Appendix to:

Physician Visits and 30-Day Hospital Readmissions in Patients Receiving Hemodialysis

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Methods

Tables and Figures

Data and Study Population:

Patient-months between January 1st 2004 and December 31st 2009 were included in our analysis. Patient-months were included if patients: 1) received in-center hemodialysis, and; 2) were covered by Medicare Parts A&B. Among the eligible patient-months, hospitalizations lasting greater than two days and where the patient was discharged in the last two days of a calendar month were selected as "index hospitalizations." An individual patient could have more than one "index hospitalization." If a patient had index hospitalizations in different calendar years, she would be assigned different values for the instrumental variable reflecting mean visits to prevalent hemodialysis patients for each year of "index hospitalization".

Our study only included patients with Medicare Parts A&B insurance coverage. Among patients receiving hemodialysis, this is a majority of the overall population. We examined the effect of this criterion on inclusion in our study by tabulating the percentage of patients receiving in-center hemodialysis at the start of each calendar year during the study period (January 1st 2004 through January 1st 2009) with Medicare Parts A&B coverage. On January 1st 2004, 72.8% of patients had Medicare Parts A&B coverage. On January 1st 2005, 72.7% had Medicare Parts A&B coverage. On January 1st 2006, 71.5% had Medicare Parts A&B coverage. On January 1st 2007, 70.0% had Medicare Parts A&B coverage. On January 1st 2008, 67.6% had Medicare Parts A&B coverage. On Janaury 1st 2009, 65.2% had Medicare Parts A&B coverage.

The instrumental variable is the mean number of provider visits to prevalent hemodialysis patients at a given patient's dialysis facility in the year of "index hospitalization." This measure was calculated for each dialysis facility in each year of the study period. Prevalent hemodialysis patients were considered "eligible" to be included in calculation of the instrumental variable in months when they were: 1) alive; 2) receiving in-center hemodialysis, and; 3) covered by Medicare Parts A&B. Patients meeting these criteria for only part of a calendar year only contributed the months when the criteria were met in calculation of mean visits at their facility for that year. The following equation illustrates how the instrumental variable was calculated:

$$MeanVisits_{facility} = \frac{\sum_{j=1}^{j=z}\left[\left(VisitsMonth_{1,j} + VisitsMonth_{2,j} + \cdots VisitsMonth_{k,j}\right)\Big/_{k}\right]}{z}$$

Where:
$VisitsMonth_{1\text{-}k}$ for patient j represents the months in the calendar year when patient j is eligible to be included in the calculation.
Patient j=1 through j=z represent all patients with months that are eligible for inclusion in the calculation receiving dialysis at a given facility in a given calendar year.

Two-Sample, Two-Stage Least Squares Analysis:

To minimize potential bias due to unobserved characteristics that are associated with physician visit frequency and the probability of re-hospitalization, and to address endogeneity (or "reverse causality") between physician visit frequency and re-hospitalization or death, we used a two-sample, two-stage least squares analysis. This methodological approach was first described by Krueger et al.[1] We also used the following measure of physician visit frequency practice patterns in a dialysis facility as an instrumental variable:

The average number of physician visits to prevalent hemodialysis patients with Medicare Parts A&B coverage at a patient's dialysis facility in a given year.

When calculating the instrument, we exclude patients who were included in our analysis cohorts. In the two-sample, two-stage least squares analysis, we use linear probability models for each cohort to estimate the relationship between visit frequency and probability of re-hospitalization – 'β' – in the following two steps:

1) In the first step (illustrated below) we use a sample of all patients in a given cohort who are not hospitalized and do not die in the month following hospital discharge to estimate the effect of the instrument Z_{it} on visit frequency in the month following hospitalization:

$$Visits_{it} = \gamma_0 + \gamma_1 Z_{it} + X'_{it}\gamma_2 + e_{it}$$

Where,
$Visits_{it}$ = Predicted frequency of physician visits in the month following hospitalization in $patient_i$ at $time_t$.
Z_{it} = Value of the instrumental variable (i.e. mean visit frequency to prevalent hemodialysis patients at a patient's dialysis facility) for $patient_i$ at $time_t$.
X'_{it} = Vector of covariates for $patient_i$ at $time_t$.

2) In the second step (illustrated below) we used the entire sample of patients in a given cohort (i.e. patients who were hospitalized and died in addition to those who were not hospitalized and did not die). For each $patient_i$ and $time_t$, based on their vector of covariates and value of the instrumental variable, we predicted the visit frequency. The predicted visit frequency (*Predicted* $Visits_{it}$) was used in the second stage equation to estimate the relationship between visit frequency and probability of re-hospitalization:

$$Rehosp_{it} = \alpha + \beta * Predicted\,Visits_{it} + X'_{it} * \delta + \omega_{it}$$

Where,
$Rehosp_{it}$ = Denotes whether a $patient_i$ at $time_t$ was re-hospitalized in the month following hospital discharge.
Predicted $Visits_{it}$ = The visit frequency that *would have* occurred in the month following hospital discharge in $patient_i$ at $time_t$ if the patient *were not* hospitalized and *did not* die as a function of the instrumental variable.
X'_{it} = Vector of covariates for $patient_i$ at $time_t$.

Because, as outlined in the *methods* and *results* sections of the manuscript, the instrument (visit frequency in prevalent hemodialysis patients receiving dialysis at a given patient's facility in the calendar year) is not associated with the primary outcome (re-hospitalization) other than through the exposure (visit frequency), the association between '*Predicted Visits*' and '*Re-hospitalization*' – (β) – provides an unbiased estimate of the relationship between physician visits and re-hospitalization.

The reduced form equation for the two-sample instrumental variable analysis is:

$$Rehosp_{it} = \theta_0 + \theta_1 * Z_{it} + X'_{it}\theta_2 + v_{it}$$

Where,
$Rehosp_{it}$ = probability of re-hospitalization in $patient_i$ at $time_t$
Z_{it} = value of instrumental variable in $patient_i$ at $time_t$
X'_{it} = Vector of covariates for $patient_i$ at $time_t$

As Manacorda and Moretti describe in their discussion of two-sample IV estimators, Angrist and Krueger's two-sample IV estimator gives a consistent estimate of 'β', which is equal to the ratio of the reduced form coefficient over the first stage coefficient[1, 2]:

$$est(B^{IV}) = est({\theta_1}^{OLS})/est({\gamma_1}^{OLS})$$

Calculating the Net Change in Cost Associated with One More Attempted Visit to Patients in the Month Following Hospitalization:

When determining the cost savings from reduced re-hospitalizations in counterfactual scenarios where providers *attempt* to see patients one additional time, we assumed that providers who *attempt* to see patients one additional time in the month following hospital discharge impart the benefit (in terms of reduced cost of re-hospitaliization) associated with one additional *predicted* visit. We calculated these cost savings by multiplying the change in probability of re-hospitalization from one additional *attempted* visit by the average cost of a re-hospitalization.

$$Expected\ Savings\ from\ Additional\ Attempted\ Visit = (Decreased\ Probability\ of\ Rehospitalization) * (Average\ Cost\ of\ Rehospitalization)$$

Where,
Decreased Probability of Re-hospitalization = estimated decrease in the probability of re-hospitalization associated with one additional predicted visit from the main analysis cohort.
Average Cost of Re-hospitalization = the average cost of re-hospitalization estimated from a generalized linear model involving all cohorts

To estimate the cost paid by Medicare for additional physician visits in the counterfactual scenario where providers *attempt* to see patients one additional time in the month following hospital discharge, we first estimated how often patients would *actually* be seen if providers *attempt* one additional visit. To do this, we took the ratio of *predicted* visits to *actual* visits in patients who were re-hospitalized (0.684) and in patients who were not re-hospitalized (0.958). [Note that this ratio does not equal 1 in patients who were not re-hospitalized because some of these patients died in the month following discharge.] We assumed that the cost (in terms of increased reimbursement from Medicare) from an additional *attempted* visit equals the cost for an additional visit multiplied by the ratio of *actual* to *predicted* visits for each group, since providers attempting to see patients one additional time don't always succeed in seeing the patients due to hospitalization or death. We assumed one extra visit was reimbursed at the rate of a 4th monthly visit ($64 USD). This calculation is represented below:

$$Cost\ from\ One\ Additional\ Attempted\ Visit = (Reimbursement\ for\ Visit) * (Ratio)$$

Where,
Reimbursement for visit = the national average difference in amount paid to providers by Medicare for four provider visits compared to two-to-three provider visits in 2009.
Ratio = the ratio of predicted to actual provider visits (0.96 in patients not re-hospitalized and 0.68 in patients who are re-hospitalized).

We assumed the added reimbursement cost of an additional *attempted* visit was equal to a weighted average of the "Cost from One Additional Attempted Visit" in patients who are re-hospitalized and in patients who are not re-hospitalized. To determine weights for calculating the weighted average, we used the percentage of re-hospitalizations observed in all of our Medicare cohorts combined (38.5%) as a baseline, and subtracted the reduced probability of re-hospitalization from our main analytic cohort (3.5%) to obtain an estimated probability of re-hospitalization 0.385 – 0.035 = 0.350 in the counterfactual scenario of one additional *attempted* visit. The weighted average calculation is displayed below:

$$Weighted\ Avg.of\ Additional\ Attempted\ Visit\ Cost = \left(Cost\ attempted\ visit\ in\ patients_{group\ a}\right) * \left(Prop_{group\ a}\right) + \left(Cost\ attempted\ visit\ in\ patients_{group\ b} * \left(Prop_{group\ b}\right)\right.$$

Where,
Group a = patients who are re-hospitalized
Group b = patients who are not re-hospitalized
$Prop_{group\ a}$ = Mean proportion of re-hospitalizations in all of our Medicare cohorts minus the reduced probability of re-hospitalization from additional attempted visit.
$Prop_{group\ b} = 1 - Prop_{group\ a}$

Finally, we subtracted the weighted average of the "Cost from One Additional *Attempted* Visit" from the "Expected Savings from Additional *Attempted* Visit" to determine the "Net Change in Cost Associated with One More *Attempted* Visit."

Estimating the Change in Total Number of Hospitalizations in Dialysis Patients from One More Attempted Visit to Each Patient:

To estimate the change in total hospitalizations per year in patients receiving hemodialysis associated with one additional *attempted* visit to all patients in the month following a hospital discharge, we first determined the total number of hospitalizations experienced by patients receiving in-center hemodialysis in 2009. This calculation was based on the total number of patients receiving in-center hemodialysis and the average number of hospitalizations per patient-year reported by the USRDS using the following equation:

- Total # of patients receiving hemodialysis in the U.S. in 2009: 378,489
- Rate of hospitalizations per year: 1.85
- Total # hospitalizations = 378,489*1.85=700,204

Assuming an annual rate of death of 0.28 in patients receiving in-center hemodialysis (reported by USRDS), a proportion of deaths occurring while hospitalized of 0.59 (reported by O'Hare et al.)[3], and an average of 1.85 hospitalizations per year (reported by USRDS), we calculated the probability of death during a hospitalization using the following equation:

$$Prob\ Death\ Hosp = {(Prob\ Death\ Yr * Prop\ Death\ Hosp)}/{Num\ Hosp\ Yr}$$

Where,
Prob Death Hosp = probability of death during a hospitalization
Prob Death Yr = Annual probability of death
Prop Death Hosp = Proportion of deaths occurring while in the hospital
Num Hosp Yr = Average number of hospitalizations per year

We assessed the accuracy of this estimate by comparing it to the probability of death during a hospitalization observed in our Medicare patient cohorts. The calculated probability of death during a hospitalization for the entire hemodialysis population was 9%, only 1% less than that which we observed empirically in our Medicare cohorts.

Using the rate of re-hospitalization in 2009 of 0.363 reported by USRDS, we imputed the total number of first hospitalizations in 2009, where first hospitalizations refers to hospitalizations in patients who were not discharged from the hospital in the previous month. The following algorithm was used to impute this value:

$$Total\ \#\ Hosp = First\ Hosp + (First\ Hosp * Prob\ Surv\ Hosp^1 * Prob\ Rehosp^1) + (First\ Hosp * Prob\ Surv\ Hosp^2 * Prob\ R\ ehosp^2) +_{\dots} (First\ Hosp * Prob\ Surv\ Hosp^n * Prob\ Rehosp^n)$$

Where,
First Hosp = the imputed value for first hospitalizations
Total # Hosp = the previously calculated total number of hospitalizations in patients receiving in-center hemodialysis in 2009
Prob Surv Hosp is the calculated probability of surviving a hospitalization equal to: 1- probability of death during a hospitalization.
Prob Rehosp is the reported probability of re-hospitalization in 2009.

This equation was carried out until n=20 and a solver function was used to impute the number of First Hospitalizations. Past n=20 there is essentially zero probability of being re-hospitalized.

We used the following equation to determine the total number of hospitalizations that would occur if physicians attempt to see patients discharged from the hospital one additional time in the subsequent month:

$$Total\ Hosp_{extra\ visit} = First\ Hosp + (First\ Hosp * Prob\ Surv\ Hosp^1 * Prob\ Rehosp\ Extra\ Visit^1) + (First\ Hosp * Prob\ Surv\ Hosp^2 * Prob\ Rehosp\ Extra\ Visit^2) +_{\dots} (First\ Hosp * Prob\ Surv\ Hosp^n * Prob\ Rehosp\ Extra\ Visit^n)$$

Where,
Total $Hosp_{extra\ visit}$ = the total number of hospitalizations in patients receiving in-center hemodialysis in 2009 if physicians attempt one additional visit in the month following discharge
First Hosp = the number of first hospitalizations (imputed in the previous equation)
Prob Surv Hosp = the calculated probability of surviving a hospitalization equal to: 1- probability of death per hospitalization
Prob Rehosp Extra Visit = the probability of re-hospitalization under the scenario where providers attempt to see patients one additional time in the month following discharge.

The "Change in Total Number of Hospitalizations" was the difference between the total number of hospitalizations per year (Total # Hosp) and the number of hospitalizations that would occur if providers tried to see patients one additional time following hospital discharge (Total $Hosp_{extra\ visit}$).

Estimating Net Aggregate Cost Implications Associated with One More Attempted Visit:

To estimate "the net aggregate cost implications of an extra *attempted* visit," we first calculated the "aggregate cost savings" associated with one additional attempted visit in the month following hospital discharge using the following equation:

$$Aggregate\ Cost\ Savings = Difference\ in\ Hospitalizations * Avg\ Cost\ Per\ Hospitalization$$

Where,
Difference in Hospitalizations = the reduction in total number of hospitalizations per year associated with one additional provider visit following hospital discharge (estimated above)
Average Cost Per Hospitalization = Added cost in month of re-hospitalization obtained from a regression analysis using our full cohort of Medicare patients

Next, we calculated the actual number of additional visits that would be expected to occur if physicians *attempted* to see patients one additional time per month following hospital discharge using the following equation:

$$Actual\ Visits = \left[Total\ Hosp_{extra\ visit} * Prob\ Rehosp_{exra\ visit} * Prob\ Visit_{rehosp}\right] + \left[Total\ Hosp * (1 - Prob\ Rehosp_{extra\ visit}) * Prob\ Visit_{no\ rehosp}\right]$$

Where,
Actual Visits = the number of actual visits to patients that would occur if providers attempted to see patients one additional time in the month following hospitalization.
Total $Hosp_{extra\ visit}$ = the calculated total number of hospitalizations that would occur if providers attempted to see patients one additional time in the month following hospitalization
Prob $rehosp_{extra\ visit}$ = the estimated probability of re-hospitalization if physicians attempted to see patients one additional time in the month following hospital discharge (note, this is identical to $Prop_{group\ a}$ above)
Prob $Visit_{Rehosp}$ = The probability of an extra visit in patients who are re-hospitalized if their physicians attempt to see them one additional time (calculated from the ratio of predicted versus actual visits in patients who are re-hospitalized)
Prob $Visit_{no\ Rehosp}$ = The probability of an extra visit in patients who are not re-hospitalized if their physicians attempt to see them one additional time (calculated from the ratio of predicted versus actual visits in patients who are not re-hospitalized)

The "aggregate cost of encouraging an extra visit" was then calculated by multiplying the cost of an extra visit (based from CMS reimbursement for a 4th visit) by the calculated "Actual Visits". Finally, the "net aggregate cost implications of an extra *attempted* visit" were calculated by subtracting the "aggregate cost of encouraging an extra visit" from the "aggregate cost savings" from an extra *attempted* visit.

Sensitivity and Additional Analyses

Sensitivity to visit frequency assumptions

To test our model's sensitivity to assumptions about the number of visits occurring when 2-3 visits and four or more visits are documented on medical claims, we performed three separate analyses in the main cohort under different visit frequency assumptions. In each case, the statistical methods were identical to those described in methods of the main text. First, we assumed that patients were seen six times in months when four or more visits were documented in Medicare claims (in our primary analysis we assumed there were four visits in these months). Second, we assumed that there were three visits in months when 2-3 visits were claimed (in the primary analysis we assumed there were 2.5 visits). Finally, we assumed that there were two visits when 2-3 visits were claimed. Estimates for the relationship between visit frequency and absolute probability of re-hospitalization ranged from -1.9% to -3.8% under these different assumptions, and all three estimates were statistically significant ($p < 0.05$). **(Table S19)**

Sensitivity to instrumental variable

We also tested the model's sensitivity to the instrumental variable used, since it is possible that patients in dialysis facilities share certain unobserved characteristics or that physicians caring for patients at the same facility have similar practice patterns regarding re-hospitalization. In a secondary analysis, we used hospital service areas (HSA) as an instrumental variable to predict visit frequency in all 5 patient cohorts. Results were similar to our primary analysis, except that the inverse association between visit frequency and re-hospitalization was of borderline statistical significance when using HSA was used as the instrumental variable. **(Table S20)**

Sensitivity to possible selection bias from two-sample least squares analysis

Our two-sample, two-stage least squares analysis makes an important assumption about the relationship between mean visit frequency at a patient's dialysis facility and the number of visits that would occur if a patient was not re-hospitalized or did not die. It assumes that this relationship (after adjusting for differences in observed covariates) is the same regardless of whether a patient lives, dies, or is hospitalized. One potential way that this assumption could lead to bias is if by reducing the likelihood of re-hospitalization, more frequent visits causes sicker patients to remain in the non-hospitalized group. If sicker patients are, on average, seen more frequently by their physician, then this could lead to an overestimation of the relationship between mean visit frequency at a patients' facility and visits to patients who were re-hospitalized by selecting sicker patients in the first-stage estimate.

To examine sensitivity to this potential bias, we performed a separate analysis on all five patient cohorts where the exposure of interest was the number of provider visits per day when a patient

was available to be seen by a physician or advanced practitioner. We assumed that on days when a patient was hospitalized or dead she was not available to be seen in an outpatient setting by her provider. The value of this new exposure variable varied from 0 to 0.134 (which is 4 visits in a 30 day month). We truncated visits per day by assuming that all patient-months with greater than 0.134 visits per day had 0.134 visits per day.

We then conducted a one-sample, two-stage least squares instrumental variable analysis using the new exposure variable. This was done for all five study cohorts. In the main study cohort, one additional provider visit per month was associated with a 1.9% (95% CI 0.1%-3.6%) reduction in the absolute probability of re-hospitalization. In the remaining four cohorts, the reduction ranged from 0.1% to 4.0%, and was statistically significant in the same groups as in the primary analysis. **(Table S21)**

This analysis demonstrates that our findings were not sensitive to possible selection bias from the two sample method. However, it is important to note that using provider visits per day available as the exposure variable likely underestimates the relationship between provider visits and re-hospitalization for the following reason: In patients who were hospitalized, there was evidence that some providers attempted to "make up" for lost days. We found that approximately 38.5% of patients who were re-hospitalized had more than the amount of visits per day available corresponding to 4 visits per month, even after accounting for differences in the length of a month. In contrast, no patients who died or were not re-hospitalized had visits per day that corresponded to more than 4 visits per month. We corrected for this, in part, by not allowing visits per day to exceed 0.134. However, among patients who were re-hospitalized, visits per day in the period prior to re-hospitalization was still likely overestimated due to our inability to exclude the proportionally higher number of visits that occur in the period following re-hospitalization in our calculation of visits per day. As a result, there would be a bias towards more visits being associated with re-hospitalization, mitigating the inverse association between visit frequency and re-hospitalization.

Sensitivity to clustering at the dialysis facility level

The probability of re-hospitalization is likely to be correlated within individuals. We account for this possibility in our analyses using block bootstrap standard errors, clustering on individual patients. However, it is possible that patients dialyzing at the same dialysis facility also have a correlation in their likelihood of re-hospitalization. We tested our model's sensitivity to this possibility by using block bootstrap standard errors where we cluster by dialysis facility. We did this for our primary study cohort. The results from 10,000 simulations are illustrated in **table S22.** The effect of one additional physician visit on the absolute probability of re-hospitalization was -3.5% (95% CI -1.5% to -5.4%), which has standard errors nearly identical to the results from our primary analysis."

Exploration of Inverse Association between Age and Re-hospitalization

Older age was inversely associated with more frequent visits in all of our cohorts. Since age was adjusted for in our analyses, this inverse association does not bias our results. However, to evaluate why this inverse association is present, we performed several exploratory analyses. First, we conducted the two-sample, two-stage least squares analysis for the entire study population (all 5 cohorts combined) after dividing age into the following three categories: 1) Age under 50; 2) Age between 50 and 75, and; 3) Age over 75. We found that the difference in rate of re-hospitalization was most prominent for the youngest group of patients (those 50 and under), with those patients experiencing relatively greater probability of re-hospitalization compared with older groups. Specifically, compared to patients 50 and younger, patients between 50 and 75 had a 5.5% decrease in the probability of re-hospitalization (95% CI -4.5% to -6.5%), while those over 75 had a 7.5% decrease (95% CI -6.3% to -8.7%). This suggests that younger patients may be different in important ways than older patients.

In the following steps we used data from the USRDS Atlas[4] to assess overall hospitalization rates for patients in each of the following three age categories: 1) under 50; 2) between 50 and 75, and; 3) over 75.

1) For each age category, we calculated the total number of prevalent hemodialysis patient-years from 2004 through 2009.
2) The USRDS publishes hospitalization and prevalent dialysis data for age groups that are subsets of the age categories used for this analysis. For each age group (and year) published by the USRDS that is a subset of a larger age category, we calculated its share of the total number of prevalent hemodialysis patient-years for the age category (calculated in step 1)
3) We multiplied the reported overall hospitalization rates for each age group and year by its share of the total number of prevalent hemodialysis patient-years in the age category.
4) We took the sum of the estimates from step 3 in each age category to determine an average unadjusted overall rate of hospitalization for each age category between 2004 and 2009.

We found the overall rate of hospitalizations was 2.33 per patient year in patients under 50 years of age, 2.36 in patients between 50 and 75, and 2.52 in patients over 75, suggesting a trend towards more hospitalizations in older patients, which is the opposite direction from that observed in patients re-hospitalized. This suggests that re-hospitalizations may be different from overall hospitalizations.

A comparison of patient characteristics from our cohort among patients under 50 and those older suggests that these groups are different in fundamental ways. Using a 10% standardized difference as a marker of heterogeneity, patients under 50 were more likely to be African American, to smoke, use drugs, and drink alcohol. They were also more likely to be HIV positive and have liver or rheumatic disease. They were less likely to be in the first year of dialysis. In contrast, patients over 50 were more likely to have certain medical co-morbidities including

cerebrovascular, pulmonary, and coronary disease in addition to heart failure, cancer, dementia, diabetes and peripheral vascular disease. **(Table S23)** We speculate that younger patients may represent a group with poorer adherence, which may contribute to their higher rate of re-hospitalization, while their improved overall health contributes to lower rates of overall hospitalization in these younger patients.

Exploring differences in effectiveness between physicians and advance practitioners

Beyond one comprehensive visit per month, additional provider visits to patients receiving outpatient hemodialysis in a given month can be performed by either physicians or advanced practitioners. It is possible that, due to different skill sets, one additional visit from physicians in the month following hospital discharge could have a different effect on the likelihood of re-hospitalization than one additional visit from an advanced practitioner. Based on Medicare claims data available to us we were unable to determine who provides visits to patients receiving hemodialysis. A strength of our analysis is that we estimate the effect of one additional visit on the probability of re-hospitalization as it would be expected to occur in clinical practice in the United States. Specifically, the finding in our primary analytic cohort that one additional visit yields a 3.5 percent reduction in the probability of re-hospitalization describes the expected effect of an additional visit provided by the people who actually see patients.

In sensitivity analyses we explored what the effect of one additional physician visit would be given certain assumptions about the proportion of visits currently performed by physicians versus advanced practitioners and assumptions about the relative efficacy of physician visits compared to advanced practitioners. In all sensitivity analyses we assumed that physician visits would be more effective at preventing re-hospitalization than visits from advanced practitioners, while acknowledging that this assumption is speculative and not based on evidence. In sensitivity analyses we examined the following two scenarios: 1) physician visits are 20% more effective than advanced practitioner visits in preventing re-hospitalization, and; 2) physician visits are 40% more effective than advanced practitioner visits in preventing re-hospitalization. We examined each of these scenarios while assuming that: 1) currently 50% of visits are performed by physicians; 2) currently 60% of visits are performed by physicians, and; 2) currently 70% of visits are performed by physicians.

These Sensitivity Analyses were performed using the following two equations:

$$3.5\% = (TxEffect_{AP}) * (PropVisits_{AP}) + (PhysicianEffect) * (TxEffect_{AP}) * \left(PropVisits_{Phys}\right)$$

$$TxEffect_{Phys} = TxEffect_{AP} * PhysicianEffect$$

Where,
3.5% is the treatment effect from the main analytic cohort
TxEffectAP is the treatment effect for advanced practitioners that was determined to solve the equation
PropVisitsAP and PropVisitsPhys are the assumed proportion of visits performed by advanced practitioners and physicians respectively
PhysicianEffect is the additional effectiveness of physician visits relative to visits from advanced practitioners.

Results from these sensitivity analyses are demonstrated in **Table S24**. Under the assumption that physician visits are 20% more effective than advanced practitioners, one additional physician visit reduced the probability of re-hospitalization by 3.68% to 3.82% depending on the current composition of provider visits (i.e. physicians versus advanced practitioners). Under the assumption that physician visits are 40% more effective than advanced practitioners, one additional physician visit reduced the probability of re-hospitalization by 3.83% to 4.08% depending on the current composition of provider visits.

Sensitivity to Additional Potential Confounders:

In an expanded model we incorporate additional potential confounders, including whether or not a dialysis facility is hospital-based, whether a patient is discharged home, to a skilled nursing facility, or to home health, and the cause of index hospitalization. Regression results from an "expanded model" in our primary analysis cohort that includes these additional covariates is illustrated on **Table S25**. Similar to the results from our primary analysis, one additional provider visit in the month following hospital discharge was associated with a 3.4% reduction in the absolute probability of re-hospitalization (95% CI 1.5% to 5.2%).

Sensitivity to Model Selection:

We assess sensitivity to our choice of a linear probability model using our primary analysis cohort (i.e. patients without Medicaid residing in metropolitan areas dialyzing in for-profit centers). Similar to in our primary analysis, we use a two-stage, two-sample least squares instrumental variable analysis. However, in this sensitivity analysis we use a probit regression model in the second stage estimation rather than a linear probability model. To avoid potential bias arising from use of an endogenous predictor generated from the first-stage linear regression model (i.e. the number of physician visits that would have occurred if patients were not re-hospitalized and did not die) to predict the study outcome (rehospitalization) in a non-linear probit model, we use a two-stage residual inclusion estimation model. This method has been shown to produce consistent estimates in a broad class of nonlinear models. [5]

In the residual inclusion model, we first calculate from the first-stage linear regression estimates the first-stage 'residual' for each patient, where the 'residual' is equal to 'Actual visits' less 'Predicted Visits'. Then, in the second-stage probit model, 'Actual Visits' and the first-stage 'residual' are included as independent variables rather than 'predicted visits' used in the linear probability model. Similar to the linear probability model, we use block-bootstrapped standard errors with 10,000 simulations. To help interpret regression results, we compare the mean predicted probability of re-hospitalization in patients under actual visit frequencies with the mean predicted probability of re-hospitalization under a scenario where there is one additional visit to each patient.

The coefficient for physician visits from the probit model is -0.117 (95%CI -0.169—0.657), indicating a statistically significant inverse relationship between more frequent visits and re-hospitalization. Based on the regression results, under a scenario where patients are seen by their physician (or advanced practitioner) the number of times that actually occurred, the mean predicted probability of re-hospitalization is 37.9%. If patients are seen one additional time, the mean predicted probability of re-hospitalization decreases to 33.9%. This is consistent with a 3.98% reduction in the probability of re-hospitalization from one additional visit. This is similar in magnitude to the 3.5% reduction observed in our main analysis using a linear probability model.

Table S1: First-Stage Instrumental Variable Regression Results for For-Profit, Non-Medicaid, Metropolitan Cohort (main cohort)

	Change in Provider Visits/Month	LCI	UCI
One additional mean visit at facility	0.586	0.552	0.619
Demographic & socioeconomic characteristics:			
Male sex	0.043	0.005	0.081
Age (10 years)	0.027	0.010	0.043
White		(reference)	
Native American	0.182	-0.076	0.440
Black	0.079	0.036	0.121
Other race	0.125	-0.002	0.252
Hispanic ethnicity	0.014	-0.055	0.084
Alcohol use	-0.120	-0.263	0.023
Drug use	-0.025	-0.122	0.073
Smoking history	-0.010	-0.082	0.062
Co-morbidities:			
Cerebrovascular disease	0.043	0.002	0.083
Peptic ulcer disease	0.028	-0.015	0.072
Coronary artery disease	0.025	-0.016	0.066
Heart failure	0.009	-0.038	0.056
Pulmonary disease	0.035	-0.005	0.074
HIV	-0.020	-0.215	0.176
Cancer	0.027	-0.026	0.081
Dementia	-0.048	-0.103	0.008
Diabetes	0.022	-0.020	0.064
Liver disease	0.076	0.017	0.136
Paralysis	-0.001	-0.088	0.087
Peripheral vascular disease	0.030	-0.009	0.068
Rheumatic disease	-0.042	-0.126	0.043
Acuity of illness:			
First year of dialysis	-0.052	-0.107	0.003
Duration of hospitalization (days)	-0.005	-0.007	-0.004
Facility Characteristics			
Facility size (25 patient difference)	0.024	0.016	0.033

Table S2: Baseline Characteristics in For-Profit, Medicaid, Metropolitan Cohort

	Re-hospitalized		
	No (n=16,321)	Yes (n=11,598)	Standardized Difference
Demographic			
Males - (%)	59.0	56.2	5.7
Age - (years)	59.9	57.9	13.2
American Indian - (%)	0.9	0.9	0.1
Black - (%)	48.9	52.6	7.5
White - (%)	45.5	42.4	6.3
Other race - (%)	4.7	4.1	3.2
Hispanic ethnicity - (%)	22.0	19.2	6.9
Socioeconomic and co-morbidities			
Alcohol use - (%)	3.9	6.9	13.2
Drug use - (%)	8.4	16.3	24.0
Smokes - (%)	14.2	21.5	19.0
Cerebrovascular disease - (%)	40.4	46.0	11.2
Peptic ulcer disease - (%)	28.5	36.5	17.3
Coronary artery disease - (%)	34.1	42.3	16.9
Heart failure - (%)	78.1	85.3	18.7
Pulmonary disease - (%)	47.3	55.7	16.7
HIV positive - (%)	3.2	4.6	7.3
Cancer - (%)	9.7	11.8	6.8
Dementia - (%)	15.3	18.0	7.1
Diabetes - (%)	74.2	76.8	6.0
Liver disease - (%)	17.8	24.4	16.2
Paralysis - (%)	6.7	8.1	5.5
PVD - (%)	46.5	51.8	10.6
Rheumatic disease - (%)	6.2	6.9	2.9
Acuity of care and facility			
First year of hemodialysis - (%)	11.1	11.6	1.7
Duration of hosp. - (days)	9.0	10.4	11.4
Facility size - (# patients)	110.5	110.7	0.3

Table S3: Evaluation of Instrument in For-Profit, Medicaid, Metropolitan Cohort

	Physician Visits			Quartile of Facility Visits Instrumental Variable[1]				
Demographic	0-3 visits (n=6,519)	4+ visits (n=14,444)	Std. diff.	1st	2nd	3rd	4th	Std. diff. (1st vs. 4th)
Males - (%)	55.4	58.5	6.4	55.3	56.1	58.5	61.6	12.6
Age - (years)	58.7	59.6	6.3	59.9	59.1	58.7	58.5	9.2
American Indian - (%)	0.9	0.9	0.1	1.3	1.0	0.7	0.6	7.4
Black - (%)	50.6	49.9	1.4	41.4	53.3	53.3	53.6	24.7
White - (%)	43.8	44.7	1.8	49.5	40.9	42.3	44.1	10.8
Other race - (%)	4.7	4.5	0.6	7.8	4.7	3.7	1.6	29.2
Hispanic ethnicity - (%)	19.5	21.9	5.9	27.0	19.8	17.2	19.1	18.8
Socioeconomic and co-morbidities								
Alcohol use - (%)	6.9	4.1	12.3	5.2	5.3	5.2	4.9	1.0
Drug use - (%)	15.4	9.5	17.9	11.6	12.4	11.7	11.0	1.8
Smokes - (%)	19.8	15.0	12.7	14.9	17.8	18.7	17.5	7.2
Cerebrovascular disease - (%)	45.7	41.1	9.4	43.9	43.9	42.4	40.8	6.3
Peptic ulcer disease - (%)	36.0	29.2	14.4	31.5	32.5	31.9	31.2	0.6
Coronary artery disease - (%)	40.8	35.4	11.1	39.2	39.6	37.5	33.8	11.3
Heart failure - (%)	84.0	79.5	11.7	81.1	82.4	81.8	79.1	5.1
Pulmonary disease - (%)	54.4	48.7	11.5	51.0	51.4	51.2	49.6	2.9
HIV positive - (%)	4.3	3.6	3.5	3.7	4.6	3.6	3.2	2.6
Cancer - (%)	12.4	10.1	7.3	11.5	10.7	10.8	9.3	7.1
Dementia - (%)	19.7	15.4	11.3	16.4	16.9	16.5	15.9	1.3
Diabetes - (%)	75.1	75.0	0.5	76.6	75.7	74.7	74.1	5.9
Liver disease - (%)	24.0	18.9	12.3	22.0	21.0	20.3	18.8	7.8
Paralysis - (%)	8.3	6.7	6.0	6.9	7.5	7.7	7.1	0.5
PVD - (%)	51.3	47.6	7.5	49.0	50.0	48.0	47.8	2.4
Rheumatic disease - (%)	6.9	6.1	3.3	6.3	5.9	6.3	7.2	3.6
Acuity of care and facility								
First year of hemodialysis - (%)	13.0	10.5	7.9	12.3	11.6	11.3	10.2	6.7
Duration of hosp. - (days)	12.0	8.6	24.9	9.6	9.6	9.5	9.5	1.1
Facility size - (# patients)	107.3	112.8	9.9	111.4	109.7	108.4	112.8	2.6

[1] n = 5,240 for each quartile.

Table S4: Instrumental Variable Regression Results in For-Profit, Medicaid, Metropolitan Cohort

	Change in probability of re-hospitalization	LCI	UCI
Physician Visits (per 1 additional)	-0.049	-0.072	-0.027
Demographic & socioeconomic characteristics:			
Male sex	-0.008	-0.020	0.004
Age (10 years)	-0.019	-0.024	-0.015
White		(reference)	
American Indian	0.028	-0.032	0.089
Black	0.016	0.002	0.031
Other race	0.005	-0.024	0.034
Hispanic ethnicity	-0.018	-0.035	-0.001
Alcohol use	0.025	-0.005	0.054
Drug use	0.104	0.083	0.125
Smoking history	0.053	0.035	0.070
Co-morbidities:			
Cerebrovascular disease	0.023	0.010	0.036
Peptic ulcer disease	0.046	0.033	0.059
Coronary artery disease	0.046	0.033	0.059
Heart failure	0.066	0.050	0.081
Pulmonary disease	0.039	0.026	0.051
HIV	0.025	-0.007	0.057
Cancer	0.045	0.026	0.065
Dementia	0.036	0.019	0.053
Diabetes	0.046	0.031	0.061
Liver disease	0.042	0.026	0.057
Paralysis	0.014	-0.010	0.037
Peripheral vascular disease	0.032	0.020	0.044
Rheumatic disease	0.010	-0.014	0.035
Acuity of illness:			
First year of dialysis	0.012	-0.006	0.031
Duration of hospitalization (days)	0.002	0.001	0.002
Facility Characteristics			
Facility size (25 patient difference)	0.002	-0.001	0.004

Table S5: First-Stage Instrumental Variable Regression Results for For-Profit, Medicaid, Metropolitan Cohort

	Change in Provider Visits/Month	LCI	UCI
One additional mean visit at facility	0.461	0.428	0.494
Demographic & socioeconomic characteristics:			
Male sex	-0.048	-0.088	-0.008
Age (10 years)	0.039	0.024	0.053
White		(reference)	
Native American	0.096	-0.102	0.294
Black	0.028	-0.019	0.074
Other race	0.033	-0.060	0.127
Hispanic ethnicity	0.040	-0.014	0.094
Alcohol use	-0.158	-0.261	-0.055
Drug use	0.006	-0.068	0.080
Smoking history	-0.061	-0.119	-0.002
Co-morbidities:			
Cerebrovascular disease	-0.010	-0.051	0.032
Peptic ulcer disease	-0.039	-0.082	0.004
Coronary artery disease	-0.011	-0.052	0.031
Heart failure	-0.003	-0.051	0.045
Pulmonary disease	-0.015	-0.055	0.025
HIV	0.034	-0.077	0.145
Cancer	0.069	0.003	0.135
Dementia	-0.020	-0.076	0.037
Diabetes	0.066	0.020	0.113
Liver disease	0.010	-0.041	0.062
Paralysis	-0.054	-0.132	0.025
Peripheral vascular disease	0.018	-0.022	0.057
Rheumatic disease	-0.014	-0.094	0.065
Acuity of illness:			
First year of dialysis	-0.068	-0.128	-0.009
Duration of hospitalization (days)	-0.007	-0.008	-0.005
Facility Characteristics			
Facility size (25 patient difference)	0.017	0.009	0.026

Table S6: Baseline Characteristics in For-Profit, Non-Medicaid, Non-Metropolitan Cohort

	Re-hospitalized		
	No (n=3,739)	Yes (n=1,906)	Standardized Difference
Demographic			
Males - (%)	43.3	43.8	1.0
Age - (years)	68.7	67.8	7.1
American Indian - (%)	2.6	2.5	0.3
Black - (%)	22.5	23.3	1.8
White - (%)	74.5	73.8	1.6
Other race - (%)	0.4	0.4	0.1
Hispanic ethnicity - (%)	5.0	4.4	3.0
Socioeconomic and co-morbidities			
Alcohol use - (%)	1.4	2.1	5.4
Drug use - (%)	4.1	5.2	5.1
Smokes - (%)	8.5	13.3	15.4
Cerebrovascular disease - (%)	38.5	43.5	10.2
Peptic ulcer disease - (%)	24.7	30.8	13.7
Coronary artery disease - (%)	34.3	39.7	11.3
Heart failure - (%)	77.6	82.3	11.7
Pulmonary disease - (%)	49.7	54.8	10.2
HIV positive - (%)	0.2	0.3	1.4
Cancer - (%)	13.4	17.1	10.4
Dementia - (%)	14.0	15.6	4.6
Diabetes - (%)	70.4	70.7	0.7
Liver disease - (%)	9.3	12.5	10.5
Paralysis - (%)	4.8	4.9	0.8
PVD - (%)	46.6	52.5	11.9
Rheumatic disease - (%)	3.7	6.6	13.1
Acuity of care and facility			
First year of hemodialysis - (%)	14.5	15.1	1.7
Duration of hosp. - (days)	8.7	10.1	13.6
Facility size - (# patients)	62.4	63.3	2.7

Table S7: Evaluation of Instrument in For-Profit, Non-Medicaid, Non-Metropolitan Cohort

	Physician Visits			Quartile of Facility Visits Instrumental Variable[1]				
Demographic	0-3 visits (n=1,381)	4+ visits (n=2,768)	Std. diff.	1st	2nd	3rd	4th	Std. diff. (1st vs. 4th)
Males - (%)	43.7	42.8	1.9	43.6	42.7	45.5	42.3	2.6
Age - (years)	69.0	68.4	5.8	69.0	68.0	68.1	68.5	0.4
American Indian - (%)	3.5	2.3	7.6	3.6	2.3	1.8	2.5	6.6
Black - (%)	20.1	24.2	10.1	15.0	21.4	26.6	28.2	32.4
White - (%)	76.1	73.0	7.1	80.5	76.1	71.5	68.9	26.7
Other race - (%)	0.3	0.5	2.9	0.9	0.1	0.2	0.4	6.1
Hispanic ethnicity - (%)	5.1	4.4	3.6	7.2	3.8	4.2	4.0	14.1
Socioeconomic and co-morbidities								
Alcohol use - (%)	1.8	1.4	3.2	1.2	2.0	1.3	2.0	6.2
Drug use - (%)	4.5	4.0	2.2	4.0	4.5	4.5	4.9	4.5
Smokes - (%)	10.3	9.4	3.0	9.8	11.3	11.0	8.4	4.9
Cerebrovascular disease - (%)	42.9	38.2	9.5	38.5	41.7	41.6	38.9	1.0
Peptic ulcer disease - (%)	27.0	26.5	1.1	24.9	27.4	26.8	27.9	6.7
Coronary artery disease - (%)	36.2	35.7	1.1	35.6	38.8	33.9	36.1	1.0
Heart failure - (%)	78.8	79.2	1.0	77.6	82.6	79.7	77.0	1.4
Pulmonary disease - (%)	53.7	50.5	6.3	52.8	52.5	53.3	47.2	11.4
HIV positive - (%)	0.4	0.3	1.3	0.1	0.3	0.4	0.2	1.7
Cancer - (%)	14.6	13.5	2.9	15.4	14.2	14.1	14.8	1.5
Dementia - (%)	16.7	13.3	9.3	13.4	15.0	14.4	15.3	5.5
Diabetes - (%)	71.4	70.4	2.2	71.2	72.8	69.9	67.9	7.2
Liver disease - (%)	11.7	9.4	7.7	11.0	9.9	11.2	9.4	5.6
Paralysis - (%)	5.1	4.4	3.1	4.3	4.9	5.6	4.5	0.7
PVD - (%)	50.2	47.3	5.9	47.1	50.7	48.9	47.5	0.8
Rheumatic disease - (%)	5.5	3.9	7.4	5.0	4.7	4.5	4.5	2.3
Acuity of care and facility								
First year of hemodialysis - (%)	16.1	14.1	5.7	14.7	15.2	15.3	13.4	3.8
Duration of hosp. - (days)	10.2	8.4	22.5	8.9	9.1	9.3	9.3	0.6
Facility size - (# patients)	57.4	66.3	14.3	53.0	59.5	68.0	70.2	11.4

[1] n=1,037 per quartile.

Table S8: Instrumental Variable Regression Results in For-Profit, Non-Medicaid, Non-Metropolitan Cohort

	Change in probability of re-hospitalization	LCI	UCI
Physician Visits (per 1 additional)	-0.016	-0.042	0.009
Demographic & socioeconomic characteristics:			
Male sex	0.013	-0.012	0.039
Age (10 years)	-0.013	-0.024	-0.001
White		(reference)	
American Indian	0.000	-0.079	0.079
Black	0.008	-0.024	0.039
Other race	0.020	-0.174	0.215
Hispanic ethnicity	-0.045	-0.103	0.013
Alcohol use	0.028	-0.077	0.133
Drug use	0.024	-0.038	0.086
Smoking history	0.093	0.048	0.138
Co-morbidities:			
Cerebrovascular disease	0.028	0.001	0.055
Peptic ulcer disease	0.045	0.016	0.075
Coronary artery disease	0.028	0.000	0.055
Heart failure	0.035	0.003	0.068
Pulmonary disease	0.019	-0.007	0.046
HIV	0.113	-0.173	0.399
Cancer	0.068	0.032	0.105
Dementia	0.018	-0.019	0.055
Diabetes	-0.001	-0.029	0.027
Liver disease	0.050	0.007	0.092
Paralysis	-0.022	-0.082	0.037
Peripheral vascular disease	0.037	0.010	0.063
Rheumatic disease	0.139	0.077	0.202
Acuity of illness:			
First year of dialysis	0.007	-0.029	0.042
Duration of hospitalization (days)	0.003	0.001	0.004
Facility Characteristics			
Facility size (25 patient difference)	0.007	-0.004	0.018

Table S9: First-Stage Instrumental Variable Regression Results for For-Profit, Non-Medicaid, Non-Metropolitan Cohort

	Change in Provider Visits/Month	LCI	UCI
One additional mean visit at facility	0.832	0.766	0.898
Demographic & socioeconomic characteristics:			
Male sex	-0.030	-0.110	0.050
Age (10 years)	0.012	-0.025	0.049
White		(reference)	
Native American	-0.022	-0.272	0.229
Black	-0.002	-0.103	0.098
Other race	0.489	-0.105	1.084
Hispanic ethnicity	-0.109	-0.291	0.072
Alcohol use	-0.029	-0.378	0.320
Drug use	-0.086	-0.286	0.113
Smoking history	0.024	-0.122	0.170
Co-morbidities:			
Cerebrovascular disease	-0.013	-0.099	0.073
Peptic ulcer disease	0.073	-0.019	0.166
Coronary artery disease	0.026	-0.061	0.112
Heart failure	0.157	0.058	0.257
Pulmonary disease	0.059	-0.024	0.142
HIV	0.413	-0.455	1.281
Cancer	0.099	-0.019	0.217
Dementia	-0.075	-0.196	0.045
Diabetes	0.009	-0.081	0.099
Liver disease	0.098	-0.042	0.239
Paralysis	0.043	-0.151	0.237
Peripheral vascular disease	0.013	-0.069	0.094
Rheumatic disease	-0.237	-0.441	-0.033
Acuity of illness:			
First year of dialysis	-0.114	-0.225	-0.003
Duration of hospitalization (days)	-0.011	-0.015	-0.007
Facility Characteristics			
Facility size (25 patient difference)	0.020	-0.014	0.054

Table S10: Baseline Characteristics in For-Profit, Medicaid, Non-Metropolitan Cohort

	Re-hospitalized		
	No (n=4,288)	Yes (n=2,422)	Standardized Difference
Demographic			
Males - (%)	61.7	59.5	4.5
Age - (years)	60.0	58.9	7.4
American Indian - (%)	5.0	4.6	1.8
Black - (%)	48.0	47.4	1.2
White - (%)	46.2	47.4	2.4
Other race - (%)	0.8	0.6	2.9
Hispanic ethnicity - (%)	10.2	8.6	5.3
Socioeconomic and co-morbidities			
Alcohol use - (%)	3.3	5.0	8.6
Drug use - (%)	6.4	10.3	14.1
Smokes - (%)	15.5	20.3	12.5
Cerebrovascular disease - (%)	36.2	42.9	13.9
Peptic ulcer disease - (%)	26.5	33.4	15.0
Coronary artery disease - (%)	30.7	36.6	12.5
Heart failure - (%)	77.5	83.9	16.1
Pulmonary disease - (%)	48.6	58.4	19.6
HIV positive - (%)	1.2	1.9	5.7
Cancer - (%)	8.9	9.9	3.5
Dementia - (%)	13.7	17.4	10.3
Diabetes - (%)	74.6	77.2	6.2
Liver disease - (%)	11.4	15.4	11.8
Paralysis - (%)	6.3	7.2	3.9
PVD - (%)	45.0	51.5	13.1
Rheumatic disease - (%)	5.0	5.4	1.6
Acuity of care and facility			
First year of hemodialysis - (%)	12.3	13.3	3.0
Duration of hosp. - (days)	8.6	10.0	12.3
Facility size - (# patients)	67.8	68.1	0.9

Table S11: Evaluation of Instrument in For-Profit, Medicaid, Non-Metropolitan Cohort

	Physician Visits			Quartile of Facility Visits Instrumental Variable[1]				
Demographic	0-3 visits (n=1,553)	4+ visits (n=3,337)	Std. diff.	1st	2nd	3rd	4th	Std. diff. (1st vs. 4th)
Males - (%)	60.8	61.3	1.1	57.7	60.6	62.8	62.5	9.9
Age - (years)	59.5	59.5	6.3	59.5	59.4	59.9	59.5	9.2
American Indian - (%)	7.4	3.3	18.3	9.5	4.3	2.7	2.8	28.2
Black - (%)	41.7	51.7	20.2	31.4	46.2	55.9	57.7	55.0
White - (%)	50.0	44.3	11.5	57.6	48.9	40.9	39.1	37.7
Other race - (%)	0.9	0.7	2.0	1.5	0.5	0.5	0.4	11.8
Hispanic ethnicity - (%)	9.8	9.4	1.4	13.0	8.9	6.7	10.0	9.2
Socioeconomic and co-morbidities								
Alcohol use - (%)	4.8	3.5	6.5	3.9	4.8	4.3	2.7	6.3
Drug use - (%)	9.5	6.8	10.0	7.9	8.3	8.8	6.2	6.5
Smokes - (%)	19.7	15.0	12.4	18.9	18.1	16.9	15.2	9.9
Cerebrovascular disease - (%)	42.0	36.2	11.9	37.7	39.7	39.9	37.2	1.0
Peptic ulcer disease - (%)	32.6	27.3	11.6	28.9	28.4	30.6	28.3	1.3
Coronary artery disease - (%)	34.2	32.4	3.9	34.9	33.5	32.2	30.8	8.7
Heart failure - (%)	80.7	78.8	4.7	79.4	79.8	81.1	79.1	0.7
Pulmonary disease - (%)	54.3	50.5	7.8	55.0	53.0	51.1	49.5	11.2
HIV positive - (%)	1.8	1.3	3.7	0.7	2.0	1.5	1.4	7.0
Cancer - (%)	11.7	8.1	12.1	9.0	9.6	9.5	8.9	0.3
Dementia - (%)	18.2	13.9	11.7	14.0	14.9	17.9	13.4	2.0
Diabetes - (%)	74.5	74.8	0.8	78.2	74.5	76.1	73.3	11.4
Liver disease - (%)	15.1	12.2	8.4	13.1	14.2	13.2	11.0	6.3
Paralysis - (%)	8.8	5.3	13.6	7.3	6.8	5.7	6.6	2.5
PVD - (%)	46.9	46.5	0.7	48.1	48.3	46.8	46.2	3.8
Rheumatic disease - (%)	5.9	5.3	2.6	4.9	5.9	4.5	5.3	1.7
Acuity of care and facility								
First year of hemodialysis - (%)	13.5	11.7	5.3	14.0	13.3	13.1	10.1	12.0
Duration of hosp. - (days)	11.5	8.1	24.9	9.5	8.9	9.3	8.7	1.1
Facility size - (# patients)	61.4	72.3	9.9	55.2	63.3	73.5	79.6	2.6

[1] n=1,222 per quartile.

Table S12: Instrumental Variable Regression Results in For-Profit, Medicaid, Non-Metropolitan Cohort

	Change in probability of re-hospitalization	LCI	UCI
Physician Visits (per 1 additional)	-0.005	-0.030	0.020
Demographic & socioeconomic characteristics:			
Male sex	-0.006	-0.030	0.019
Age (10 years)	-0.018	-0.027	-0.009
White	(reference)		
American Indian	-0.008	-0.067	0.052
Black	-0.008	-0.034	0.018
Other race	-0.074	-0.211	0.062
Hispanic ethnicity	-0.040	-0.082	0.001
Alcohol use	0.026	-0.038	0.090
Drug use	0.055	0.006	0.103
Smoking history	0.032	-0.002	0.066
Co-morbidities:			
Cerebrovascular disease	0.033	0.007	0.059
Peptic ulcer disease	0.047	0.021	0.074
Coronary artery disease	0.022	-0.004	0.048
Heart failure	0.044	0.014	0.074
Pulmonary disease	0.061	0.036	0.086
HIV	0.095	-0.013	0.202
Cancer	0.021	-0.019	0.061
Dementia	0.053	0.018	0.088
Diabetes	0.022	-0.007	0.052
Liver disease	0.039	0.002	0.077
Paralysis	0.010	-0.039	0.059
Peripheral vascular disease	0.042	0.017	0.067
Rheumatic disease	0.004	-0.052	0.059
Acuity of illness:			
First year of dialysis	0.021	-0.014	0.056
Duration of hospitalization (days)	0.002	0.001	0.003
Facility Characteristics			
Facility size (25 patient difference)	0.002	-0.008	0.012

Table S13: First-Stage Instrumental Variable Regression Results for For-Profit, Medicaid, Non-Metropolitan Cohort

	Change in Provider Visits/Month	LCI	UCI
One additional mean visit at facility	0.833	0.770	0.896
Demographic & socioeconomic characteristics:			
Male sex	-0.054	-0.127	0.019
Age (10 years)	0.003	-0.023	0.029
White		(reference)	
Native American	-0.164	-0.334	0.005
Black	-0.017	-0.095	0.061
Other race	0.428	0.024	0.832
Hispanic ethnicity	-0.018	-0.142	0.106
Alcohol use	0.097	-0.103	0.297
Drug use	-0.022	-0.170	0.127
Smoking history	-0.122	-0.223	-0.021
Co-morbidities:			
Cerebrovascular disease	0.042	-0.036	0.119
Peptic ulcer disease	-0.066	-0.145	0.014
Coronary artery disease	-0.006	-0.084	0.072
Heart failure	-0.003	-0.090	0.085
Pulmonary disease	0.035	-0.039	0.108
HIV	0.118	-0.215	0.452
Cancer	-0.149	-0.272	-0.026
Dementia	0.054	-0.054	0.161
Diabetes	0.062	-0.024	0.147
Liver disease	0.016	-0.097	0.128
Paralysis	-0.117	-0.265	0.031
Peripheral vascular disease	0.040	-0.032	0.113
Rheumatic disease	0.004	-0.156	0.164
Acuity of illness:			
First year of dialysis	-0.026	-0.130	0.078
Duration of hospitalization (days)	-0.004	-0.007	0.000
Facility Characteristics			
Facility size (25 patient difference)	0.042	0.013	0.071

Table S14: Baseline Characteristics in Nonprofit Cohort

	Re-hospitalized		
	No (n=12,270)	Yes (n=7,957)	Standardized Difference
Demographic			
Males - (%)	49.5	49.2	0.8
Age - (years)	64.1	61.9	14.4
American Indian - (%)	2.0	1.6	3.2
Black - (%)	38.0	44.1	12.5
White - (%)	56.3	50.6	11.3
Other race - (%)	3.7	3.6	0.3
Hispanic ethnicity - (%)	9.2	9.3	0.1
Socioeconomic and co-morbidities			
Alcohol use - (%)	3.5	5.4	9.4
Drug use - (%)	6.5	11.8	18.3
Smokes - (%)	11.0	14.4	10.1
Cerebrovascular disease - (%)	36.6	43.3	13.6
Peptic ulcer disease - (%)	26.2	34.6	18.4
Coronary artery disease - (%)	34.1	42.3	17.0
Heart failure - (%)	75.3	82.3	17.1
Pulmonary disease - (%)	45.5	53.4	15.8
HIV positive - (%)	2.5	3.3	5.2
Cancer - (%)	12.9	14.7	5.1
Dementia - (%)	13.8	16.1	6.3
Diabetes - (%)	68.8	72.9	9.1
Liver disease - (%)	20.1	25.5	12.8
Paralysis - (%)	5.2	7.1	8.0
PVD - (%)	49.0	53.6	9.3
Rheumatic disease - (%)	5.0	6.1	4.8
Acuity of care and facility			
First year of hemodialysis - (%)	10.5	11.1	1.9
Duration of hosp. - (days)	9.0	10.6	13.2
Facility size - (# patients)	99.0	98.5	0.6

Table S15: Evaluation of Instrument in Nonprofit Cohort

	Physician Visits			Quartile of Facility Visits Instrumental Variable[1]				
Demographic	0-3 visits (n=4,735)	4+ visits (n=10,698)	Std. diff.	1st	2nd	3rd	4th	Std. diff. (1st vs. 4th)
Males - (%)	48.5	49.8	2.6	48.4	49.1	48.3	51.8	6.8
Age - (years)	63.2	63.6	1.7	62.6	63.5	63.4	63.5	9.2
American Indian - (%)	2.0	1.6	3.2	2.3	1.5	1.4	2.1	1.7
Black - (%)	39.4	40.7	2.7	38.4	44.7	40.5	38.1	0.7
White - (%)	54.3	54.1	0.2	51.9	49.7	56.0	58.7	13.6
Other race - (%)	4.3	3.5	4.0	7.3	4.1	2.1	1.2	31.1
Hispanic ethnicity - (%)	9.0	9.4	1.4	12.8	11.5	7.6	5.0	27.4
Socioeconomic and co-morbidities								
Alcohol use - (%)	5.2	3.5	8.3	4.8	4.3	4.1	3.6	5.8
Drug use - (%)	11.3	7.0	15.0	9.7	9.0	8.4	7.2	9.3
Smokes - (%)	12.9	11.5	4.2	12.8	12.5	11.6	12.6	0.5
Cerebrovascular disease - (%)	41.4	37.9	7.1	38.2	41.4	39.4	38.1	0.1
Peptic ulcer disease - (%)	31.2	28.6	5.7	30.1	30.9	28.3	28.9	2.8
Coronary artery disease - (%)	39.1	37.0	4.3	38.9	39.9	36.9	33.5	11.2
Heart failure - (%)	80.5	76.9	8.9	77.6	78.0	79.6	77.0	1.4
Pulmonary disease - (%)	50.9	46.8	8.1	47.1	48.1	50.4	48.9	3.6
HIV positive - (%)	3.3	2.6	4.4	2.8	3.5	2.9	1.9	5.6
Cancer - (%)	15.2	13.0	6.3	13.5	14.0	14.2	12.8	2.2
Dementia - (%)	16.6	14.0	7.3	14.3	15.8	15.3	13.6	2.0
Diabetes - (%)	70.5	70.2	0.6	69.7	70.4	70.4	71.2	3.3
Liver disease - (%)	22.9	22.1	1.9	20.2	23.8	22.6	22.4	5.3
Paralysis - (%)	6.9	5.6	5.4	6.2	6.1	6.4	5.0	5.4
PVD - (%)	49.9	50.9	2.0	49.0	51.0	53.0	50.2	2.4
Rheumatic disease - (%)	5.4	5.2	0.6	5.5	5.1	6.2	4.9	2.7
Acuity of care and facility								
First year of hemodialysis - (%)	12.1	10.0	6.7	10.3	11.4	10.5	10.6	1.1
Duration of hosp. - (days)	12.0	8.8	2.9	9.4	9.5	10.1	9.5	1.1
Facility size - (# patients)	99.9	98.6	0.5	108.4	93.6	101.0	92.2	2.6

[1] n=3,858 per quartile.

Table S16: Instrumental Variable Regression Results in Nonprofit Cohort

	Change in probability of re-hospitalization	LCI	UCI
Physician Visits (per 1 additional)	-0.036	-0.055	-0.017
Demographic & socioeconomic characteristics:			
Male sex	0.000	-0.014	0.014
Age (10 years)	-0.021	-0.026	-0.015
White	(reference)		
American Indian	-0.012	-0.061	0.038
Black	0.037	0.021	0.053
Other race	0.013	-0.024	0.051
Hispanic ethnicity	0.002	-0.023	0.026
Alcohol use	0.019	-0.017	0.056
Drug use	0.090	0.062	0.117
Smoking history	0.012	-0.010	0.035
Co-morbidities:			
Cerebrovascular disease	0.035	0.020	0.050
Peptic ulcer disease	0.061	0.045	0.076
Coronary artery disease	0.044	0.029	0.059
Heart failure	0.055	0.038	0.072
Pulmonary disease	0.046	0.032	0.061
HIV	0.008	-0.036	0.051
Cancer	0.036	0.016	0.056
Dementia	0.021	0.001	0.041
Diabetes	0.040	0.025	0.056
Liver disease	0.036	0.018	0.053
Paralysis	0.040	0.010	0.070
Peripheral vascular disease	0.025	0.011	0.039
Rheumatic disease	0.031	0.000	0.063
Acuity of illness:			
First year of dialysis	0.012	-0.010	0.034
Duration of hospitalization (days)	0.002	0.001	0.003
Facility Characteristics			
Facility size (25 patient difference)	-0.002	-0.005	0.000

Table S17: First-Stage Instrumental Variable Regression Results for For Nonprofit Cohort

	Change in Provider Visits/Month	LCI	UCI
One additional mean visit at facility	0.663	0.622	0.703
Demographic & socioeconomic characteristics:			
Male sex	-0.005	-0.050	0.040
Age (10 years)	0.021	0.004	0.037
White		(reference)	
Native American	-0.057	-0.215	0.102
Black	0.039	-0.011	0.090
Other race	0.013	-0.106	0.132
Hispanic ethnicity	0.127	0.048	0.207
Alcohol use	-0.143	-0.270	-0.016
Drug use	-0.059	-0.155	0.037
Smoking history	0.009	-0.066	0.084
Co-morbidities:			
Cerebrovascular disease	0.053	0.003	0.102
Peptic ulcer disease	0.046	-0.005	0.097
Coronary artery disease	0.018	-0.031	0.066
Heart failure	0.023	-0.032	0.077
Pulmonary disease	0.004	-0.042	0.050
HIV	-0.006	-0.153	0.142
Cancer	-0.019	-0.086	0.049
Dementia	-0.005	-0.073	0.063
Diabetes	0.061	0.010	0.111
Liver disease	0.081	0.024	0.138
Paralysis	-0.007	-0.111	0.098
Peripheral vascular disease	0.051	0.005	0.098
Rheumatic disease	0.090	-0.014	0.195
Acuity of illness:			
First year of dialysis	-0.068	-0.139	0.004
Duration of hospitalization (days)	-0.006	-0.008	-0.004
Facility Characteristics			
Facility size (25 patient difference)	-0.004	-0.012	0.003

Table S18: Regression Results for Cost Analysis

	Coef.	LCI	UCI
Re-hospitalized	1.22	1.20	1.23
Demographic & socioeconomic characteristics:			
Male sex	0.00	0.00	0.00
Age (1 year)	-0.92	-1.47	-0.37
White		(reference)	
American Indian	0.009	-0.006	0.023
Black	0.073	0.035	0.111
Other race	-0.028	-0.049	-0.007
Hispanic ethnicity	0.014	0.000	0.029
Alcohol use	-0.044	-0.069	-0.019
Drug use	-0.055	-0.076	-0.035
Smoking history	-0.041	-0.060	-0.021
Co-morbidities:			
Cerebrovascular disease	0.000	-0.014	0.015
Peptic ulcer disease	-0.016	-0.030	-0.002
Coronary artery disease	0.017	0.000	0.034
Heart failure	-0.004	-0.018	0.009
Pulmonary disease	0.126	0.082	0.169
HIV	0.031	0.012	0.050
Cancer	0.046	0.027	0.064
Dementia	0.038	0.023	0.053
Diabetes	0.020	0.003	0.038
Liver disease	0.029	0.002	0.056
Paralysis	0.067	0.054	0.081
Peripheral vascular disease	0.032	0.004	0.060
Rheumatic disease	-0.044	-0.080	-0.009
Acuity of illness:			
First year of dialysis	0.006	0.006	0.007
Duration of hospitalization (days)	7.898	7.857	7.938
Facility Characteristics			
Facility size (one patient)	0.001	-0.001	0.004

Note: The model also adjusted for geographic location (represented by RUCA code). Based on this estimate, costs in the month following hospital discharge increase by $e^{\wedge 1.22} = 3.39$ times the cost without re-hospitalization.

Table S19. Sensitivity Analyses – Estimated Probability of Re-hospitalization under Alternative Visit Frequency Assumptions:

	Change in probability of re-hospitalization from 1 more visit	LCI	UCI
Assumption:			
Claims for 4 or more visits = 6 visits	-0.019	-0.030	-0.009
Claims for 2-3 visits equals 3 visits	-0.038	-0.059	-0.017
Claims for 2-3 visits equals 2 visits	-0.032	-0.049	-0.014

Table S20: Sensitivity Analyses – Probability of Re-hospitalization using Mean Visit Frequency by Health Service Area as an Instrumental Variable

	Change in probability of re-hospitalization from 1 more visit	LCI	UCI	p-value
For Profit				
Metropolitan				
No Medicaid (main cohort)	-0.038	-0.060	-0.016	<0.001
Medicaid	-0.059	-0.089	-0.030	<0.001
Non metropolitan				
No Medicaid	-0.016	-0.042	0.011	0.25
Medicaid	-0.011	-0.038	0.015	0.40
Non Profit	-0.021	0.046	0.000	0.05

Note: UCI and LCI are 95% confidence intervals.
Health Service Area (HSA) was assigned to patients based upon the HSA from the zip code at the facility where they dialyzed. In these analyses we used mean visit frequency to prevalent hemodialysis patients by HSA as an instrumental variable to predict physician visits in the month following hospital discharge. Otherwise, the same methods were in these analyses as were used in the primary analyses (described in "Methods" in the manuscript).

Table S21: Sensitivity Analyses – Change in the probability of re-hospitalization associated with one more visit per month using visits per available day as the exposure.

	Change in probability of re-hospitalization	LCI	UCI
For-profit			
Metropolitan			
Non-medicaid (primary cohort)	-0.018	-0.036	-0.001
Medicaid	-0.040	0.000	-0.060
Non-metropolitan			
Non-medicaid	-0.012	-0.035	0.010
Medicaid	-0.004	-0.026	0.018
Nonprofit	-0.030	-0.048	-0.011

Note: UCI and LCI are 95% confidence intervals. Estimates for one more visit per month are obtained by multiplying regression results (which correspond to one additional visit per day) by 0.032854, which is 1/(average number of days per month).

Table S22: Sensitivity Analyses – Controlling for clustering within dialysis facilities in the primary study cohort

	Change in probability of re-hospitalization	LCI	UCI
Physician Visits (per 1 additional)	-0.035	-0.054	-0.015
Demographic & socioeconomic characteristics:			
Male sex	0.020	0.008	0.033
Age (10 years)	-0.015	-0.021	-0.010
White		(reference)	
Native American	-0.058	-0.136	0.020
Black	0.011	-0.003	0.025
Other race	-0.024	-0.063	0.016
Hispanic ethnicity	-0.014	-0.037	0.008
Alcohol use	0.018	-0.024	0.059
Drug use	0.061	0.031	0.092
Smoking history	0.049	0.026	0.072
Co-morbidities:			
Cerebrovascular disease	0.022	0.009	0.035
Peptic ulcer disease	0.041	0.027	0.055
Coronary artery disease	0.063	0.049	0.076
Heart failure	0.067	0.052	0.082
Pulmonary disease	0.032	0.019	0.045
HIV	0.029	-0.035	0.093
Cancer	0.029	0.013	0.045
Dementia	0.029	0.011	0.046
Diabetes	0.030	0.016	0.043
Liver disease	0.045	0.026	0.064
Paralysis	0.001	-0.026	0.028
Peripheral vascular disease	0.036	0.024	0.048
Rheumatic disease	-0.027	-0.053	0.000
Acuity of illness:			
First year of dialysis	0.003	-0.014	0.020
Duration of hospitalization (1 day)	0.002	0.001	0.002
Facility Characteristics			
Facility size (25 patient difference)	-0.003	-0.005	0.000

Table S23: Comparison of Characteristics by Age Group

	Over 50 (n=73542)	Under 50 (n=16,326)	Standardized Difference
Demographic			
Males - (%)	46.6	51.1	9.1
Age - (years)	68.6	40.2	
American Indian - (%)	1.3	1.6	2.1
Black - (%)	37.6	56.6	38.8
White - (%)	57.9	39.8	36.9
Other race - (%)	3.2	2.1	6.9
Hispanic ethnicity - (%)	12.2	12.4	0.4
Socioeconomic and co-morbidities			
Alcohol use - (%)	2.8	7.9	22.7
Drug use - (%)	5.2	21.3	49.2
Smokes - (%)	9.9	27.5	46.6
Cerebrovascular disease - (%)	44.2	28.2	33.7
Peptic ulcer disease - (%)	29.2	30.6	3.0
Coronary artery disease - (%)	38.5	29.4	19.4
Heart failure - (%)	81.5	72.3	22.0
Pulmonary disease - (%)	51.5	43.0	17.1
HIV positive - (%)	1.1	7.8	32.6
Cancer - (%)	14.3	7.0	23.9
Dementia - (%)	17.7	6.1	36.5
Diabetes - (%)	75.0	58.6	35.4
Liver disease - (%)	15.6	26.1	26.0
Paralysis - (%)	6.4	5.6	3.3
PVD - (%)	52.6	35.1	35.9
Rheumatic disease - (%)	4.6	10.3	22.0
Acuity of care and facility			
First year of hemodialysis - (%)	12.6	9.2	10.9
Duration of hosp. - (days)	9.7	9.3	3.0
Facility size - (# patients)	97.0	97.8	1.3

Table S24: Reduction in Absolute Probability of Re-hospitalization from an Additional Physician Visit Under Alternative Scenarios about Relative Efficacy

	Percent of visits performed by physicians[2]		
	50%	60%	70%
Physicians are 20% more effective than APs[1]	3.82	3.75	3.68
Physicians are 40% more effective than APs[1]	4.08	3.95	3.83

[1] Effectiveness refers to effectiveness in preventing re-hospitalization

[2] the remaining visits are assumed to be performed by advanced practitioners

AP - Advanced Practitioner.

Table S25: Expanded Model – Primary Study Cohort

	Change in probability of re-hospitalization	LCI	UCI
Physician Visits (per 1 additional)	-0.034	-0.052	-0.015
Demographic & socioeconomic characteristics:			
Male sex	0.019	0.007	0.031
Age (10 years)	-0.018	-0.024	-0.013
White		(reference)	
Native American	-0.052	-0.135	0.031
Black	0.014	0.000	0.028
Other race	-0.019	-0.059	0.021
Hispanic ethnicity	-0.010	-0.032	0.013
Alcohol use	0.016	-0.026	0.058
Drug use	0.058	0.028	0.088
Smoking history	0.052	0.030	0.074
Co-morbidities:			
Cerebrovascular disease	0.018	0.005	0.031
Peptic ulcer disease	0.039	0.025	0.054
Coronary artery disease	0.064	0.051	0.077
Heart failure	0.067	0.052	0.081
Pulmonary disease	0.034	0.021	0.046
HIV	0.027	-0.035	0.090
Cancer	0.029	0.013	0.045
Dementia	0.021	0.004	0.039
Diabetes	0.024	0.011	0.038
Liver disease	0.045	0.027	0.064
Paralysis	-0.005	-0.032	0.021
Peripheral vascular disease	0.031	0.019	0.043
Rheumatic disease	-0.028	-0.054	-0.001
Acuity of illness:			
First year of dialysis	0.002	-0.016	0.019
Duration of hospitalization (days)	0.001	0.001	0.002
Facility Characteristics			
Facility size (25 patient difference)	-0.002	-0.006	0.001
Hospital based facility	0.052	-0.011	0.116

Table S25 (Continued)

	Change in probability of re-hospitalization	LCI	UCI
Discharge characteristics:			
To Skilled Nursing Facility	0.015	-0.008	0.038
To Home	-0.045	-0.068	-0.023
To Home Health	-0.012	-0.036	0.012
Reason for Index Hospitalization			
Circulatory disorder	0.001	-0.014	0.016
Digestive disorder	0.004	-0.019	0.026
Endocronologic disorder	0.027	0.003	0.051
Infectious disorder	0.013	-0.011	0.038
Respiratory disorder	-0.012	-0.032	0.008

Note: Cause of index hospitalization is determined by the primary ICD 9 diagnosis code. Disease categories were defined using methods reported from the USRDS Atlas[4] in the following way: Circulatory diseases: ICD 9 390-459; Digestive diseases: ICD 9 520-579; Endocrine diseases: ICD 9 240 – 279; Respiratory diseases: ICD 9 460 – 519; Infectious diseases: ICD 9 001 – 139.

Table S26: Linear Regression Results without Using Instrumental Variable

	Change in probability of re-hospitalization	LCI	UCI
Physician Visits (per 1 additional)	-0.090	-0.092	-0.088
Demographic & socioeconomic characteristics:			
Male sex	0.008	0.002	0.015
Age (10 years)	-0.019	-0.021	-0.017
White		(reference)	
Native American	-0.025	-0.052	0.001
Black	0.026	0.019	0.033
Other race	0.001	-0.017	0.019
Hispanic ethnicity	-0.004	-0.014	0.006
Alcohol use	0.019	0.002	0.036
Drug use	0.071	0.059	0.084
Smoking history	0.039	0.029	0.048
Co-morbidities:			
Cerebrovascular disease	0.024	0.017	0.030
Peptic ulcer disease	0.044	0.038	0.051
Coronary artery disease	0.046	0.039	0.052
Heart failure	0.054	0.046	0.062
Pulmonary disease	0.035	0.028	0.041
HIV	0.025	0.004	0.046
Cancer	0.027	0.018	0.036
Dementia	0.019	0.010	0.028
Diabetes	0.031	0.024	0.038
Liver disease	0.038	0.030	0.047
Paralysis	0.010	-0.003	0.023
Peripheral vascular disease	0.032	0.026	0.038
Rheumatic disease	0.006	-0.007	0.020
Acuity of illness:			
First year of dialysis	0.002	-0.007	0.011
Duration of hospitalization (days)	0.001	0.001	0.001
Facility Characteristics			
Facility size (25 patient difference)	0.002	0.000	0.003

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