

Physician Patient-sharing Networks and the Cost and Intensity of Care in US Hospitals

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Background: There is substantial variation in the cost and intensity of care delivered by US hospitals. We assessed how the structure of patient-sharing networks of physicians affiliated with hospitals might contribute to this variation.

Methods: We constructed hospital-based professional networks based on patient-sharing ties among 61,461 physicians affiliated with 528 hospitals in 51 hospital referral regions in the US using Medicare data on clinical encounters during 2006. We estimated linear regression models to assess the relationship between measures of hospital network structure and hospital measures of spending and care intensity in the last 2 years of life.

Results: The typical physician in an average-sized urban hospital was connected to 187 other doctors for every 100 Medicare patients shared with other doctors. For the average-sized urban hospital an increase of 1 standard deviation (SD) in the median number of connections per physician was associated with a 17.8% increase in total spending, in addition to 17.4% more hospital days, and 23.8% more physician visits (all $P < 0.001$). In addition, higher "centrality" of primary care providers within these hospital networks was associated with 14.7% fewer medical specialist visits ($P < 0.001$) and lower spending on imaging and tests (−9.2% and −12.9% for 1 SD increase in centrality, $P < 0.001$).

Conclusions: Hospital-based physician network structure has a significant relationship with an institution's care patterns for their patients. Hospitals with doctors who have higher numbers of connections have higher costs and more intensive care, and hospitals with primary care-centered networks have lower costs and care intensity.

Key Words: health care costs, network analysis, primary care, health care systems, hospitals, health care variation

(*Med Care* 2012;50: 152–160)

American regions and hospitals within those regions differ markedly in health care spending and resource use.^{1,2} Even after risk adjustment and price standardization, a significant amount of variation in spending and resource use remains unexplained.^{3,4} These findings are concerning in light of the growth in US health care costs, as hospitals with higher spending and resource use do not appear to have better outcomes and have similar performance on health care quality indicators compared with lower spending hospitals.^{5–7} Prior research has shown that regional levels of health care spending and utilization are associated with physicians' tendency towards aggressive care.^{8–10} It is possible that these regional and institutional patterns of high-cost or low-cost care may be reflected in the networks of physician interactions as collectively, physician interactions contribute to the culture and knowledge of a region or institution. For instance, physicians rely on each other as trusted sources of medical advice and information, often to the exclusion of published research.^{11,12} Therefore, one unexplored area that might contribute to hospital-level variations in care is the structure of the networks of hospital-affiliated physicians as defined by physician-to-physician interactions.¹³ As recently shown, physician interactions may be measured by examining whether or not physicians treat patients in common.¹⁴

We examined how networks based on physician relationships might be associated with care delivery for patients using network analysis.^{15,16} Network analysis had prior successful applications in understanding the behavior of organizations such as academic departments, company boards of directors, and artistic collaborations.^{17–19} Some prior research has used these methods to examine physician advice networks and the diffusion of information among physicians; however, these studies included relatively small samples of physicians or focused on a single technology or drug.^{20–23}

We used data from the Medicare program regarding 2.6 million patients cared for by 61,146 physicians associated with 528 hospitals to study professional networks of physicians defined by patient sharing. We focused our study on networks defined by physicians affiliated with individual hospitals because of the importance of hospitals to the US health care system and the depth of data available for

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Supported by a grant from the National Institute on Aging (P-01 AG-031093) in addition to the Doris Duke Charitable Foundation.

N.A.C. is a founder of and B.E.L. is a member of scientific advisory board of MedNetworks, a company using similar methods for health care applications. There are no other relationships or activities that could appear to have influenced the submitted work.

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Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Website, www.lww-medicalcare.com.

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ISSN: 0025-7079/12/5002-0152

describing hospital performance. We hypothesized that network measures reflecting poorer coordination of care within physicians' professional networks would be associated with higher costs and care intensity within hospitals.

To evaluate this hypothesis, we map the networks of all physicians affiliated with these nationally representative hospitals and characterize these networks with well-accepted measures from the discipline of network science that reflect aspects of care coordination. For instance, the number of physicians who share care for a patient (a measure related to physician degree within the network, described below), has been shown to be associated with increased costs and utilization in prior studies.²⁴⁻²⁶

We extend this prior by adopting concepts developed within network science. Such measures can reveal patterns of medical care that would otherwise be difficult to measure, adding a new set of tools for insight into health care delivery.

METHODS

Data Sources

We used encounter data from the 2006 Medicare Carrier File for 100% of patients enrolled in Medicare Part A (hospital care) and Part B (physician services, outpatient care, and durable medical equipment) in 50 randomly sampled hospital referral regions (HRRs) and the Boston HRR to define physician relationships. We excluded patients enrolled in capitated Medicare Advantage plans as we did not have claims for these patients, and the measures of cost and intensity used (described below) were calculated for fee-for-service enrollees. We obtained descriptive information for hospitals and physicians from the 2006 American Hospital Association annual survey and American Medical Association Masterfile. We defined physicians as primary care physicians (PCPs), medical or surgical specialists, or "other" (psychiatry).

We obtained measures of cost and care intensity for hospitals from the Dartmouth Atlas of Health Care, which were derived using data from 2001 to 2005.²⁷ For each hospital, we examined 3 measures of health care spending (total inpatient and outpatient, imaging, and laboratory tests) and 6 measures of utilization, including hospital days [total, intensive care unit (ICU), and general medical/surgical combined], and number of physician visits (including visits to PCPs and medical specialists). These measures were defined based on a population of patients hospitalized at least once for 1 of 9 life-threatening chronic illnesses (eg, congestive heart failure) who were in the last 2 years of life.²⁸ All Dartmouth measures were adjusted for patient age, sex, race, type of chronic illness, and presence of multiple chronic illnesses.²⁹ Thus, the measures represent the case-mix-adjusted cost and intensity of care for a population of older patients with roughly comparable levels of illness.

Assigning Physicians to a Primary Hospital

We assigned each physician with an office located in a sampled HRR (assessed using the American Medical Association Masterfile) to a principal hospital based on where

they filed the plurality of inpatient claims, or if they did not do any inpatient work, to the hospital where the plurality of patients they saw received inpatient care.³⁰

Our sample initially included 65,757 eligible physicians in office-based patient care specialties (excluding pathologists, emergency medicine, radiologists, and anesthesiologists) affiliated with 867 general medical surgical hospitals within the selected regions. After excluding low-volume hospitals for which the outcomes measured could not be ascertained (≤ 400 deaths annually) and physicians with no ties within their assigned hospital (mostly applicable to physicians located at the border of an HRR who primarily used a hospital outside of our sample), our final sample included 61,461 physicians affiliated with 528 hospitals.

Ascertaining and Measuring Hospital-affiliated Networks

To define a network of relationships between the physicians in our dataset, we identified a relationship (tie) between 2 doctors if they each had a significant encounter with 1 or more common patients. These encounters included face-to-face visits or meaningful procedures with a value of at least 2 relative value units. This was done to capture encounters where an office visit might not be billed such as those related to bundled surgical procedures. After identifying significant encounters between physicians and patients, as depicted in Figure 1A, we then created a tie between any 2 doctors who cared for 1 or more patients in common (outlined schematically in Figure 1B). The use of shared patients to identify network ties has been validated in a recent study.¹⁴

We focused on 2 structural measures commonly used in network analyses that we hypothesized would reflect care coordination within the network. These measures are briefly summarized below, and are schematically explained in Figure 1C with additional details presented in the Appendix Supplemental Digital Content 1, <http://links.lww.com/MLR/A234>.

Degree is defined as the number of ties an individual physician has in the network, or equivalently, the number of other doctors a physician is connected with through the sharing of patients. The doctors contributing to a physician's degree can be any doctors a physician's patients have seen in the physician's HRR. To account for a physician's Medicare patient volume, we adjusted degree by dividing each physician's degree by the total number of Medicare patients the physician shared in 2006 with other doctors (controlling for a physician having higher degree simply because he sees more patients). A physician with a high adjusted degree shares his patients with a broader array of other doctors than a physician with a low adjusted degree. This measure is independent of the number of doctors seen per patient, as, for example, a physician's fixed panel of patients could all see the same 20 specialists or could see 200 specialists. As our analysis was at the hospital level, we then summarized this measure across the physicians in a hospital network by using the median adjusted degree of all physicians at a hospital. We hypothesized that hospitals whose physician networks had a higher median degree would have higher costs and care

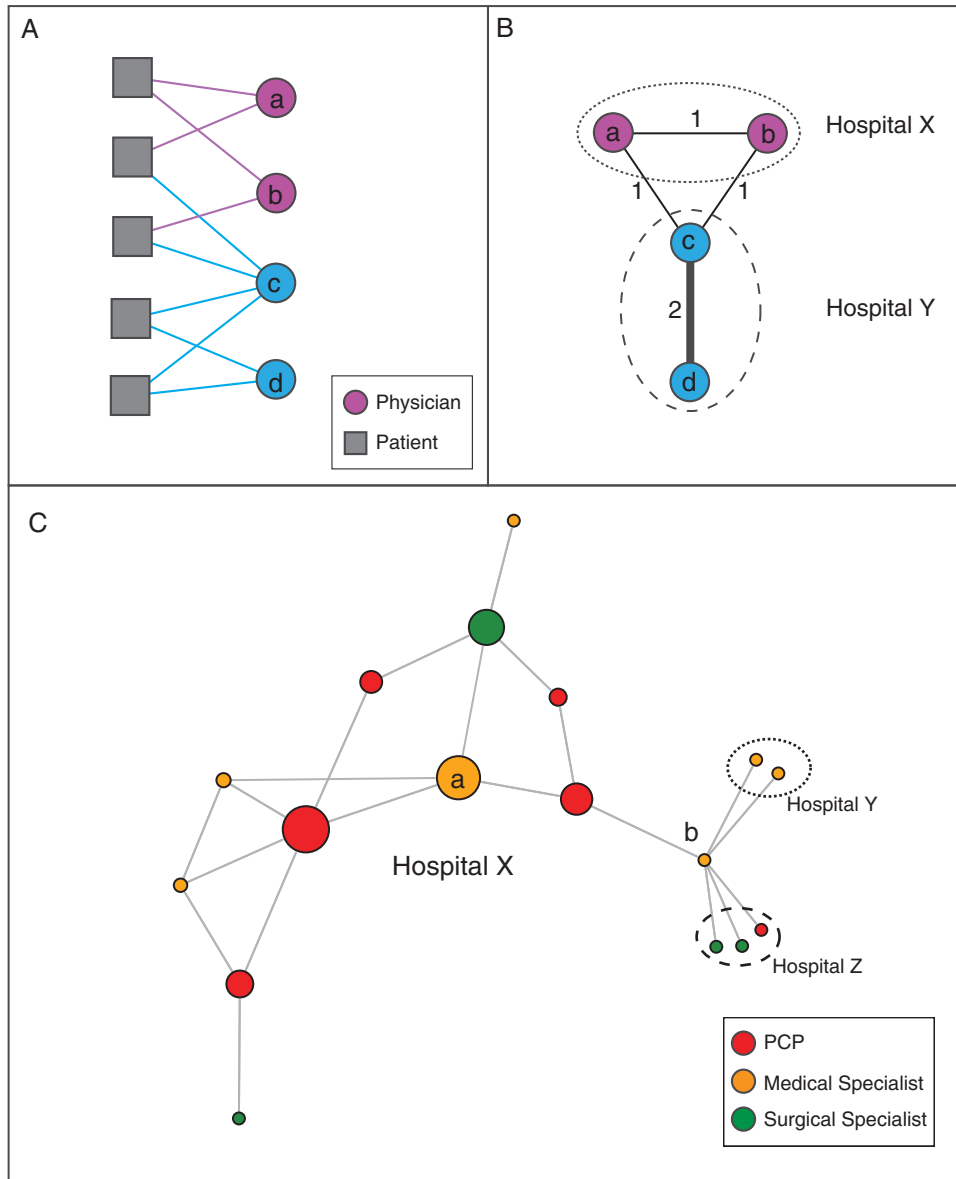


FIGURE 1. Panel A illustrates the observed connections between a hypothetical group of physicians and patients (denoted by solid lines connecting patients to physicians), the first step in creating a physician network. In Panel B, the group of patient-physician ties depicted in panel A is transformed into a physician-physician network in which physicians are linked by a tie with strength equal to the number of patients they share. For instance, in panels A and B, physicians A and C share 1 patient, and physicians C and D share 2 patients. Also depicted in panel B is that physicians are assigned to hospitals, and their networks can extend within and outside their affiliated hospitals. Panel C shows a simple network to illustrate the network measures of degree and centrality used in this study. Each circle represents a physician and is colored by its specialty. **Degree:** The adjusted degree measures how many colleagues physicians share patients with, adjusted for the number of patients they treat. In panel C, doctor A has a degree of 4 because she is connected to 4 other physicians. Doctor B has a degree of 6. If doctor A treated 10 Medicare patients in 2006, her adjusted degree would be 40 colleagues per 100 shared patients. Similarly, if doctor B also treated 10 Medicare patients in 2006, her adjusted degree would be 60 colleagues per 100 shared patients. **Centrality:** The size of each circle is proportional to its betweenness centrality within hospital X (which by definition is 0 for physicians in hospitals Y and Z). The betweenness centrality measures the centrality of a physician in her network by quantifying how often the physician functions as an intermediary in the shortest paths connecting each physician to every other physician (see Appendix, Supplemental Digital Content 1, <http://links.lww.com/MLR/A234> for details). In this study, we adapt centrality to calculate a measure called "relative centrality", which is illustrated with larger, real hospital networks in Figure 2.

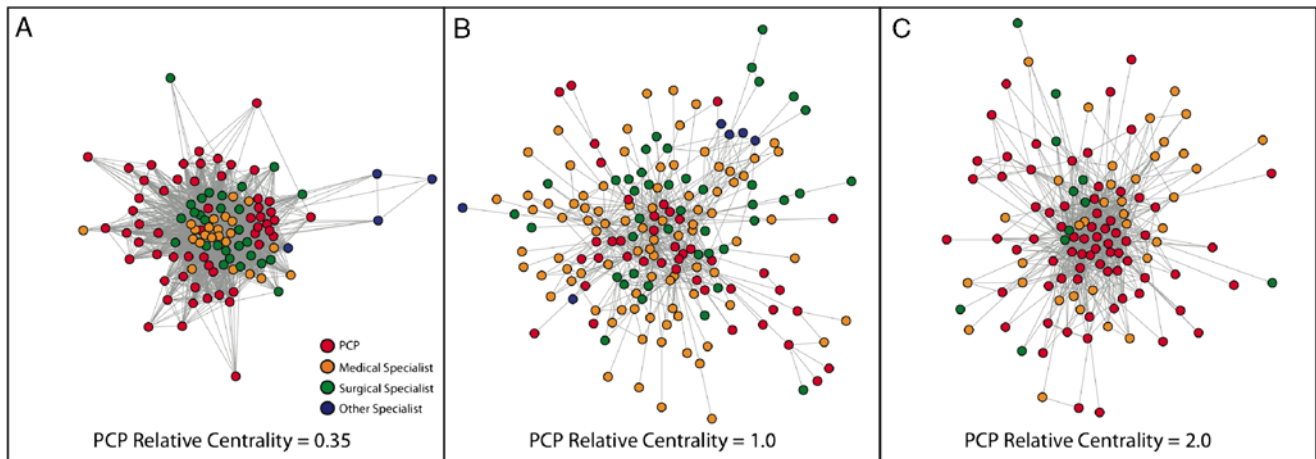


FIGURE 2. Example hospital networks: illustrating relative centrality. Three example hospital networks from the dataset in this study are depicted in panels A to C. Each point represents a physician, colored by the specialty of that physician [red = primary care, orange = medical specialist, green = surgical specialist (including general surgeons), blue = other specialist]. Each tie between 2 physicians represents the sharing of 5 or more patients. This figure depicts both the complex organization of physicians in different hospitals, but also visually demonstrates how the concept of relative centrality reflects changes in physician networks. In panel A, the PCP relative centrality (explained in panel C) is 0.35, so PCPs are about a third as central as other physicians in this network. This is reflected by the tight group of medical and surgical specialists at the center of this physician network, with the many PCPs in the network pushed to the periphery of this network. In panels B and C, PCPs move more toward the center of patient-sharing exchanges as the PCP relative centrality grows.

intensity due to the greater challenges of care coordination as a physician shares patients with more colleagues.^{24–26,31} A physician sharing patient care with a broad set of colleagues may have more difficulty consolidating his patients' clinical information and guiding their care than a physician sharing patients with fewer colleagues.

Betweenness centrality is a measure that describes the tendency of a physician to be located in the middle of the network surrounding him.³² The betweenness centrality of a physician is calculated in the following way: consider connecting each physician to every other physician in the network going through as few intermediate relationships as possible; the betweenness centrality of a physician is proportional to the number of times he lies on any of these paths as an intermediary (see the Appendix, Supplemental Digital Content 1, <http://links.lww.com/MLR/A234> for equation and details). Visually, doctors with high betweenness centrality lie in the middle, rather than on the periphery, of a network map visualized with standard algorithms.³³ Physicians with higher betweenness centrality are well positioned in their network to have greater access to, and influence on, the flow of information among doctors in their network. In Figure 1C, the size of each circle (representing a physician) is proportional to that physician's betweenness centrality. The calculation of betweenness centrality is confined to doctors within a hospital.

We were interested in how central PCPs were in a hospital network relative to all other doctors in the network. To calculate this measure, we used the ratio of the average centrality of PCPs over the average centrality of all other doctors in a hospital (see Appendix, Supplemental Digital Content 1, <http://links.lww.com/MLR/A234>). The resulting

relative centrality value can be interpreted as how much more or less central PCPs are when compared with the other doctors in a hospital network. Given the importance of primary care systems for health care costs,³⁴ we hypothesized that hospitals whose networks of patient sharing were more centered around PCPs would have lower costs and care intensity. Hospitals with networks focused around PCPs may have improved capacity for care coordination because specialists are more likely to share patients with a core set of PCPs in those systems (Fig. 2).

Hospital Control Variables

Hospital-level control variables included the number of hospital beds, number of physicians assigned to a hospital, location (urban or suburban/rural/isolated),³⁵ teaching hospital status [major (member of the Council of Teaching Hospitals), minor (any nonmajor teaching hospital with medical school affiliation or residency program), none], ownership (not-for-profit, for-profit, government),³⁶ nurse full time equivalents per 1000 inpatient days, and the percentage of admissions from Medicare and Medicaid patients. In addition, we controlled for the proportion of physicians assigned to a hospital who were PCPs and the mean shared patient volume per physician at a hospital, defined for each physician as the number of patients shared in 2006 with other doctors.

Statistical Analysis

We compared our sample of hospitals with hospitals nationally using χ^2 or *t* tests and assessed differences in network measures across hospitals using 1-way analysis of variance. We used multivariable weighted linear regression to model the effect of each network structure measure on

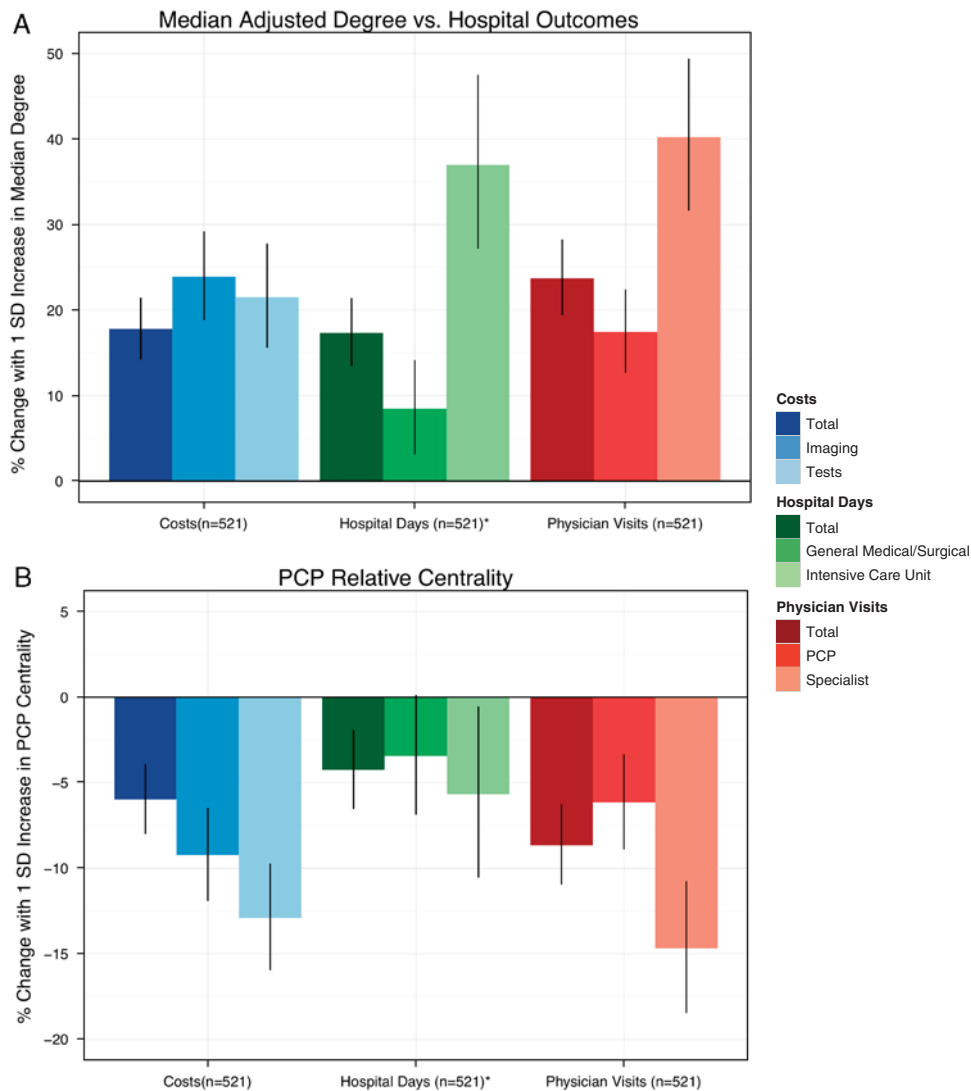


FIGURE 3. Adjusted estimates of hospital network structure versus cost and utilization outcomes. Each section represents the estimated effect of increasing a network measure (A), median adjusted degree, (B), PCP relative centrality by 1 standard deviation for the average-sized urban, nonprofit, nonteaching hospital in our sample on 3 different cost, hospital day, and physician visit outcomes. All estimates are adjusted for several hospital characteristics described in the Methods, including hospital size, urban/rural location, and case mix. Error bars show 95% confidence intervals for each estimate. *5 hospitals had missing data for the general medical/surgical and intensive care unit (ICU) hospital days outcomes, but did have data for the total hospital days outcome.

cost or care intensity outcomes, adjusting for the hospital characteristics detailed above. To account for skewness, we log-transformed each outcome variable, and to account for the precision with which each outcome was measured, we weighted observations by the number of annual deaths used by the Dartmouth Atlas group to measure the cost and utilization data.²⁷ We also used robust heteroscedastic-consistent standard error estimation in model fitting^{37,38} to account for the possibility that the variance of an observations varies with the mean value of the predictors.

As some small hospitals had excessively large or small centrality ratios, we set outliers to equal the 1st and 99th percentile values, respectively (see Appendix, Supplemental

Digital Content 1, <http://links.lww.com/MLR/A234>).³⁹ To enable regression coefficients to be directly compared, we centered each continuous network predictor and hospital covariate to have mean 0 and standard deviation 1 over the entire sample. Regression coefficients are reported as percent change expected in the outcome of interest for an average-sized urban hospital (the median hospital) associated with an increase of 1 standard deviation in the network measure predictor to aid comparison across the models presented. As network measures differed for urban and nonurban hospitals, we performed a secondary analysis of covariance for each model described above that included an interaction between the network variable of interest and urban/rural location.

TABLE 1. Sample Characteristics

	All US General Hospitals (n = 4597) Mean (SD)	Study Sample (n = 528) Mean (SD)
Beds	166 (181)	248 (240)
Nursing FTE/1000 inpatient days	8.6 (18.7)	6.5 (2.5)
Percent Medicare admissions	49% (19)	45% (10)
Percent Medicaid admissions	17% (20)	19% (9)
	n (%)	n (%)
Urban/rural (RUCA)		
Urban	2282 (50%)	332 (63%)
Suburban/rural	1741 (38%)	179 (34%)
Isolated	570 (12%)	17 (3%)
Teaching status		
None	3517 (77%)	345 (65%)
Minor	849 (19%)	128 (24%)
Major	231 (5%)	55 (10%)
Governance		
Not for profit	2760 (60%)	348 (66%)
Public	1145 (25%)	90 (17%)
For profit	692 (15%)	90 (17%)
US region		
Northeast	605 (13%)	127 (24%)
South	1742 (38%)	207 (39%)
Midwest	1366 (30%)	101 (19%)
West	884 (19%)	93 (18%)

FTE indicates full time equivalent.

t tests and χ^2 tests were performed, as appropriate, to evaluate differences between the population of hospitals in the US and the sample hospitals. All comparisons were significant at the $P < 0.001$ level.

Five hospitals had missing data for the general medical/surgical and ICU hospital days outcomes; in addition, 7 hospitals were missing data for PCP relative centrality due to undefined values (see Appendix, Supplemental Digital Content 1, <http://links.lww.com/MLR/A234>). As these missing values were the outcomes and key predictors of interest, the hospitals with missing data were excluded from the relevant models (reflected in the sample sizes shown in Figure 3). We performed extensive sensitivity analyses to test the decisions made in the modeling process and found that our results were robust under a variety of conditions, including when accounting for Medicare Advantage penetration (data not shown, see Appendix, Supplemental Digital Content 1, <http://links.lww.com/MLR/A234>). Complete results for all covariates included in the models are in Appendix Table 2, Supplemental Digital Content 1, <http://links.lww.com/MLR/A234>.

All analyses were performed in R version 2.10,⁴⁰ using the *igraph* package (version 0.5.3) for calculating network structure measures and the *Zelig* package (version 3.4–8) for multivariable regression models.^{41,42} We visualized hospital networks using the Fruchterman-Reingold algorithm as implemented in *igraph*.^{33,43} This study was approved by the Institutional Review Board at Harvard Medical School.

RESULTS

We studied 528 hospitals and the 61,461 physicians caring for 2.6 million Medicare patients who comprised their

associated physician networks. Compared with all general medical/surgical hospitals in the US, our sample contained larger hospitals that were more likely to be in urban settings ($P < 0.001$ for both) (Table 1).

Hospital Characteristics and Network Structure

The average median adjusted degree of a mid-sized hospital in our sample was 187 [standard deviation (SD) = 86] and ranged from 155 (SD = 57) for smaller hospitals to 281 (SD = 124) for larger hospitals ($P < 0.001$) (Table 2). Therefore, the typical physician in a mid-sized hospital shared patients with 187 other doctors for every 100 patients shared with other doctors. PCP relative centrality decreased with hospital size, from a mean of 1.11 (SD = 0.87) in smaller hospitals to 0.80 (SD = 0.54) in larger hospitals ($P < 0.001$).

To illustrate the concept of relative centrality, the network graphs of 3 similarly sized hospitals are depicted in Figure 2. In the network for the hospital in Figure 2A, medical specialists and surgeons are far more central, with almost all PCPs being located in the periphery of the network. In contrast, the networks of the hospitals in Figure 2B and C have PCPs more prominently participating as central physicians. The relative centrality of PCPs in hospitals A, B, and C are 0.35, 1.0, and 2.0, respectively.

Relationship Between Hospital Networks and Care Patterns

The unadjusted relationships between median adjusted degree, PCP centrality, and total Medicare spending per hospital are depicted in Appendix Figure 1, Supplemental Digital Content 1, <http://links.lww.com/MLR/A234>.

Adjusted relationships between hospital network structure and hospital outcomes, controlling for hospital characteristics, are presented in Figure 3. For the average-sized, urban hospital in our sample, an increase of 1 SD in the median adjusted degree (corresponding to an addition of 107 doctors per 100 patients shared to the typical doctor's number of contacts) was associated with a 17.8% [95% confidence intervals (CI), 13.2, 22.5] increase in total Medicare spending, 17.4% (95% CI, 12.6, 22.4) more hospital days, and 23.8% (95% CI, 18.6, 29.1) more physician visits in the last 2 years of life.

In contrast, higher centrality of primary care within an average-sized urban hospital network was with a decrease in overall spending of 6.0% (95% CI, -9.5, -2.4), along with 9.2% (95% CI, -13.1, -5.1) lower spending on imaging and 12.9% (95% CI, -17.0, -8.6) lower spending on tests for a 1 SD increase. In addition, higher PCP centrality was accompanied by 8.6% (95% CI, -12.1, -5.0) fewer physician visits and 14.7% (95% CI, -19.4, -9.7) fewer medical specialist visits.

In analyses examining the interaction between the network measures and urban/nonurban location, the association between median adjusted degree and all 9 cost and utilization outcomes was unaffected by the urban/nonurban location of hospitals (all $P > 0.05$ for interaction). The association between PCP relative centrality and the 9 outcomes was mostly nonsignificant, although still negative, for nonurban hospitals (all $P < 0.001$ for interaction except

TABLE 2. Average Network Measures by Selected Hospital Characteristics

	n (%)	Median Degree Per 100 Shared Patients		PCP Relative Centrality*	
		Mean (SD)	P	Mean (SD)	P
All	528 (100%)	208 (107)	N/A	0.90 (0.68)	N/A
No. beds					
Smaller (<123)	176 (33%)	155 (57)	<0.001	1.11 (0.87)	<0.001
Mid-size (123–265)	176 (33%)	187 (86)		0.79 (0.54)	
Large (>265)	176 (33%)	281 (124)		0.80 (0.54)	
Urban/rural location					
Urban	332 (63%)	253 (110)	<0.001	0.78 (0.49)	<0.001
Suburban/rural/isolated	196 (37%)	131 (36)		1.11 (0.88)	
Percent Medicare admissions					
Low (<42%)	175 (33%)	270 (126)	<0.001	0.90 (0.72)	0.21
Medium (42%–50%)	183 (35%)	190 (88)		0.83 (0.57)	
High (>50%)	170 (32%)	163 (68)		0.97 (0.73)	
Percent Medicaid admissions					
Low (<15%)	188 (36%)	197 (90)	0.008	0.84 (0.62)	0.24
Medium (15%–20%)	156 (30%)	197 (103)		0.89 (0.63)	
High (>20%)	184 (35%)	228 (123)		0.97 (0.77)	
Teaching status					
None	345 (65%)	170 (77)	<0.001	0.95 (0.75)	0.002
Minor	128 (24%)	236 (98)		0.73 (0.48)	
Major	55 (10%)	378 (106)		0.97 (0.56)	
Profit governance					
Not for profit	348 (66%)	213 (109)	0.10	0.86 (0.64)	0.30
Public	90 (17%)	186 (108)		0.98 (0.74)	
For profit	90 (17%)	209 (95)		0.96 (0.76)	
US region					
Northeast	127 (24%)	242 (116)	<0.001	0.79 (0.55)	0.004
South	207 (39%)	182 (88)		1.02 (0.78)	
Midwest	101 (19%)	219 (119)		0.93 (0.78)	
West	93 (18%)	206 (106)		0.77 (0.41)	

P values calculated using 1-way analysis of variance.

*For PCP relative centrality, outlier values were set equal to 1st and 99th percentile values. In addition, PCP centrality cannot be lower than 0, so the large SD also reflects the degree of positive skew in the data.

PCP indicates primary care physicians.

for general medical/surgical hospital days, $P=0.06$ and ICU days, $P=0.14$, results not shown).

DISCUSSION

This is the first large-scale analysis to explore how the structure of patient-sharing relationships among physicians is related to care patterns within hospitals. In addition, we present a novel method for using readily available administrative data to construct networks of physicians that will be useful for studying physician practice patterns.¹⁴ We found that the structure of physician patient-sharing networks is significantly associated with Medicare spending and care patterns. Higher adjusted degree is associated with higher spending and health care utilization even after adjusting for hospital characteristics. In contrast, higher PCP relative centrality is associated with lower spending and utilization. These results are consistent with the hypothesis that network measures reflective of poorer coordination of care within hospitals are associated with higher costs and care intensity.

We found that hospitals with physicians whose patients see a broader array of other doctors (higher adjusted degree) have higher levels of spending. They also use more hospital care, physician visits, and imaging. These associations may reflect the difficulty of care coordination as physicians have

to manage information from an increasing number of colleagues, which could be either a cause or an effect of increased health care utilization.

Another possible explanation for this phenomenon might be that hospitals whose physicians have high median adjusted degree have sicker patients who see more physicians, leading to higher costs and utilization of services. Our methods make this unlikely for 2 reasons. First, our outcome measures are risk-adjusted to reflect similar patient populations, so differences in costs are not reflective of differences in burden of illness.¹³ Second, the adjusted degree measure is distinct from the number of physicians that patients see. The difference between a broad and focused network of physicians among the doctors caring for patients is the factor measured by the median adjusted degree.

In contrast, a network measure that likely reflects greater coordination of care, PCP relative centrality, was associated with lower imaging and test spending in addition to fewer ICU days and specialist visits. These findings build upon prior state-level analyses showing that states with more PCPs have lower costs,⁴⁴ but extend this work to more formal network analysis considering the relative location of PCPs within a network of their colleagues. Interestingly, PCP relative centrality did not have a significant association with costs and utilization in nonurban hospitals. One possible interpretation

of this result is that urban hospitals without primary care centered networks may be more likely to use readily available specialist services, whereas in nonurban areas, this may not be as relevant because of less access to specialists.⁴⁵ Further research is needed to understand the interaction between PCP centrality in urban and nonurban settings, but this approach could provide insight into how PCPs might best be utilized to contain costs and care utilization.

A prior study showed that the average PCP shares patients with approximately 99 other physicians based at 53 other practices per 100 Medicare patients treated.³¹ However, that analysis was based on patients assigned to individual PCPs. We demonstrate that, when considering all patients being cared for by all physicians, including both PCPs and specialists, physicians are connected to 155 to 281 doctors per 100 Medicare patients shared with other doctors. This network-based perspective illustrates the challenge of care coordination among physicians.

Our study is subject to several limitations. First, we ascertained network structure based on the presence of shared patients using administrative data. Although this technique has been validated,¹⁴ we nevertheless cannot know what information or behaviors, if any, pass across the ties defined by shared patients. In addition, our data are cross-sectional and only included elderly patients insured by the Medicare program. The local network of physicians and patients in a hospital or region is likely to be in flux, and future analyses would be enhanced by longitudinal data. Furthermore, the sample of hospitals we used is representative of larger, urban hospitals rather than all US hospitals. However, because the sample included a full range of hospital sizes, and because our focus is on the relationship between variables (not population aggregates or means), the representativeness should be less of a concern. In addition, we used risk-adjusted hospital-level data on costs and care intensity averaged over 2001 to 2005 for our outcome measures, although our networks were mapped with 2006 data. However, this discrepancy would tend to bias our results towards the null.

Next, our main dependent variables were calculated using several years of data from the Medicare program by the Dartmouth Atlas of Healthcare. Although others have noted the possibility of inadequate risk adjustment or failure to account for differences in the prices paid for services in different regions,^{46,47} substantial variation in spending remains even after further risk adjustment.^{3,4} In addition, our models include several hospital-level characteristics that are likely to be associated with unmeasured case-mix, including size, urban versus rural location, and teaching hospital affiliation. With regard to prices, although the spending measures were not adjusted for regional payment differences, regional variation is reduced only modestly when taking prices into account.⁴⁷ Moreover, our 6 utilization measures (eg, hospitalizations) would not be affected by price differences and the findings for these outcomes serve to validate the findings we observed for spending.

Lastly, due to the observational design of this study, our results should not necessarily be interpreted as causal. Further work is needed to determine the causal mechanisms

underlying these associations. In addition, although we adjusted for numerous covariates, we cannot rule out the possibility of unobserved confounders that could help explain the mechanisms driving the associations we observe. These unmeasured confounders could reflect local medical culture and market dynamics.

In summary, we studied a large sample of physician networks to examine how network structures reflect health care in a national sample of hospitals. This analysis highlights the importance of physician relationship networks—networks that are embedded in institutional structures and that may inform health policy and physician workforce management. We demonstrate that the characteristics of physician networks affiliated with a hospital are correlated with a hospital's performance in a manner consistent with the hypothesis that poorer coordination of care is associated with greater spending and care intensity.

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