Supply and Distribution of Vascular Access Physicians in the United States: A Cross-Sectional Study

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Abstract

**Background:** As functioning permanent vascular access (arteriovenous fistulas [AVF] or arteriovenous grafts [AVG]) is crucial for optimizing patient outcomes on hemodialysis, the supply of physicians placing vascular access is key. We investigated whether area-level demographic and healthcare market attributes were associated with the distribution and supply of AVF/AVG access physicians in the U.S.

**Methods:** A nationwide registry of physicians placing AVF/AVG in 2015 was created using data from the US Renal Data System and the American Physician Association’s Physician Masterfile. We linked the registry information to the Area Health Resource File to assess the supply of AVF/AVG access physicians and their professional attributes by Hospital Referral Region (HRR). Bivariate analysis and Poisson regression were performed to examine the relationship between AVF/AVG access physician supply and demographic, socioeconomic, and health resources conditions of HRRs. Setting: All 50 states. The main outcome was supply of AVF/AVG access physicians, defined as the number of physicians performing AVF and/or AVG placement per 1,000 prevalent end stage kidney disease patients.

**Results:** The majority of vascular access physicians were aged 45-64 (average age=51.6), male (90.8%), trained in the U.S. (76.4%), and registered in a surgical specialty (73.6%). The supply of physicians varied substantially across HRRs. The supply was higher in HRRs with higher % White population (β=0.44; SE=0.14; p=0.002), lower unemployment rates (β=-10.74; SE=3.41; p=0.002), and greater supply of primary care physicians (β=0.18; SE=0.05; p=0.001) and nephrologists (β=15.89; SE=1.22; p<0.001).

**Conclusions:** Geographic variation was observed in the supply of vascular access physicians. Higher supply of such specialist physicians in socially and economically advantaged areas may
explain disparities in vascular access and outcomes in the U.S. and should be the subject of further study and improvement.
Vascular access is a lifeline to the health and wellbeing for patients receiving chronic hemodialysis; it is also one of the most challenging and expensive aspects of hemodialysis care.\textsuperscript{1,2} The Medicare fee-for-service program spent an estimated $2.8 billion for services related to dialysis vascular access, half of which was dedicated to inpatient vascular access procedures or complications.\textsuperscript{3} In 2004, the Centers for Medicare and Medicaid Services (CMS) established the Fistula First Breakthrough Initiative (FFBI) in the wake of initial evidence on arteriovenous fistulas’ (AVF) durability, low rates of infection and thrombosis, and low patient mortality.\textsuperscript{4-6} The FFBI set a goal of optimizing vascular access that prioritized AVF over arteriovenous grafts (AVG) and central venous catheters.\textsuperscript{7,8} While there has been demonstrated improvement in fistula frequency since FFBI implementation, newer research reveals similar patency outcomes between AVF and AVG in the U.S.\textsuperscript{9-12}

When providers and patients discuss vascular access options, currently the choice of fistula or graft relies heavily on patient-level factors such as age, race, and vessel caliber. Despite careful considerations of these factors, over 30% of fistulas have primary failure, and over 60% need interventions prior to use.\textsuperscript{13} Potential explanations for the poor primary and secondary outcomes of AVF and AVG have continued to focus on patient factors that are often unmodifiable. An important but under-studied factor in the choice and success of vascular access is the physician who creates the fistula or graft. Earlier studies have examined the role of surgeons in vascular access outcomes. A single-site German study found the surgeon performing the procedure was the strongest predictor of AVF failure in the early 1990s.\textsuperscript{14} O’Hare and colleagues found Veterans Health Administration surgeons’ practice patterns in 2000-2001 were associated with type of vascular access use.\textsuperscript{15} Using data from 12 countries in the Dialysis and Practice Patterns Study, Saran et al. showed surgical training was key to fistula placement and
survival, consistent with Goodkin and colleagues’ (2010) review that vascular access surgery performed by surgeons who had placed a greater number of AVFs during their training was associated with higher odds of AVF placements and a reduced risk of AVF failure.

While this heterogenous group of studies suggests that physicians who create vascular access may be an important driver of vascular access utilization and outcomes, no study has examined systematically the supply, location, and types of physicians creating vascular access across the U.S. We sought to demonstrate the feasibility of developing a nationwide registry using existing data sources. In this paper, we described the methodology toward developing such a registry and examined the geographic distribution and characteristics of physicians placing permanent vascular access – specifically, AVF and AVG. Furthermore, we investigated area-level socioeconomic status (SES) and market attributes in relation to the distribution of AVF/AVG access physicians (i.e., physicians who performed AVF and/or AVG placement). Lastly, we examined whether the distribution of AVF/AVG access physicians was related to the supply of primary care physicians and nephrologists in the local area.

Methods

To test the feasibility of creating a nationwide registry of physicians who performed AVF and AVG placements, we conducted a cross-sectional observational study based on patient-level 2015 Medicare claims data. We then matched this claims-based registry to the American Physician Association (AMA) Physician Masterfile and Area Health Resource File to identify vascular access physicians’ demographic, specialty, training and certification attributes, practice locations, and area attributes of their practice locations. Variables were aggregated to the hospital referral region (HRR) level. HRRs are a common measure of healthcare markets; their
boundaries are based on actual patient utilization, reflecting the geographic extent of healthcare markets for tertiary care. They are appropriate for studies of end stage renal disease (ESRD) services because ESRD patients receive a significant amount of specialized non-dialysis care in tertiary settings.

Data Sources

The primary source of data was the U.S. Renal Data System (USRDS), which is the national repository of data and trends on all ESRD patients and providers. Patient information came from the Medical Evidence Report (CMS Form 2728), which ESRD providers are required to complete any time a patient begins or re-enters dialysis treatment or kidney transplantation services. Medicare claims data included inpatient, outpatient, and physician/supplier claims and were used to identify physicians who performed vascular access procedures. Data from these files were merged to construct a comprehensive baseline patient record and aggregated to the HRR level for covariate adjustment.

We used the AMA Physician Masterfile to ascertain professional and practice attributes of physicians performing AVF and/or AVG placement procedures. The AMA Physician Masterfile contains demographic, medical training, certification and specialty information on >1,168,000 physicians (>98% coverage), members and non-members, residents and medical students in the U.S.

We used information in the Area Health Resources File (AHRF) to measure demographic and socio-economic conditions of HRRs. AHRF contains a comprehensive array of county-level population statistics, including population counts, healthcare resources, personal income, and land area statistics. We converted county-level demographic and socio-economic statistics from
AHRF to the zip code-level based on land-area weighting, and then aggregated zip code-level information to HRRs. Zip code assignments to HRRs were obtained from publicly available geographic boundary files from the Dartmouth Atlas of Health Care.

Participants

The primary subjects of the study were physicians who performed AVF and/or AVG placement procedures in 2015. To construct a registry of such physicians over a single year, we first identified all pre-ESRD or ESRD patients in the USRDS data with evidence of a Medicare claim for AVF or AVG placement during January 1 through December 31, 2015 (N=151,428) (Figure 1). Current Procedural Terminology (CPT) codes 36800, 36810, 36818, 36819, 36820, 36821, and 35825 were used to identify claims of AVF placement. CPT code 36830 was used to identify claims of AVG placement. We excluded claims (1) without a national provider identifier (NPI), a unique identifier of the physician who performed the placement procedure (N=2); (2) related to care for patients who were 20 and younger and patients who did not have Medicare as the primary insurer in 2015 (N=71,154); and (3) that were duplicative (N=29,740). From the remaining 50,532 claims, we identified a total of 5,464 unique clinicians who performed at least one AVF or AVG access placement procedure in 2015. After excluding clinicians practicing in U.S. Territories (N=97), we removed another 615 clinicians (11%) because their NPIs did not have a match in the AMA Physician Masterfile. In total, we identified 4,752 vascular access physicians in 2015.

Measurement
The main outcome in this study was the supply of AVF/AVG access physicians, defined as the number of physicians performing AVF and/or AVG placement per 1,000 prevalent ESRD patients, across HRRs in 2015.

Linked NPI and AMA Physician Masterfile were used to obtain the following physician characteristics: age, sex, zip code, MD vs. DO, indicator of U.S. vs. international medical graduates, year of graduation (before 1980, 1980-1989, 1990-2000, after 2000), years in practice (<=10, 11-20, 21-30, 31-40, 41-50, >50), and primary specialty (vascular surgery, thoracic/cardiac surgery, transplant surgery, urology, general surgery, other surgery, urology, radiology, nephrology, others).

We characterized the demographic and socio-economic conditions of physicians’ HRRs in 2015 as % White population, % urban population, % adults with a high school diploma population, % population in poverty, unemployment rate, and per capita income (average income earned per person in the HRR). We also calculated the supply of primary care physicians (number of primary care physicians per 1000 ESRD patients) and nephrologists (number of nephrologists per 1000 ESRD patients) in each HRR based on physician counts in the AMA Physician Masterfile.

Statistical Analyses

Descriptive statistics (counts, mean, 95% confidence interval, and proportions) were used to examine the dispersion and distribution of AVF/AVG access physician supply and professional characteristics (e.g., specialty, year of practice). Choropleth maps were generated to display the regional (HRR) supply of AVF/AVG access physicians across the U.S. We then employed multivariate analysis using Poisson regression in General Linearized Models (GLM)
to examine the relationship between AVF/AVG access physician supply (response variable) and demographic/socioeconomic conditions of HRRs.

All analyses used SAS statistical software (version 9.4; Statistical Analysis Institute Inc.) and R (version 3.5.0; R Foundation for Statistical Computing). Statistical significance was defined as $p<0.05$.

**Results**

Supply, Geographic Distribution, and Characteristics of AVF/AVG Access Physicians

A total of 4,752 unique physicians performed 50,532 Medicare claims for vascular access procedures in 2015. Of those physicians, 1,979 performed AVF placement only, 288 performed AVG placement only, and 2,485 performed both AVF and AVG. On average, there were 20.1 AVF/AVG access physicians in HRRs per 1,000 ESRD prevalent patients. There was substantial variation across HRRs (Figure 2), ranging from 2.6 in Wichita Falls, TX (HRR 276) to 68.3 in Hinsdale, IL (HRR 86). The supply of vascular access physicians appeared to be higher in the New England, Mideast, Great Lakes regions, as well as the area between the Midwest/Plains and Mountain West regions. By contrast, many HRRs in the South (Georgia, Alabama, Mississippi, and Louisiana), Appalachia, and Midwest/Plains regions had low supply of vascular access physicians.

The average age of AVF/AVG access physicians was 51.6 years, with the majority in the 45-64 age group (57.5%) (Table 1). An overwhelming majority of the physicians were male (90.8%), had an MD degree (95.5%), and received their medical school education in the U.S. (76.4%). The distribution of physicians by medical school graduation year was skewed towards recent decades, consistent with the distribution by number of years in practice, where nearly a
third of physicians (32.4%) had less than 10 years of practice experience with an average length of practice of 17.4 years. In terms of medical specialty, 44.8% of physicians identified vascular surgery as their primary specialty, 38.8% more in other surgical specialties (thoracic/cardiac, transplant, general, urology, and others), and the remainder were in nephrology (2.7%), radiology (0.1%), and other medical specialties (13.5%).

A substantial portion of vascular access physicians performed only one type of vascular access placement, rather than both. We suspected that this practice pattern may be associated with personal and professional attributes. Thus, for comparison, Table 1 also reports the personal and professional attributes of physicians who placed AVF only (N=1,979), AVG only (N=288), and both AVF and AVG (N=2,485). There are several notable differences. In comparison to physicians who placed both AVF and AVG, physicians who performed only one type of vascular access placement were more likely to be female (11.3% [AVF only] and 15.6% [AVG only] versus 6.9% [AVG and AVG]), to receive their medical school education outside the U.S. (27.0% [AVF only] and 26.7% [AVG only] versus 20.6% [AVF and AVG]), to be in nephrology (5.2% [AVF only] and 6.6% [AVG only] versus 0.3% [AVF and AVG]) and other medical specialties (26.4% [AVF only] and 20.1% [AVG only] versus 2.5% [AVF and AVG]), and less likely to have vascular surgery as their primary specialty (30.5% [AVF only] and 38.5% [AVG only] versus 57.0% [AVF and AVG]).

The practice volume of vascular access physician varied substantially. The large majority of physicians (N=3,494; 73.5%) performed less than 10 procedures in 2015. Of the 1,258 physicians performing more than 10 procedures in 2015, 1,197 performed both AVF and AVG, 61 performing AVF only, and none performing AVG only. In general, high-volume physicians were older, more likely to be male, graduated from the medical school in earlier years, and had
more years of practice than physicians who performed less than 10 vascular access procedures in 2015. With few exceptions (1.7%), all of them had a surgical background and 68.4% were vascular surgeons (detailed results available from the corresponding author).

Analysis of the Vascular Access Physician Supply

As a framework for assessing factors that were associated with the distribution of AVF/AVG access physicians, we drew on location theory. The theory assumes generally that physicians are economic agents acting in their own self-interest and that their choice of practice location reflects personal preferences for income as well as environmental and professional considerations. Based on these assumptions, we expected there would be a greater supply of AVF/AVG access physicians in HRRs with a higher degree of urbanicity, higher % White population, higher % population with a high school diploma, and better economic conditions, because these HRR conditions meant there would be a higher demand for vascular access placement and the living conditions would be more favorable to physicians. Similarly, AVF/AVG access physicians may be more likely to practice in HRRs with a higher supply of primary care physicians and nephrologists, because there would be more patient referrals and better medical support for vascular access services.

Figure 3 displays the distribution of AVF/AVG access physician supply by HRR characteristics. As expected, the supply of AVG/AVG access physicians was significantly higher in HRRs with a higher % White population (r=0.22, p<0.001), a higher % population with high school diploma (r=0.25, p<0.001), a higher level of per capita income (r=0.15, p=0.01); and the supply was significantly lower in HRRs with a higher % population in poverty (r=-0.24, p<0.001) and a higher unemployment rate (r=-0.23, p<0.001). Consistent with our expectation,
the supply of AVF/AVG access physicians was also positively associated with the supply of primary care physicians ($r=0.36$, $p<0.001$) and nephrologists ($r=0.53$, $p<0.001$) in HRRs. There was no difference in AVF/AVG access physician supply by the level of urbanicity ($r=-0.03$, $p=0.63$).

In adjusted analysis (Table 2), % White population ($\beta=0.44$; SE=0.14; $p=0.002$), supply of primary care physicians ($\beta=0.18$; SE=0.05; $p=0.001$), and supply of nephrologists ($\beta=15.89$; SE=1.22; $p<0.001$) were significantly and positively associated with the distribution of vascular access physicians across HRRs. On the other hand, unemployment rates of HRRs ($\beta=-10/74$; SE=3.41; $p=0.002$) were significantly and negatively associated with the supply of vascular access physicians.

We also compared the location differences between AVF only, AVG only, and AVF and AVG physicians and between high (>10 procedure) and low-volume (<=10 procedures) physicians (detailed results are available from the corresponding author). In general, physicians performing AVF only and AVG only were more likely to be located in HRRs with higher % White population, better economic conditions (i.e., lower poverty, lower unemployment rates, and higher per capita income), and higher supply of primary care physicians and nephrologists. In multivariate analysis, the only factor significantly associated with the geographic distribution of high-volume (>10) physicians, who were more likely to perform both AVF and AVG, was the supply of nephrologists, suggesting their practice location was determined primarily by referral sources.
Discussion

In this nationally representative study, we developed a novel registry of 4,752 vascular access physicians by systematically matching Medicare-claims data on ESRD and pre-ESRD patients with the AMA Physician Masterfile for the year 2015. We found the majority of physicians creating fistulas and grafts were vascular surgeons or general surgeons. While the majority of these physicians created both types of access, surprisingly 31.1% created only AVF while 6.1% created only AVG. A minority of vascular access physicians performed more than 10 placements in 2015 and they almost exclusively were surgeons. Furthermore, the registry demonstrated marked variation in the supply of vascular access physicians across the country. Additionally, area-level characteristics were associated with the supply of vascular access physicians.

Building on the methodology in Shahinian et al., our study is one of the first to detail the demographic and specialty profiles of vascular access physicians across the 50 states of the U.S. It is interesting to note that the vast majority of vascular access physicians are male, likely reflecting the general gender distribution of physicians in surgical specialties. Similar to previous studies using U.S. and international data, we found wide variation in specialty among vascular access physicians. Physicians in surgical specialties – primarily those in vascular surgery (45%) and general surgery (29%) – constituted the vast majority (84%) of physicians who performed AVF and/or AVG placement procedures in 2015. In contrast, a Dialysis Outcomes and Practice Patterns Study (DOPPS) showed that, in 2003, 61% of vascular access surgeries in the U.S. were conducted by vascular surgeons and 31% by general surgeons. The different findings suggest a possibility that there may be increasing involvement of medical
specialists in vascular access creation over time, and a shift in the professional background of vascular access physicians from surgical to medical specialties.

Our findings reveal a stark contrast in the role of medical specialists in vascular access creation. According to our analysis, nephrologists constituted only 3% of vascular access physicians in the U.S. This rate was lower than those observed in other countries. Approximately 30% of vascular access surgeries in Japan were conducted by nephrologists; in Italy, nephrologists were the primary vascular access operators in 85% of hemodialysis facilities. Such practice pattern differences may be due to medical training and credential issues across countries and may continue to evolve with the introduction of percutaneous AVF creation technique. Moreover, the medical specialties represented in our study were considerably diverse – including pulmonary critical care medicine, internal medicine, critical care medicine, anesthesiology, cardiovascular disease, family practice, and vascular and interventional radiology – and a small percentage of those physicians claims surgery as their second specialty. This level of diversity appears unique in the U.S. and has important implications regarding the quality of vascular access placement in consideration of a small number of placement procedures they tended to perform as well as three prior research findings. First, research indicated that adequate training in vascular access creation predicted vascular access patency in hemodialysis patients. Second, a surgeon’s prior volume of AVF placement was shown to be associated with successful AVF maturation. Third, U.S. surgeons had less vascular access training than surgeons in other countries. Medical specialists, conceivably, may receive even less training on vascular access placement; they may not focus a significant portion of their practice on the procedures; and the volume they performed tended to be small. If so, a sizable number of the vascular access procedures performed in the U.S. may not produce reliable and sustainable
access for hemodialysis patients. To verify this concern, future research linking the professional background and specialty of vascular access physicians to quality and outcomes of vascular access procedures is needed.

Surprisingly, we found nearly half of vascular access physicians performed only AVF or AVG placement in 2015. The reasons for this specialization is not clear, and cannot be plausibly attributable to the measured physician characteristics such as gender, country of medical graduation, and others. In a comparison of high and low-volume vascular access physicians we found high-volume physicians were more likely to performed both AVF and AVG and were more likely to be in areas with lower % White population and poorer economic conditions. These findings suggest that the degree of specialization may be related to local practice patterns or reimbursement. Future research is needed to further investigate and corroborate the findings.

Our analysis showed substantial geographic variation in physician supply. Comparatively, HRRs in the South (particularly, Georgia, Alabama, Mississippi, and Louisiana), Appalachia, and Midwest/Plains regions were underserved by physicians who performed vascular access procedures for hemodialysis patients. Besides such regional differences, the distribution of vascular access physicians was associated with demographic, economic, and health resources conditions of HRRs in a manner that is consistent with the prediction of the location theory. Specifically, we found vascular access physicians were more likely to locate in HRRs with a higher % White population and less likely to be in HRRs with higher unemployment rates.

These findings are interesting in light of the persistent geographic and demographic variation in fistula prevalence despite the overall success of the FFBI initiative. Geographic variation has been observed across the 18 End Stage Renal Disease Networks. Hemodialysis
patients in New England have the highest rates of initiation with AVF, while patients in the
Southeast have the lowest rates. At the county level, variation in incident and baseline
prevalent AVF rates was associated with the concentration of poverty in a dialysis center’s
county. Moreover, racial and ethnic variation has been observed in AVF utilization. Using
CMS Medical Evidence Report data, Arce et al. found that Hispanics were less likely to use AVF
for first outpatient HD compared with non-Hispanics. In a different study, Zarkowsky et al.
showed that Black and Hispanic patients were less likely to initiate hemodialysis with an AVF
than White patients despite being younger and having fewer comorbidities and that the
differences were not explained by factors related to healthcare such as medical insurance status
and pre-dialysis nephrology care. In consideration of all this previous evidence, the findings of
our study suggest that the supply of vascular access physicians may be a crucial and previously
overlooked factor. Specifically, the tendency of vascular access physicians to practice in socially
and economically advantaged areas may explain the persistent evidence that minority dialysis
patients have a lower frequency of functional AVF and AVG than White patients. If this is
confirmed by further research that directly links the supply of vascular access physicians to
prevalence and success of AVG and AVG placement, improvement in the medical school
curriculum and training of vascular access as well as change in reimbursement policy would be
needed to increase the supply of vascular access physicians in underserved areas and
disadvantaged patient populations.

We also found that vascular access physicians, particularly those who performed a high
number of procedures, tended to practice in HRRs where there was abundant supply of primary
care physicians and nephrologists. This finding suggests that solving maldistribution of vascular
access physicians needs to consider the overall distribution of medical resources, as indicated by supply of primary care physicians and nephrologists.

Our study was limited by its cross-sectional design. We have demonstrated the feasibility of reliably identifying vascular access physicians, their professional attributes and practice information using ESRD and pre-ESRD claims data and existing secondary datasets. Future work to expand the registry using longitudinal data to track the supply of vascular access surgeons and specialists would enable further important examination of the relationships between supply, professional background, skill, and practice settings of those physicians to vascular access use and outcomes in hemodialysis patients. It should be noted that we did not capture all permanent vascular access procedures in 2015 – particularly, those that were performed on patients age under 65 – due to Medicare’s eligibility and coverage rules for new ESRD program enrollees and transition to Medicare primary payer coverage. This may not be a major limitation and was unlikely to affect the construction of the physician registry because very few vascular access physicians, if any, perform AVF procedures exclusively on non-Medicare patients.

The overall supply, professional background and skill of vascular access surgeons are arguably some of the most important, yet understudied, factors of vascular access quality. Identifying the drivers of the observed findings may help to develop policy changes to reimbursement or other incentives that would increase the supply of vascular access surgeons and specialists in underserved areas with disadvantaged patient populations. Furthermore, periodic updates to the registry would enable longitudinal monitoring of the supply of vascular access physicians and track the changes in physician attributes and practices. The information would contribute to improving vascular access care and inform the needs for modifying medical
training and physician workforce policy to enhance the supply of vascular access physicians, particularly in underserved areas.

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Table 1. Characteristics of physicians performing AVF/AVG placement.

|                        | All (N=4752) | AVF only (N=1979) | AVG only (N=288) | AVF and AVG (N=2485) |
|------------------------|--------------|-------------------|------------------|----------------------|
| **Age**                |              |                   |                  |                      |
| 18-44                  | 51.6 (51.2, 51.9) | 50.9 (50.4, 51.4) | 51.4 (49.9, 52.8) | 52.1 (51.7, 52.5)   |
| 45-64                  | 29.8%        | 32.6%             | 31.9%            | 27.3%                |
| 64-74                  | 11.0%        | 9.8%              | 13.9%            | 11.7%                |
| >75                    | 1.6%         | 1.9%              | 1.7%             | 1.4%                 |
| **Sex**                |              |                   |                  |                      |
| Female                 | 9.2%         | 11.3%             | 15.6%            | 6.9%                 |
| Male                   | 90.8%        | 88.7%             | 84.4%            | 93.1%                |
| **D.O. Flag**          |              |                   |                  |                      |
| M.D.                   | 95.5%        | 95.6%             | 94.1%            | 95.7%                |
| D.O.                   | 4.5%         | 4.4%              | 5.9%             | 4.4%                 |
| **U.S. Trained**       |              |                   |                  |                      |
| Yes                    | 76.4%        | 73.0%             | 73.3%            | 79.4%                |
| No (IMG**)             | 23.6%        | 27.0%             | 26.7%            | 20.6%                |
| **Year of Graduation** |              |                   |                  |                      |
| Before 1980            | 19.0%        | 17.0%             | 21.5%            | 20.3%                |
| 1980-1989              | 27.3%        | 26.7%             | 25.4%            | 28.0%                |
| 1990-2000              | 28.5%        | 29.2%             | 23.6%            | 28.6%                |
| After 2000             | 25.2%        | 27.2%             | 29.5%            | 23.1%                |
| **Year in Practice**   |              |                   |                  |                      |
| <=10 years             | 32.4%        | 34.7%             | 34.7%            | 30.3%                |
| 11-20 years            | 27.7%        | 28.6%             | 22.2%            | 27.6%                |
| 21-30 years            | 20.9%        | 19.5%             | 20.1%            | 22.0%                |
| 31-40 years            | 13.8%        | 12.3%             | 14.6%            | 15.0%                |
| 41-50 years            | 2.0%         | 1.9%              | 2.1%             | 2.1%                 |
| >50 years              | 0.1%         | 0.1%              | 0.4%             | 0.1%                 |
| **Specialty Group**    |              |                   |                  |                      |
| Vascular Surgery       | 44.8%        | 30.5%             | 38.5%            | 57.0%                |
| General Surgery        | 29.3%        | 29.1%             | 22.9%            | 30.1%                |
| Thoracic/Cardiac Surgery | 7.5%    | 6.5%              | 9.4%             | 8.1%                 |
| Transplant Surgery     | 1.0%         | 0.6%              | 0.4%             | 1.5%                 |
| Urology                | 0.1%         | 0.2%              | 0.0%             | 0.0%                 |
| Other Surgery***       | 0.9%         | 1.4%              | 2.1%             | 0.4%                 |
| Nephrology             | 2.7%         | 5.2%              | 6.6%             | 0.3%                 |
| Radiology              | 0.1%         | 0.2%              | 0.0%             | 0.0%                 |
| Other Medical Specialties**** | 13.5%  | 26.4%             | 20.1%            | 2.5%                 |

* Age as of January 1, 2015.
** IMG: International Medical Graduates; physicians who obtained their medical school diplomas outside the U.S.
*** Other Surgery includes the following specialty categories in AMA file: Critical Care Surgery, Traumatic surgery, Abdominal Surgery, Colon & Rectal Surgery, Pediatric Surgery, Neurological Surgery, Orthopedic Surgery, Pediatric Cardiothoracic Surgery and Plastic Surgery.
**** Other Specialty primarily includes Pulmonary Critical Care Med., Internal Medicine, Critical Care Medicine, Anesthesiology, Cardiovascular Disease, Family Practice, and Vascular & Interventional Radiology.
Table 2. Poisson regression analysis.

|                                | Coefficient | SE    | p-value     |
|--------------------------------|-------------|-------|-------------|
| Intercept                      | 2.24        | 0.34  | 3.5e-11     |
| White population               | 0.44        | 0.14  | 0.002       |
| High school diploma            | 0.59        | 0.37  | 0.112       |
| Urban population               | -0.04       | 0.10  | 0.648       |
| Per capita income              | -1.36e-06   | 1.86e-06 | 0.4923     |
| Unemployment rate              | -10.74      | 3.41  | 0.002       |
| Primary care physician supply* | 0.18        | 0.05  | 0.001       |
| Nephrologist supply*           | 15.89       | 1.22  | 1.46e-38    |

* Supply represents the count of vascular access performing physicians per 1000 prevalent ESRD patients.
Figure 1. Flowchart of the Processes for Identifying Physicians Performing AVF/AVG Placements in 2015
Figure 2. Choropleth map showing the supply of AVF/AVG access physicians across HRRs
Figure 3. Bivariate analysis for AVF/AVG access physician supply and HRR characteristics.

* Primary care physician supply and nephrology supply represent the count of physician per prevalent ESRD patients.