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Vascular Imaging for Hemodialysis Vascular Access Planning

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Abstract

Introduction—Central venous catheters (CVC) increase risks associated with hemodialysis (HD), but may be necessary until an arteriovenous fistula (AVF) or graft (AVG) is achieved. The impact of vascular imaging on achievement of working AVF and AVG has not been firmly established.

Methods—Retrospective cohort of patients initiating HD with CVC in 2010–11, classified by exposure to venography or Doppler vein mapping, and followed through December 31, 2012. Standard and time-dependent Cox models were used to determine hazard risk (HRs) of death, working AVF, and any AVF or AVG. Logistic regression was used to assess the association of pre-operative imaging with successful AVF or AVG among 18,883 individuals who had surgery. Models were adjusted for clinical and demographic factors.

Findings—Among 33,918 patients followed for a median of 404 days, 39.1% had imaging and 55.7% had surgery. Working AVF or AVG were achieved in 40.6%; 46.2% died. Compared to non-imaged patients, imaged patients were more likely to achieve working AVF [HR=1.45 (95% confidence interval (CI) 1.36, 1.55), $P<0.001$], any AVF or AVG [HR=1.63 (1.58, 1.69), $P>0.001$], and less likely to die [HR=0.88 (0.83–0.94), $P<0.001$]. Among patients who had surgery, the odds ratio for any successful AVF or AVG was 1.09 (1.02–1.16, $P=0.008$).

Discussion—Fewer than half of patients who initiated HD with a CVC had vascular imaging. Imaged patients were more likely to have vascular surgery and had increased achievement of working AV fistulas and grafts. Outcomes of surgery were similar in patients who did and did not have imaging.

Introduction

Achievement of a reliable arteriovenous fistula (AVF) is a crucial determinant of health and survival for patients receiving hemodialysis (HD).¹ Transition from a central venous catheter (CVC) to an AVF or an arteriovenous graft (AVG) reduces the risks of infection, hospitalization, and mortality.^{2–7} Unfortunately, even patients with seemingly adequate

blood vessels and timely referral to an experienced surgeon may experience primary thrombosis or failure of their fistulas to mature.⁸⁻¹⁰

Contrast venography and Doppler ultrasound can evaluate blood vessels that cannot be appreciated on visual inspection, but these procedures are costly, time-consuming, and require expertise. The impact of vascular imaging on AV fistulas has been studied in small, single-center studies; there are very few randomized trials. A recent systematic review did not support routine use of preoperative ultrasound vessel mapping.¹¹ Most studies have shown increases in the numbers of vascular surgeries and greater short-term fistula patency among imaged patients, but have not examined maturation or long term outcomes.¹²⁻¹⁷ Some studies suggest that imaging promotes performance of surgery on inadequate vessels, increasing early fistula failure.¹⁶⁻¹⁷ Currently, the performance of imaging procedures is determined by individual provider preference.¹¹

This study was performed to ascertain the utilization of imaging in patients who initiated HD with CVC as their sole vascular access in a large national sample. We also sought to assess the associations of imaging with the performance of vascular access surgery and with achievement of working AVF and AVG.

Materials and Methods

Patient Population

United States Renal Data System (USRDS) Standard Analytical Files were linked with Medicare claims for the years 2008-12. The study population consisted of patients who initiated HD for the first time between April 1, 2010 and December 31, 2011, in whom CVC was the sole vascular access present at initiation of outpatient HD treatment. We restricted our analysis to Medicare beneficiaries > 20 years of age who had Medicare coverage two years prior to the date of first HD according to the USRDS Payer History file. We imposed an additional requirement for at least two existing pre-dialysis Medicare claims, at least six months apart, with one or more of these at least 365 days before the first HD. These restrictions defined a population in which we were able to determine the use of imaging prior to HD initiation, and derive accurate information on comorbid conditions from claims data. The vascular access at HD initiation was obtained from the USRDS Medical Evidence form (CMS Form 2728) and verified by examination of HD treatment claims for the first 6 weeks. Patients were excluded for inconsistent vascular access data if HD claims showed AVF use within 6 weeks or AVG use within 3 weeks after HD initiation, to eliminate patients who likely had maturing AVF or AVG at the time of HD initiation.

Exposures to Imaging and Surgery

Vascular imaging was determined from Medicare claims for the two years prior to HD initiation and during the follow-up time thereafter. Imaging studies performed after conversion to a first working AVF or AVG were not included. We ascertained imaging with Common Procedural Terminology (CPT) codes for venography of the upper extremity or central veins (CPT 36005, 75820, 75822, and 75827) and for Doppler vein mapping for dialysis access planning (CPT G0365). Imaging studies of the lower extremities were not

included. We counted one imaging event per day on any individual patient, regardless of the number of codes available.

Performance of dialysis vascular access surgery was ascertained from claims for AVF (CPT 36818, 36819, 36820, and 36821) and AVG (CPT 36825 and 36830) creation. Surgical codes occurring after achievement of the first working vascular access were not included.

Primary Outcomes

The primary outcomes were time to first working AVF, time to first working AVF or AVG, and time to death. Vascular access type was determined from the modifier codes on individual HD treatment claims. Conversion to AVF or AVG was defined by the first day of the first 30-day period in which all available vascular access modifiers on all HD treatment claims were for V7 (AVF) or V6 (AVG) with no intervening codes for V5 (CVC), based on established definitions for a working AVF.²¹⁻²² Patients were followed until death, transplant, transfer to another dialysis modality or December 31, 2012, whichever came first.

Covariates

Comorbid conditions were determined directly from pre-dialysis Medicare claims.²⁰ Diabetes could be ascertained either by Medicare claims or by a primary diagnosis on CMS Form 2728. CMS Form 2728 was used to determine age at first HD, sex, race, body mass index, primary causes of kidney failure, pre-HD nephrology care, pre-HD erythropoietin use, inability to ambulate, and pre-enrollment laboratory values (hemoglobin, albumin, and creatinine).

Statistical Analyses

Continuous variables were summarized as means and medians, with t-tests, Wilcoxon rank sum tests and chi-squared tests used for normally and non-normally distributed baseline variables as appropriate. Cox proportional hazard analyses were used to evaluate the associations of imaging with time from HD initiation to first working AVF, to first working AVF or AVG, or death. All analyses were adjusted for age, sex, race, body mass index, primary kidney failure diagnosis, and comorbid conditions, as well as pre-dialysis nephrology care, erythropoietin use, albumin, creatinine, and hemoglobin prior to HD initiation.

Imaging was classified as pre-HD or post-HD, depending upon whether the date of the procedure preceded the date on which Form 2728 reported that “regular chronic dialysis began,” which was the time origin for all Cox models. Assumptions of proportional hazards were evaluated using Schoenfeld residuals. To reduce the influence of a few patients with large numbers of imaging events, we dichotomized both the pre-dialysis and the post-dialysis imaging variables as any vs. none. The earliest post-dialysis CPT code for venous imaging defined the time of exposure for the time dependent post-HD imaging variable, even if subsequent imaging studies were performed.

We conducted a subset analysis restricted to patients who underwent at least one surgery, to distinguish between the effects of imaging on intent to perform surgery versus the impact

upon surgical success. Logistic models were constructed for outcomes of 'AVF-only', 'AVG-only', and 'any AVF or AVG.' The primary exposure variable was whether or not any images had been performed on or before the day of surgery, and models were adjusted for all other covariates.

Sensitivity analyses

We performed sensitivity analyses to explore potential weaknesses and biases in our primary analyses. We examined the subsets of patients who survived for 60 days and for 90 days. We excluded all cases in which patients died, recovered function, received a kidney transplant or transferred to peritoneal dialysis. We also performed a sensitivity analysis excluding all patients with a diagnosis of acute kidney failure, as well as a time-dependent model for the impact of imaging upon death that adjusted for whether or not any AVF/AVG was achieved.

This study was approved by the Tufts University Health Sciences Campus Institutional Review Board and deemed exempt from requirement for informed consent given the use of de-identified data. All analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC).

Results

A total of 33,918 patients satisfied inclusion criteria (Figure 1). The major reason for exclusion was lack of pre-dialysis Medicare coverage in 69% of incident patients, followed by the presence of a working or maturing AV fistula or graft at HD initiation in 12%. Vascular imaging was performed in 13,267 patients (39.1%). Only 2,510 patients (7.4%) had any imaging performed prior to HD initiation. Among the patients who had imaging, 50.3% had Doppler vein mapping only, 37.4% had venography only, and 12.3% had both. Imaged patients received 9,757 Doppler vein mapping studies and 9,267 venograms; 85.7% of imaging studies were performed after HD initiation. Median time to first image after HD initiation was 52 days (interquartile range (IQR) = 24-113 days). Although individual patients had large numbers of studies, 96.5% of patients had two or fewer imaging studies performed.

Baseline Characteristics

The average age of our study population was 72.6 years; 47.1% were women, 73.2% were white and 22.5% black. Median follow-up was 404 days (IQR 103-680 days). Table 1 compares baseline characteristics of patients who ever had any imaging studies to those who had none. Patients who had imaging were more likely to be female and black, to have had pre-dialysis nephrology care, to have kidney failure due to hypertension or diabetes, and to have heart disease, peripheral vascular disease or stroke, but were less often non-ambulatory, and had less liver disease and cancer. Compared to those with post-dialysis imaging only, individuals who had imaging prior to HD initiation were more likely to have received pre-dialysis erythropoietin and nephrology care, and had more diabetes, hypertension, and heart disease (Supplemental Table 1). Patients who underwent one or more surgeries were younger, with higher BMI and more pre-dialysis nephrology care and EPO, more likely to

have kidney failure due to diabetes or hypertension, and had overall lower frequencies of all comorbid conditions (Supplemental Table 2).

Vascular Access and Mortality

Among 33,918 patients, 30% achieved a working AVF, 10.7% achieved a working AVG, 59.4% had persistent use of CVC throughout the observation period, and 46.2% died. Compared to patients who were never imaged, patients who had imaging had more fistulas and grafts and lower proportions of death and persistent CVC use (Table 2). Consistent with longer expected fistula maturation times, the median number of catheter days was 210 (IQR, 151-296) in patients who received fistulas compared to 164 (IQR, 108-262) in those who received grafts ($P<0.001$). Among patients who received fistulas, median catheter days were 221 (IQR, 161, 310) if imaging was undertaken and 198 (IQR, 141, 277) if it was not ($P<0.001$). Similarly, among patients who received grafts median catheter days were 175 (IQR, 117, 281) if imaging was pursued, versus 154 (IQR 102, 242) if it was not.

In multivariable adjusted baseline Cox models (Table 3), patients with imaging prior to HD initiation were 33% more likely to achieve a working fistula, 55% more likely to achieve a working fistula or graft, and 12% less likely to die during follow-up than those who did not have pre-dialysis imaging. Pre-dialysis and post-dialysis imaging had similar, but independent associations with all three outcomes (Table 3).

Performance and Outcomes of Surgery

We identified 32,341 vascular access surgeries in 18,883 patients. Surgery was performed in a higher proportion of imaged patients than non-imaged patients (70.9% vs. 45.9%, $P=0.002$). Among 18,883 patients who underwent at least one surgery, 49.8% had an imaging study performed by the date of surgery. The number of surgical procedures per patient was higher in imaged patients compared to non-imaged patients (1.8 vs. 1.6, $P<0.001$) and the number of images performed increased with the number of surgical attempts (Supplemental Figure 1).

Among the patients who had surgery, a working AVF/AVG was achieved in 71.3% of imaged patients and 69.7% of non-imaged patients ($P=0.02$). After adjustment for all baseline covariates, the odds ratio (OR) for achieving any working AVF or AVG was 1.09 (95% CI=1.02, 1.16), favoring imaged patients. Corresponding models for AVF only and AVG only were not significant (OR 1.03, 95% CI=1.02, 1.16 for AVF; OR 1.07, 95% CI=0.97, 1.18 for AVG).

Sensitivity analyses are presented in Supplemental Table 3. Compared to the baseline model, hazard ratios for vascular access outcomes increased with restriction for both 60 day and 90 day survival. When patients censored due to death, kidney transplantation, or transition to peritoneal dialysis were eliminated, the hazard ratios for post-dialysis imaging were preserved but the hazard ratios for pre-dialysis imaging were reduced. Hazard ratios for the three outcomes were unchanged when patients with acute kidney injury were excluded, in standard and time-dependent analyses. When achievement of a fistula or graft was added as a covariate to the time-dependent model for death, the hazard ratios (HR) for pre-dialysis

and post-dialysis imaging remained significant at 0.93 (95% CI=0.87, 0.99), and 0.88 (95% CI=0.85, 0.91).

Discussion

In a cohort of catheter-dependent Medicare beneficiaries receiving HD, vascular imaging performed before or after HD initiation was strongly associated with increases in both AVF and AVG, even after adjustment for baseline comorbid conditions and other relevant confounders. In the subset of patients who underwent surgery, we demonstrated small but statistically significant differences in surgical outcomes associated with imaging. Median catheter duration was longer by approximately 3 weeks when imaging was undertaken. Higher survival in the imaged cohort was consistent with increased transition from CVC to AVF or AVG.

Fewer than 40% of patients who were dialyzing without any AVF or AVG had any vascular imaging, and imaging was often delayed, suggesting that clinicians are ambivalent about performing these studies. This may reflect an ambiguous literature, consisting primarily of single-center studies that have focused upon short-term surgical outcomes rather than fistula maturation or usability.^{11, 17-18} This study evaluated clinically meaningful endpoints, defined by the vascular access utilized during HD treatments, in a large national sample.

Our data address a knowledge gap identified in a recent systematic review that suggested that the evidence was insufficient to conclude that imaging affected fistula outcomes. This review included only two single-center trials that examined fistula maturation.¹¹ One study showed that imaging prior to fistula surgery was associated with lower early failure and better assisted patency, but no difference in one-year fistula survival.²³ The other selected HD patients with visible superficial veins, and concluded that imaging did not improve surgical success in this group.²⁴ We found that if any vascular access surgery was attempted, the proportion of patients in this cohort who achieved any working AVF or AVG was approximately 70% whether or not imaging was performed. The increased achievement of working AVF/AVG in imaged patients was therefore predominantly due to surgery being attempted upon a much higher proportion of the imaged patients than non-imaged patients. Our findings contrast with those of a retrospective analysis of 256 local procedures, in which the fistula maturation rate decreased after implementation of a preoperative imaging protocol, resulting in a hypothesis that imaging promoted unsuccessful vascular surgery by detecting marginal blood vessels that would otherwise have been left untouched.¹⁹

Working AVF and AVG were both achieved more frequently in imaged patients, despite the imaged group having more comorbid conditions and less favorable demographics. The proportion of AVGs in imaged patients was higher in imaged patients than in non-imaged patients. These findings support the notion that imaging was more selectively performed in more complex clinical scenarios where the vasculature was not ideal. Much has been written about prolonged catheter use as an unintended consequence of the pursuit of AVF in patients with insufficient vasculature.^{19, 25-28} Our data suggest that accurate assessment of vessel quality may guide surgeons to appropriate, patient-centered choices of procedures that minimize catheter days. Taken together, the increased probability of surgery and more

appropriate choice of procedure suggest that imaging may be a marker for clinical engagement and quality of care, hypotheses that would be best assessed using a prospective study design.

The strength of this study is the large national population in which the frequency and timing of imaging, surgery, and working AVF/AVG could all be ascertained. Certain limitations merit discussion. Our study was limited to patients who had Medicare coverage two years prior to the date of the first hemodialysis treatment, selecting a group that was older than the HD population overall, with potentially fewer visible veins, a bias that could accentuate the potential benefit of imaging. Ascertainment of imaging studies and surgical procedures depended upon accurate coding practices. Under ascertainment would misclassify imaged patients as having had no exposure, which would promote underestimation of the potential associations between imaging and vascular access, which were nonetheless robust.

The most important limitations of our findings arise from the observational nature of this data, in which we are unable to assess the physical examination findings, imaging results, and the motivations for clinical decision-making, which could potentially confound the relationship between performance of imaging and performance of surgery. Surgeons may prefer to create vascular access using vessels that they can visualize and palpate, and imaging may be less likely to be obtained when vessels are obvious. Therefore, the non-imaged group would contain more patients with large visible veins for whom surgical outcomes were likely to be good, and the imaged group would be more likely to have patients with unfavorable venous anatomy. Alternatively, the non-imaged group could contain the patients for whom the pursuit of vascular access was deferred due to poor prognosis. Planned transitions to kidney transplant or peritoneal dialysis could also reduce likelihoods of both imaging exposures and vascular access creation. Patients with acute kidney failure were potentially problematic, because of their potential to recover kidney function, and their reduced opportunities for imaging and surgery due to their high severity of illness. We addressed these uncertainties by subjecting our findings to multiple sensitivity analyses, in which the directionality and magnitude of our associations were similar to our primary study findings. Residual confounding may have been present due to variables not available in this administrative dataset. The associations we identified were robust and clinically plausible, but further study is needed to determine causation.

Conclusions

Only 40% of patients who initiated HD with CVC as their sole vascular access had vascular imaging studies performed. Approximately 70% of patients who had surgery had successful achievement of a working AVF or AVG, whether or not imaging had been used. Imaging had strong positive associations with future achievement of working AV fistulas and grafts and better survival, despite similar surgical outcomes, because patients who were imaged were much more likely to undergo vascular surgery. Further work is needed to disentangle the effects of imaging from those of active clinician engagement in vascular access planning and determine the optimal role of vascular imaging.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations

HD	hemodialysis
AVF	arteriovenous fistula
AVG	arteriovenous graft

Figure 1.
Flowchart representing inclusion and exclusion criteria for the study population.

Table 1
Baseline patient characteristics at HD initiation, by imaging status

	All	Any Image	No Image	P-values*
N	N=33,918	N=13,267 (39.1%)	N=20,651 (60.9%)	
Age (years), mean (std)	72.6 (11.3)	72.1 (11.3)	72.9 (11.3)	<0.001
Female (%)	47.1	49.1	45.9	<0.001
Race, (%)				<0.001
White	73.2	69.7	75.5	
Black	22.5	26.0	20.2	
Other	4.3	4.3	4.3	
Body Mass Index, mean (std)	28.8 (7.8)	29.2 (7.9)	28.6 (7.7)	<0.001
Pre-ESRD PICC exposure (%)	7.2	7.5	7.1	0.1
Pre-ESRD Nephrology care (%)	47.3	49.9	45.7	<0.001
Pre-ESRD erythropoietin use (%)	15.2	15.7	14.8	0.10
Primary ESRD Diagnosis				<0.001
Diabetes	41.7	44.8	39.8	
Hypertension	32.5	33.5	31.9	
Primary Glomerulonephritis	3.2	3.0	3.3	
Other	22.6	18.7	25.0	
Comorbid conditions (%)				
Atherosclerotic Heart Disease	49.6	51.1	48.7	<0.001
Congestive Heart Failure	45.7	48.1	44.1	<0.001
Other Cardiac Conditions	31.1	32.4	30.2	<0.001
Arrhythmia	29.8	30.3	29.5	0.1
Peripheral Vascular Disease	28.6	29.7	27.9	<0.001
Pulmonary Disease	26.9	27.3	26.7	0.3
Diabetes, not cause of ESRD	23.8	23.3	24.1	0.1
Inability to Ambulate	12.5	10.9	13.6	<0.001
Stroke	14.4	15.0	14.1	0.02
Cancer	11.7	11.2	11.9	0.04
Gastrointestinal Disease	5.3	5.4	5.2	0.5
Liver Disease	4.2	3.8	4.4	0.006
Pre-ESRD labwork, mean (std)				
Serum albumin (g/dL)	3.0 (0.7)	3.0 (0.7)	3.0 (0.7)	0.1
Serum creatinine (mg/dL)	5.3 (2.7)	5.3 (2.7)	5.3 (2.7)	0.1
Hemoglobin (g/dL)	9.8 (1.5)	9.8 (1.5)	9.8 (1.5)	0.06

Abbreviations: ESRD (end-stage renal disease)

Any Image includes all patients receiving any venogram or any Doppler vein mapping, either before or after HD initiation, or both.

Note: Conversion factors for units: serum creatinine in mg/dL to $\mu\text{mol/L}$, $\times 88.4$.

Table 2
Vascular Access Outcomes and Mortality

	Total	Imaged	Never imaged	<i>P</i>-value*
N	33,918	13,267	20,651	
Vascular Access Achieved				<0.001
Persistent CVC use, n (%)	20,159 (59.4)	5,502 (41.5)	14,657 (71.0)	
AV fistula, n (%)	9,899 (29.2)	5,441 (41.0)	4,458 (21.6)	
AV graft, n (%)	3,860 (11.4)	2,324 (17.5)	1,536 (7.4)	
Death, n (%)	15,686 (46.2)	5,231 (39.4)	10,455 (50.6)	<0.001
Surgery Performed	18,883			0.002
None (%)		29.1	54.1	
Failed surgery (%)		20.3	13.9	
Successful AVF/AVG (%)		50.6	32.0	

* *P*-values for independent proportions between imaged and never imaged groups

Abbreviations: CVC (central venous catheter), AV (arteriovenous)

Table 3

Associations of Imaging with Vascular Access and Death

	n	Exposure	Timing of imaging	Death	Outcome Any AVF/AVG	Fistula Only
Baseline Cox Model	33,918		Pre-HD	0.88 (0.83, 0.94)	1.55 (1.47, 1.64)	1.33 (1.25, 1.43)
Cox Model, with time dependent variables	33,918		Pre-HD	0.88 (0.82, 0.93)	1.57 (1.49, 1.66)	1.36 (1.27, 1.45)
			Post-HD	0.85 (0.82, 0.88)	1.63 (1.58, 1.69)	1.45 (1.40, 1.51)

* Adjusted for: age, sex, race, pre-dialysis Nephrology care, pre-dialysis erythropoietin, primary diagnosis for kidney failure, body mass index, hemoglobin, albumin, creatinine, PICC placement, and all comorbid conditions

Abbreviations: AV (arteriovenous), CI (confidence interval), pre-HD (pre-hemodialysis)