Variation in Patient-Sharing Networks of Physicians Across the United States

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Context Physicians are embedded in informal networks that result from their sharing of patients, information, and behaviors.

Objectives To identify professional networks among physicians, examine how such networks vary across geographic regions, and determine factors associated with physician connections.

Design, Setting, and Participants Using methods adopted from social network analysis, Medicare administrative data from 2006 were used to study 4,586,044 Medicare beneficiaries seen by 68,288 physicians practicing in 51 hospital referral regions (HRRs). Distinct networks depicting connections between physicians (defined based on shared patients) were constructed for each of the 51 HRRs.

Main Outcomes Measures Variation in network characteristics across HRRs and factors associated with physicians being connected.

Results The number of physicians per HRR ranged from 135 in Minot, North Dakota, to 8,197 in Boston, Massachusetts. There was substantial variation in network characteristics across HRRs. For example, the mean (SD) adjusted degree (number of other physicians each physician was connected to per 100 Medicare beneficiaries) across all HRRs was 27.3 (range, 11.7-54.4); also, primary care physician relative centrality (how central primary care physicians were in the network relative to other physicians) ranged from 0.19 to 1.06, suggesting that primary care physicians were more than 5 times more central in some markets than in others. Physicians with ties to each other were far more likely to be based at the same hospital (69.2% of unconnected physician pairs vs 96.0% of connected physician pairs; adjusted rate ratio, 0.12 [95% CI, 0.12-0.12]; P < .001), and were in closer geographic proximity (mean office distance of 21.1 km for those with connections vs 38.7 km for those without connections, P < .001). Connected physicians also had more similar patient panels in terms of the race or illness burden than unconnected physicians. For instance, connected physician pairs had an average difference of 8.8 points in the percentage of black patients in their 2 patient panels compared with a difference of 14.0 percentage points for unconnected physician pairs (P < .001).

Conclusions Network characteristics vary across geographic areas. Physicians tend to share patients with other physicians with similar physician-level and patient-panel characteristics.

ORIGINAL CONTRIBUTION

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For editorial comment see p 294.
important for identifying levers to influence how physicians exchange information with one another. Herein, we discuss the use of novel, validated methods from social network analysis to define professional networks based on patient sharing among physicians, and examine how such networks vary across geographic areas. We also identify physician and patient population factors that are associated with patient-sharing relationships.

METHODS

Sharing of patients based on administrative data can identify information-sharing ties among pairs of physicians.6 Physician encounter data from the Medicare program were used to define networks of physicians based on shared patients.7 A social network is defined as a set of actors and the relationships or connections that link these actors together (Box). Social network analysis can be used to study the structure of a social system and to understand how this structure influences the behavior of constituent actors. In this study of physician patient-sharing networks, nodes represent the individual physicians in the network and ties (or edges) represent shared patients between nodes. The presence of shared patients was used to infer information-sharing relationships between 2 physicians. Ties vary in their weight according to the number of shared patients, with more shared patients implying stronger connections between physicians.6 This study was approved by the Harvard Medical School institutional review board, which also approved a waiver of consent for participants in the study.

Identifying the Sharing of Patients

Shared patients were identified using Medicare claims from 2006. To maximize data on shared patients among physicians practicing in local areas, we obtained data for 100% of Medicare beneficiaries (including those aged <65 years) living in 50 market areas (defined as hospital referral regions [HRRs]) randomly sampled with probability proportional to their size; this was the maximum amount of data that the Centers for Medicare & Medicaid Services would release to us. The HRRs represent regional markets for tertiary care, which were defined based on referral patterns for cardiovascular and neurosurgical procedures performed.8 In addition, the Boston HRR was included to aid in the development and testing of the methods of the study because it is familiar to us. We included patients enrolled in both Medicare Parts A and B and excluded patients enrolled in Medicare Advantage plans, for whom encounter data were not available.

Encounters with physicians were defined based on paid claims in the carrier file. We excluded claims for specialties in which physicians were not involved in direct patient care or were not selected specifically (eg, radiology, anesthesiology). We identified all evaluation and management services, and also included procedures with a relative value unit of at least 2.0 to capture surgical procedures that are often reimbursed via bundled fees that include preprocedure and postprocedure assessments. We excluded claims for laboratory and other services not reimbursed via bundled fees that include preprocedure and postprocedure assessments. We excluded claims for laboratory and other services not requiring a physician visit and claims generated from physicians who saw fewer than 30 Medicare patients during 2006 or who practice outside of the included HRRs. Although the latter exclusions increase the risk of excluding physicians who work on the geographic boundary of a HRR, information on these physicians would have been incomplete.

Characteristics of Physicians and Patients

Physician characteristics including age, sex, medical school, and place of residency were defined using data from the
Constructing Physician Networks

Physician networks were discerned from a patient-physician bipartite or 2-mode network. The term bipartite means that nodes in the network can be partitioned into 2 sets (eg, physicians and patients) and that all relationships link nodes from 1 set to the other. A unipartite (physician-physician) network was formed by connecting each pair of physicians who shared patients with one another, and a weight was assigned to such ties based on the number of patients shared (Figure 1). A key decision involved determining the minimum number of shared patients that could optimally be used to define connections representing important relationships. We previously found (using these same Medicare data) that physicians in a single academic health care system who shared 8 or more patients had an 80% probability of having a validated information-sharing relationship. This threshold might differ depending on specialty and the clinical activity of each physician.

We explored both absolute thresholding (using the same threshold for each physician and specialty) and relative thresholding (creating a customized threshold for each physician). We found that using a relative threshold that maintained the strongest 20% of ties for each physician appeared to best maintain intrinsic network characteristics while also eliminating noise that might result from spurious connections. Although this method likely eliminated some ties that represent true relationships, it maintains the strongest ties for each physician and therefore maintains the relationships likely to be most influential to that physician. In sensitivity analyses, using the top 10% and 30% of ties, our main results were similar (eAppendix).

Network Descriptive Measures

The networks were described after applying our thresholding procedure and by focusing on a set of measures applicable across all types of physicians: adjusted physician degree, number of patients shared by the physician, relative betweenness centrality, and physician-level clustering coefficient (Figure 1 and Box).

Degree was defined as the number of physicians connected to a given physician through patient sharing. Because the number of connections was influenced by patient volume, we adjusted the degree by dividing each physician’s degree by the total number of Medicare patients that the physician shared with other physicians (adjusted degree). Thus, physicians with a higher degree were connected to and shared patients with more physicians. The number of shared patients was defined as the total number of shared patients across all ties for a physician and reflects the number of patients that physician cared for, as well as his/her tendency to share care with other physicians. The betweenness centrality of a physician represented how central a physician was within his/her network of colleagues.

To calculate relative betweenness centrality for PCPs or medical specialists in each HRR-level network, mean PCP or specialist centrality for that network was first calculated and then later divided by the mean centrality of all other physicians in the network. Central physicians in a network are likely to have more influence. The clustering coefficient of a physician in the network refers to the proportion of a physician’s colleagues who also shared patients with one another. A physician could share patients with 10 other physicians, none of whom share patients with each other, or a physician could share patients with 10 other physicians, all of whom were interconnected. A network with a high-clustering coefficient was more densely connected.

For descriptive purposes, each physician was assigned to a principal hospital based on where they filed the plurality of inpatient claims or, if they did not do inpatient work, to the hospital where the plurality of patients they saw received inpatient care.

Statistical Analyses

The networks in each of the 51 HRRs were first characterized. Selected networks were visualized using the Fruchterman-Reingold algorithm. Unadjusted differences in network measures across regions were assessed using 1-way analysis of variance.

To examine factors associated with the existence of ties between physicians, we first compared the characteristics of pairs of connected physicians within each of the regions with the characteristics of all other potential pairs for
Figure 1. Basic Social Network Concepts

Basic elements of network diagrams
The basic elements of a network are nodes and edges (also called ties or connections).

A network between 2 types of nodes (physicians and patients)

A network between a single type of node (physicians)

Two-mode (bipartite) network

One-mode (unipartite) network

Network metric definitions
Degree quantifies the number of connections a node has.

Physician 6 has a degree of 5.

Physician 4 has a degree of 2.

Physician 3 has a degree of 3.

Clustering coefficient quantifies the extent to which other nodes connected to a node of interest are also connected to each other.

The clustering coefficient of Physician 6 is 0.5 calculated by:

No. of actual ties that exist between nodes connected to a node of interest

Overall no. of ties that could exist between those connected nodes

Betweenness centrality quantifies the structural centrality of a node in the network. It is proportional to the number of times the node lies on the shortest path between 2 nodes in the network considering all the shortest paths between all node pairs.

Below is an example of a node (○) that lies on many of the shortest paths between node pairs in the network.

The network below demonstrates the variation in betweenness centrality among nodes in the network.

Low centrality

High centrality
which there was no connection. These analyses included all physicians and ties (not just the 20% of strongest ties used for the descriptive network analyses). For each physician pair, whether connected or not, difference measures were defined for each of the main independent variables of interest. For instance, distance was defined as the number of kilometers between the zip code centroid for each pair’s office addresses (and was log-transformed to limit the effect of outliers). Shared patients were excluded from the calculation of patient-panel attributes for each physician pair, so the results are not inflated by the fact that shared patients have identical characteristics.

Bivariate differences were evaluated using 2-sided t tests or χ² tests (as appropriate) and were considered significant if the P value was less than .05. Because our analyses are hypothesis-generating, we did not adjust P values for multiple comparisons. We then estimated univariable and multivariable models to identify characteristics associated with having a tie and increasing tie strength between 2 physicians within the network (ie, the extent to which characteristics of 2 physicians connected to each other are similar, also known as homophily). The dependent variable was the number of shared patients between any pair of physicians and the predictors were the difference measures. Because the prevalence of potential ties with 0 patients was large, we found that a negative binomial distribution best fit the data.

To make the results easier to interpret, regression coefficients were converted to standard rate ratios because the outcome is not binary. For the differences in patient characteristics measured as percentages, we present rate ratios representing the increase in the number of ties for each 10% difference in a patient population characteristic across the 2 physicians. All analyses were performed with SAS version 9.2 (SAS Institute Inc).

RESULTS
We studied 4,586,044 Medicare beneficiaries from 51 HRRs who were seen by 68,288 physicians. The randomly sampled HRRs are distributed across all regions of the country and include urban and rural locations (eFigure 1 at http://www.jama.com). The characteristics of all included physicians and patients are presented in Table 1. The mean physician age was 48.8 years and about 80% were male. Among the Medicare patients, the mean age was 71 years and 40% were male. The distribution of the number of shared patients between linked physicians for the entire data set is depicted in eFigure 2.

After applying the relative thresholding rule (keeping only ties with strength in the top 20th percentile for each physician), the mean number of patients shared per 100 Medicare benef-

Table 1. Characteristics of Physicians, Patients, and Networks Stratified by Hospital Referral Region

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Hospital Referral Region</th>
<th>Boston, MA</th>
<th>Minot, ND</th>
<th>Joliet, IL</th>
<th>Miami, FL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physicians No.</td>
<td>1339 (1621) [135-8197]</td>
<td>8197</td>
<td>135</td>
<td>496</td>
<td>3600</td>
</tr>
<tr>
<td>Age, y</td>
<td>48.5 (1.3) [46.1-51.7]</td>
<td>48.3</td>
<td>48.1</td>
<td>46.3</td>
<td>51.7</td>
</tr>
<tr>
<td>Males, %</td>
<td>80.3 (4.9) [69.2-89.7]</td>
<td>70.1</td>
<td>82.4</td>
<td>77.8</td>
<td>84.1</td>
</tr>
<tr>
<td>Type of practice, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary care</td>
<td>41.9 (5.4) [27.6-53.3]</td>
<td>38.5</td>
<td>50.4</td>
<td>40.1</td>
<td>39.0</td>
</tr>
<tr>
<td>Medical specialist</td>
<td>30.0 (4.8) [20.7-47.1]</td>
<td>36.8</td>
<td>20.7</td>
<td>33.5</td>
<td>35.7</td>
</tr>
<tr>
<td>Surgical specialist</td>
<td>28.0 (3.3) [21.3-35.5]</td>
<td>24.7</td>
<td>28.9</td>
<td>26.4</td>
<td>25.2</td>
</tr>
<tr>
<td>Patients No.</td>
<td>279 (84) [126-447]</td>
<td>224</td>
<td>260</td>
<td>317</td>
<td>228</td>
</tr>
<tr>
<td>Whites, %</td>
<td>86.6 (11.5) [49.4-98.8]</td>
<td>89.1</td>
<td>92.7</td>
<td>89.4</td>
<td>61.7</td>
</tr>
<tr>
<td>Blacks, %</td>
<td>8.9 (10.1) [0.1-42.1]</td>
<td>6.2</td>
<td>0.2</td>
<td>8.7</td>
<td>111.9</td>
</tr>
<tr>
<td>Hispanics, %</td>
<td>1.8 (4.0) [0-24.2]</td>
<td>1.5</td>
<td>0</td>
<td>0.9</td>
<td>24.2</td>
</tr>
<tr>
<td>Females, %</td>
<td>59.9 (2.0) [54.4-64.2]</td>
<td>60.8</td>
<td>58.0</td>
<td>61.6</td>
<td>61.1</td>
</tr>
<tr>
<td>Medicaid, %</td>
<td>23.0 (10.0) [7.7-51.9]</td>
<td>27.7</td>
<td>12.0</td>
<td>14.7</td>
<td>51.9</td>
</tr>
<tr>
<td>Age, y</td>
<td>70.7 (1.6) [67.1-74.6]</td>
<td>70.8</td>
<td>73.2</td>
<td>71.4</td>
<td>71.6</td>
</tr>
<tr>
<td>Hierarchical clinical condition score</td>
<td>1.9 (0.3) [1.5-2.8]</td>
<td>2.2</td>
<td>1.7</td>
<td>2.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Episode treatment group intensity score</td>
<td>1.03 (0.06) [0.9-1.2]</td>
<td>1.1</td>
<td>1.2</td>
<td>1.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

| Networks No. of ties             | 50,927 (75,963) [1568-392,582] | 392,582   | 1568      | 12,914     | 218,136   |
| Adjusted degree                  | 27.3 (10.4) [11.7-54.4]     | 51.4       | 11.7      | 18.6       | 54.4      |
| No. of shared patients           | 852 (336) [297-1504]        | 835        | 498       | 1222       | 1146      |
| Clustering                       | 0.55 (0.06) [0.40-0.67]     | 0.48       | 0.67      | 0.62       | 0.47      |
| Relative centrality              |                           |            |           |            |           |
| Primary care physician           | 0.38 (0.17) [0.19-1.06]     | 0.52       | 0.41      | 0.19       | 0.46      |
| Medical specialist               | 3.47 (1.33) [0.48-7.40]     | 1.62       | 5.59      | 3.98       | 2.12      |

aIndicates the number of other physicians each physician was connected in each hospital referral region.

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ties between physicians in different hospitals/St Paul, Minnesota, there are many network configurations). In Minneapolis/St Paul, Minnesota, there are many ties between physicians in different hospitals, with primary care physicians centering their patient sharing around a pool of medical and surgical specialists in multiple hospitals. Thus, although physicians are clustered according to their principal hospital affiliation, the close proximity of the clusters is indicative of multiple ties across hospitals. Alternatively, in Albuquerque, New Mexico, network connections are mostly confined within hospitals, and connections are generally confined to their hospital. Consequently, the hospital clusters in Albuquerque are more distinct and separated in space.

Factors Associated With Network Ties

Among all physicians and ties (rather than just the 20% of strongest ties) across the 51 HRRs, male physicians were more likely to have ties with other male physicians (65.1% of connected physician pairs were male-male vs 54.6% of unconnected physician pairs, \( P < .001 \)), but female physicians were less likely to have ties with other female physicians (3.8% of connected physician pairs vs 6.4% of unconnected physician pairs, \( P < .001 \)) (Table 2). Physicians with ties were also closer in age (mean difference of 11.5 years for those with ties vs 12.5 years for those without ties, \( P < .001 \)).

Patterns varied by physician specialty as well. Physicians with ties to each other were far more likely to be based at the same hospital (69.2% of unconnected physician pairs vs 96.0% of connected physician pairs; adjusted rate ratio, 0.12 [95% CI, 0.12-0.12]; \( P < .001 \)). Connected physician pairs also were more likely to be in close geographic proximity. The mean distance for connected pairs was 21.1 km vs 38.7 km for unconnected pairs (\( P < .001 \)). Connected physicians also had more similar practice intensity as measured by episode treatment groups\(^1\) (a difference of 0.29 for linked physicians vs a difference of 0.31 for unlinked physicians, \( P < .001 \)).

Characteristics of physicians’ patient populations also were associated with the presence of ties between physicians. Across all racial and ethnic groups, connected physicians had more similar racial compositions of their patient panels (net of any shared patients) than unconnected physicians. For instance, connected physician pairs had an average difference of 8.8 points in the percentage of black patients in their 2 patient panels compared with a difference of 14.0 percentage points for unconnected physician pairs (\( P < .001 \)). Similarly, differences in mean patient age and percentage of Medicaid patients also were smaller for connected physicians than unconnected physicians. Medical comorbidities (measured by the Hierarchical Condition Categories score) were also more similar, suggesting that connected physicians had more similar patients in terms of clinical complexity than unconnected physicians. All of these results were confirmed in multivariable regression models (Table 2).

Physicians thus tend to cluster together along attributes that characterize their own backgrounds and the clinical circumstances of their patients. We observed similar patterns when repeating the analyses using logistic regression after applying the thresholding criteria.

**Comment**

Our results demonstrate substantial variation in physician network characteristics across geographic areas in terms of both topological features and dyadic ties, even for networks of generally similar size. It has long been known that physician behavior varies across geographic areas, yet our understanding of the factors that contribute to these geographic differences is incomplete.\(^1\) Our findings suggest that variation according to network attributes might help explain health care variation across geographic areas, particularly given what is known about how networks function. However, additional studies are needed to ascertain the extent to which the structural variation in physician interactions—on both macro and micro scales—can help explain variation in medical practice across geographic areas.

Our results show that physicians tend to share patients with colleagues who have similar personal traits, practice styles, and patient panels, although the influence of some of these traits is small in magnitude. Working at the same primary hospital and having similar sociodemographic characteristics among patients in their patient...
Figure 2. Examples of Variations in Patient-Sharing Physician Networks

A Variations in network configurations based on the number of patient-sharing connections between physicians at different hospitals

<table>
<thead>
<tr>
<th>Hospital affiliation</th>
<th>Specialty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary care physician</td>
<td>Medical specialist</td>
</tr>
<tr>
<td>Surgical specialist</td>
<td>Other specialist</td>
</tr>
</tbody>
</table>

- **Loosely connected network**
  - Hospital A
  - Hospital B
  - Hospital C
  - Hospital D

In a network in which physician connections are mostly within hospitals, the network has tight hospital clusters but loose connections between hospital clusters.

- **Tightly connected network**
  - Hospital A
  - Hospital B
  - Hospital C
  - Hospital D

In networks with more physician connections across hospitals, the hospital clusters are closer together and the overall network becomes tighter.

B Example of a loosely connected network: Albuquerque, NM (n=1391 physicians)

C Example of a tightly connected network: Minneapolis/St Paul, MN (n=596 physicians)
VARIATION IN PATIENT-SHARING NETWORKS OF PHYSICIANS

The network interactions among physicians that we discerned differ from the formal networks sometimes established by health plans or health systems because they reflect actual patient flows across physicians. Formal networks are import-

tant, as evidenced by the unsurprising finding that physicians associated with the same hospital are far more likely than other physicians to be connected. Yet this is not always the case. For instance, although hospital affiliation appears to be a strong predictor of ties in the Albuquerque, New Mexico, market, this is not the case in Minneapolis/St Paul, Minnesota.

Our ability to discern these organic, natural networks is relevant to the current push toward the creation of accountable care organizations. Herein, we de-

Table 2. Physician and Patient Characteristics Associated With Physician-Physician Relationships

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>With Ties</th>
<th>Without Ties</th>
<th>Unadjusted</th>
<th>Adjustedb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physicians Overall difference</td>
<td>92.2</td>
<td>7.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male-male</td>
<td>65.1</td>
<td>54.6</td>
<td>1.68 (1.68-1.69)</td>
<td>1.32 (1.32-1.32)</td>
</tr>
<tr>
<td>Female-female</td>
<td>3.8</td>
<td>6.5</td>
<td>0.72 (0.71-0.72)</td>
<td>0.79 (0.78-0.79)</td>
</tr>
<tr>
<td>Male-female</td>
<td>29.1</td>
<td>36.8</td>
<td>1 [Reference]</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Difference in age</td>
<td>11.5</td>
<td>12.5</td>
<td>0.80 (0.80-0.80)</td>
<td>0.88 (0.88-0.88)</td>
</tr>
<tr>
<td>Specialty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCP-PCP</td>
<td>10.1</td>
<td>15.8</td>
<td>0.77 (0.76-0.77)</td>
<td>0.62 (0.62-0.62)</td>
</tr>
<tr>
<td>PCP-medical</td>
<td>28.0</td>
<td>27.1</td>
<td>1 [Reference]</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>PCP-surgical</td>
<td>17.5</td>
<td>20.3</td>
<td>0.72 (0.72-0.72)</td>
<td>0.65 (0.65-0.65)</td>
</tr>
<tr>
<td>Medical-medical</td>
<td>16.9</td>
<td>12.1</td>
<td>1.52 (1.52-1.53)</td>
<td>1.36 (1.36-1.36)</td>
</tr>
<tr>
<td>Medical-surgical</td>
<td>20.7</td>
<td>17.9</td>
<td>0.94 (0.94-0.95)</td>
<td>0.90 (0.89-0.90)</td>
</tr>
<tr>
<td>Surgical-surgical</td>
<td>7.0</td>
<td>6.7</td>
<td>0.76 (0.76-0.77)</td>
<td>0.66 (0.66-0.66)</td>
</tr>
<tr>
<td>Office distance, km</td>
<td>21.1</td>
<td>38.7</td>
<td>0.99 (0.99-0.99)</td>
<td>0.98 (0.98-0.98)</td>
</tr>
<tr>
<td>Different hospital, %</td>
<td>69.2</td>
<td>96.0</td>
<td>0.07 (0.07-0.07)</td>
<td>0.12 (0.12-0.12)</td>
</tr>
<tr>
<td>Completed medical school at different medical school</td>
<td>6.1</td>
<td>3.6</td>
<td>0.53 (0.53-0.53)</td>
<td>0.99 (0.99-0.99)</td>
</tr>
<tr>
<td>Completed residency at different institution</td>
<td>5.3</td>
<td>2.7</td>
<td>0.55 (0.54-0.55)</td>
<td>0.88 (0.88-0.89)</td>
</tr>
<tr>
<td>Practice stylec</td>
<td>0.29</td>
<td>0.31</td>
<td>0.91 (0.91-0.91)</td>
<td>0.93 (0.92-0.93)</td>
</tr>
</tbody>
</table>

| Patients                          |           |              |            |           |
| Difference in %                   |           |              |            |           |
| Whites                            | 11.5      | 20.2         | 0.72 (0.72-0.72) | 0.89 (0.89-0.89) |
| Blacks                            | 8.8       | 14.0         | 0.75 (0.75-0.75) | 0.92 (0.92-0.92) |
| Hispanics                         | 2.9       | 5.3          | 0.59 (0.59-0.59) | 0.75 (0.75-0.76) |
| Females                           | 13.0      | 15.6         | 0.80 (0.80-0.81) | 0.86 (0.86-0.86) |
| Medicaid                          | 15.3      | 24.4         | 0.69 (0.69-0.69) | 0.86 (0.86-0.86) |
| Difference in age                  | 4.1       | 5.4          | 0.42 (0.42-0.42) | 0.75 (0.75-0.76) |
| Hierarchical clinical conditions score | 1.0 | 1.1 | 0.78 (0.78-0.78) | 0.93 (0.93-0.93) |

Abbreviation: PCP, primary care physician.
bRate ratios reflect the increase in the expected number of shared patients (and thus likelihood of a true information sharing relationship) for every 10% point difference in patient panel characteristics (not applicable to hierarchical clinical condition score). All comparisons yielded P values of less than .001.
cCalculated using a negative binomial regression model adjusted for all variables in the table. Rate ratios were used because the outcome (number of shared patients) is a count rather than binary. Results were similar when a binary outcome variable was analyzed using logistic regression.
dMeasured by episode treatment group intensity score.
acteristics included physician ties only if they were in the top 20% of ties for each individual physician. Some ties that we eliminated were likely to be true information-sharing relationships and conversely some that we retained may be ad hoc or happenstance (though our sensitivity analyses confirmed the robustness of the findings). Moreover, our approach fails to capture physician interactions with other physicians across the country through professional societies and likely underestimates information sharing among physicians within a specialty. Fourth, our model of characteristics associated with ties assumes conditional independence of dyads; currently available statistical methods precluded accounting for potential network-generated dependencies in data sets of our size. Fifth, the rapid adoption of electronic medical records since 2006 could lead to different relationship patterns.28 Sixth, although we demonstrate variation in networks across geographic areas, additional research is needed to establish whether network characteristics are associated with variations in care.

In conclusion, we used novel methods to define social networks among physicians in geographic areas based on shared patients, examined how such networks vary across different geographic regions, and identified physician and patient population factors that are associated with physician patient-sharing relationships. This approach might have useful applications for policy makers seeking to influence physician behavior (whether related to accountable care organizations or innovation adoptions) because it is likely that physicians are strongly influenced by their network of relationships with other physicians.

Author Contributions: Dr Landon had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Landon, Keating, Barnett, Onnella, O’Malley, Christakis.

Acquisition of data: Landon, Christakis.

Analysis and interpretation of data: Landon, Keating, Barnett, Onnella, O’Malley, Keegan, Christakis.

Drafting of the manuscript: Landon, Onnella, O’Malley, Christakis.

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Statistical analysis: Landon, Barnett, Onnella, Paul, O’Malley.

Obtained funding: Landon, O’Malley, Keegan, Christakis.

Administrative, technical, or material support: Keegan, Christakis.

Study supervision: O’Malley, Christakis.

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Online-Only Material: The eAppendix, eTable, eFigures 1 through 3, and interactive that goes with Figure 2A are available at http://www.jama.com.

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