Differences Among Cardiologists in Rates of Positive Coronary Angiograms

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Background—Understanding the sources of variation for high-cost services has the potential to improve both patient outcomes and value in health care delivery. Nationally, the overall diagnostic yield of coronary angiography is relatively low, suggesting overutilization. Understanding how individual cardiologists request catheterization may suggest opportunities for improving quality and value. We aimed to assess and explain variation in positive angiograms among referring cardiologists.

Methods and Results—We identified all cases of diagnostic coronary angiography at Massachusetts General Hospital from January 1, 2012, to June 30, 2013. We excluded angiograms for acute coronary syndrome. For each angiogram, we identified clinical features of the patients and characteristics of the requesting cardiologists. We also identified angiogram positivity, defined as at least 1 epicardial coronary stenosis ≥50% luminal narrowing. We then constructed a series of mixed-effects logistic regression models to analyze predictors of positive coronary angiograms. We assessed variation by physician in the models with median odds ratios. Over this time period, 5015 angiograms were identified. We excluded angiograms ordered by cardiologists requesting <10 angiograms. Among the remaining 2925 angiograms, 1450 (49.6%) were positive. Significant predictors of positive angiograms included age, male patients, and peripheral arterial disease. After adjustment for clinical variables only, the median odds ratio was 1.23 (95% CI 1.0–1.36), consistent with only borderline clinical variation after adjustment. In the full clinical and nonclinical model, the median odds ratio was 1.07 (95% CI 1.07–1.20), also consistent with clinically insignificant variation.

Conclusions—Substantial variation exists among requesting cardiologists with respect to positive and negative coronary angiograms. After adjustment for clinical variables, there was only borderline clinically significant variation. These results emphasize the importance of risk adjustment in reporting related to quality and value. **(*J Am Heart Assoc*. 2015;4:e002393 doi: 10.1161/JAHA.115.002393)**

Key Words: coronary angiography • outcomes research • variation analysis

Utilization of high-cost health services has been shown to vary among physicians.[1–3] Statistical models that adjust for patient and visit-level characteristics can explain much of this variation among physicians.[4] Understanding the sources of variation for high-cost services has the potential to improve patient outcomes, by directing patients to providers who share their treatment preferences, and value in health care delivery.

Coronary angiography is the gold standard for the diagnosis of coronary artery disease, although less invasive and less expensive methods are available. Current guidelines for the diagnosis of coronary artery disease list coronary angiography as a class 1 indication only when clinical characteristics and results of noninvasive testing indicate a high likelihood of disease,[5] favoring noninvasive strategies in other situations to conserve health care resources and to reduce patient risk.

Despite evidence of declining utilization,[6] the overall diagnostic yield of diagnostic coronary angiography is low nationally,[7] raising a question about overutilization. Coronary angiography is used nearly 4 times more frequently in the United States than in the United Kingdom.[8] The optimal frequency of diagnostic coronary angiography and the optimal threshold at which to refer for diagnostic angiography are not clear. Indeed, some evidence exists of continued increases in

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detection of high-risk coronary disease with higher rates of testing.[9] Nevertheless, the increased risk of the procedure itself may not justify the incremental use of this procedure at high rates of utilization.

Large national databases, such as the National Cardiovascular Data Registry, provide great insight into variation in cardiac procedures; however, they do not contain information about physicians who refer for these types of procedures. The decision to pursue coronary angiography is typically made by a referring cardiologist, not by the cardiologist performing the procedure. As such, variation in decision making by the referring cardiologist is important to understand so as to guide efforts to reduce unwarranted utilization. Prior work does not explain whether such variation exists or whether any variation results from case mix or practice style. Determining whether coronary angiograms requested by different referring cardiologists yield different results may demonstrate opportunities to reduce overutilization. In that context, we sought to characterize both the extent and the origin of variation in the outcomes of coronary angiography at a large academic medical center.

Methods

Analytic Aims

To characterize both the extent and origin of variation, we posed 2 analytic aims. First, we assessed the extent to which variation exists in rates of positive angiograms among all referring providers. Second, to explain the sources of variation, we evaluated selected physician characteristics and individual physicians as predictors of positive angiograms while controlling for patient factors that are known to predict positive angiograms.

Study Population

Massachusetts General Hospital is the largest hospital affiliated with Harvard Medical School and the largest volume center for diagnostic coronary angiography and percutaneous coronary intervention in New England. For each diagnostic coronary angiogram, physicians enter patient data into an electronic database, including demographic information, the clinical indication for the procedure, and the names of the referring physician and the physicians performing the procedure. Of physicians who request angiograms, the majority are staff cardiologists at the hospital (74 of 117, 63%).

Outcomes and Covariates

From the hospital's catheterization database, we identified all cases of diagnostic coronary angiography performed at Massachusetts General Hospital from January 1, 2012, to June 30, 2013. We defined the outcome as a positive coronary angiogram with at least 1 lesion ≥50% narrowing of an epicardial coronary artery.

We grouped all angiograms by referring cardiologist. To determine characteristics of the referring cardiologist, we linked angiogram data to administrative data about each physician, including age, physician gender, clinical full-time equivalent, volume of catheterizations requested, and academic rank at Harvard Medical School (instructor, assistant professor, associate professor, or professor).

We identified patient characteristics such as indication for catheterization (ST-segment elevation myocardial infarction [STEMI], non-STEMI, unstable angina, stable angina, atypical chest pain, or no symptoms), history of cardiac transplantation, cardiac valvular disease, cardiomyopathy, previous percutaneous coronary intervention, previous coronary artery bypass grafting, previous myocardial infarction, cardiogenic shock, congestive heart failure, diabetes, renal insufficiency, and peripheral vascular disease.

We also defined a variable, called *patient–practice category*, based on the requesting cardiologist's primary affiliation within cardiology (invasive/interventional, electrophysiology, heart failure, noninvasive). Patient–practice category was considered a physician-level variable because it reflected the practice group of the cardiologist. As a sensitivity analysis, we considered the patient–practice category as a patient-level variable because it might also have reflected differences among patients.

We also linked patient records to hospital billing data identifying patient clinical characteristics including hypothyroidism, liver disease, solid tumor without metastasis, collagen vascular disease, obesity, weight loss, fluid and electrolyte disorders, drug abuse, psychosis, depression, and hypertension. We chose these variables because they are known to affect either coronary disease or health status generally.

Statistical Analysis

We explored the relative effects of physician characteristics and patient characteristics in determining the results of diagnostic angiograms. As such, we excluded angiograms for the indications of STEMI, non-STEMI, and unstable angina because we assumed that the decision to pursue coronary angiography would vary less by individual referring physicians in the setting of acute coronary syndrome. We also excluded angiograms ordered by physicians who had requested <10 angiograms. Consequently, all angiograms included were requested by staff cardiologists at Massachusetts General Hospital the faculty of Harvard Medical School.

Using the binary outcome of diagnostic catheterization as either positive or negative, we sought to explain the extent and source of variance in the results of diagnostic catheterization using a series of mixed-effects models. We estimated 3 different models. The first, the unadjusted model, included only ordering physician as a random effect. This model was designed to measure the extent of crude variation before adjusting for patient and physician factors. The second model, the clinical model, included patient characteristics only. This model was designed to capture variation associated with clinical conditions. The third model, the clinical and nonclinical model, added physician factors: age, physician gender, clinical full-time equivalent, patient–practice category, and Harvard academic ranking. The difference in variation between models 2 and 3 can be considered variance due to style or practice of physicians. In all 3 models, the ordering physician is a cluster variable with patients clustered among individual physicians.

For each of the 3 mixed-effects models, we calculated the median odds ratio (MOR) to measure variance among ordering physicians after adjustment for variables in the sequential models. The MOR is a measure of intraphysician variance in mixed-effect logistic models that estimates the difference in likelihood of a positive angiogram for 2 randomly selected physicians.[10] By definition, the MOR is always ≥1.0. An MOR of 1.0 would suggest no variation among physicians, and a greater MOR would suggest the presence of variation among individual physicians. An MOR >1.2 has been recognized as a marker of clinically significant variation.[11,12]

To explore the validity of our primary findings, we performed 3 sensitivity analyses. First, we combined the professor and associate professor categories into a single category. Second, to explore the possibility that patient–practice category reflects differences between patients rather than differences between physicians, we considered patient–practice category as a patient-level variable instead of a physician-level variable. Third, we included unstable angina in the analysis.

The institutional review board at Partners Healthcare waived the need for formal review because this work was performed for administrative purposes. In that context, the need for informed consent was waived. Analyses were performed with SAS version 9.4 (SAS Institute).

Results

Over the time period of this study, 5015 total coronary angiograms were performed at Massachusetts General Hospital. For the variance analysis, we excluded angiograms ordered by physicians who requested <10 angiograms. We also excluded angiograms for the indications of STEMI, non-STEMI, and unstable angina. After application of the exclusion criteria, 2925 angiograms (58.3%) remained in the analysis. Characteristics of the angiograms appear in Table 1. Among the 2925 angiograms, 1450 (49.6%) were positive, according to the definition that we had established. Positivity rates by individual clinicians appear in Figure 1. In univariate analyses, catheterizations were more likely to be positive for patients with stable angina, cardiomyopathy, previous percutaneous coronary intervention, or previous coronary artery bypass grafting and were more likely to be negative for patients with atypical chest pain, female patient gender, valvular disease, chronic pulmonary disease, and liver disease.

After exclusions, 49 ordering physicians were represented in 4 patient–practice categories. Of those, 24 were noninvasive cardiologists (49%), 9 were electrophysiologists (18%), 11 were interventional or invasive cardiologists (22%), and 5 were heart failure cardiologists (10%). The mean ages for instructors, assistant professors, associate professors, and professors, respectively, were 44.4, 49.6, 54.9, and 66.4 years (P=0.0006).

Before statistical adjustment, catheterizations requested by invasive/interventional cardiologists were more likely to be positive, and catheterizations requested by heart failure cardiologists were more likely to be negative (P<0.01 for both). Catheterizations requested by physicians did not differ by level of Harvard academic rank in the unadjusted analyses (Figure 2).

Adjusted Results

Tables 2 and 3 present the estimates of the clinical and nonclinical model. Including both patient and physician variables as fixed effects and individual physicians as random effects, catheterizations requested by professors at Harvard Medical School (relative to instructors, the lowest academic rank) were more likely to be negative (odds ratio [OR] 0.51, P<0.01). Catheterizations requested by associate professors were also more likely to be negative, although this finding was of marginal statistical significance (OR 0.77, P=0.11). Catheterizations requested by assistant professors were positive at similar rates to catheterizations requested by instructors (OR 1.13, P=0.31). Catheterizations requested by male and female cardiologists did not have different proportions of positive catheterizations after multivariate adjustment (OR for female cardiologists 1.02, P=0.92). With respect to patient–practice category, angiograms for patients requested by noninvasive cardiologists, electrophysiologists (P=0.51), heart failure cardiologists (P=0.79), and invasive/interventional cardiologists (P=0.93) had similar positivity rates.

With respect to patient variables in the clinical and nonclinical model, angiograms were more likely to be positive for older patients; for patients with stable angina, previous myocardial infarction, previous coronary artery bypass grafting, or previous percutaneous coronary intervention; or for patients with peripheral artery disease, diabetes with complications, and weight loss. Angiograms were more likely to be

Table 1. Characteristics of Positive and Negative Angiograms

Characteristic	Negative (n=1475)	Positive (n=1450)	*P* Value
Patient characteristics			
Atypical chest pain	372	152	<0.0001
Stable angina	153	594	<0.0001
No symptoms or angina	950	704	<0.0001
Cardiac transplant	159	49	<0.0001
Cardiomyopathy	190	300	<0.0001
Previous PCI	189	535	<0.0001
Previous CABG	31	382	<0.0001
Previous MI	148	575	<0.0001
Cardiogenic shock	13	12	0.86
Female gender (patient)	607	337	<0.0001
Congestive heart failure	242	222	0.41
Valvular disease	189	146	0.02
Pulmonary circulation disease	59	26	<0.0001
Peripheral vascular disease	162	279	<0.0001
Paralysis	9	3	0.09
Other neurological disorders	54	62	0.4
Chronic pulmonary disease	236	198	0.07
Diabetes without chronic complications	213	277	<0.001
Diabetes with chronic complications	52	82	0.006
Hypothyroidism	116	107	0.62
Renal failure	214	265	0.006
Liver disease	66	37	<0.001
Peptic ulcer disease	0	1	0.32
Lymphoma	7	7	0.98
Metastatic cancer	4	3	0.72
Solid tumor without metastasis	11	12	0.79
Rheumatoid arthritis/collagen vascular disease	45	51	0.48
Coagulopathy	52	53	0.85
Obesity	301	307	0.62
Weight loss	15	5	0.03
Fluid and electrolyte disorders	102	107	0.63
Chronic blood loss anemia	4	3	0.72
Iron deficiency anemias	115	124	0.46
Drug abuse	30	14	0.02
Psychoses	25	18	0.31
Depression	155	122	0.05
Hypertension	736	853	<0.0001

Continued

Table 1. Continued

Characteristic	Negative (n=1475)	Positive (n=1450)	*P* Value
Physician characteristics			
Noninvasive cardiologist	497	491	0.91
Interventional cardiologist	608	702	<0.0001
EP cardiologist	105	111	0.58
Heart failure cardiologist	266	146	<0.0001
Female physician	127	147	0.15
Instructor	501	492	0.98
Assistant professor	459	445	0.8
Associate professor	275	296	0.23
Professor	240	217	0.33

CABG indicates coronary artery bypass grafting; EP, electrophysiologist; MI, myocardial infarction; PCI, percutaneous coronary intervention.

negative for female patients, patients with atypical chest pain, patients with no symptoms, and patients with a history of cardiac transplantation.

Full results of the clinical and nonclinical model, including both patient and physician variables, are shown in Figure 3.

Variation by Individual Physicians After Adjustment

In the unadjusted model, the MOR was 1.47 (95% CI 1.32–1.60), consistent with clinically significant variation. In the clinical model, which included patient variables but not nonclinical provider variables such as physician age, physician gender, clinical full-time equivalent, cardiology subspecialty, and Harvard rank, the MOR was 1.23 (95% CI 1.0–1.36), suggesting borderline significant variation. In the full clinical and nonclinical model, the MOR was 1.07 (95% CI 1.0–1.20), also consistent with clinically insignificant variation. The MOR and the associated variance of the 3 models are shown in Table 4. The ORs for positive catheterizations by referring cardiologists according to the 3 models appear together in Figure 4.

Sensitivity Analyses

Given the association of Harvard academic rank with test outcome, we performed a sensitivity analysis to test the strength of our findings. We recategorized the Harvard academic rank variable such that associate professors and full professors were combined into 1 category. The new combined variable was significant (OR 0.63, P=0.008), with a magnitude in between the ORs of the 2 independent categories. Because the patient –practice category might

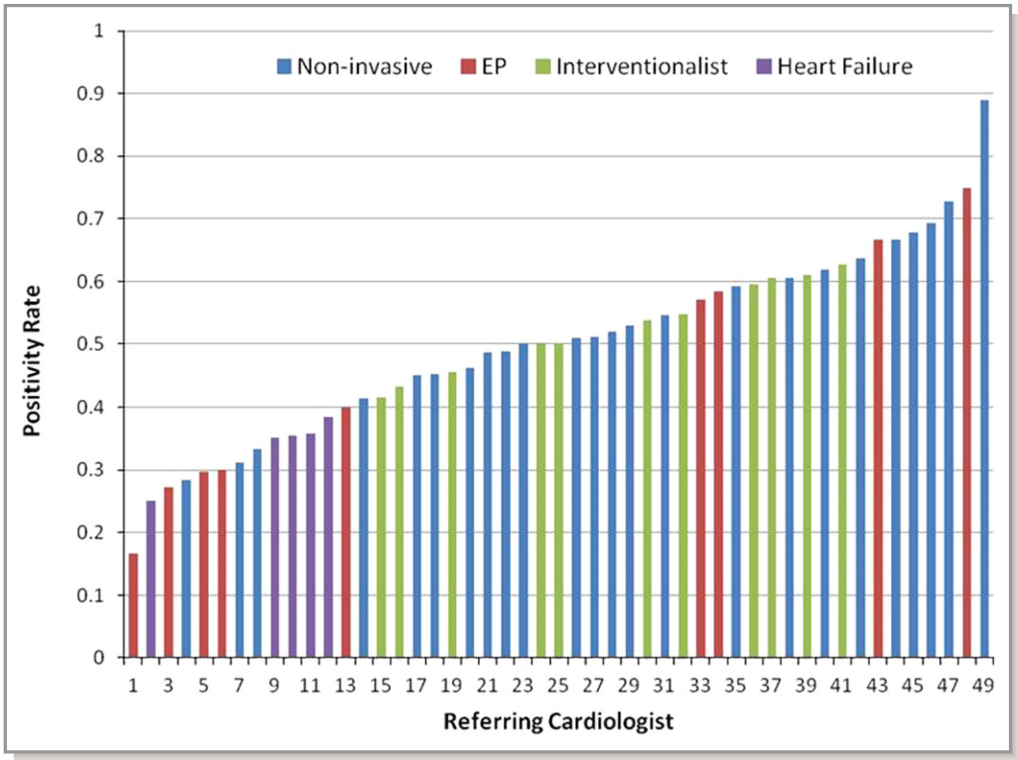

Figure 1. Unadjusted catheterization positivity rate, by referring cardiologist (unadjusted model). EP indicates electrophysiologist.

reflect differences among either patients or cardiologists, we also performed a sensitivity analysis considering this variable as a patient-level variable. This sensitivity analysis did not change the value of the variable for any particular catheterization but characterized the variable among the "patient" attributes rather than the "physician" attributes. Consequently, the sensitivity analysis included this variable in both the clinical model and the clinical and nonclinical model, whereas the primary analysis included the variable only in the clinical and nonclinical model. The MOR for the models did not substantially change. Finally, including patients with unstable angina in the analysis did not substantially change the MORs of the 3 models. Because all of these sensitivity analyses demonstrated the robustness of the primary analysis, only the results of the primary analysis are presented.

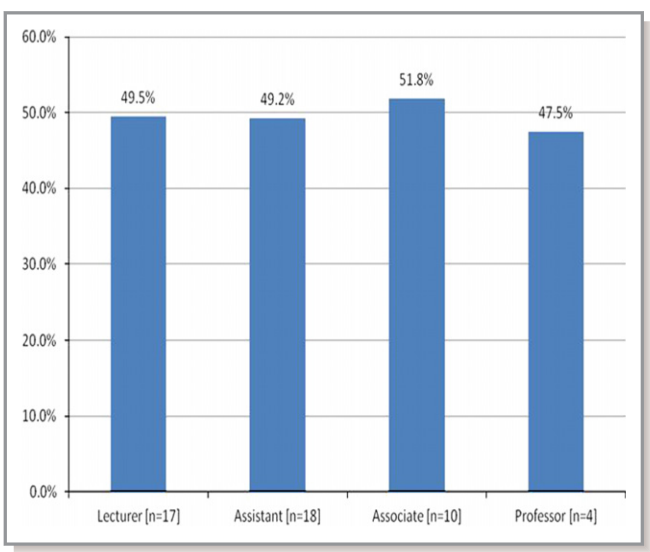

Figure 2. Positive catheterizations, divided among physicians by Harvard academic rank.

Discussion

In this study, we found substantial variance in results of diagnostic coronary angiography among cardiologists. After adjustment for clinical variables, variation by individual requesting physician was of only borderline clinically significance (MOR 1.23, 95% CI 1.0–1.36). These results emphasize that in measuring the performance of individual physicians, controlling for patient characteristics is essential.

Our findings on patient characteristics are consistent with findings from the National Cardiovascular Data Registry, which also found that patient-level variables including higher age, male patient gender, peripheral arterial disease, renal failure, and typical angina are associated with positive angiograms.[7] Variance in rates of normal coronary angiography among hospitals has been previously found to be substantial.[13] We have extended those results to apply to individual referring cardiologists.

Table 2. ORs for Positive Angiograms (Patient Characteristics)

Patient Characteristics	Parameter Estimates		OR		
	Coefficient	*P* Value	OR	95% CI	
Patient female	−0.741	<0.0001	0.48	0.39	0.58
Patient age	0.02953	<0.0001	1.03	1.02	1.04
Atypical chest pain	−0.6416	<0.0001	0.53	0.39	0.70
Stable angina	1.5452	<0.0001	4.69	3.49	6.30
History of cardiac transplantation	−1.7091	<0.0001	0.18	0.13	0.25
Cardiomyopathy	0.2363	0.0553	1.27	0.99	1.61
History of myocardial infarction	1.0809	<0.0001	2.95	2.23	3.89
History of CABG	2.1367	<0.0001	8.47	4.75	15.12
History of PCI	0.654	<0.0001	1.92	1.43	2.58
Valvular disease	−0.2441	0.1733	0.78	0.55	1.11
Pulmonary vascular disease	−0.8148	0.0021	0.44	0.26	0.74
Peripheral vascular disease	0.4208	<0.0001	1.52	1.24	1.88
Diabetes without chronic complications	0.06911	0.5394	1.07	0.86	1.34
Diabetes with chronic complications	0.607	0.0077	1.83	1.17	2.87
Renal failure	0.1456	0.3698	1.16	0.84	1.59
Liver disease	−0.4809	0.0436	0.62	0.39	0.99
Weight loss	−1.0133	0.0058	0.36	0.18	0.75
Drug abuse	−0.4039	0.2043	0.67	0.36	1.25
Hypertension	0.2469	0.0287	1.28	1.03	1.60

CABG indicates coronary artery bypass grafting; OR, odds ratio; PCI, percutaneous coronary intervention.

We found, for example, that catheterizations requested by full professors and associate professors were more likely to be negative than catheterizations requested by assistant professors and instructors. The effect was graded by academic rank, with an OR for professors relative to instructors of 0.51 (P=0.001) and an OR for associate professors relative to instructors of 0.77 (borderline significance, P=0.11). This consistent gradation by academic rank suggests the presence of an actual effect. Although physician age is correlated with Harvard rank, the model included both variables so the reported effect of Harvard rank reflects adjustment for age. We also found this result to be a robust finding in sensitivity analyses. The strong relationship between incremental increases in Harvard academic rank and negative angiograms has multiple plausible explanations.

Table 3. ORs for Positive Angiograms (Provider Characteristics)

Provider Characteristics	Parameter Estimates		OR		
	Coefficient	*P* Value	OR	80% interval odds ratio	
Provider age	0.006725	0.2216	1.01	0.68	1.50
Provider female	0.01938	0.9231	1.02	0.69	1.52
Clinical FTE (%)	−0.1674	0.5945	0.85	0.57	1.26
Referral volume (per catheterization requested)	0.001588	0.258	1.00	0.67	1.49
Rank (relative to instructor)					
Assistant	0.1222	0.3073	1.13	0.76	1.68
Associate	−0.2621	0.1148	0.77	0.52	1.14
Professor	−0.6809	0.0018	0.51	0.34	0.75
Specialty (relative to noninvasive)					
EP	0.15	0.5123	1.16	0.78	1.73
Heart failure	0.04625	0.7925	1.05	0.70	1.56
Interventionalist	−0.01547	0.9326	0.98	0.66	1.46

EP indicates electrophysiologist; FTE, full-time equivalent; OR, odds ratio.

First, Harvard academic rank may be associated with an unmeasured confounder. Our full patient and physician model adjusted for many of these plausible confounders, including patient age, aspects of patient history (previous percutaneous coronary intervention, previous coronary artery bypass grafting, previous myocardial infarction, valvular disease), type of physician practice, and physician age and gender. Second, Harvard academic rank may be associated with treatment selection bias insofar as different types of patients are referred to senior and junior clinicians. In particular, patients with challenging symptoms or previous inconclusive evaluations may be more likely to seek the care of senior staff. As such, the threshold for testing these patients with diagnostic angiography may differ. In fact, the unadjusted positivity rate did not differ among clinicians divided by Harvard academic rank. The fact that higher levels of academic rank were associated with more negative angiograms after statistical adjustment suggests that patient case mix differs for senior and junior physicians.

The linkage between angiogram outcome and angiogram decision is important because it establishes physician variance at the level of the individual clinician who actually makes the decision to pursue angiography. In national surveys, cardiologists have been shown to vary substantially in propensity to request cardiac catheterization for "other than purely clinical reasons," including meeting patient expectations, meeting peer expectations, and malpractice concerns.[14] Physician practice style may also influence

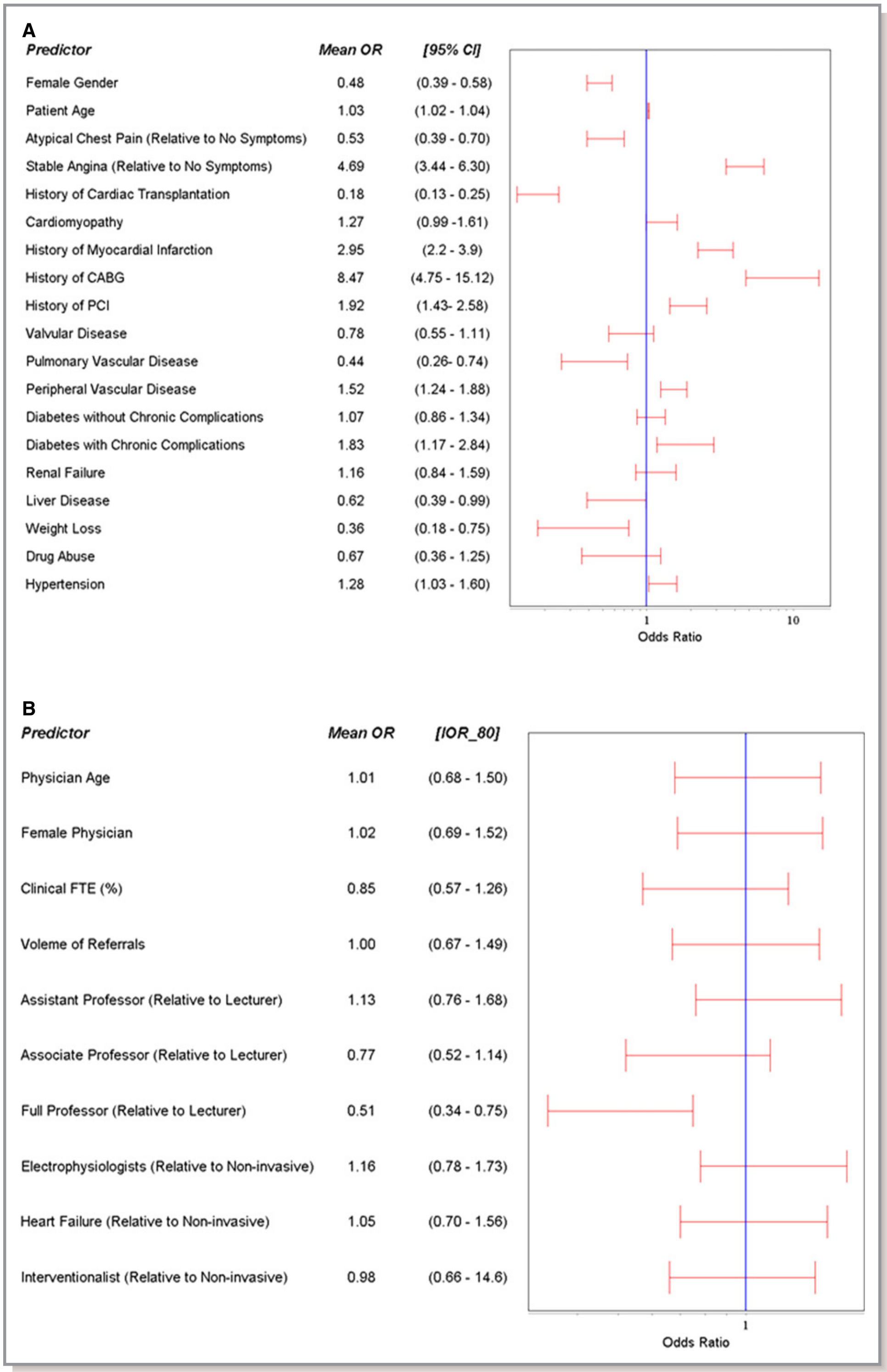

Figure 3. Odds ratios for positive catheterizations in the full model, including both (A) patient and (B) physician variables. CABG indicates coronary artery bypass grafting; FTE, full-time equivalent; IOR 80, 80% interval odds ratio; OR, odds ratio; PCI, percutaneous coronary intervention.

individual physicians' propensity to pursue coronary angiography. This has important implications for improving both quality and value because these results suggest that feedback to physicians that have low proportions of positive catheterizations may decrease the overall negative rate, potentially reducing costs.

At the same time, by including both patient- and physician-level variables in a mixed-effects regression model, we

Table 4. Variance in Angiogram Positivity Among Physicians in the Unadjusted Model, the Clinical Model, and the Clinical and Nonclinical Model

Model	Unadjusted Model	Clinical Model	Clinical and Nonclinical Model
Variance among providers (standard error)	0.1622 (0.0397)	0.04585 (0.0305)	0.00492 (0.01602)
Median odds ratio (95% CI)	1.47 (1.32–1.60)	1.23 (1.0–1.36)	1.07 (1.0–1.20)

demonstrated that a substantial proportion of the explained variation is related to patient variables. Any attempt to provide feedback to clinicians should acknowledge and incorporate patient-level variables and report risk-standardized odds of positive angiograms. Importantly, although invasive/interventional cardiologists were more likely to

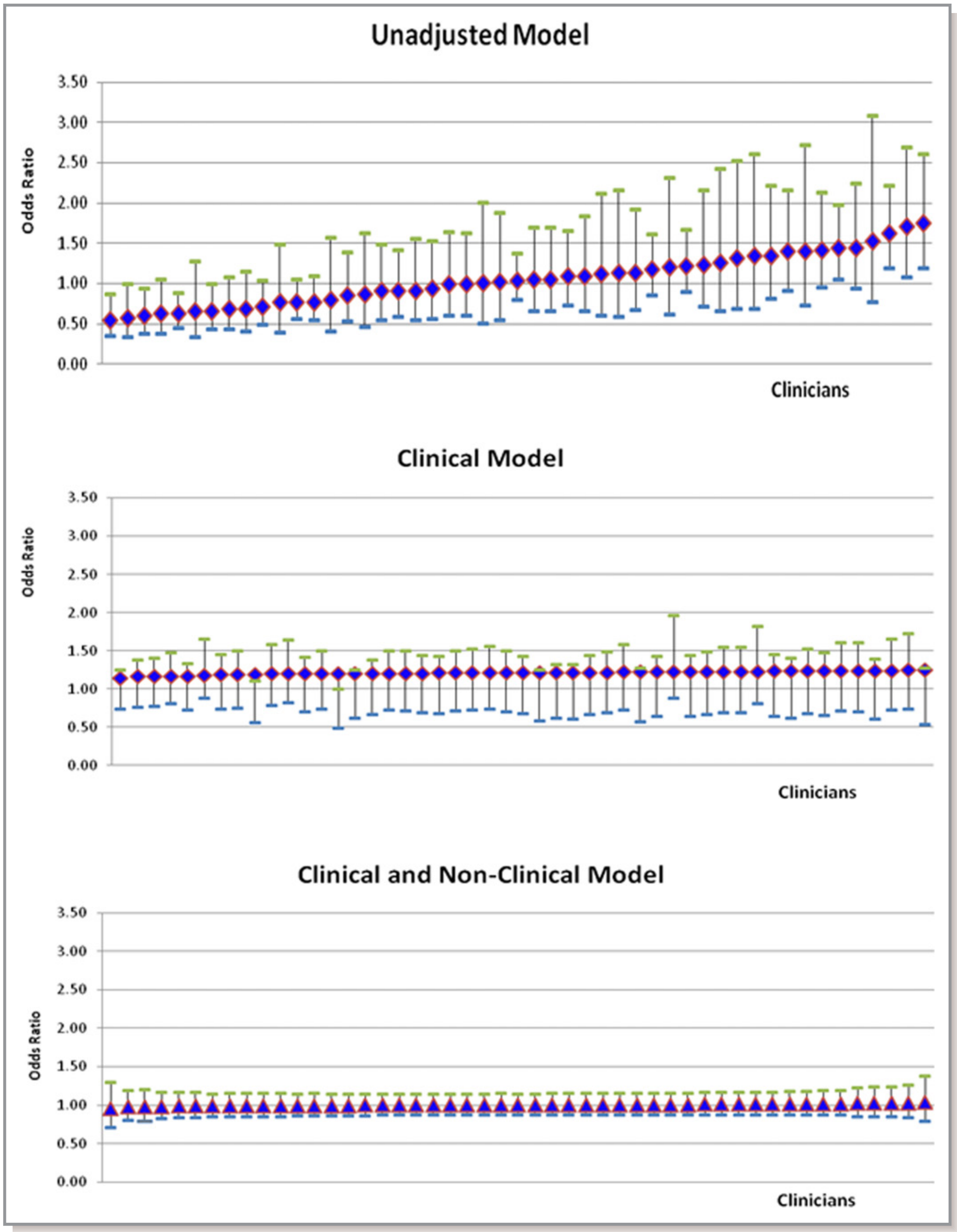

Figure 4. Odds ratios for positive catheterizations, by referring cardiologist, with and without statistical adjustment. A, Unadjusted model. B, Clinical model. C, Clinical and nonclinical model.

obtain positive angiograms and heart failure cardiologists were more likely to obtain negative angiograms in unadjusted bivariate analysis, after adjusting for confounding with the full model, cardiology subspecialty was not significant. We believe this result is probably related to confounding between patient factors and the types of cardiologists that care for them. Consequently, improperly adjusted analyses judging cardiologists on metrics of utilization used for either public reporting or pay for performance could unfairly designate groups of cardiologists as either positive or negative outliers. This point highlights the essential role of proper risk adjustment in analyzing physician performance.

Because the 95% CI of the MOR in the clinical model encompasses the threshold of clinical significance, it is also possible that our study was underpowered to detect clinically significant variation attributable to nonclinical variables, including academic rank. If clinical variation exists in the clinical model and is reduced by variables in the clinical and nonclinical model in ways that do not reflect differences in case mix, this would suggest potential opportunities for actionable quality improvement. In particular, groups of clinicians associated with high negative rates could review practice patterns associated with negative catheterizations. The hypothesis that some existing variation is associated with specific physician groups could be tested in a larger data set.

Our study has important limitations. First, as a single-center study, the extent to which we can generalize our findings to other health care settings is unclear. In particular, as the largest general hospital in New England and as a teaching hospital, the extent to which we can generalize these results to smaller and nonteaching hospitals is unclear. The challenge with studying this question through national databases remains that those databases do not have granular information about physicians referring for procedures. We believe, however, that these results emphasize the importance of risk adjustment in variation analyses, no matter the hospital setting. Second, we did not capture the true denominator, the number of patients evaluated for coronary angiography, because many do not ultimately receive the procedure; therefore, we cannot draw precise conclusions about propensity to test. We used the positivity ratio as a proxy for propensity to test, with the implication that providers with more negative angiograms have more propensity (a lower threshold) to test. Third, the true optimal positivity rate—or risk-adjusted positivity rate—is uncertain, so we cannot make prescriptive judgments about an individual provider's positivity rate. Nevertheless, in the context of high negative rates both locally and nationally, we believe that this information should encourage providers with lower risk-adjusted positivity rates to review their referral patterns. In particular, the strong presence of patient-level factors in predicting positivity rates encourages proper risk stratification before referral. Fourth, by excluding providers with <10 requested catheterizations, we may have introduced selection bias by excluding cases referred to low-volume or primarily research-oriented cardiologists. Fifth, we were not able to distinguish between inpatient and outpatient referrals, and that may have been a potential source of unmeasured confounding. Finally, our database did not include information about appropriate use criteria, which was not available, so that does not appear as a variable in our analysis. We believe that following of appropriate use criteria may vary between individual physicians, so including appropriateness as a fixed effect may have disguised variation between individual physicians.

In conclusion, we demonstrated that there is substantial variance among referring providers at a large academic medical center with respect to the proportion of positive results in requested coronary angiograms. After adjustment for clinical variables, residual variance was not clinically significant. These findings underscore the importance of accounting for risk factors in analyzing physician performance.

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References

1. Papic JC, Finnell SME, Leys CM, Bennett WE, Downs SM. Referring physicians' decision making for pediatric anti-reflux procedures. *Surgery*. 2014;155:851–859.
2. Haymart MR, Banerjee M, Yang D, Stewart AK, Sisson JC, Koenig RJ, Doherty GM, Griggs JJ. Variation in the management of thyroid cancer. *J Clin Endocrinol Metab*. 2013;98:2001–2008.
3. Sistrom CL, Weilburg JB, Dreyer KJ, Ferris TG. Provider feedback about imaging appropriateness by using scores from order entry decision support: raw rates misclassify outliers. *Radiology*. 2014;275(2):141092.

4. Wong HJ, Sistrom CL, Benzer TI, Halpern EF, Morra DJ, Gazelle GS, Ferris TG, Weilburg JB. Use of imaging in the emergency department: physicians have limited effect on variation. *Radiology*. 2013;268:779–789.

5. Fihn SD, Gardin JM, Abrams J, Berra K, Blankenship JC, Dallas AP, Douglas PS, Foody JM, Gerber TC, Hinderliter AL, King SB, Kligfield PD, Krumholz HM, Kwong RYK, Lim MJ, Linderbaum JA, Mack MJ, Munger MA, Prager RL, Sabik JF, Shaw LJ, Sikkema JD, Smith CR, Smith SC, Spertus JA, Williams SV. 2012 ACCF/AHA/ACP/AATS/PCNA/SCAI/STS guideline for the diagnosis and management of patients with stable ischemic heart disease: executive summary: a report of the American College of Cardiology Foundation/ American Heart Association task force on practice. *Circulation*. 2012; 126:3097–3137.

6. Riley RF, Don CW, Powell W, Maynard C, Dean LS. Trends in coronary revascularization in the United States from 2001 to 2009: recent declines in percutaneous coronary intervention volumes. *Circ Cardiovasc Qual Outcomes*. 2011;4:193–197.

7. Patel MR, Peterson ED, Dai D, Brennan JM, Redberg RF, Anderson HV, Brindis RG, Douglas PS. Low diagnostic yield of elective coronary angiography. *N Engl J Med*. 2010;362:886–895.

8. Collins-Nakai R, Huysmans H, Scully H. Task force 5: access to cardiovascular care: an international comparison. *J Am Coll Cardiol*. 1992;19:1477–1485.

9. Clement FM, Manns BJ, Brownell B, Faris PD, Graham MM, Humphries K, Love M, Knudtson ML, Ghali WA. A multi-region assessment of population rates of cardiac catheterization and yield of high-risk coronary artery disease. *BMC Health Serv Res*. 2011;11:323.

10. Larsen K, Merlo J. Appropriate assessment of neighborhood effects on individual health: integrating random and fixed effects in multilevel logistic regression. *Am J Epidemiol*. 2005;161:81–88.

11. Maddox TM, Chan PS, Spertus JA, Tang F, Jones P, Ho PM, Bradley SM, Tsai TT, Bhatt DL, Peterson PN. Variations in coronary artery disease secondary prevention prescriptions among outpatient cardiology practices: insights from the NCDR (National Cardiovascular Data Registry). *J Am Coll Cardiol*. 2014;63:539–546.

12. Chan PS, Maddox TM, Tang F, Spinler S, Spertus JA. Practice-level variation in warfarin use among outpatients with atrial fibrillation (from the NCDR PINNACLE program). *Am J Cardiol*. 2011;108:1136–1140.

13. Bradley SM, Maddox TM, Stanislawski MA, O'Donnell CI, Grunwald GK, Tsai TT, Ho PM, Peterson ED, Rumsfeld JS. Normal coronary rates for elective angiography in the VA health care system: insights from the VA CART program. *J Am Coll Cardiol*. 2013;63:417–426.

14. Lucas FL, Sirovich BE, Gallagher PM, Siewers AE, Wennberg DE. Variation in cardiologists' propensity to test and treat: is it associated with regional variation in utilization? *Circ Cardiovasc Qual Outcomes*. 2010;3:253–260.