Physician supply, treatment, and amputation rates for peripheral arterial disease

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Objective: To test whether the availability of vascular surgeons and interventional radiologists in a region affects revascularization and amputation rates for patients with peripheral arterial disease (PAD).

Methods: We identified all patients with PAD in the Medicare claims database in 1994 and tracked their claims through 1999. We aggregated risk-adjusted data on the 143,202 patients who survived through 1999 by Hospital Referral Region and merged this data with information on local physician supply and other regional characteristics. Instrumental variables analysis was used to account for unobserved illness severity. Main outcome measures were risk-adjusted rates of lower extremity bypass surgery, angioplasty, and amputation by region.

Results: Increasing vascular surgeon supply in a region by approximately one standard deviation (.30/10,000 Medicare beneficiaries) is associated with a 0.9 percentage point increase in bypass surgery rates and a 1.6 percentage point reduction in amputation rates. Factors reflecting regional attractiveness, such as the rating of a region based on climate, recreation, crime, and other attributes, were strong independent predictors of the number of vascular surgeons and interventional radiologists in an area.

Conclusions: Availability of specialists affects outcomes for PAD patients. Regional variability in specialists who treat PAD is influenced by factors other than regional medical needs. Policies aimed at increasing the supply of vascular surgeons and interventional radiologists and their provision of bypass surgery in underserved areas may help to reduce regional disparities in amputation. (J Vasc Surg 2005;42:81-7.)

The Dartmouth Atlas reports that amputations resulting in limb loss varied more than tenfold among Medicare beneficiaries, from 0.37 per 1,000 Medicare enrollees in Grand Junction, Colorado to 4.35 in Corpus Christi, Texas in 1996-1997. Peripheral arterial disease (PAD) accounts for approximately half of all amputations among diabetic patients and is the major cause of amputation for non diabetic patients. The gold standard for revascularization is bypass surgery, although percutaneous transluminal angioplasty is frequently recommended for patients with localized disease in larger arteries. Regional variations in bypass surgery and angioplasty rates also exist.

The likelihood that a patient undergoes revascularization and, therefore, long-term outcome, may depend on access to vascular specialists. We tested whether regional differences in amputation rates and revascularization for patients with PAD are determined by the local availability of vascular surgeons who perform bypass surgery and interventional radiologists who perform angioplasty.

METHODS

We identified all Medicare beneficiaries aged ≥65 in the 1994 physician claims files with an ICD-9 diagnosis code for lower extremity atherosclerosis (440.20 to 440.29). We also selected patients with CPT codes for arteriography of the abdominal vessels or lower extremity arteries (75630 or 75710) and a diagnosis or procedure code consistent with PAD; for example, stricture of artery or gangrene. Altogether, 358,050 patients met these criteria.

We then searched the Medicare hospital inpatient and outpatient standard analytic files to identify lower extremity bypass surgery (ICD-9 procedure codes 39.25 or 39.29), angioplasty (39.50), and major lower extremity amputations (84.10, 84.13 to 84.17) for these patients in the years 1994 through 1999. An angioplasty was not counted if the claim also included an ICD-9 code for occlusion and stenosis of the precerebral arteries (433) or atherosclerosis of the renal artery (440.1). Amputations preserving the heel and therefore the patient’s ability to ambulate were not considered major amputations. We searched the outpatient files for CPT codes for these same procedures using an ICD-9 to CPT Procedural Coding Crosswalk.

To control for disease severity and to focus analysis on patients most likely to benefit from revascularization, the sample was limited to the 143,202 patients who remained alive at the end of 1999. Of these patients, 21.8% received an arteriography in 1994. The unit of analysis was the bypass surgery, angioplasty, or amputation rate in one of 306 Hospital Referral Regions (HRRs) as defined by the Dartmouth Atlas of Health Care. HRRs are naturally oc-
curring tertiary care markets within which Medicare beneficiaries receive inpatient services. Treatment and amputation rates were assigned by each patient’s residence rather than the region in which patients received care. The explanatory variables of interest are the number of vascular surgeons and interventional radiologists in a HRR. Counts of board certified vascular surgeons and interventional radiologists were available for the year 1996. During the study period, cardiologists may have been less inclined to recommend revascularization and more inclined to medically manage PAD. Therefore, we also recorded counts of cardiologists by HRR in 1996. A small fraction of patients (6.4%) underwent more than one revascularization during the study period. For these patients, we only analyzed the first revascularization. Some patients (1.6%) had an amputation prior to reported revascularization. Because these amputations are more likely a marker for disease severity than a result of access to specialists over the sample period, amputations that occurred before a reported revascularization were excluded from the calculation of regional amputation rates.

All rates were adjusted for illness severity by using the method of indirect standardization, which involves multiplying the procedure’s national rate by the ratio of the crude rate to the predicted rate for the HRR. The predicted rate was obtained from a patient-level logistic regression of bypass surgery, angioplasty, or amputation on indicator variables for age (70 to 74, 75 to 79, age 80+), gender, mild-to-moderate diabetes mellitus, diabetes mellitus with chronic complications, prior acute myocardial infarction, and amputation during the sample period prior to revascularization. Diabetes mellitus and prior acute myocardial infarction were coded by using a Charlson comorbidity index that was adapted for administrative data. Values for these indicators were determined from data in the 1994 claims files.

Although 90% of patients in the sample reported a PAD diagnosis in 1994, 59% of these diagnoses did not report PAD severity, such as intermittent claudication, rest pain, ulceration, or gangrene. Given its potential for measurement error, PAD severity was not used in risk adjustment.

Linear regressions were estimated to test whether bypass surgery, angioplasty, and amputation rates are associated with the number of vascular surgeons, interventional radiologists, or cardiologists per Medicare enrollee in an HRR. The number of cardiologists was only included in these regressions if for this variable was <.20.

The regressions include an illness index for each HRR to further control for regional differences in health status. The index is based on mortality rates and rates of five types of hospitalizations that are proxies for disease incidence: hip fracture, cancer of the colon or lung treated surgically, gastrointestinal hemorrhage, acute myocardial infarction, or stroke.

More PAD in an area may attract more specialists who can provide treatment. Although risk-adjusted treatment rates and the regional illness index are included in the analyses, any residual differences in regional health status will bias the estimates of the impact of physician availability on treatment and amputation rates. Therefore, we tested for the need for an instrumental variables analysis for the number of vascular surgeons, interventional radiologists, and cardiologists, and implemented this framework where indicated.

Instrumental variables analysis controls for confounding that may be introduced by crude measures of illness severity in administrative data. “Instruments” are variables in observational data that effectively allocate patients to different levels of the treatment that are not confounded by illness severity. For example, distance from a hospital providing cardiac catheterization has been used as an instrument to explain whether or not acute myocardial infarction patients receive catheterization. Those patients who live closest to a hospital with a cardiac catheterization laboratory are most likely to be catheterized after an acute myocardial infarction. The effectiveness of cardiac catheterization in a population was therefore assessed by comparing the risk-adjusted mortality rates of acute myocardial infarction patients who live close to a laboratory compared with patients who live far from any hospital with a catheterization facility.

Instrumental variables methods are ideally suited to address the question, “What would be the effect of increasing the supply of vascular surgeons in an HRR by, for example, one fourth?” They do not address the question, “What would be the expected outcome for a specific patient if she were treated by a vascular surgeon versus received medical management alone?” For clinical decisions involving treatment of individual patients, the answer to the latter question is more useful. For policy decisions affecting the treatment of entire populations, the former is likely to be more useful.

We used variables that measure the general attractiveness of an HRR as instruments for the region’s number of vascular surgeons and interventional radiologists. Most specialists work in cities where they did not grow up, often migrating to areas with greater social amenities. Thus, the livability of an area should affect the availability of specialists who treat PAD, but it is unlikely to be correlated with residual PAD severity. Variations in the availability of vascular surgeons and interventional radiologists because of differences in the attractiveness of each region provide an estimate of the effect of specialist availability on revascularization and amputation rates that is unaffected by unmeasured illness severity.

The variables characterizing regional attractiveness are the mean score in the Places Rated Almanac, the average July temperature in an HRR, and the number of accountants per capita. The 1997 Almanac assigned 351 metropolitan areas a mean score determined from costs of living, job outlook, transportation, education, health care, crime, the arts, recreation, and climate. The Area Resource File reported July temperatures by county. The number of accountants per 10,000 residents by county was reported in the 1997 Bureau of Labor Statistics survey on Covered Employment and Wages proxies for regional attractiveness.
to another relatively mobile profession. These variables were crosswalked to HRRs using city names for each region in the Atlas and county ZIP code crosswalks. These diagnostic tests avoid the possibility of reaching illogical conclusions, which occurred in earlier instrumental variables studies. Instrumental variables were used only in regressions where test results indicated they were appropriate. Each treatment and amputation rate was weighted in the regressions according to the number of PAD patients in the sample in that region. Estimation was conducted using Stata 8.0 (StataCorp LP, College Station, Tex).

RESULTS

We analyzed 143,202 Medicare beneficiaries with PAD in 1994 who survived through 1999, an average of 468 patients per HRR. The mean risk-adjusted bypass surgery rate for the 306 regions was 22.2%. Risk-adjusted angioplasty and amputation rates were 7.6% and 6.9%. The mean number of vascular surgeons, interventional radiologists, and cardiologists per HRR were 0.42, 0.32, and 5.20 per 10,000 Medicare enrollees, respectively.

Table I summarizes how regional attractiveness allocates areas to differing specialist availability. Regions in the lowest third of the Places Rated Almanac rating were compared with regions in the top third that received the most favorable scores. Regions in the highest tertile had more vascular surgeons (0.53 vs 0.35) and more interventional radiologists (0.43 vs 0.22) per 10,000 Medicare beneficiaries than lower tertile regions. Regions in the highest tertile also experienced lower amputation rates (5.6% vs 7.7%), suggesting that greater availability of vascular surgeons and interventional radiologists leads to lower amputation rates.

Regions in the Almanac’s highest tertile had patients who were slightly older and more likely to have had a previous myocardial infarction. Low tertile regions had slightly higher shares of diabetic patients and prior amputation rates. The absence of large or systematic differences by tertile in health characteristics provides some validation that the Almanac scores allocate areas to differing specialist availability in a manner that is independent from local health status. This observation is best confirmed in a regression framework, however.

Contrary to our hypothesis, more attractive HRRs displayed lower bypass surgery and angioplasty rates. These regions also had larger supplies of cardiologists, who may have been more inclined to treat PAD medically rather than revascularize during the study period. Therefore, the independent supply effect for each of these specialties is best assessed with regressions.

Endogeneity tests indicated that instrumental variables analysis was not necessary to control for unobserved patient severity in regressions explaining bypass surgery and angioplasty rates (P = .09 to .91). Therefore, Table II presents weighted least squares estimates of the relation between specialist availability and risk-adjusted treatment rates. Column I suggests a positive association between the number of vascular surgeons per 10,000 Medicare beneficiaries in an HRR and risk-adjusted bypass surgery rates for PAD patients (coefficient = 0.030, P = .04). To provide perspective, a one standard deviation difference in the number of vascular surgeons in a region equals approximately .30 patients per 10,000 Medicare beneficiaries. The regression estimates suggest that a .30 increase in the number of vascular surgeons per 10,000 Medicare beneficiaries is associated with a 0.9 percentage point increase in bypass surgery rates. Higher numbers of interventional radiologists per capita in a region are associated with a decrease in risk-adjusted bypass surgery rates (coefficient = −0.029, P = .08). Higher numbers of cardiologists per capita are also associated with reduced bypass rates (coefficient = −0.10, P < .001).

Column 2 reports factors explaining angioplasty rates. The estimates provide weak evidence that greater availability of interventional radiologists is associated with increased angioplasty rates (coefficient = 0.009; P = .28) Increases in both the number of vascular surgeons and cardiologists per 10,000 Medicare beneficiaries are associated with decreases in risk-adjusted angioplasty rates. The effect sizes for these two specialties are smaller than those observed in column 1.

Table III presents regression estimates of the impact of regional attractiveness on specialist availability in each HRR. A higher score in the Places Rated Almanac is

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Lowest tertile (n = 102)</th>
<th>Highest tertile (n = 102)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>54.9</td>
<td>57.3</td>
</tr>
<tr>
<td>Mean age 1994, y (SD)</td>
<td>74.5 (1.47)</td>
<td>75.0 (1.40)</td>
</tr>
<tr>
<td>Comorbid disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illness index (SD)</td>
<td>1.01 (0.11)</td>
<td>1.00 (0.08)</td>
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<tr>
<td>Mild diabetes mellitus</td>
<td>21.6</td>
<td>20.8</td>
</tr>
<tr>
<td>Diabetes w/chronic complications</td>
<td>3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Prior myocardial infarction</td>
<td>4.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Prior amputation</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Specialists per 10,000 Medicare beneficiaries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vascular surgeons (SD)</td>
<td>0.35 (0.26)</td>
<td>0.53 (0.26)</td>
</tr>
<tr>
<td>Interventional radiologists (SD)</td>
<td>0.22 (0.22)</td>
<td>0.43 (0.32)</td>
</tr>
<tr>
<td>Cardiologists (SD)</td>
<td>4.18 (1.63)</td>
<td>6.71 (2.38)</td>
</tr>
<tr>
<td>Revascularization and amputation rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bypass surgery</td>
<td>23.2</td>
<td>22.0</td>
</tr>
<tr>
<td>Angioplasty</td>
<td>8.4</td>
<td>6.9</td>
</tr>
<tr>
<td>Amputation</td>
<td>7.7</td>
<td>5.6</td>
</tr>
</tbody>
</table>

*All entries are percentages except for mean age, illness index, and number of specialists.
associated with both more vascular surgeons and interventional radiologists per capita ($P \leq .01$ in each case). A city ranked in the 10th percentile of the Almanac for overall attractiveness had a score of 37.57, and a city in the 90th percentile received a score of 71.11.

The coefficients in Table III suggest that the predicted increase in the number of specialists associated with this ratings differential is 0.13 vascular surgeons (0.004 × 33.54) and 0.20 interventional radiologists (0.006 × 33.54) per 10,000 Medicare beneficiaries. Likewise, an increase in a region’s July temperature reduces the number of vascular surgeons per capita ($P < .001$), although no such relation is found for interventional radiologists ($P = .80$). More accountants in each region is also associated with more vascular surgeons and interventional radiologists ($P \leq .03$ in each case). F-tests for the joint significance of the regional attractiveness measures indicate that the variables do well in explaining variation in both vascular surgeon ($F = 19.61$, $P < .001$) and interventional radiologist ($F = 54.58$, $P < .001$) availability per 10,000 Medicare beneficiaries, which is a necessary requirement for instrumental variables.22

Table IV presents instrumental variables estimates of the association between the number of specialists per capita and amputation rates across HRRs. An endogeneity test indicated that standard weighted least squares estimation would yield biased coefficient estimates ($P = .01$). An overidentification test did not detect a correlation between regional attractiveness measures and unexplained differences in patient severity ($P = .61$). Therefore, the instrumental variable estimates are unlikely to be confounded by differences in patient severity when the determinants of regional amputation rates are measured. In preliminary specifications, the coefficient on cardiologist supply was imprecisely estimated ($P = .90$), so these specialists were excluded from the final regressions.

Increasing availability of vascular surgeons per 10,000 Medicare beneficiaries is associated with a decrease in regional amputation rates (coefficient $= -0.053$, $P = .01$). The 10th and 90th percentiles of the distribution of vascular surgeon supply are 0.08 and 0.76 surgeons per 10,000 Medicare beneficiaries. The coefficient estimates in Table IV suggest that increasing availability of vascular surgeons by this differential amount reduces amputation rates by 3.6 percentage points ($-0.053 \times 0.68$). Increasing interventional radiologist supply is also associated with a lower amputation rate, although the effect is less precisely estimated (coefficient $= -0.031$, $P = .07$). Sensitivity analyses indicated that the results were robust to substituting individual components of the Almanac ratings such as climate, crime, and jobs as well as employment counts of other professionals (legal professionals or engineers).
Table IV. Weighted instrumental variables estimates of the determinants of amputation rates by Hospital Referral Region*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Risk-adjusted amputation rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vascular surgeons‡</td>
<td>$-0.053\ ( -0.095\ to -0.012)^6$</td>
</tr>
<tr>
<td>Interventional radiologists‡</td>
<td>$-0.031\ ( -0.063\ to 0.002) $</td>
</tr>
<tr>
<td>Illness index</td>
<td>0.129 (0.091 to 0.168)</td>
</tr>
<tr>
<td>Constant</td>
<td>$-0.045\ ( -0.082\ to -0.007) $</td>
</tr>
<tr>
<td>N</td>
<td>306</td>
</tr>
</tbody>
</table>

*Estimates are weighted by the number of patients in each Hospital Referral Region.
†Rate is adjusted by indirect standardization at the patient level using age, gender, diabetes, prior acute myocardial infarction, and prior amputation.
‡Estimates based on instrumental variables models using Almanac score, July temperature, and number of accountants as instruments for number of physicians per 10,000 Medicare beneficiaries.
§95% confidence intervals in parentheses.

DISCUSSION

Regional variation in amputation rates indicates outcome disparities that cause significant pain and suffering for patients. Our results suggest that greater availability of specialists in an area influences treatment rates and reduces amputations. The distribution of specialists in the United States is strongly correlated with local factors such as climate, transportation, education, and crime. Therefore, variations in regional attractiveness that influence specialist supply have significant implications for treatment and outcomes for PAD patients.

A 0.30 increase in the number of vascular surgeons per 10,000 Medicare beneficiaries leads to an increase in bypass surgery (0.9 percentage points) that is smaller in absolute value than the corresponding reduction in amputations ($0.30 \times 0.053 = -1.6$ percentage points). This finding may seem counterintuitive. However, like cardiologists, vascular surgeons offer medical management of atherosclerosis. Furthermore, vascular surgeons are trained in all aspects of limb salvage, such as wound care, which may in some cases prevent amputation without the need for bypass surgery.

We also investigated the association between the availability of vascular surgeons and repeat risk-adjusted bypass surgery rates, excluding the results from the tables for brevity. Increased rates of repeat bypass surgery may further prolong adequate circulation in the lower limbs, reducing the need for amputation. Greater availability of vascular surgeons is associated with reduced repeat bypass surgery rates (coefficient $= -0.017$), although the effect is imprecisely estimated ($P = .28$).

An increasing local interventional radiologist supply is associated with higher angioplasty rates and lower amputation rates, although the effects are not precisely estimated. The Dartmouth Atlas series does not publish information on the number of interventional radiologists by HRR. Therefore, counts of vascular and interventional radiologists practicing in 1996 were obtained from the American Medical Association Masterfile, which didn’t include this specialty category until 1992.

Because specialty is self-designated, older physicians may have failed to reclassify their specialty, leading to undercounts of interventional radiologists in the Masterfile. The rate of undercounting is likely to be similar across HRRs, so that we can still study the effects of differential supply across regions. However, the measured association between interventional radiologist supply and both angioplasty and amputation rates may be biased upwards in absolute value, and the undercounting is likely to influence the precision of the estimates. Further study of interventional radiologist supply will require substantial resources to identify these specialists from counts of procedures performed in the Medicare claims data, as is commonly done in the Dartmouth Atlas.

Higher local cardiologist supply is associated with decreased revascularization rates and no measurable relation to rates of amputation. During the study period 1994 to 1999, cardiologists may have been inclined to treat PAD medically rather than through invasive techniques. A premier cardiology journal noted that the role of angioplasty for PAD remained controversial in 1993, and the American Heart Association guidelines regarding medical management versus revascularization for PAD patients were not published until 1996. However, with improvement in endovascular technology, cardiologists may have become more inclined to recommend invasive techniques or perform revascularization themselves. When more recent data become available, these relationships should be examined once again.

General surgeons performed 33% of surgical bypass procedures for lower extremity atherosclerosis among Medicare enrollees, and cardiologists performed 22% of lower extremity angioplasties in 1996. We repeated our analysis including counts of general surgeons and interventional cardiologists from the Dartmouth Atlas in our regressions. Although we do not present these results in the tables, we found no evidence of an association between these specialties and revascularization or amputation rates. The effects were all imprecisely estimated, with $P = .34$ to .85. Again, these results should be revisited when more recent data become available.

If greater specialist supply leads to more PAD diagnoses, then our sample may contain less diseased patients in high supply areas. We divided HRRs into thirds based on their supply of vascular surgeons and interventional radiologists. Mean age, rates of diabetes mellitus, prior myocardial infarction, and prior amputation were all insignificantly different across high and low tertiles of specialist supply. It is therefore unlikely that sample selection bias explains our results.

Socioeconomic status and ethnicity have influenced health outcomes in past studies. We estimated an alternative specification of the instrumental variables amputation rate regression, including the 1995 median household income of each HRR, crosswalked from county-level census estimates. Although higher income was associated with lower amputation rates, the relation was insignificant ($P = .65$). We chose to not adjust for...
race or ethnicity in this study, because areas of the country that are more desirable to live in may have fewer minority residents. The association between higher specialist supply and lower amputation rates could therefore be masked by a greater minority presence in low-supply areas. Teasing out the effects of specialist supply versus minority status is beyond the scope of this report but is an important area for future research.

This study provides a useful framework for learning what factors attract specialists to different geographic locations and how the resulting local variations in specialist supply can influence treatment rates in the population. The less-precise association between interventional radiologist supply and amputation rates does not imply that angioplasty is ineffective in treating PAD. Evidence from randomized clinical trials more appropriately tests the effectiveness of bypass surgery and angioplasty in well-defined patient populations. Instead, observational analysis provides information that is useful to policy makers on how specialist availability influences treatment rates and outcomes and what factors influence regional surgeon and interventional radiologist supply.

The analysis does not account for mortality that may result from lower-extremity bypass surgery, which was 3.2% in the early 1990s. Past studies have identified lower mortality associated with bypass surgery compared with amputation, suggesting that increased lower extremity bypass rates do not increase mortality. Even if vascular surgeon availability improves in underserved areas, noticeable disparities in amputation rates would remain because of disparities in PAD detection and in outpatient care. Increased preventive measures such as foot examinations, smoking cessation, and drug treatment could reduce disparities in amputation rates. Nevertheless, 21.8% of patients in our sample received an arteriography in 1994, which is a marker for advanced disease. For these patients, it is particularly important to consider access to specialists performing revascularization.

Policies that increase the supply of specialists who can perform revascularization in underserved areas may help to reduce regional disparities in amputation rates. All aspects of physician recruitment and retention are potential policy levers. Past studies have shown that physician location decisions are responsive to higher reimbursement and greater expected future income.

Programs similar to the National Health Service Corps or loan forgiveness provisions for physicians that have been used in the past to encourage physicians to practice in rural areas could be applied. Alternatively, policy makers could consider targeting of graduate medical education financing to encourage increased vascular specialty training in underserved areas. Although these interventions will not eliminate regional disparities in amputation rates, the results in this study suggest that they could improve quality of life for PAD patients in underserved areas.

REFERENCES

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