

Physician Clinical Knowledge, Practice Infrastructure, and Quality of Care

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About a decade ago, several important policies were initiated that promoted practice infrastructure to support patient-centered care.¹⁻⁴ In response, the adoption of basic electronic health records (EHRs) increased from 20% to more than 50% for office-based physicians between 2009 and 2015, and the number of providers participating in medical home initiatives, which utilize practice infrastructure to promote patient-centered care, increased from 14,000 to more than 63,000 during this period.⁴⁻⁷ Underlying these policies is the assumption that better practice infrastructure would lead to better patient care, although subsequent research consisting mostly of patient-centered medical home evaluations has yielded mixed evidence regarding the effectiveness of improving practice infrastructure.^{2,8-12} That said, heterogeneity observed across medical home interventions suggests that idiosyncratic aspects of the practices themselves may be critical to translating infrastructure improvements into higher-quality care.¹¹

One such factor that may be important to effectively leveraging infrastructure is the underlying skill of the physicians whose care is supported by practice infrastructure. Conceivably, practice infrastructure could preferentially benefit physicians with either higher or lower skill. For example, it might be that lower-skilled physicians benefit more from infrastructure supports, such as embedded clinical reminders or guideline standards, when developing care plans. Alternatively, synergy could exist between a physician's skills and the ready access to patient information and electronic tools that are embedded in higher-quality systems, and so higher-skilled providers might deliver better care than lower-skilled providers when supported by practice infrastructure. However, we are unaware of any studies examining whether and how physician skill affects the relationship between practice infrastructure and care quality.

We address this gap by examining whether one dimension of physician skill, namely a physician's clinical knowledge as measured by performance on the American Board of Internal Medicine (ABIM)'s Maintenance of Certification (MOC) examination, moderates the relationship between practice infrastructure and the quality of diabetes or hypertension care among general internists.

ABSTRACT

OBJECTIVES: To understand if and how one dimension of physician skill, clinical knowledge, moderates the relationship between practice infrastructure and care quality.

STUDY DESIGN: We included 1301 physicians who certified in internal medicine between 1991 and 1993 or 2001 and 2003 and took the American Board of Internal Medicine (ABIM)'s Maintenance of Certification (MOC) exam and completed ABIM's diabetes or hypertension registry during their 10-year recertification period between 2011 and 2014. Composite quality scores (overall, process, and intermediate outcome) were based on chart abstractions. Practice infrastructure scores were based on a web-based version of the Physician Practice Connections Readiness Survey. Our measure of clinical knowledge was drawn from MOC exam performance.

METHODS: We regressed a physician's composite care quality scores against the interaction between their practice infrastructure and MOC exam scores with controls for physician, practice, and patient panel characteristics.

RESULTS: We found that a physician's exam performance significantly moderated the association between practice infrastructure and care quality (P for interaction = .007). For example, having a top quintile practice infrastructure score was associated with a quality care score that was 7.7 [95% CI, 4.3-11.1] percentage points ($P < .001$) higher among physicians scoring in the top quintile of their MOC exam, but it was unrelated [0.7 [95% CI, -3.8 to 5.3] percentage points; $P = .75$] to quality among physicians scoring in the bottom quintile on the exam.

CONCLUSIONS: Physician skill, such as clinical knowledge, is important to translating patient-centered practice infrastructure into better care quality, and so it may become more consequential as practice infrastructure improves across the United States.

Am J Manag Care. 2019;25(10):497-503

TAKEAWAY POINTS

Physician clinical knowledge significantly moderated the relationship between patient-centered practice infrastructure and care quality.

- ▶ We found that better practice infrastructure was associated with higher-quality care, especially performance on process measures, only among physicians scoring in the top 2 or 3 quintiles on their Maintenance of Certification exam.
- ▶ These data suggest that individual physician skill may become more important as practice infrastructure improves across the country.
- ▶ In addition, these findings highlight that it is important for patients to be informed about both practice infrastructure quality and a physician's skill when selecting a doctor.

identified by the physician as important to their practice; (3) appropriate standards, such as guideline reminders; (4) proactive management of important conditions; (5) patient-centered self-care support and education; (6) patient access and communication; and (7) systematic processes such as e-prescribing, test tracking, referral tracking, and interoperable EHRs. The overall score ranges from 0 to 100 and was computed using the National Committee for Quality Assurance scoring algorithm.^{15,16}

METHODS

We identified 1301 primary care physicians (ie, nonspecializing general internists) who initially certified between either 1991 and 1993 or 2001 and 2003 and participated in either a diabetes or hypertension Process Improvement Module (PIM) registry from 2011 through 2014.^{13,14} PIM registries were completed during either the first or second 10-year recertification cycle and involved physicians recording data used to assess their care quality and completing a web-based version of the Physician Practice Connections Readiness Survey (PPC-RS) developed by the National Committee for Quality Assurance.^{15,16} Data were compiled and merged using ABIM administrative identifiers, which were removed prior to analysis. The study was deemed exempt from review by the Advarra institutional review board.

Measures of Physician Care Quality

Each physician in the study abstracted information from 25 sequential (or randomly chosen) charts for patients aged 15 to 90 years with a visit in the past year and noted as having the applicable condition for at least a year. Prior research has demonstrated that patients treated by physicians who elected to complete the PIMs are representative of the patients with diabetes and hypertension typically treated by board-certified internists.¹⁷ From each chart, physicians abstracted the patient's receipt of screening/monitoring tests, laboratory values, and demographics, which were used to assess concordance with process and intermediate outcome quality measures.^{18,19} Quality measures were used to construct 3 composites using an algorithm designed by an expert panel—(1) an overall quality composite, (2) a process composite, and (3) an intermediate outcomes composite—that each reflect the weighted average compliance across the individual measures (ranging from 0% to 100%; see [eAppendix A](#) [eAppendices available at [ajmc.com](#)] for individual measure criteria and scoring details).²⁰⁻²²

Measures of Practice Infrastructure

As part of the PIM, each physician completed a web-based version of the PPC-RS.^{15,16} This survey is a self-assessment tool designed to enable physicians to benchmark their practice infrastructure across 7 subscores: (1) quality measurement and improvement; (2) patient data-tracking systems to follow patients with conditions

Measure of Physician Clinical Knowledge

Our measure of physician clinical knowledge was their performance on ABIM's MOC exam. Exam scores were equated to account for differences in difficulty between exam administrations and scored on a 200- to 800-point scale.²³

Physician and Patient Characteristics

Physician control variables included their gender, whether they were born and/or attended medical school in the United States, the year and type of PIM completed, and whether they completed the PIM during their first or second round of MOC. Practice characteristics used included practice setting (ie, academic, group, or other), size, and HHS region.^{24,25} We also included zip code-level median household income and hospital service area-level age-, sex-, and race-adjusted Medicare mortality rate to account for the general well-being of the community in which each physician practices.^{26,27} Patient panel characteristics, collected in the PIMs for risk adjustment, were used as control variables in the analysis, including the percentage of women, percentage in each racial group (white non-Hispanic, black non-Hispanic, Hispanic, Asian or Pacific Islander, or other), percentage in each age group (<45, 45-54, 55-64, 65-74, or >74 years), and percentage with barriers to care (due to language or insurance/payment issues).

Empirical Methods

We used a share regression (ie, fractional response probit regression) to measure associations with our care quality measures.^{28,29} The advantage of this modeling approach is that it accounts for our dependent measure being a percentage score bounded by 0 and 1 (inclusive) and so, unlike linear regression, ensures that all predictions lie within this interval. Applying this model, we regressed each of the 3 quality composites against practice infrastructure score quintile indicators, MOC exam score quintile indicators, and the measures of physicians' practice setting, training, demographic characteristics, and patient panel characteristics described previously. All controls were included in the final model, regardless of their statistical significance. To evaluate whether the relationship between quality care and practice infrastructure was moderated by physician clinical knowledge, we include interactions between the practice infrastructure score quintile

TABLE 1. Regression-Adjusted Relationship Between Overall Physician Quality and PI-Q at Each Physician MOC Exam Score Quintile

Exam score quintile	Difference in Overall Quality Score Among PI-Qs, Percentage Points (95% CI) ^a					Overall P of the Interaction ^b
	PI-Q 1 (0-45)	PI-Q 2 (46-58)	PI-Q 3 (59-70)	PI-Q 4 (71-83)	PI-Q 5 (84-100)	
Exam quintile 1 (200-442)	Ref	-1.3 [-6.4 to 3.8]	0.2 [-4.2 to 4.5]	1.7 [-3.1 to 6.5]	0.7 [-3.8 to 5.3]	.007
Exam quintile 2 (443-491)	Ref	0.4 [-4.0 to 4.8]	3.3 [-0.6 to 7.3]	-1.2 [-5.6 to 3.2]	1.8 [-3.2 to 6.9]	
Exam quintile 3 (492-535)	Ref	-0.6 [-4.7 to 3.4]	0.4 [-3.4 to 4.3]	0.3 [-3.9 to 4.4]	3.2 [-0.6 to 6.9]	
Exam quintile 4 (536-591)	Ref	1.0 [-2.7 to 4.8]	2.8 [-1.7 to 7.3]	3.2 [-0.8 to 7.3]	5.9 [1.2-10.6]*	
Exam quintile 5 (592-800)	Ref	2.8 [-0.8 to 6.4]	5.2 [1.8-8.5]**	6.0 [2.6-9.5]**	7.7 [4.3-11.1]***	

MOC indicates Maintenance of Certification; PI-Q, practice infrastructure score quintile; ref, reference.

*P < .05; **P < .01; ***P < .001.

^aValues are marginal effects estimated using Stata’s *margins* function and reflect the percentage-point difference in the quality score between physicians in a particular PI-Q and the bottom quintile of practice infrastructure (labeled “ref”). Each row of the table reflects estimates at a specific quintile of exam score.

^bOverall P value of the interaction was estimated by applying a contrast test of the linear trend in predicted quality score marginal means across levels of both increasing practice infrastructure and exam score quintiles.

indicators and MOC exam score quintile indicators. However, as we are using a nonlinear regression model, Ali and Norton point out that the magnitude, sign, and statistical significance of the interaction effect cannot be directly determined from the coefficients on the interaction terms.³⁰ Karaca-Mandic and colleagues demonstrate that an appropriate method for calculating effects for such interactions is the cross partial derivative method.³¹ In our application, we used the *margins* function in Stata version 14 (Stata Corp; College Station, Texas) to estimate the percentage-point difference in quality score (ie, the marginal effect based on the average derivative across the sample) between each practice infrastructure quintile indicator and the lowest practice infrastructure quintile at each quintile of exam performance.³¹⁻³³ We also estimated an overall P value, which tests the hypothesis that the value of the infrastructure–exam score quintile associations increases with higher value of both the exam score quintiles and practice infrastructure quintiles by applying a contrast test of the linear trend in predicted quality score marginal means across levels of both increasing practice infrastructure and increasing exam score quintiles using Stata’s *margins*, *contrast* function.³⁴ Lastly, we conducted a policy simulation for each exam score quintile to estimate the overall change in quality scores that might be expected if we assumed each physician moved from their observed quintile of practice infrastructure to the top quintile level of practice infrastructure.

In addition to examining the overall practice infrastructure score, we also conducted a secondary analysis in which we regressed the overall quality composite score against practice infrastructure subscores controlling for the remaining infrastructure score (ie, the total infrastructure score minus the subscore).

RESULTS

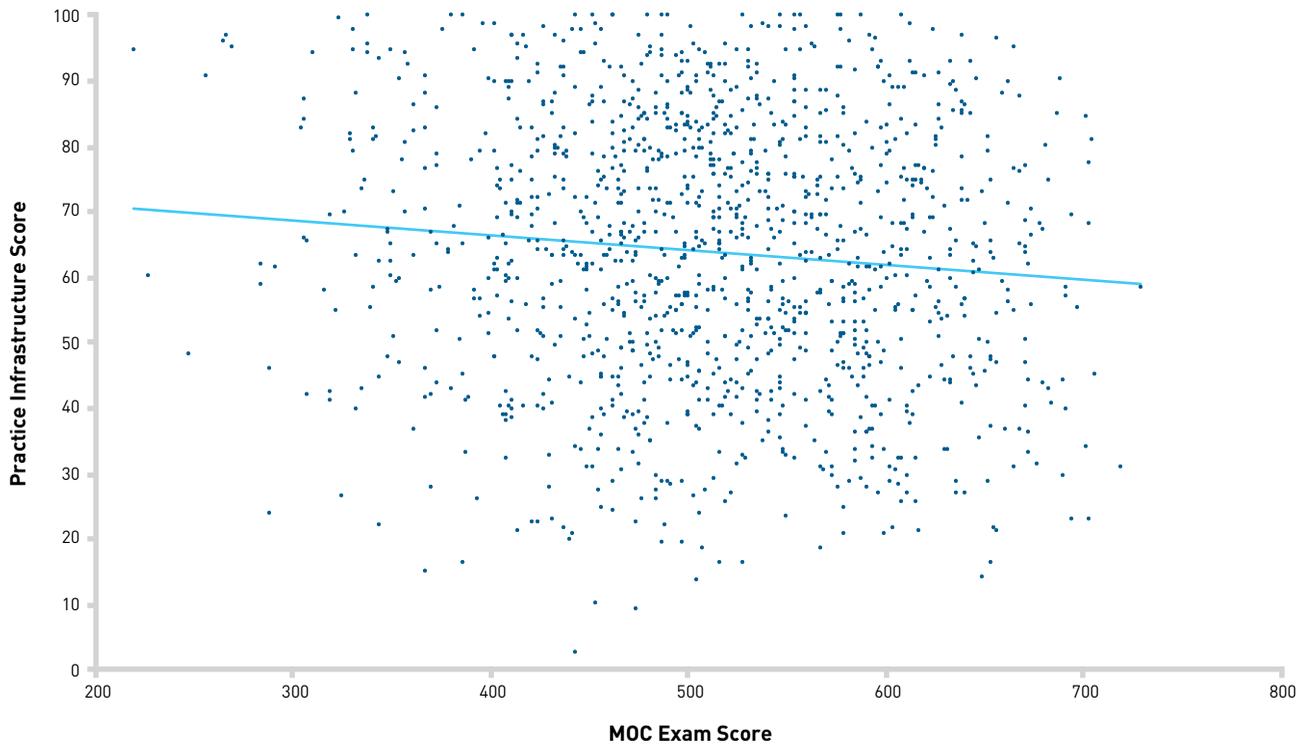
We found that practice infrastructure was more strongly associated with the overall quality score among physicians who performed better on their MOC exam (overall P value of the interaction = .007) (Table 1). For example, as shown in Table 1, the regression-adjusted

difference in the overall quality score between the top and bottom practice infrastructure quintiles is 7.7 percentage points (95% CI, 4.3-11.1; P < .001) among physicians who scored in the top quintile of their MOC exam compared with 0.7 percentage points (95% CI, -3.8 to 5.3; P = .75) among physicians who scored in the bottom quintile of their MOC exam. The Figure demonstrates that despite a negative correlation existing between the MOC exam and practice infrastructure scores (r = -0.10; P = .004), a sizable portion of high and low exam performers worked in both high- and low-infrastructure practices, suggesting enough variation existing within levels of exam performance to evaluate the interaction. See eAppendix B for the main effect associations without any interactions, eAppendix C for the probit regression coefficients, and eAppendix D for mean values of the control variables.

Table 2 describes the results of the policy simulation in which we estimated the potential increase in the overall quality score associated with moving every physician from their observed practice infrastructure quintile to the top practice infrastructure quintile. Among physicians scoring in the top exam quintile, transitioning each physician from their observed practice infrastructure quintile to the top quintile predicts an overall increase in the average overall quality score of 3.7 percentage points (95% CI, 1.4-6.0; P = .001). This increase in quality would account for a 12% reduction in the gap in quality between the average quality score (70.1%) and the maximum possible quality score. These simulations were not significant for physicians scoring in the bottom quintile (0.4 percentage points; 95% CI, -2.3 to 3.0; P = .79).

Table 3 describes the associations when we separately examine the process or intermediate outcome quality scores. The interaction between practice infrastructure and physician clinical knowledge was statistically significant only for the process composite score (overall P value of the interaction = .006). For example, among physicians with a top-quintile exam score, practicing in a top-versus bottom-quintile infrastructure system was associated with a process quality score that was 14.1 percentage points higher (95% CI, 9.0-19.1; P < .001). This association was 1.8 percentage points and not

FIGURE. Scatter Plot Comparing Interval MOC Exam and Practice Infrastructure Scores*



MOC indicates Maintenance of Certification.

*Solid line represents linear best fit line; Pearson $r = -0.10$; $P = .004$.

TABLE 2. Policy Simulation Estimating the Predicted Change in Overall Quality From Transitioning Each Physician From Their Observed PI-Q to the Top Quintile

Exam score quintile	Predicted Change in Overall Quality From Transitioning Each Physician to the Top Quintile of Practice Infrastructure, Percentage Points (95% CI) ^a	P
Exam quintile 1 (200-442)	0.4 (-2.3 to 3.0)	.79
Exam quintile 2 (443-491)	1.0 (-2.2 to 4.2)	.55
Exam quintile 3 (492-535)	2.5 (0.2-4.8)	.03
Exam quintile 4 (536-591)	3.5 (0.4-6.7)	.03
Exam quintile 5 (592-800)	3.7 (1.4-6.0)	.001

PI-Q indicates practice infrastructure score quintile.

^aThe percentage-point difference in the overall quality scores across all the physicians within an exam score quintile if each of these physicians had a top-quintile practice infrastructure score versus their observed PI-Q.

statistically significant (95% CI, -4.8 to 8.5; $P = .59$) for physicians who performed in the bottom quintile on their MOC examination.

Table 4 delineates analyses examining the 7 practice infrastructure subscores. We found that physician exam performance significantly moderated the association between infrastructure and overall

quality for only subscore 7 (having systematic processes such as e-prescribing, test tracking, referral tracking, and interoperable EHRs). The association between a 5-point increase in this subscore was associated with an increase of 1.0 percentage points (95% CI, 0.1-2.0; $P = .03$) in the overall quality score among physicians in the top quintile of exam performance, but it was not statistically significant among physicians with bottom-quintile exam scores (-1.0 percentage points; 95% CI, -2.2 to 0.3; $P = .13$).

DISCUSSION

We found that individual physicians may be key to translating high-quality practice infrastructure into better care quality experienced by patients, as measured by each physician's performance across an amalgam of individual process and intermediate outcome measures. In particular, we observed that better practice infrastructure was associated with higher care quality only among physicians with better clinical knowledge, as indicated by their scoring in either of the top 2 quintiles on ABIM's MOC exam. In general, the observed association with care quality was largely driven by better performance on process-of-care measures.

Why might practice infrastructure matter for physicians who performed well on their MOC exam but not for physicians who

TABLE 3. Regression-Adjusted Process and Intermediate Outcome Quality Score Differences by PI-Q Across Quintiles of Physician MOC Exam Score

	Difference in Either Process or Intermediate Outcome Quality Score Among PI-Qs, Percentage Points (95% CI) ^a					Overall P Value of the Interaction ^b
	PI-Q 1 (0-45)	PI-Q 2 (46-58)	PI-Q 3 (59-70)	PI-Q 4 (71-83)	PI-Q 5 (84-100)	
Process Measure Score						
Exam score quintile						
Exam quintile 1 (200-442)	Ref	-2.0 [-9.6 to 5.5]	1.1 [-5.3 to 7.4]	3.0 [-2.9 to 8.9]	1.8 [-4.8 to 8.5]	.006
Exam quintile 2 (443-491)	Ref	1.6 [-5.1 to 8.2]	7.2 [1.2-13.3]*	0.2 [-6.5 to 6.8]	5.2 [-2.1 to 12.5]	
Exam quintile 3 (492-535)	Ref	-0.9 [-6.7 to 4.8]	3.7 [-2.4 to 9.7]	0.6 [-5.5 to 6.7]	7.7 [2.0-13.3]**	
Exam quintile 4 (536-591)	Ref	4.7 [-0.8 to 10.3]	4.0 [-2.5 to 10.6]	9.0 [2.9-15.1]**	7.0 [0.4-13.6]*	
Exam quintile 5 (592-800)	Ref	5.2 [-0.3 to 10.7]	8.3 [3.3-13.2]**	10.9 [6.0-15.9]***	14.1 [9.0-19.1]***	
Intermediate Outcome Score						
Exam score quintile						
Exam quintile 1 (200-442)	Ref	-0.6 [-5.6 to 4.4]	-0.2 [-4.7 to 4.3]	1.1 [-4.2 to 6.4]	0.3 [-4.4 to 5.0]	.07
Exam quintile 2 (443-491)	Ref	-0.3 [-4.7 to 4.0]	1.1 [-2.7 to 4.9]	-2.2 [-6.6 to 2.3]	-0.1 [-5.0 to 4.8]	
Exam quintile 3 (492-535)	Ref	-0.2 [-4.2 to 3.8]	-1.2 [-5.1 to 2.7]	0.2 [-3.9 to 4.3]	0.8 [-3.1 to 4.6]	
Exam quintile 4 (536-591)	Ref	-1.1 [-5.0 to 2.8]	2.2 [-2.4 to 6.7]	-0.1 [-4.5 to 4.3]	5.1 [0.1-10.1]*	
Exam quintile 5 (592-800)	Ref	1.4 [-2.5 to 5.3]	3.4 [-0.4 to 7.1]	3.3 [-0.6 to 7.1]	4.1 [0.3-7.9]*	

MOC indicates Maintenance of Certification; PI-Q, practice infrastructure score quintile; ref, reference.

*P < .05; **P < .01; ***P < .001.

^aValues are marginal effects estimated using Stata's *margins* function and reflect the percentage-point difference in the quality score between physicians in a particular practice infrastructure quintile and the bottom PI-Q. Each row of the table reflects estimates within a specific quintile of exam score.

^bOverall P value of the interaction was estimated by applying a contrast test of the linear trend in predicted quality score marginal means across levels of both increasing practice infrastructure and exam score quintiles.

TABLE 4. Relationship Between the Overall Quality Care Score and Each Practice Infrastructure Subscore Overall and by MOC Exam Score Quintile

	Infrastructure Score (%)		Difference in Overall Quality Associated With a 5-Point Difference in the Infrastructure Score, Percentage Points (95% CI) ^a			
	Max	Mean (SD)	Overall Effect	Interacted With MOC Exam Score Quintile		
				Quintile 1	Quintile 5	Difference (quintile 5 minus quintile 1)
Total infrastructure score	100	64.0 (20.2)	0.3 [0.1-0.5]***	0.1 [-0.3 to 0.4]	0.7 [0.4-0.9]***	0.6 [0.2-1.0]**
Subscores						
(1) Institution of processes for quality measurement and improvement	12	6.8 (4.5)	1.0 [0.2-1.9]*	1.3 [-0.7 to 3.4]	1.0 [-0.6 to 2.6]	-0.3 [-2.9 to 2.2]
(2) Use of patient data tracking systems to follow patients with important conditions	10	6.1 (3.8)	-0.4 [-1.4 to 0.6]	-2.3 [-4.7 to 0.1]	0.5 [-1.3 to 2.3]	2.8 [-0.2 to 5.8]
(3) Ensure all providers follow appropriate standards (eg, reminders)	17	12.3 (3.3)	1.2 [0.1-2.3]*	1.7 [-1.1 to 4.6]	2.3 [0.4-4.2]*	0.6 [-2.9 to 4.0]
(4) Practice staff organized to proactively manage important conditions	13	9.7 (3.9)	0.2 [-0.7 to 1.0]	1.7 [-0.8 to 4.3]	0.3 [-1.3 to 1.9]	-1.4 [-4.4 to 1.5]
(5) Provide patient-centered self-care support and education	6	4.2 (2.0)	-0.5 [-2.3 to 1.2]	1.4 [-3.2 to 6.0]	-1.2 [-4.9 to 2.4]	-2.6 [-8.4 to 3.2]
(6) Patient access and communication	8	4.9 (2.3)	0.5 [-1.2 to 2.1]	1.2 [-2.9 to 5.3]	-3.8 [-7.0 to -0.7]*	-5.0 [-10.1 to 0.1]
(7) Systematic processes such as e-prescribing, test tracking, referral tracking, and interoperable EHRs	34	20.1 (8.0)	0.2 [-0.3 to 0.7]	-1.0 [-2.2 to 0.3]	1.0 [0.1-2.0]*	2.0 [0.4-3.6]*

EHR indicates electronic health record; max, maximum; MOC, Maintenance of Certification.

*P < .05; **P < .01; ***P < .001.

^aValues are marginal effects estimated using Stata's *margins* function and reflect the percentage-point difference in the quality score for a 5-point difference in the practice infrastructure score controlling for other practice infrastructure elements. A 5-point change in score was selected to allow for comparison of effect sizes across subscores and with the overall total score because a 5-point difference is within range for all infrastructure step scores. Regressions for each subscore also control for the remaining practice infrastructure score (ie, the total infrastructure score minus the subscore) interacted with the exam score quintiles to account for other practice infrastructure elements.

performed more poorly? To help address this question, we examined the individual subscores that comprise the overall practice infrastructure score. We discovered significant differences in the practice infrastructure–quality relationship between top- and bottom-quintile exam performers for the practice infrastructure subscore related to having systematic processes for managing health information. This includes infrastructure elements such as having an EHR that stores structured patient data, including from external organizations; a system for managing and tracking referrals; and a system for ordering tests, retrieving results, and tracking whether they have been completed. This suggests that infrastructure elements that provide ready access to patient information and track whether care plans are being followed may be important drivers of quality among physicians with higher clinical knowledge. For example, a physician with a higher level of clinical knowledge may be able to take advantage of these infrastructure elements to ensure that their patients are following through on care plans that may be more comprehensive than for a physician with a lower level of clinical knowledge. However, if these 2 physicians work in a system where they have difficulty accessing patient records or tracking their patients' health data, then neither might be able to consistently deliver high-quality care, regardless of how comprehensive their care plans are, because they may be limited in their ability to delineate patients who would benefit from more follow-up.

Another explanation for our findings is that a dimension of physician skill other than knowledge, such as professionalism, may be correlated with both clinical knowledge and diligence in applying the information and tools accessible in high infrastructure systems. For example, it could be that physicians with a greater commitment to professionalism may be both more committed to maintaining their clinical knowledge, and so score better on their MOC exam, and more motivated to use higher-quality infrastructure to improve their practice, and so take the time to experiment with and optimize use of these systems for improving care. However, in the absence of high-level practice infrastructure, these physicians may be hamstrung in their ability to improve quality. Supporting this, Haber and colleagues have found that performance on ABIM's certification examination is correlated with other Accreditation Council for Graduate Medical Education physician core competencies, including patient care and professionalism.³⁵ Furthermore, Pham and colleagues report based on interviews with physicians that those physicians who scored well on ABIM's examination tended to be more reflective in discussing their clinical quality, often describing their "good performance as an amalgamation of skills."³⁶ In contrast, physicians who scored lower on their MOC exams tended to be less reflective and typically framed their quality in terms of their numerical scores compared with their peers.³⁶

These findings suggest that evaluations of interventions designed to improve practice infrastructure should consider characteristics of the providers who comprise these practices, regardless of whether they are driven by differences in clinical knowledge or another correlated dimension of physician skill.³⁷ This is consistent with

a recent review of medical home evaluations that reported a great deal of heterogeneity in effectiveness across interventions, which the authors partially attributed to local contextual factors.¹⁰ In part, this could be due to differences in the medical home interventions themselves, such as variable implementation strategies or placing more or less emphasis on particular practice infrastructure elements.¹⁰⁻¹² However, our findings suggest that characteristics of the physicians comprising a practice may be important to successfully translating medical home interventions into higher-quality care and so should be considered by policy makers looking to encourage such practice transformations. Further, that we found physicians who performed slightly less well on their MOC exam to have better practice infrastructure suggests that opportunities exist to more efficiently distribute infrastructure investment. These data suggest that it would be more efficient if high-quality infrastructure were positively correlated with exam performance, given our observation that the mixture of higher-quality infrastructure and better exam performance is associated with higher-quality care.

Limitations

Several limitations must be considered when applying our results. First, because we rely on cross-sectional comparisons, we cannot account for reverse causality in the practice infrastructure and care quality relationship. As such, the overall positive correlation observed between practice infrastructure and care quality might simply be the result of high-quality practices being more likely to improve their infrastructure. However, if these results were the product of high-quality practices acquiring better practice infrastructure, then one would expect the relationship between practice infrastructure and quality to be the same regardless of how the physicians who practice in these systems performed on their MOC exam. That we found the practice infrastructure–quality relationship to be moderated by a physician's clinical knowledge suggests that for reverse causality, or an unobserved confounding factor, to explain our findings, it would have to be present only among physicians who scored well on their MOC exam and work in a high-infrastructure practice but not present among physicians who (1) scored well but work in a low-infrastructure practice, (2) scored poorly but work in a high-infrastructure practice, or (3) scored poorly and work in a low-infrastructure practice.

Another limitation is that these data reflect only physicians who completed a diabetes or hypertension PIM. In order to complete either PIM, a physician needs a patient panel that is comprised of enough patients with either condition. However, these conditions are widely prevalent among adults in the United States^{38,39} and so presumably most primary care physicians would have a practice capable of supporting either of these PIMs. Further, prior research using PIM data has found that the patients treated by physicians who completed a diabetes or hypertension PIM are representative of the patients typically cared for by primary care physicians certified in internal medicine.¹⁷ That said, these are all physicians who decided to maintain their certification and so these findings may not generalize to physicians who do not participate in MOC.

CONCLUSIONS

We found that better practice infrastructure was associated with higher-quality care only among physicians who performed well on their MOC exam. This finding implies that individual physician skill may be important to successfully translating infrastructure improvements into higher-quality care and that future research is needed to understand what types of support are needed to help lower-skilled physicians leverage practice infrastructure. This is especially important given that these latter physicians are likely to treat underserved populations.⁴⁰ These findings also highlight that it is important for patients to be informed about both practice infrastructure quality and physician skill when selecting a doctor. ■

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Source of Funding: Financial and material support was provided by the American Board of Internal Medicine. Data used in the current study were collected by the American Board of Internal Medicine.

These data were in part previously presented at the 2016 Academy Health Annual Research Meeting.

Author Disclosures: The authors report no relationship or financial interest with any entity that would pose a conflict of interest with the subject matter of this article.

Authorship Information: Concept and design (JLV, BMG); analysis and interpretation of data (JLV, BMG); drafting of the manuscript (JLV, BMG); critical revision of the manuscript for important intellectual content (JLV, BMG); and statistical analysis (JLV, BMG).

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eAppendix for: “Physician clinical knowledge, practice infrastructure, and quality of care”

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eAppendix A: Individual measures used to construct the overall, process, and intermediate outcome quality composite scores

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eAppendix A. Individual measures used to construct the overall, process, and intermediate outcome quality composite scores

The score for each individual measure was computed by multiplying the percentage of a physician’s patients who met the standard by the measure’s weight. For process measures, if the percentage of patients meeting the standard fell below the minimum criteria the physician was assigned a score of zero for that measure. The minimum criteria were developed by an expert panel to reflect the minimally acceptable level of care for a physician’s diabetic and/or hypertensive patient and were also used to create weights for scoring with the Dunn-Rankin method (Dunn-Rankin P. *Scaling methods*. Hillsdale, NJ: Lawrence Erlbaum; 1983). Total scores were computed by summing each physician’s individual scores and then normalized the score to a zero to one scale (i.e. percentage) by dividing by the maximum possible score (i.e. the sum of the weights). The physicians in the sample had an average overall quality score of 70.1% (SD=12.3%); an average process quality score of 77.6% (SD=18.2%); and an average intermediate outcomes quality score of 65.9% (SD=13.2%).

Quality measure	Measure criteria	Minimum criteria	Weight	% Patient meeting standard, mean (SD)	Score, mean (SD)
Diabetes measures					
Process measures					
Eye exam	Within prior 13 months or 25 months if no retinopathy	28.8	9	50.0 (27.9)	4.2 (2.9)
Urinary protein assessment	Within prior 13 months, prior positive test for nephropathy, or are receiving ACE/ARB therapy (excludes ESRD patients)	73.1	10	90.9 (15.2)	8.6 (2.8)
Foot exam	Within prior 13 months (excludes patients with amputation of both feet)	35.6	4	59.8 (36.8)	2.3 (1.6)
Smoking cessation counseling	Within prior 13 months or documented non-smoker	67.5	7	96.8 (7.5)	6.7 (0.8)
Intermediate outcome measures					
HbA1c control	Most recent HbA1c <= 9.0% within the last 13 months	na	10	87.8 (11.7)	8.8 (1.2)

HbA1c superior control	Most recent HbA1c $\leq 7.0\%$ or $\leq 8.0\%$ if age ≥ 65 or had cardiovascular disease or end stage renal disease or significant vision loss. Tested within the last 13 months	na	7	67.5 (17.0)	4.7 (1.2)
Blood pressure control	Most recent blood pressure $< 140/90$ mm Hg within last 13 months	na	10	76.2 (14.2)	7.6 (1.4)
Blood pressure superior control	Most recent blood pressure $< 130/80$ mm Hg within last 13 months	na	9	42.2 (15.8)	3.8 (1.4)
LDL control	Most recent LDL < 130 mg/dl within the last 13 months	na	10	83.0 (14.2)	8.3 (1.4)
LDL superior control	Most recent LDL < 100 md/dl within the last 13 months	na	8	63.3 (16.7)	5.1 (1.3)
Hypertension measures					
Process measures					
Aspirin (or comparable) therapy	Under age 30 or low Framington risk or receiving aspirin or anticoagulant therapy	58	4	69.1 (20.0)	2.3 (1.4)
Lipid profile testing	Within prior 25 months	57.5	5	91.0 (15.8)	4.5 (1.1)
Urinary protein assessment	Documented test or diagnosis of chronic kidney disease	50	4	75.4 (26.1)	2.8 (1.4)
Serum creatinine testing	Within prior 13 months	67.5	4	93.1 (13.6)	3.7 (0.8)
Diabetes screening	Documented test or diagnosis of diabetes	81.7	4	94.0 (13.4)	3.5 (1.2)
Smoking cessation counseling	Within prior 13 months or documented non-smoker	80	5	97.1 (6.8)	4.8 (0.7)
Diet & physical activity counseling	Received any of the following dietary counseling: (1) Dietary saturated fat and cholesterol restriction for patients with heart disease, peripheral vascular disease, stroke or heart attack, diabetes, history of elevated LDL or low HDL, or overweight/obese; (2) Calorie restriction as part of weight reduction program for overweight/obese patients; (3) DASH eating plan; (4) Dietary sodium restriction; (5) Increased fruits, vegetables, and/or soluble	63	4	80.6 (23.7)	2.9 (1.5)

	fiber. Documented activity status and exercise counseling for inactive patients.				
Intermediate outcome measures					
Blood pressure control	Blood pressure <140/90 mm or <130/80 mm Hg with chronic kidney disease or diabetes. Tested within last 13 months.	na	29	56.8 (16.4)	16.4 (4.7)
LDL control	LDL <160 mg/dl; or <100 mg/dl with coronary heart disease, stroke, peripheral artery disease or diabetes; or <130 mg/dl with coronary heart disease, stroke, peripheral artery disease or diabetes and either of the following risk factors: low HDL (<40 mg/dl), on HDL raising medication, age ≥45 for men or ≥ 55 for women, family history of coronary heart disease, or smoking (or two risk factors if HDL ≥60 mg/dl). Tested within last 13 months.	na	25	67.9 (17.6)	17.0 (4.4)

eAppendix B. Regression adjusted relationship between physician quality and practice infrastructure overall

Regression adjusted overall care quality scores (mean 70.1%, SD 12.3%) were higher among physicians with top quintile practice infrastructure than those in the bottom quintile (3.9 percentage point difference: 95% CI 1.8 to 5.9, p<0.001). This positive relationship was also observed between process quality (mean 77.6%, SD 18.2%) and practice infrastructure (p<.001). No significant relationship was observed between intermediate outcomes quality (mean 65.9%, SD 13.2%) and practice infrastructure scores (p=0.27).

Quality measure	Practice infrastructure score quintile, percentage point (95% CI) ^a					Overall P-value
	Q1 (0 to 45)	Q2 (46 to 58)	Q3 (59 to 70)	Q4 (71 to 83)	Q5 (84 to 100)	
Overall quality composite score	ref	0.6 (-1.2 to 2.4)	2.5 (0.7 to 4.3)**	2.1 (0.2 to 4.0)*	3.9 (1.8 to 5.9)***	P=0.003
Process measure composite score	ref	2.1 (-0.6 to 4.8)	5.1 (2.4 to 7.8)***	4.9 (2.1 to 7.6)***	7.3 (4.4 to 10.3)***	P<.001
Intermediate outcome composites score	ref	-0.2 (-2.1 to 1.7)	1.1 (-0.7 to 2.9)	0.6 (-1.5 to 2.6)	1.9 (-0.2 to 4.0)	P=0.27

* P<0.05; ** P<0.01; *** P<0.001

^aAdjusted for patient panel characteristics (% female and in age and racial groups, % with language and/or insurance barriers), practice characteristics (practice type, practice size, rural practice, HHS region, zip code–level median household income, hospital service area age, sex, and race–adjusted Medicare mortality rates), and physician characteristics (training and nativity, gender, round of MOC completed and year and type of PIM completed).

eAppendix C. Probit regression coefficients with the overall quality composite score as the dependent variable

Numbers of obs. = 1,301		
Wald $\chi^2(66) = 386.31$		
Prob. > $\chi^2 = 0.000$		
Pseudo $R^2 = 0.0145$		
Overall quality composite score	b (se)	p
Practice infrastructure score quintile		
Q1: <=45	ref	
Q2: 45 to 58	-0.037 (0.075)	0.62
Q3: 59 to 70	0.005 (0.065)	0.94
Q4: 71 to 83	0.050 (0.072)	0.49
Q5: >83	0.021 (0.067)	0.75
Exam score quintile		
Q1: <443	ref	
Q2: 443 to 491	-0.052 (0.067)	0.44
Q3: 492 to 535	0.025 (0.066)	0.70
Q4: 536 to 591	-0.041 (0.067)	0.55
Q5: >591	-0.071 (0.061)	0.24
Practice infrastructure (PI) by Exam score interactions		
Exam Q2*PI score Q2	0.049 (0.098)	0.62
Exam Q2*PI score Q3	0.092 (0.086)	0.28
Exam Q2*PI score Q4	-0.083 (0.095)	0.38
Exam Q2*PI score Q5	0.031 (0.099)	0.75
Exam Q3*PI score Q2	0.018 (0.096)	0.85
Exam Q3*PI score Q3	0.008 (0.088)	0.93
Exam Q3*PI score Q4	-0.042 (0.097)	0.67
Exam Q3*PI score Q5	0.074 (0.089)	0.41
Exam Q4*PI score Q2	0.067 (0.092)	0.47
Exam Q4*PI score Q3	0.077 (0.093)	0.41
Exam Q4*PI score Q4	0.044 (0.093)	0.64
Exam Q4*PI score Q5	0.154 (0.097)	0.11
Exam Q5*PI score Q2	0.117 (0.091)	0.20
Exam Q5*PI score Q3	0.146 (0.081)	0.07
Exam Q5*PI score Q4	0.127 (0.088)	0.15
Exam Q5*PI score Q5	0.208 (0.084)	0.01
Practice type		
Group/office-based	ref	
Academic/teaching	0.057 (0.041)	0.17
Other (e.g. VA, military)	-0.105 (0.034)	0.002
Practice size		
Solo	ref	
2 to 10 physicians	-0.023 (0.025)	0.36

11 or more physicians	0.025 (0.027)	0.35
Unknown	-0.179 (0.056)	0.001
PIM completed		
Hypertension	ref	
Diabetes	0.067 (0.018)	<.001
Year PIM completed		
2011	ref	
2012	-0.063 (0.024)	0.009
2013	-0.076 (0.025)	0.002
2014	-0.123 (0.037)	0.001
Round on MOC		
First	ref	
Second	0.023 (0.019)	0.23
Training and nativity		
International born: international medical school	ref	
US born: international medical school	0.022 (0.052)	0.67
International born: US medical school	-0.055 (0.032)	0.09
US born: US medical school	0.028 (0.061)	0.65
Female physicians	0.112 (0.021)	<.001
Unknown median household income	0.086 (0.053)	0.11
Median household income	0.000 (0.000)	0.85
Rural practice	-0.112 (0.031)	<.001
Health and Human Service (HHS) region		
HHS Region 1: Boston	ref	
HHS Region 2: New York	-0.050 (0.040)	0.21
HHS Region 3: Philadelphia	-0.058 (0.040)	0.15
HHS Region 4: Atlanta	-0.047 (0.036)	0.19
HHS Region 5: Chicago	-0.064 (0.038)	0.09
HHS Region 6: Dallas	-0.032 (0.044)	0.47
HHS Region 7: Kansas City	-0.017 (0.058)	0.76
HHS Region 8: Denver	-0.023 (0.068)	0.74
HHS Region 9: San Francisco	-0.056 (0.041)	0.17
HHS Region 10: Seattle	-0.103 (0.073)	0.16
Unknown HHS region	-0.397 (0.214)	0.06
Hospital Service Area (HSA) Medicare mortality rate (sex/age/race adjusted)	-0.059 (0.020)	0.004
Unknown Medicare mortality rate	0.160 (0.192)	0.40
% Female patients	-0.229 (0.055)	<.001
% Patients with language barriers	-1.006 (0.207)	<.001
% Patient with healthcare costs/insurance barriers	-0.019 (0.057)	0.75
% Patient age		
<45 years old	ref	
45-54 years old	0.556 (0.171)	0.001

55-64 years old	0.872 (0.131)	<.001
65-74 years old	0.933 (0.130)	<.001
>75 years old	0.788 (0.121)	<.001
Unknown	-1.197 (3.802)	0.75
% Patient race		
White NH	ref	
Black NH	-0.083 (0.049)	0.09
Hispanic	-0.107 (0.051)	0.03
Asian/ PI	0.113 (0.063)	0.07
Other	-0.014 (0.089)	0.88
Constant	0.231 (0.167)	0.17

eAppendix D. Comparison of control variables across quintiles of practice infrastructure

Overall, mean comparisons indicate that there was slightly negative relationship between MOC exam score and our practice infrastructure measure ($p=0.04$). Practice infrastructure was also related to their training ($p<0.001$) and cycle of MOC ($p=0.02$) as well as their practice size ($p=0.03$), type ($p<.001$), and US region ($p=0.04$). Patient panel characteristics were similar across practices with different levels of practice infrastructure ($P_s>0.19$) except that physicians in the highest infrastructure practices had significantly fewer female patients ($p=0.01$).

Characteristics	Total	Practice infrastructure score quintile					P-value
		Q1 (0 to 45)	Q2 (46 to 58)	Q3 (59 to 70)	Q4 (71 to 83)	Q5 (83 to 100)	
Physician characteristics							
Exam score quintile, No. (col %)							
Q1 (<443)	263 (20.2)	48 (18.4)	38 (14.4)	62 (24.1)	55 (20.9)	60 (23.3)	
Q2 (443 to 491)	258 (19.8)	54 (20.7)	49 (18.6)	51 (19.8)	51 (19.4)	53 (20.6)	
Q3 (492 to 535)	265 (20.4)	43 (16.5)	55 (20.9)	47 (18.3)	62 (23.6)	58 (22.6)	0.04
Q4 (536 to 591)	257 (19.8)	50 (19.2)	71 (27.0)	47 (18.3)	47 (17.9)	42 (16.3)	
Q5 (>591)	258 (19.8)	66 (25.3)	50 (19.0)	50 (19.5)	48 (18.3)	44 (17.1)	
Training and nativity, No. (col %)							
US born and medical school	591 (45.4)	131 (50.2)	139 (52.9)	128 (49.8)	117 (44.5)	76 (29.6)	
US born: International medical school	47 (3.6)	31 (11.9)	19 (7.2)	29 (11.3)	20 (7.6)	26 (10.1)	<.001
International born: US medical school	125 (9.6)	13 (5.0)	8 (3.0)	9 (3.5)	11 (4.2)	6 (2.3)	
International born and medical school	538 (41.4)	86 (33.0)	97 (36.9)	91 (35.4)	115 (43.7)	149 (58.0)	
Female physicians, No. (col %)	549 (42.2)	109 (41.8)	106 (40.3)	110 (42.8)	106 (40.3)	118 (45.9)	0.68
PIM completed, No. (col %)							
Hypertension	718 (55.2)	149 (57.1)	140 (53.2)	138 (53.7)	143 (54.4)	148 (57.6)	0.79
Diabetes	583 (44.8)	112 (42.9)	123 (46.8)	119 (46.3)	120 (45.6)	109 (42.4)	
Year PIM completed, No. (col %)							
2011	259 (19.9)	64 (24.5)	62 (23.6)	54 (21.0)	44 (16.7)	35 (13.6)	
2012	442 (34.0)	95 (36.4)	97 (36.9)	84 (32.7)	98 (37.3)	68 (26.5)	0.001
2013	480 (36.9)	84 (32.2)	84 (31.9)	95 (37.0)	96 (36.5)	121 (47.1)	
2014	120 (9.2)	18 (6.9)	20 (7.6)	24 (9.3)	25 (9.5)	33 (12.8)	

Round of MOC, No. (col %)							
First	850 (65.3)	157 (60.2)	173 (65.8)	158 (61.5)	174 (66.2)	188 (73.2)	0.02
Second	451 (34.7)	104 (39.8)	90 (34.2)	99 (38.5)	89 (33.8)	69 (26.8)	
Practice characteristics							
Practice type, No. (col %)							
Group/office-based	1,086 (83.5)	227 (87.0)	222 (84.4)	226 (87.9)	208 (79.1)	203 (79.0)	
Academic/teaching	50 (3.8)	15 (5.7)	8 (3.0)	9 (3.5)	13 (4.9)	5 (1.9)	<.001
Other (e.g., VA, military)	165 (12.7)	19 (7.3)	33 (12.5)	22 (8.6)	42 (16.0)	49 (19.1)	
Practice size, No. (col %)							
Solo	294 (22.6)	62 (23.8)	57 (21.7)	70 (27.2)	52 (19.8)	53 (20.6)	
2 to 10 physicians	590 (45.3)	125 (47.9)	140 (53.2)	109 (42.4)	108 (41.1)	108 (42.0)	0.03
11 or more physicians	378 (29.1)	67 (25.7)	58 (22.1)	70 (27.2)	94 (35.7)	89 (34.6)	
Unknown	39 (3.0)	7 (2.7)	8 (3.0)	8 (3.1)	9 (3.4)	7 (2.7)	
Health and Human Service (HHS) region, No. (col%)							
HHS Region 1: Boston	94 (7.2)	16 (6.1)	14 (5.3)	17 (6.6)	25 (9.5)	22 (8.6)	
HHS Region 2: New York	178 (13.7)	40 (15.3)	46 (17.5)	33 (12.8)	34 (12.9)	25 (9.7)	
HHS Region 3: Philadelphia	143 (11.0)	37 (14.2)	26 (9.9)	25 (9.7)	26 (9.9)	29 (11.3)	
HHS Region 4: Atlanta	277 (21.3)	49 (18.8)	55 (20.9)	59 (23.0)	54 (20.5)	60 (23.3)	
HHS Region 5: Chicago	225 (17.3)	33 (12.6)	37 (14.1)	52 (20.2)	53 (20.2)	50 (19.5)	0.04
HHS Region 6: Dallas	109 (8.4)	21 (8.0)	35 (13.3)	18 (7.0)	20 (7.6)	15 (5.8)	
HHS Region 7: Kansas City	36 (2.8)	6 (2.3)	12 (4.6)	5 (1.9)	10 (3.8)	3 (1.2)	
HHS Region 8: Denver	28 (2.2)	6 (2.3)	4 (1.5)	8 (3.1)	6 (2.3)	4 (1.6)	
HHS Region 9: San Francisco	160 (12.3)	41 (15.7)	26 (9.9)	34 (13.2)	23 (8.7)	36 (14.0)	
HHS Region 10: Seattle	31 (2.4)	7 (2.7)	5 (1.9)	5 (1.9)	8 (3.0)	6 (2.3)	
Unknown HHS region	20 (1.5)	5 (1.9)	3 (1.1)	1 (0.4)	4 (1.5)	7 (2.7)	
Rural practice, No. (col %)	112 (8.6)	28 (10.7)	25 (9.5)	28 (10.9)	19 (7.2)	12 (4.7)	0.06
Median household income (Zip code), mean (SD)	61,008 (26,084)	61,787 (26,699)	61,752 (26,643)	61,881 (26,382)	60,660 (26,352)	58,862 (24,289)	0.66
Unknown median household income, No. (%)	49 (3.8)	10 (3.8)	8 (3.0)	3 (1.2)	15 (5.7)	13 (5.1)	0.06

Hospital Service Area (HSA) Medicare mortality rate (age, sex, and race adjusted), mean (SD)	4.5 (0.6)	4.4 (0.6)	4.5 (0.6)	4.5 (0.6)	4.5 (0.5)	4.5 (0.5)	0.97
Unknown Medicare mortality rate, No. (%)	22 (1.7)	6 (2.3)	3 (1.1)	1 (0.4)	4 (1.5)	8 (3.1)	0.14
Mean patient panel characteristics							
% Female patients, mean (SD)	50.4 (19.6)	53.2 (15.9)	51.4 (18.0)	51.0 (18.9)	48.5 (20.4)	48.0 (23.5)	0.01
% Patients with language barriers, mean (SD)	1.1 (4.2)	1.1 (3.6)	0.9 (3.4)	1.2 (4.0)	1.3 (6.6)	0.9 (2.5)	0.73
% Patient with healthcare costs/insurance barriers, mean (SD)	6.9 (14.4)	7.4 (14.1)	6.7 (13.2)	7.3 (15.3)	7.4 (15.2)	5.8 (14.4)	0.67
% Patient age groups, mean (SD)							
<45 years old	7.3 (8.6)	7.7 (9.8)	7.6 (9.4)	7.1 (7.2)	6.7 (7.1)	7.6 (9.1)	0.61
45-54 years old	15.6 (10.4)	15.3 (10.1)	15.5 (10.3)	15.9 (10.0)	16.0 (11.3)	15.0 (10.2)	0.83
55-64 years old	27.3 (11.5)	26.9 (12.5)	27.6 (11.7)	27.7 (11.3)	27.2 (10.4)	26.9 (11.5)	0.88
65-74 years old	29.3 (12.5)	28.5 (12.3)	29.0 (13.3)	29.3 (11.5)	28.6 (11.9)	30.9 (13.1)	0.19
>75 years old	20.5 (14.4)	21.5 (15.0)	20.2 (15.4)	20.0 (14.0)	21.4 (13.5)	19.6 (13.8)	0.42
Unknown	<0.1 (0.2)	<0.1 (<0.1)	<0.1 (0.2)	<0.1 (<0.1)	<0.1 (0.3)	<0.1 (<0.1)	0.26
% Patient race groups, mean (SD)							
White non-Hispanic (NH)	63.3 (31.9)	62.6 (31.9)	63.6 (31.8)	64.2 (32.1)	65.1 (31.1)	60.8 (32.8)	0.59
Black NH	16.3 (22.5)	16.6 (22.2)	15.9 (22.2)	15.3 (22.8)	15.2 (20.2)	18.7 (24.8)	0.37
Hispanic	10.7 (19.4)	9.9 (18.3)	11.2 (20.1)	10.6 (19.1)	10.5 (19.0)	11.3 (20.6)	0.91
Asian/ PI NH	6.4 (17.0)	7.3 (17.6)	5.4 (15.9)	6.7 (17.3)	6.1 (17.8)	6.4 (16.2)	0.77
Other	2.5 (9.4)	2.5 (8.7)	3.2 (11.4)	2.8 (10.8)	2.2 (8.1)	1.8 (7.1)	0.49