psychiatr. Res.* **20,** 40–49 (2011).
4. Montez-Rath, M. E., Winkelmayer, W. C. & Desai, M. Addressing Missing Data in Clinical Studies of Kidney Diseases. *Clin. J. Am. Soc. Nephrol.* **9,** 1328–1335 (2014).
5. White, I. R., Daniel, R. & Royston, P. Avoiding bias due to perfect prediction in multiple imputation of incomplete categorical variables(). *Comput. Stat. Data Anal.* **54,** 2267–2275 (2010).
6. Rubin, D. B. *Multiple Imputation for Nonresponse in Surveys*. (John Wiley & Sons, 1987).
7. Schomaker, M. & Heumann, C. Bootstrap Inference when Using Multiple Imputation. *ArXiv Prepr. ArXiv160207933* (2016).