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Complete List of Authors:	Gray, Bradley Michael; American Board of Internal Medicine Vandergrift, Jonathan; American Board of Internal Medicine McCoy, Rozalina; Mayo Clinic, Division of Endocrinology, Department of Medicine Lipner, Rebecca; American Board of Internal Medicine Landon, Bruce; Harvard Medical School, Department of Health Care Policy
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Diagnostic Knowledge, Diagnostic Error and Risk of Death, Hospitalization and Emergency Department Visits

Bradley M. Gray, PhD, corresponding author

Email: bgray@abim.org, Phone: 202-213 6646, FAX 202-213 6646

American Board of Internal Medicine

510 Walnut Street, Suite 1700, Philadelphia, Pennsylvania 19106, USA

Jonathan L. Vandergrift, MS

American Board of Internal Medicine Philadelphia, Pennsylvania, USA

Rozalina, G. McCoy, MD

Mayo Clinic, Rochester, Minnesota, USA

Rebecca S. Lipner, PhD

American Board of Internal Medicine Philadelphia, Pennsylvania, USA

Bruce E. Landon, MD

Harvard Medical School, Boston, Massachusetts, USA

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Objective

Diagnostic error is a key health care concern with large associations with morbidity and mortality. Yet no study has quantified associations between outcomes whose cause was at risk for diagnostic errors and one potentially large contributor to these errors: deficiencies in diagnostic knowledge. Our objective was to measure that associations between diagnostic knowledge and adverse outcomes at risk for diagnostic errors.

Setting

US primary care

Participants

1,410 general internists treating 42,407 Medicare beneficiaries during 48,632 outpatient visits.

Outcome measures

Using Medicare claims from general internists who recently took their American Board of Internal Medicine Maintenance of Certification exam, we identified outpatient "index" visits for new complaints at risk for diagnostic error because the presenting complaint was related to pre-specified diagnostic error sensitive conditions.

Design

Using a cross-sectional design, we related performance on ABIM-MOC diagnostic exam questions to 90-day risk of all-cause death, and, for outcome conditions related to the index visits diagnosis, emergency department (ED) visits and hospitalizations.

Results

Rates of 90-day adverse outcomes per 1,000 index visits were 7 for death, 11 for hospitalizations, and 14 for ED visits. Being seen by a physician in the top versus bottom third of diagnostic knowledge during an index visit for a new compliant at risk for diagnostic error was associated with 2.9 fewer all-cause deaths (95% confidence interval (CI) -5.0 to -0.7, P=.008), and 4.1 fewer applicable hospitalizations (95% CI -6.9 to -1.2, P=0.006), and 4.9 fewer applicable ED visits (95% CI -8.1% to -1.6%, P=0.003) per 1,000 visits.

Conclusion

Higher diagnostic knowledge was associated with lower risk of adverse outcomes at heightened risk for diagnostic error.

Strength Limitations

- **Strengths**
  - Unique diagnostic knowledge measure
  - Linking diagnostic knowledge with adverse outcomes
  - Scalable adverse outcome measures
  - Extensive sensitivity analyses
- **Limitation**
  - Omitted variable bias
  - No direct diagnostic error measure

Introduction

Diagnostic error has been identified as a key health care delivery concern and contributes to significant potentially preventable morbidity and mortality.(1-3) Ambulatory care, and especially primary care, is a practice setting with a particularly high risk for diagnostic error(4, 5) because of the wide variety of presentations encountered and the concomitant difficulty of distinguishing harmful conditions from routine self-limited complaints, compounded by the well-known time constraints faced by practitioners in that setting. Sing et. al., estimated that at least 5% of ambulatory visits are associated with diagnostic error, half of which may result in considerable patient harm.(6) Similarly, Newman-Toker et al. reported that the cause of most malpractice suits was diagnostic error and that the majority of these occurred in the ambulatory care settings.(6, 7)

Deficiencies in diagnostic knowledge are likely to be an important contributor to these diagnostic errors that could impact, for example, the breadth of diagnoses considered, appropriate ordering and interpretation of tests, and/or synthesis of data more generally.(8-11) Because of this, measuring physician diagnostic knowledge has become a major focus of organizations throughout the developed world that are tasked with licensing and certifying physicians with the underlying, although largely untested, hypothesis being that diagnostic knowledge will be a measurable and strong predictor of diagnostic error.(12-15) Testing this hypothesis and quantifying this relationship is therefore a critical public policy concern both in terms of the

importance of board certification and other programs designed to enhance lifelong learning for physicians.

In the US, the American Board of Internal Medicine (ABIM) is a leading organization that certifies primary care physicians, most notably general internists. In fact, most general internists in the US are certified by the ABIM and these physicians represent about 45% of all adult primary care physicians in the US.(16) Unlike medical licensure, board certification is not a legal requirement to practice medicine in the US, though many hospitals require board certification as one criterion to obtain privileges and insurers often require board certification to be included in covered physician panels.(17, 18) To maintain their certification, general internists must pass an initial certifying exam and, periodically, pass a recertification exam thereafter (referred to as Maintenance of Certification (MOC) exams).(19, 20) Diagnostic knowledge is a major component of these exams representing about half of all exam questions for the Internal Medicine MOC (IM-MOC) exam.

One explanation for the lack of research on this topic is the difficulty in studying the relationship between general diagnostic knowledge and diagnostic error because of the inability to quantify diagnostic knowledge and identifying diagnostic errors at a population level, especially in the outpatient setting.(21) We address this gap in the literature by applying a unique measure of diagnostic knowledge, performance on diagnostic related questions on ABIM's IM-MOC exam, and relating this measure to deaths, hospitalizations, and emergency department visits that occurred after outpatient visits for new complaints at heightened risk for diagnostic error.

Methodology

Physician and Index Visit Sample

Our physician sample included general internists who were initially ABIM board certified in 2000 and took their IM-MOC exam between 2008 and 2011 (Figure 1). We identified Medicare beneficiary outpatient Evaluation & Management (E&M) visits with these physicians using their National Provider Identifier (NPI) during the calendar year following their exam (2009 to 2012). These patients were age 65 or older and continuously enrolled in Medicare fee-for-service (Medicare insures most of the US population over 65) during the physician's one year follow-up period and the year prior. To ensure that any presenting complaints being evaluated were new (i.e., not follow up), we restricted these visits to those that were the first visit for a new complaint (the "*index visit*") because these visits were preceded by a 90-day clean period with no previous inpatient or outpatient visit. The 90-day clean period is consistent with the US government Centers for Medicare and Medicaid Services criteria used by its Bundled Payments for Care Improvement Program for defining new episodes of care and with the patterns of visits we observed (see Appendix Section 1 for related analysis).(22, 23)

We further restricted these index visits to those at heightened risk for diagnostic errors because the recorded diagnosis in the Medicare claims (the "*index visit diagnosis"*), which includes recording of symptom (e.g. loss of balance), could have been the initial presenting complaint for one or more of 13 pre-specified diagnostic error sensitive conditions such as congestive heart failure or bacteremia/sepsis (see Table 1). These 13 conditions (see Appendix Section 2 for a list

and applicable ICD-9 codes) were an acute non-cancerous subset of 20 conditions previously noted by Schiff et al. to be at high risk for serious diagnostic error.(24) For instance, index visits with diagnosis codes for chest pain, dyspepsia, shortness of breath, hypoxemia/hypoxia, respiratory distress, weakness/fatigue, edema or ascites could all be the initial presentation of congestive heart failure, which is one of the 13 diagnostic error sensitive conditions.

We used a three-step process to identify eligible index visit diagnoses. First, two physician authors (RGM and BEL) identified all diagnoses that could be presenting complaints for the 13 diagnostic error sensitive conditions: what complaints/diagnoses might someone who ultimately presented with a diagnostic-error sensitive condition have presented with initially? Second, because the original list of identified index visit diagnoses was large (76), we reduced this list to 38 by applying a relative risk (RR) criteria. For a specific index visit diagnosis to meet this criteria, all index visits with that diagnosis had to have a greater portion of later ED visits or hospitalizations with the related outcome condition discharge diagnosis than index visits where the specific at risk diagnosis was not present. For example, dizziness was chosen as an eligible index visit diagnosis for stroke, one of the diagnostic error sensitive conditions, both because it was identified as a potential presenting symptom of a stroke by physician authors and because index visits with that diagnosis had a greater proportion of later hospitalization or ED visits for stroke than visits without this diagnosis. Third, we also included index visits where the actual diagnosis was one of the 13 diagnostic error sensitive conditions because we wanted to include cases where diagnostic errors were and were not made. Therefore, we also included index visits with a diagnosis of congestive heart failure itself as being at risk for the underlying condition congestive heart failure.

There was no patient/public involvement in the design, conduct or reporting for this study.

Outcome Measures

We examined the risk of three serious adverse outcomes within 90 days of the index visit that we hypothesized would occur more frequently in cases of misdiagnosis: all-cause mortality, hospitalizations, and ED visits. We did not count these events as adverse outcomes if they occurred on the same day as the index visit because this may reflect a positive action (the physician correctly diagnosed a patient with stroke and referred/admitted them to the hospital) or be unavoidable regardless of the accuracy of the index visit diagnosis (the patient died despite immediately admitting a patient to the hospital who exhibited stroke symptoms). Based on Medicare billing codes, hospitalizations were limited to non-elective hospitalizations initiated through the ED or trauma center. The ED and hospitalization outcomes were also limited to cases where the discharge diagnosis was for one of the 13 diagnostic error sensitive conditions following an index visit with the applicable diagnosis. We therefore presumed that these discharge diagnoses were a reasonable representation of the underlying condition of the patient at the time of the index visit. For example, we would count a hospitalization with a discharge diagnosis of stroke as an adverse outcome if it occurred after an index visit for dizziness because dizziness was identified as being a potential presenting complaint for stroke. However, we did not count hospitalizations with a discharge diagnosis for acute coronary syndrome following an index visit for dizziness because dizziness was not identified as a presenting complaint for acute coronary syndrome. The rationale is that if there were no presenting complaints during the index visit related to coronary syndrome, either because the underlying condition was not present or

could not be detected at the time of the index visit, then the index visit physician could not have prevented the hospitalization regardless of their diagnostic knowledge.

Measure of Diagnostic Knowledge

Our measure of diagnostic knowledge was calculated as the percent of correct answers on the IM-MOC exam for questions coded as "diagnosis related" by ABIM's IM-MOC exam committee. In our study, these questions comprised 53% of all IM-MOC exam questions, with the remaining 42% addressing treatment and 5% related to other topics such as epidemiology or pathophysiology. Exam questions are designed to replicate real world clinical scenarios and/or patient encounters(25) and do not rely on rote memorization. Questions coded as "diagnosis related" typically test knowledge and skills related to diagnostic inference, differential diagnosis, and diagnostic testing and therefore are measuring diagnostic knowledge and decision-making. Psychometric analysis indicates that scores on exam questions related to diagnosis were meaningfully correlated, and thereby represent an independent underlying construct that could be interpreted as diagnostic knowledge (see Appendix Section 3).

Statistical methods

Using Probit regression we estimated the associations with each adverse outcome, with standard errors adjusted for correlations resulting from the nesting of visits within patients within physicians.(26, 27) To measure associations with diagnostic knowledge we included categorical regression explanatory variables for top and middle third of percent correct scores on diagnosis related questions (bottom third was the reference category). Other exam level explanatory variables included tertile indicators for performance on treatment-related questions and

performance on other question types. Since these variables measure knowledge unrelated to diagnosis, they account for correlations between factors such as unmeasured practice or patient characteristics that might be correlated with exam performance and our outcome measures (e.g., high scoring physicians may be more likely to practice in an academic setting or other such settings that might be independently related to diagnostic error). Exam form indicators accounted for differences in exam difficulty across exam administrations.

We also included physician, patient and visit level regression controls. Physician level controls included: practice size (indicators for solo practice and practices larger than 50 physicians), practice type (indicators for academic, group), demographic (gender), and training characteristics (medical school location interacted with country of birth). Patient level controls included: demographic characteristics (age and age squared, gender and race/ethnicity indicators) and a Medicaid eligibility indicator. Lagged patient risk adjusters included 27 indicators for chronic conditions and Medicare's Hierarchal Condition Category (HCC) risk adjustment score. Patient index visit location level controls included: an indicator for residing in a rural ZIP code, ZIP code median household income, and indicators for 10 US Health and Human Services regions. Index visit level controls included: indicators of any outpatient visit, hospitalization or ED visits within the prior year and number of days since the most recent of these events, visit year indicators to control for secular changes in quality. We also included an indicator for whether or not the patient had a previous contact with the index visit physician during the year prior to the index visit to account for differences in physician-patient continuity (see Appendix Sections 4 and 6 for a full list of controls).

Sensitivity Analysis

We performed numerous sensitivity analyses to test the robustness of our results (detailed in Appendix Section 5). First, we expanded the index visit sample to include all index visits with the original 76 diagnoses identified by the physician authors regardless of whether they met the relative risk criteria. Second, we expanded and contracted the index visit clean period by seven days. Third, we excluded physician in academic medical centers to consider the possibility that the unobserved physician characteristics related to where they worked or who they worked with could be were independently both related to the underlying physician diagnostic skill and our outcome measures. Fourth, to consider the possibility that these utilizations were only avoided because the patient died, for the ED and hospitalization outcome, we also included instances where the patient died. Fifth, as a falsification test we limited the index visits to those that were unrelated to the 13 diagnostic error sensitive conditions. Under this sensitivity, we expected then that the associations with diagnostic knowledge would decline. The index visit physician's diagnostic knowledge cannot impact a future adverse outcome if the underlying condition that caused that outcome was not present or detectible at the time of index visit. Therefore, this reduction in association should be especially true for the hospitalization and ED measures where adverse outcomes were limited to the 13 diagnostic error conditions and so were unrelated to the index visit diagnoses in this sensitivity. Similarly, for the last sensitivity, we applied elective hospitalizations as an outcome measure to consider the possibility that there could be a correlation between the overall propensity to hospitalize in an area and physician knowledge.

The Advarra Institutional Review Board approved our study protocol and all analyses were performed using Stata version 15 (College Station, TX). Patients and the public were not

involved in the design or execution of this study as the existing patient claims data used were de-identified by the Center for Medicaid and Medicare Services prior to analysis.

Results

Of 2,492 general internists who initially certified in 2000 and who took an IM-MOC exam between 2009 and 2012, 1,722 had outpatient visits with a fee-for-service Medicare beneficiary during the study period. Those without visits generally practiced hospital medicine. Of these, 1,410 were included in the study because they had at least one outpatient index visit that met our study inclusion criteria during the year after they took their IM-MOC exam. In total, 48,632 index visits with 42,407 patients treated by 1,410 physicians met study inclusion criteria (Figure 1). Table 1 lists frequency of index visits and subsequent outcomes for each diagnostic error sensitivity condition.

The mean percent correct on diagnosis questions ranged from 84.3% among top third performers to 65.5% among bottom third performers (Table 2). Patient and visit characteristics were similar across tertiles of physician diagnostic knowledge. For example, there were no statistically significant differences in the HCC risk adjuster across tertiles (P=.19) However, there were differences in some physician and practice characteristics. When compared to physicians in the bottom tertile of diagnostic knowledge, physicians in the top were significantly less likely to be in solo practice (12.8% versus 24.4%, P=0.009), and more likely to be in academic practice (9.7% versus 3.4%, P<.001). However, the proportion graduating from a US medical school was

similar across diagnostic knowledge tertiles (70.0% versus 63.3%, P=.30). Although performance on diagnosis and treatment related questions were highly correlated, 36% of the variation in diagnosis exam performance was not explained by performance on other parts of the exam.

Associations between diagnostic knowledge and patient adverse outcomes

The overall rates of 90-day adverse outcomes per 1,000 index visits was 6.5 for death, 11.1 for hospitalizations, and 13.6 for ED visits (with the latter two directly associated with one of the diagnostic error sensitive conditions whose antecedent was present in the index applicable index visit). Being seen by a physician scoring in the top versus bottom third of diagnostic knowledge on the MOC exam was associated with 2.9 fewer deaths per 1,000 visits (95% confidence interval (CI) -5.0 to -0.7, P=.008) which reflects a 35.3% lower risk of death (95% CI -52.8 to -11.2, P=.008), (Table 3). Our finding also suggest that this difference in exam performance was associated with a 4.1 fewer applicable hospitalizations (95% CI -6.9 to -1.2, P=0.006), and 4.9 fewer applicable ED visits (95% CI -8.1 to -1.6, P=0.003) per 1,000 visits (Table). These reductions correspond with about a 30% lower risk for these utilization measures (hospitalizations: -30.5%, 95% CI -46.1 to -10.4, P=.003, ED: -29.8%, 95% CI -44.4 to -11.4).

We also found a significant dose response relationship across all three regression adjusted relative risk measures (P-trends <0.008). For example, the regression-adjusted 90-day risk of death per 1,000 patients whose index visit physician scored in the top third of diagnostic knowledge was 5.2 (95% CI 4.1 to 6.3), compared to 6.5 (95% CI 5.4 to 7.6) for the middle third, and 8.1 (95% CI 6.5 to 9.7) for the bottom third (P-trend 0.008).

Sensitivity Analyses

Our sensitivity analyses (Appendix Section 5) confirmed that base case associations with diagnostic knowledge were robust to different index visit clean periods, and diagnosis code inclusion criteria. Suggesting that our results were not influenced by omitted variable bias, we found that associations with diagnostic knowledge and our outcome measures became small and statistically insignificant when we limited the sample to index visits with diagnoses unrelated to any of the 13 diagnostic sensitive error conditions, and so were at lower risk for diagnostic error (P>0.50 and associations were at most about a tenth of the base case percent difference between top and bottom third of diagnostic knowledge). We also found no significant association between lack of diagnostic knowledge and elective hospitalizations (P=0.63).

Discussion

We found that higher diagnostic knowledge among US outpatient internal medicine physicians was associated with significant reductions in subsequent adverse outcomes whose cause was at risk for diagnostic error. Indeed, for every 1,000 index visits for a new compliant at risk for diagnostic error, being seen by a physician in the top versus bottom third of diagnostic knowledge was associated with 2.9 fewer all-cause death and, for diagnostic error sensitive conditions, 4.1 fewer hospitalizations and 4.9 fewer ED visits within 90 days. These figures correspond to a reduction in risk for these adverse events by about a third. Although some prior studies have demonstrated the high morbidity and mortality of diagnostic error(1-3), this is the first study to demonstrate and quantify the direct association between serious adverse outcomes

and the diagnostic knowledge of their first contact primary care physician. These finding support the notion that gaps in diagnostic knowledge between physicians is an important contributor to the diagnostic error problem plaguing the healthcare system worldwide.

We measured the association between diagnostic knowledge and potential diagnostic error by using Medicare claims data to identify patients who presented for outpatient visits with complaints at heightened risk for serious diagnostic errors and examining the occurrence of clinically relevant adverse outcomes soon thereafter. Although this approach lacks the precision of individual chart audits(6), it is both clinically plausible and scalable in that it can be used to monitor the care of large numbers of patients, making the method itself an important contribution to the literature on diagnostic error. Although we did not directly measure diagnostic errors through chart audits, the fact that we found associations with diagnostic knowledge and the diagnostic error sensitive outcome conditions we studied coupled with the fact that we did not find associations with treatment knowledge, nor did we find associations when the underlying diagnostic error sensitive condition was likely not present during the outpatient index visit because no antecedent diagnoses recorded indicates that the associations we report in this study were likely driven by association with diagnostic errors that occurred during these visits. Furthermore, our approach builds on prior studies that used claims data to infer diagnostic error incidence for ED visits, in that we identified index visit diagnoses at risk for diagnostic error that were clinically plausible and verified empirically, and we assured that we were studying new problems by requiring that the patient not have had a visit over the previous 3 months contacts.(28-30) We expanded on these studies by focusing on outpatient care and by examining a much more comprehensive set of presenting complaints that may have been precursors to one

of 13 diagnostic error prone conditions that we studied. This approach was necessary in order to study diagnostic error in the more low acuity setting of outpatient general internal medicine.

Our findings suggest an association between diagnostic knowledge and adverse outcomes. Yet, there are important limitations to consider. We did not directly determine whether a diagnostic error had occurred through chart review. Because our analyses were cross sectional, we cannot rule out the possibility that observed associations were the result of omitted variable bias related to either physician or patient characteristics, and do not reflect a causal relationship between diagnostic knowledge and adverse outcomes. That said, there is no reason to believe that these characteristics would be correlated with diagnostic knowledge independent of treatment knowledge, which we were able to control for. Furthermore, had associations with diagnostic knowledge been driven by omitted variable bias then we would have expected them to be similar when estimated across index visits with lower or higher risk for diagnostic error, and they were not. We also found that diagnosis exam performance was not associated with elective hospitalizations, which are, presumably, unrelated to underlying diagnostic knowledge but may be related to the overall propensity to hospitalize. Additional limitations include the fact that we studied select conditions among older patients enrolled in the Medicare program so we cannot extrapolate these findings to a younger population, other conditions we did not consider, or populations with no or different health insurance coverage. Finally, diagnostic error may also stem from factors outside of inadequate diagnostic knowledge, which are likely not represented by test exam scores but could be correlated with diagnostic knowledge (e.g., poor patient/physician communication skills and related system failures).(31, 32) That said, there is no reason to believe that these other contributors to diagnostic error would not also be correlated

with the other aspects of the exam we do account for. Furthermore, based on an analysis of malpractice claims, Newman-Toker et al. (7) reported that clinical judgement played an important role in 86% of diagnostic errors, while poor patient/physician communication and system failures played a role in far fewer diagnostic errors that resulted in malpractice suits (35% and 22% respectively). Suggesting that improving communication will not reduce stroke related diagnostic error, Kerber et al. (33) reported that frontline providers rarely ask the right questions when patients present with dizziness. Communication ability is only valuable in terms of reducing diagnostic error if the physician knows what questions to ask and what the answers mean. Although we cannot say with certainty that our finding are driven by an underlying association between diagnostic knowledge and diagnostic errors, at a minimum, our finding suggest that diagnostic knowledge may be particularly important in terms avoiding these adverse outcome at heighted risk for diagnostic errors.

We found that diagnostic knowledge at the point of primary care is a risk factor for outcomes at heightened risk for diagnostic error. The fact that there exists a link between general diagnostic knowledge and diagnostic error may not be surprising, the magnitude of the associations we found suggests that interventions ignoring the role of physician knowledge maybe inadequate to address the crisis of diagnostic error. Interventions targeted at improving diagnostic knowledge could include such things as a greater focus on diagnostic training during graduate medical education (i.e., medical school, residency, and fellowship). Knowledge-focused interventions could also include incentivizing broad-based learning as well as targeted learning pursued through continuing medical education (CME) activities (see Newman-Toker and McKay for a similar observation(28)). During visits identified as being at risk for diagnostic errors,

physicians could be given related information at the point of care. ABIM and other certifying organizations could also enhance awareness around deficiencies in diagnostic knowledge by providing physicians with diagnosis specific exam performance feedback as well as resources to improve their diagnostic knowledge. Physicians who have demonstrated heightened diagnostic expertise might be utilized when patients present with symptoms at heightened risk for diagnostic error.

In conclusion, gaps in diagnostic knowledge between first contact primary care physicians is an important risk factor for serious diagnostic error sensitive outcomes and therefore should be a target for interventions to reduce diagnostic errors.

Statements

A. Contribution statement: Design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication were all conducted by the authors independently of the American Board of Internal Medicine.

B. Conflicts: Bradley Gray, Jonathan Vandergrift, and Rebecca Lipner are paid employees of the American Board of Internal Medicine. Bruce Landon is a paid consultants for the American Board of Internal Medicine.

C. Funding: Financial and material support was provided by the American Board of Internal Medicine.

D. Data Sharing: Administrative data describing physician characteristics and exam performance can be obtain from the ABIM through a data sharing agreement that assures physician confidentiality and its used for legitimate research purposes. Access to de-identified Medicare claims data for this study were obtained through a special data use agreement with the Centers for Medicare and Medicaid services which is a process available to researchers in the US.

E. Patient and public statement: Patients and the public were not involved in the design or execution of this study as the existing patient claims data used were de-identified by the Center for Medicaid and Medicare Services prior to analysis. In terms of dissemination, ABIM's communication department in collaboration with the authors of this study we write a press release whose goal is to inform the public regarding the finding of the study.

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Table 1. Frequency of Index Visits Related to each Diagnostic Error Sensitive Condition

Thirteen diagnostic error sensitive conditions	Index visits with a diagnosis code related to a diagnostic error sensitive condition (percentages can add to greater than 100% because of antecedent index visit diagnoses related to more than one diagnostic error sensitive condition)	Hospitalization[a,b]	Emergency department visit[a]	Death[c]
	Number (percent of index visits)	Number (percent of hospitalizations with a diagnostic error sensitive condition)	Number (percent of emergency department visits with a diagnostic error sensitive condition)	Number (percent of deaths)
	48,632 (100.0)	541 (100)	663 (100)	316 (100)
Acute Coronary Syndrome	16,228 (33.4)	48 (8.9)	56 (8.4)	103 (32.6)
Fracture	13,409 (27.6)	60 (11.1)	100 (15.1)	60 (19.0)
Depression	12,637 (26.0)	Not Reported[d]	Not Reported[d]	121 (38.3)
Anemia	12,410 (25.5)	54 (10.0)	59 (8.9)	110 (34.8)
Pneumonia	12,183 (25.1)	91 (16.8)	107 (16.1)	107 (33.9)
Congestive Heart Failure	12,137 (25.0)	227 (42.0)	254 (38.3)	120 (38.0)
Aortic Aneurysm	11,491 (23.6)	17 (3.1)	23 (3.5)	79 (25.0)
Stroke	10,026 (20.6)	69 (12.8)	82 (12.4)	71 (22.5)
Pulmonary Embolism	8,534 (17.5)	12 (2.2)	13 (2.0)	89 (28.2)
Spinal Cord Compression	6,386 (13.1)	Not Reported[d]	Not Reported[d]	36 (11.4)
Bacteremia / Sepsis	5,567 (11.4)	19 (3.5)	21 (3.2)	46 (14.6)
Appendicitis	2,584 (5.3)	Not Reported[d]	Not Reported[d]	17 (5.4)
Abscess	1,005 (2.1)	Not Reported[d]	13 (2.0)	Not Reported[d]

[a]Condition specific outcomes for one of the 13 diagnostic error sensitive conditions within 90 days of an outpatient index visit at risk for that condition

[b]Hospitalizations include non-elective hospitalizations either initiated through the ED or a trauma center.

[c]All cause mortality within 90 days of the index visit.

[d]Not reported because observations were less than 11.

Table 2. Physician and Patient Characteristics by Diagnostic Exam Performance Tertile

	Total	Diagnosis question percent correct			P-value[a]
		Top (78.5 to 95.8)	Middle (71.4 to 78.4)	Bottom (42.9 to 71.3)	
Exam performance, Mean (standard deviation) [a]					
Diagnosis question percent correct	74.5 (0.4)	84.3 (0.3)	74.8 (0.1)	65.5 (0.3)	<.001
Other question percent correct	72.6 (0.7)	80.2 (1.0)	72.1 (1.1)	66.4 (1.5)	<.001
Treatment question percent correct	77.3 (0.3)	83.4 (0.4)	77.2 (0.4)	72.0 (0.5)	<.001
Physician Characteristics, count (%)					
Female Physician	19,428 (39.9)	6,546 (43.8)	6,357 (37.5)	6,525 (39.0)	0.37
US born physician	28,462 (58.5)	9,284 (62.1)	9,932 (58.6)	9,246 (55.3)	0.37
US medical school	31,960 (65.7)	10,471 (70.0)	10,900 (64.3)	10,589 (63.3)	0.30
Practice Type					
Solo physician practice	9,452 (19.4)	1,914 (12.8)	3,462 (20.4)	4,076 (24.4)	0.009
Small group practice (2 to 10)	20,563 (42.3)	5,543 (37.1)	7,529 (44.4)	7,491 (44.8)	0.19
Medium physicians group practice (11 to 50)	7,442 (15.3)	2,899 (19.4)	2,402 (14.2)	2,141 (12.8)	0.25
Large physician group practice (>50 physicians)	5,391 (11.1)	2,150 (14.4)	1,655 (9.8)	1,586 (9.5)	0.14
Academic practice	2,708 (5.6)	1,447 (9.7)	697 (4.1)	564 (3.4)	<.001
Other practice	3,076 (6.3)	1,005 (6.7)	1,211 (7.1)	860 (5.1)	0.59
Beneficiary characteristics					
Beneficiary Race, count (percent)					
White	40,086 (82.4)	12,652 (84.6)	13,778 (81.3)	13,656 (81.7)	0.13
Black	3,958 (8.1)	926 (6.2)	1,609 (9.5)	1,423 (8.5)	0.03
Other	4,588 (9.4)	1,380 (9.2)	1,569 (9.3)	1,639 (9.8)	0.88
Beneficiary age (per year), Mean (SD) [a]	76.6 (0.1)	76.8 (0.1)	76.5 (0.1)	76.6 (0.1)	0.23
CCW chronic conditions, count (percent)					
Alzheimer's Disease and Related Disorders or Senile Dementia	5,151 (10.6)	1,497 (10.0)	1,793 (10.6)	1,861 (11.1)	0.16
Alzheimer's Disease	2,061 (4.2)	627 (4.2)	704 (4.2)	730 (4.4)	0.82
Acute Myocardial Infarction	1,408 (2.9)	394 (2.6)	494 (2.9)	520 (3.1)	0.13
Anemia	22,450 (46.2)	6,706 (44.8)	7,766 (45.8)	7,978 (47.7)	0.11
Asthma	4,424 (9.1)	1,313 (8.8)	1,548 (9.1)	1,563 (9.3)	0.39
Atrial Fibrillation	4,225 (8.7)	1,265 (8.5)	1,478 (8.7)	1,482 (8.9)	0.69
Breast Cancer	2,485 (5.1)	779 (5.2)	831 (4.9)	875 (5.2)	0.48
Colorectal Cancer	1,139 (2.3)	357 (2.4)	406 (2.4)	376 (2.2)	0.68
Endometrial Cancer	352 (0.7)	113 (0.8)	109 (0.6)	130 (0.8)	0.39
Lung Cancer	435 (0.9)	151 (1.0)	152 (0.9)	132 (0.8)	0.19
Prostate Cancer	1,662 (3.4)	507 (3.4)	600 (3.5)	555 (3.3)	0.66
Cataract	31,095 (63.9)	9,601 (64.2)	10,773 (63.5)	10,721 (64.1)	0.74
Heart Failure	9,207 (18.9)	2,786 (18.6)	3,155 (18.6)	3,266 (19.5)	0.54
Chronic Kidney Disease	6,904 (14.2)	2,083 (13.9)	2,392 (14.1)	2,429 (14.5)	0.62
Chronic Obstructive Pulmonary Disease	9,108 (18.7)	2,635 (17.6)	3,165 (18.7)	3,308 (19.8)	0.02
Depression	12,042 (24.8)	3,728 (24.9)	4,145 (24.4)	4,169 (24.9)	0.83
Diabetes	13,296 (27.3)	3,947 (26.4)	4,590 (27.1)	4,759 (28.5)	0.16
Glaucoma	10,030 (20.6)	3,086 (20.6)	3,501 (20.6)	3,443 (20.6)	0.99
Hip/Pelvic Fracture	1,531 (3.1)	430 (2.9)	535 (3.2)	566 (3.4)	0.15
Hyperlipidemia	37,132 (76.4)	11,266 (75.3)	12,898 (76.1)	12,968 (77.6)	0.11
Benign Prostatic Hyperplasia	5,815 (12.0)	1,792 (12.0)	1,987 (11.7)	2,036 (12.2)	0.76
Hypertension	37,607 (77.3)	11,345 (75.8)	13,011 (76.7)	13,251 (79.3)	<.001
Hypothyroidism	11,425 (23.5)	3,490 (23.3)	3,862 (22.8)	4,073 (24.4)	0.25

Ischemic Heart Disease	18,713 (38.5)	5,616 (37.5)	6,393 (37.7)	6,704 (40.1)	0.06
Osteoporosis	14,171 (29.1)	4,372 (29.2)	4,794 (28.3)	5,005 (29.9)	0.34
Rheumatoid Arthritis	23,352 (48.0)	6,879 (46.0)	8,275 (48.8)	8,198 (49.0)	0.02
Stroke	6,255 (12.9)	1,880 (12.6)	2,212 (13.0)	2,163 (12.9)	0.70
Number of chronic conditions, count (percent)					
<=4	5,066 (10.4)	1,459 (9.8)	1,744 (10.3)	1,863 (11.1)	0.08
5 to 7	16,861 (34.7)	5,392 (36.0)	5,981 (35.3)	5,488 (32.8)	0.006
8 to 10	16,230 (33.4)	4,907 (32.8)	5,664 (33.4)	5,659 (33.8)	0.35
>=11	10,475 (21.5)	3,200 (21.4)	3,567 (21.0)	3,708 (22.2)	0.28
Mental health visit, count (percent)	6,347 (13.1)	2,040 (13.6)	2,119 (12.5)	2,188 (13.1)	0.46
Hierarchical Condition Category (HCC) score, Mean (SD)[a]	0.98 (0.01)	0.96 (0.01)	0.98 (0.01)	0.99 (0.01)	0.19
Household medium income, mean $ (SD)[a]	59,852 (643)	61,574 (1,106)	59,113 (1,144)	59,063 (1,075)	0.19
Medicaid dual eligible, count (percent)	6,392 (13.1)	1,793 (12.0)	2,411 (14.2)	2,188 (13.1)	0.28
Rural county residence, count (percent)	7,392 (15.2)	2,207 (14.8)	2,866 (16.9)	2,319 (13.9)	0.64
Visit characteristics					
Visit with same doctor in last year, Count (percent)	37,726 (77.6)	11,369 (76.0)	13,154 (77.6)	13,203 (79.0)	0.08
Visit with any physician in last year, count (percent)	44,852 (92.2)	13,711 (91.7)	15,647 (92.3)	15,494 (92.7)	0.08
Days since last visit with any physician (if any visit in last year), Mean (SD)[a]	144.2 (0.6)	147.1 (0.8)	144.4 (1.0)	141.4 (1.3)	<.001
ED visit in prior year, count (percent)	8,101 (16.7)	2,428 (16.2)	2,879 (17.0)	2,794 (16.7)	0.43
Days since last ED visits (if ED visit in last year), Mean (SD)[a]	222.8 (0.9)	221.2 (1.5)	223.5 (1.5)	223.4 (1.5)	0.47
Hospitalization in prior year, Count (percent)	4,227 (8.7)	1,280 (8.6)	1,489 (8.8)	1,458 (8.7)	0.85
Days since last hospitalization (if hospitalization in last year), Mean (SD)[a]	229.6 (1.2)	229.1 (2.1)	229.7 (2.1)	230.1 (1.9)	0.95
Index visit diagnosis groups, Count (percent)					
Abscess	1,005 (2.1)	268 (1.8)	394 (2.3)	343 (2.1)	0.21
Anemia	12,410 (25.5)	3,817 (25.5)	4,369 (25.8)	4,224 (25.3)	0.93
Aortic aneurysm	11,491 (23.6)	3,495 (23.4)	4,165 (24.6)	3,831 (22.9)	0.18
Appendicitis	2,584 (5.3)	845 (5.6)	949 (5.6)	790 (4.7)	0.01
Bacteremia	5,567 (11.4)	1,660 (11.1)	1,929 (11.4)	1,978 (11.8)	0.83
Congestive heart failure	12,137 (25.0)	3,633 (24.3)	4,221 (24.9)	4,283 (25.6)	0.67
Acute coronary syndrome	16,228 (33.4)	4,627 (30.9)	5,740 (33.9)	5,861 (35.1)	0.02
Depression	12,637 (26.0)	3,932 (26.3)	4,312 (25.4)	4,393 (26.3)	0.78
Fracture	13,409 (27.6)	4,324 (28.9)	4,364 (25.7)	4,721 (28.2)	0.11
Pulmonary embolism	8,534 (17.5)	2,683 (17.9)	2,984 (17.6)	2,867 (17.1)	0.71
Pneumonia	12,183 (25.1)	3,773 (25.2)	4,224 (24.9)	4,186 (25.0)	0.97
Spinal cord compression	6,386 (13.1)	1,985 (13.3)	2,218 (13.1)	2,183 (13.1)	0.94
Stroke	10,026 (20.6)	3,003 (20.1)	3,542 (20.9)	3,481 (20.8)	0.79

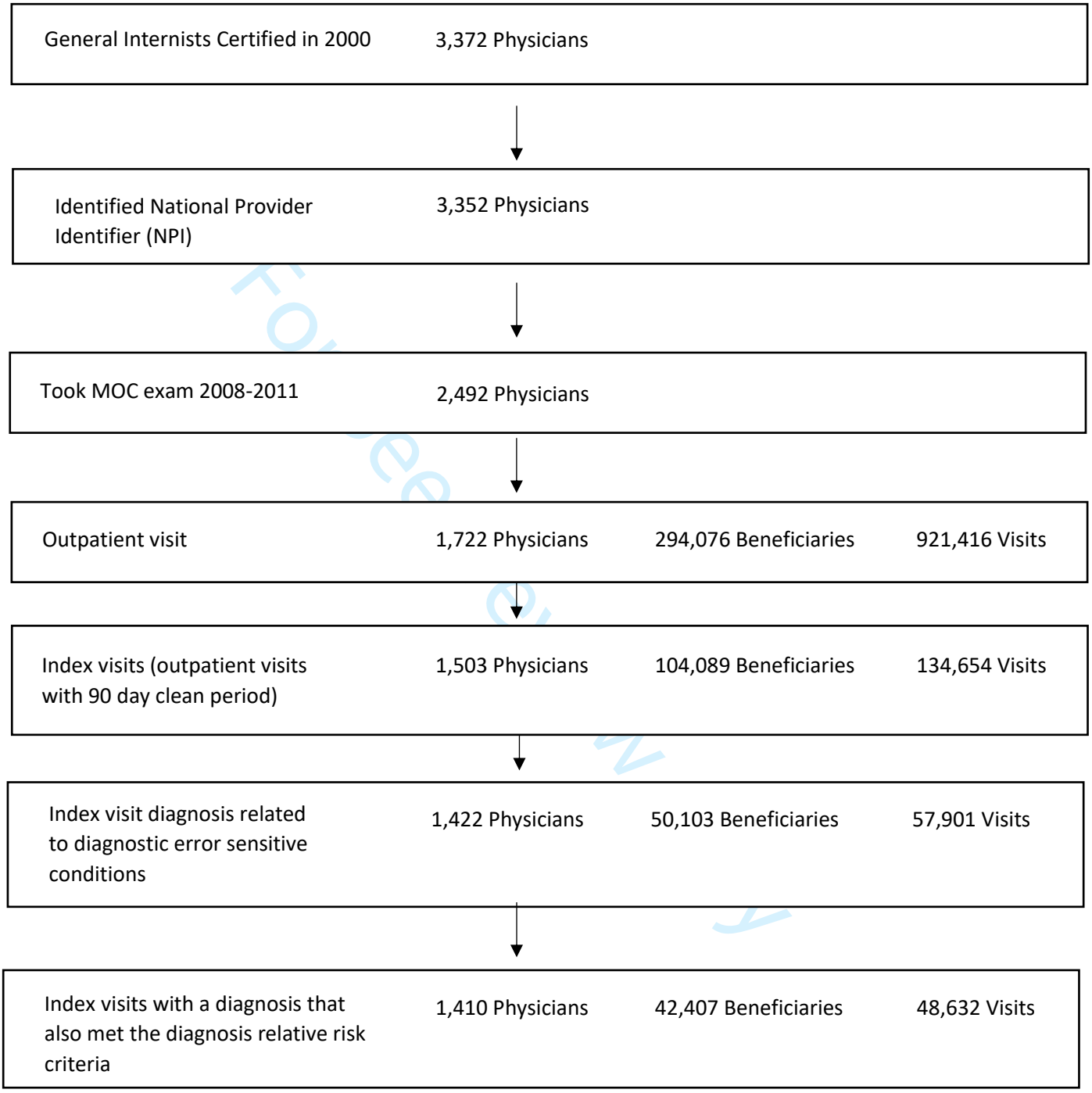
[a]P-values and standard deviation accounted for correlated errors within physicians

Table 3. Associations with diagnostic knowledge and adverse events per 1,000 index visits

Diagnostic knowledge tertile	Death[a]				Emergency department visit[b]				Hospitalization[c]			
	Unadjusted[e]	Regression adjusted[d,e]			Unadjusted[e]	Regression adjusted[d,e]			Unadjusted[e]	Regression adjusted[d,e]		
	Events per 1,000 visits (95% CI interval)	Events per 1,000 visits (95% CI interval)	Difference (95% CI)	P-value	Events per 1,000 visits (95%CI)	Events per 1,000 visits (95%CI)	Difference (95% CI)	P-value	Events per 1,000 visits (95% CI)	Events per 1,000 visits (95% CI)	Difference (95% CI)	P-value
Top	6.2 (5.0 to 7.4)	5.2 (4.1 to 6.3)	-2.9 (-5.0 to -0.7)	0.008	13.0 (11.2 to 14.8)	11.5 (9.8 to 13.2)	-4.9 (-8.1 to -1.6)	0.003	10.4 (8.8 to 12.1)	9.2 (7.7 to 10.8)	-4.1 (-6.9 to -1.2)	0.006
Middle	6.6 (5.4 to 7.8)	6.5 (5.4 to 7.6)	-1.6 (-3.6 to 0.3)	0.09	13.0 (11.2 to 14.7)	13.2 (11.5 to 15.0)	-3.1 (-6.1 to -0.1)	0.04	10.8 (9.2 to 12.4)	11.0 (9.4 to 12.6)	-2.3 (-4.9 to 0.4)	0.09
Bottom	6.6 (5.5 to 7.8)	8.1 (6.5 to 9.7)	reference		14.9 (13.0 to 16.8)	16.4 (14.0 to 18.7)	reference		12.1 (10.4 to 13.8)	13.3 (11.2 to 15.4)	reference	

[a]All cause mortality within 90 days of an outpatient index visit with a diagnosis at risk for one of 3 diagnostic error sensitive conditions.
[b]Emergency department visit for one of the 13 diagnostic error sensitive conditions within 90 days of an outpatient index visit with a visit at risk for that condition.
[c]Hospitalizations were for non-elective hospitalizations either initiated through the ED or a trauma center with a discharge diagnosis for one of 13 diagnostic error sensitive conditions within 90 days of the index visit with a diagnosis at risk for that condition.

Figure 1. Sample Selection



Appendix

Diagnostic Knowledge, Diagnostic Error and Risk of Death, Hospitalization and Emergency Department Visits

Contents

Section 1: 90-day Index Visit Clean Period Derivation

Figure 1.1 displays the visit periodicity between each of the 921,416 visits to an internist in the sample and the most recent visit prior to that one.

To determine what the index visit clean period was we assumed that when two contacts happen "close" together they are more likely to be visits for the same acute episode of care. Therefore, if we exclude all but the first visit that happen "close" together then the remaining visits are highly likely to represent the first visit for a new episode of care (i.e., a new problem). However, the visit periodicity threshold that distinguishes visits that are "close" versus "not close" is unknown.

To help delineate this threshold, Figure 1.1 visit shows periodicity between each of the 921,416 visits to an internist in the sample and the most recent adjacent visit prior to that one. In Figure 1.1, you can see the slope of frequency curve is falling until about a 90 day gap between visits. This indicates that many of the visits prior to this point may be related to an existing episode of care. After 90 days, the periodicity slope begins to flatten out which indicates that the timing between visits is likely random and so it is less likely that the two visits are related to the same episode of care.

This flattening of the slope after 90 days is more clearly displayed in Figure 1.2 which displays the 15 day moving average of the change in visit counts per day (i.e., the changing slope). Here the slope stabilizes at about zero beginning around 90 days suggesting that a 90 day clean period for physician visits is likely to exclude most visits that are a follow-up to an ongoing episode of care from the index visit sample.

Figure 1.1. Visit Periodicity Plot for the 921,416 Outpatient Visits to Physicians in the Sample

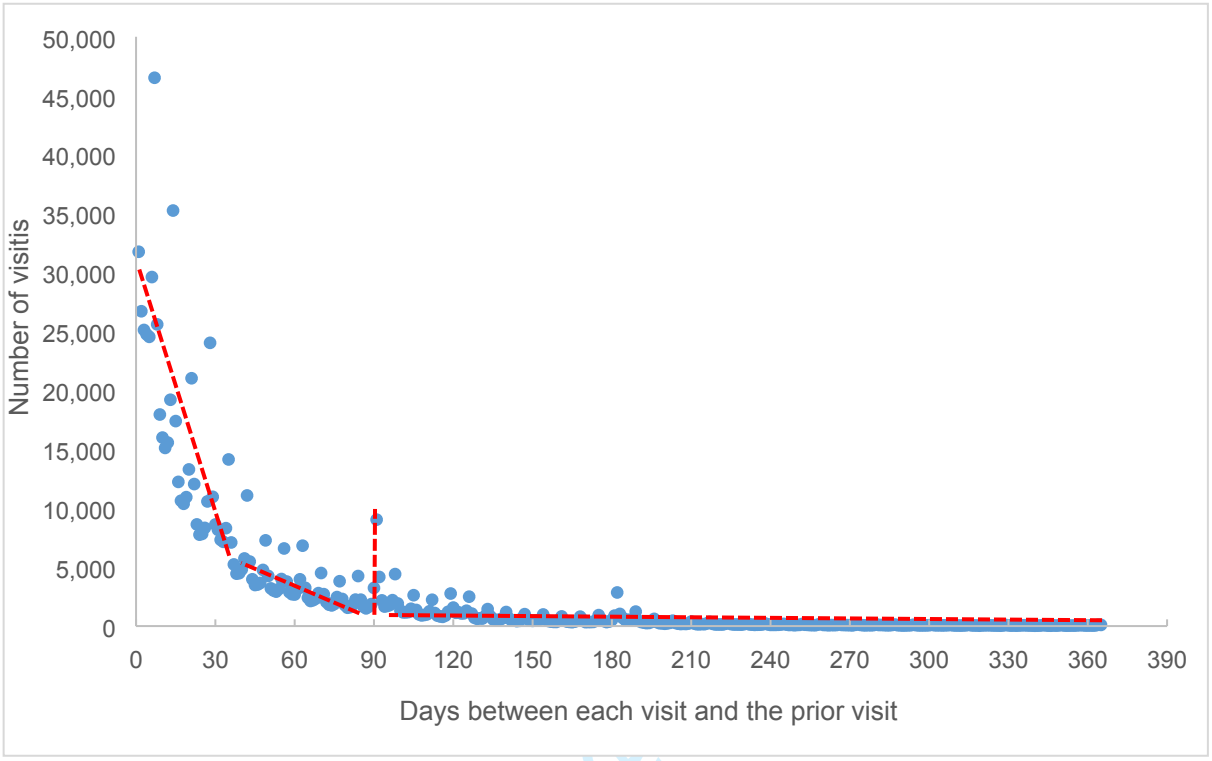
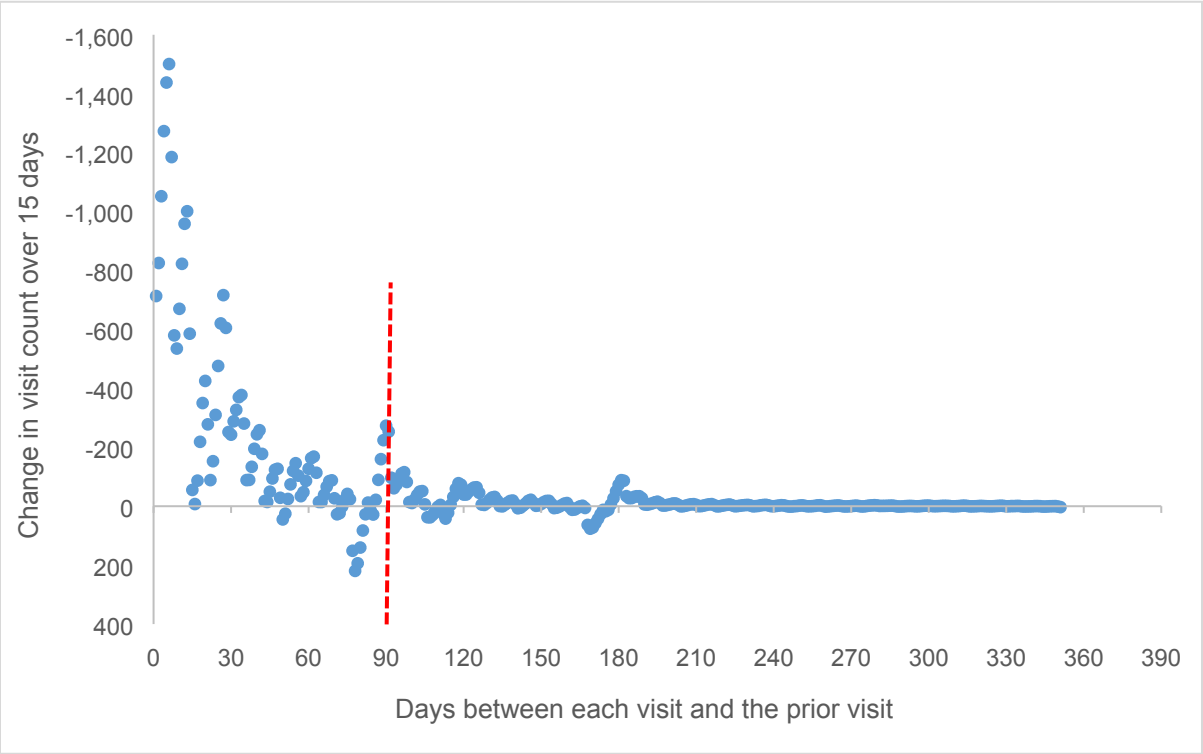


Figure 1.2. Average Change in Visit Count over the 15 days (15-day slope) Following each Data Point Listed in Figure 1



Section 2. ICD-9 Code Codes for Diagnostic Error sensitive Conditions and ICD-9 Code Groups for Index Visit Eligibility and Related Relative Risks

The Section includes a list the list of diagnostic error sensitive condition ICD-9 diagnoses (Table 2.1), index visit eligible ICD-9s diagnoses groups (Table 2.2), and relative risks for each index visit diagnosis group (Table 2.3).

eTable 2.1. ICD-9 Code Codes for Diagnostic Error Sensitive Conditions

Diagnostic Error Sensitive Conditions	ICD-9 groups
Abscess	681, 682
Acute Coronary Syndrome	410, 411.1
Anemia	280-284
Appendicitis	540-542, 543.0, 543.9
Aortic aneurysm	441
Bacteremia/Sepsis	038, 003.1, 020.2, 022.3, 036.2, 054.5, 449, 771.81, 790.7, 995.91, 995.92
Depression	296.2, 296.3
Fracture	800-829, 733.81
Congestive Heart failure	428
Pneumonia	480-486
Pulmonary embolism	415.1
Spinal cord compression	336.9
Stroke	430-437

eTable 2.2. ICD-9 Code Groups for Index Visit Eligibility

Index visit ICD-9 recorded diagnosis ICD-9 codes (76 different diagnoses)	ICD-9s	Met at least one diagnostic error sensitive relative risk criterion (38 met this criteria)
Abdominal pain	789.0	Yes
Abdominal tenderness	789.6	No
Abnormal respiration	786.0	Yes
Alcohol	291.0-291.5, 291.8, 291.9, 357.5, 425.5, 571.0-571.3, 303, 305.00-305.03, 535.30-535.31, E860.0	No
Amphetamines	304.4	No
Anxiety	300.0	Yes
Ascites	785.5	Yes
Back pain	724.5	Yes
Bronchitis	466.0, 466.1	Yes
Cannabis	304.3, 305.2	No
Celiac disease	579.0	No
Chest Pain	786.50, 786.51, 786.59	Yes
Chills	780.64	No
Cocaine	304.2, 305.6, E938.25	No
Confusion	298.2	Yes
Cough	786.2	Yes
Deep vein thrombosis	453.40	No
Delirium	293.0, 780.97	Yes
Diverticulitis	562.11	Yes
Dizziness	780.4	Yes
Drug Mental Disease	292	No
Dyspnea	786.09	Yes
Dysthymia	300.4	Yes
Edema	782.3	Yes
Elevated blood pressure	796.2	No
Esophageal disease	530.1, 530.3-530.9	Yes
Facial weakness	728.87	Yes
Falls	v15.88	No
Fatigue	780.7	Yes
Fever	780.60, 780.61	Yes
Gait instability	781.2	Yes
Gastritis	535	No
Gastrointestinal bleeding	578.9	Yes
Hallucinogens	304.5, 305.3, 969.6, E854.1, E939.6	No
Headache	339, 346, 784.0	Yes
Heart Burn	787.1	No
Hemoptysis	786.30, 786.39	Yes
Hyperparathyroidism	262.0	Yes
Hypoxemia/Hypoxia	799.02	Yes
Influenza	487.0, 487.1, 487.8, 488	No
Lack coordination	781.3	Yes
Lower respiratory disease	519.8	No
Lung cancer	162	Yes
Menorrhagia	626.2	No
Mood disorder	293.83, 293.84	No

Nausea	787.01, 787.02	Yes
Opioids	304.0, 304.7, 305.5, 965.0, E850.0-E850.2, E935.0-E935.2	No
Osteopenia	733.90	No
Osteoporosis	733.0	Yes
Other back pain	721.2-721.9, 722.1, 722.2, 722.5, 722.6, 722.70, 722.72, 722.73, 722.80, 722.82, 722.83, 722.90 722.92, 722.93, 724.0, 724.1	Yes
Other respiratory issue	786.00,786.01, 786.06, 786.07, 786.52, 786.1, 786.2	Yes
Otitis media	381-383, 387, 055.2, 384.2, 384.8, 384.9, 385.0-385.2	No
Personality disorder	301	No
Pain respiration	786.52	Yes
Peripheral neuropathy	337.9, 337.1	No
Reflux disease	530.81	Yes
related alcohol disease	291.9, 292, 304.0-304.6	No
Respiratory Distress	518.81	No
Sedatives	304.1	No
Shortness of breath	786.05	Yes
Sinusitis	473	Yes
Speech disturbance	784.5	Yes
Stress	308	No
Stress fracture	733.94-733.98	No
Tachycardia	785.0	Yes
Tension headache	307.81	No
Thunderclap headache	339.43	No
Transient ischemic attack	435.0-435.3, 435.8, 435.9	Yes
Upper respiratory disease	472, 476, 477, 478.8	No
Viral illness	079.99	No
Vitamin D deficiency	268	Yes
Vomiting	787.01, 787.03	Yes
Weakness/Fatigue	728.87, 708.7	Yes
Weight gain	783.1	No
Weight loss	783.2	Yes

eTable 2.3 Relative Risks for each Index Visit Diagnosis

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Abscess	Fever	2.65
	Chills	0.00
Anemia	Gastrointestinal bleeding	25.20
	Weight loss	4.09
	Shortness of breath	3.51
	Weakness/Fatigue	2.35
	Hypoxemia/Hypoxia	2.11
	Dyspnea	2.05
	Chest Pain	1.82
	Headache	1.29
	Menorrhagia	0.00
Aortic Aneurysm	Dyspnea	4.98
	Abdominal pain	4.93
	Shortness of breath	3.80
	Chest pain	2.42
	Other back pain	1.64
	Back pain	1.01
	Elevated blood pressure	0.00
Appendicitis	Vomiting	30.79
	Diverticulitis	30.45
	Nausea	16.81
	Abdominal pain	15.60
	Abdominal tenderness	0.00
	Fever	0.00
Bacteremia/Sepsis	Vomiting	6.99
	Fever	5.10
	Nausea	3.82
	Tachycardia	2.67
	Weakness/Fatigue	1.75
Heart failure	Hypoxemia/Hypoxia	9.99
	Shortness of breath	5.09
	Dyspnea	3.33
	Edema	3.27
	Chest Pain	2.46
	Weakness/Fatigue	1.42
	Ascites	0.00
	Respiratory Distress	0.00

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Acute Coronary Syndrome	Chest pain	8.38
	Dyspnea	7.29
	Shortness of breath	3.65
	Hypoxemia/hypoxia	2.01
	Reflux disease	1.23
	Esophageal disease	1.22
	Weakness/Fatigue	1.14
	Nausea	1.05
	Other respiratory issue	0.86
	Respiratory distress	0.00
	Gastritis	0.00
	Heart Burn	0.00
Depression	Delirium	32.76
	Heart failure	6.16
	Anxiety	5.04
	Dysthymia	4.99
	Weight loss	4.73
	Anemia	2.74
	Fatigue	1.06
	Alcohol	0.00
	Amphetamines	0.00
	Cannabis	0.00
	Cocaine	0.00
	Drug Mental Disease	0.00
	Hallucinogens	0.00
	Opioids	0.00
	Personality disorder	0.00
	related alcohol disease	0.00
	Sedatives	0.00
	Stress	0.00
	Weight gain	0.00
	Mood disorder	0.00
Fracture	Gait instability	2.53
	Edema	1.79
	Osteoporosis	1.66
	Hyperparathyroidism	1.09
	Vitamin D deficiency	1.08

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Fracture (con't)	Osteopenia	0.54
	Celiac disease	0.00
	Falls	0.00
	Stress fracture	0.00
Pulmonary embolism	Tachycardia	12.16
	Hypoxemia/hypoxia	10.98
	Shortness of breath	6.75
	Dyspnea	6.54
	Abnormal respiration	6.35
	Heart failure	4.51
	Chest pain	4.31
	Cough	1.48
	Other respiratory issue	1.34
	Deep vein thrombosis	0.00
	Respiratory distress	0.00
	Fever	0.00
	Heart burn	0.00
	Hemoptysis	0.00
Pneumonia	Hypoxemia/hypoxia	8.24
	Hemoptysis	7.57
	Lung cancer	7.53
	Fever	6.19
	Delirium	5.18
	Bronchitis	3.07
	Shortness of breath	2.99
	Cough	2.77
	Abnormal respiration	2.38
	Pain respiration	2.13
	Dyspnea	2.05
	Weakness/Fatigue	1.38
	Sinusitis	1.26
	Chest Pain	1.00
	Upper respiratory disease	0.71
	Otitis media	0.48
	Influenza	0.00
	Lower respiratory disease	0.00
	Viral illness	0.00

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Spinal cord compression	Abdominal pain	31.20
	Back pain	15.03
	Peripheral neuropathy	0.00
	Weakness/Fatigue	0.00
Stroke	Facial weakness	65.24
	Confusion	48.93
	Speech disturbance	19.60
	Transient ischemic attack	7.82
	Delirium	4.96
	Dizziness	3.20
	Lack coordination	2.92
	Gait instability	2.92
	Vomiting	2.15
	Weakness/Fatigue	1.54
	Headache	1.37
	Nausea	1.17
	Thunderclap headache	0.00
	Tension headache	0.00

[a]Outcomes include any hospitalization or emergency department visit for the diagnostic conditions within 90 days of the index visits including same day events

[b]Index visit diagnoses groups applied in the analysis include those with a relative risk greater than one. Relative risks were computed as the probability of an outcome if the index visit diagnosis group was recorded in the index visit divided by the probability of an outcome if the diagnosis group was not recorded.

Section 3. Psychometric Analysis of Whether Diagnosis Related Questions Reflect an Underlying Construct

To examine the degree to which treatment and diagnosis related questions represented an underlying construct, we calculated separate Cronbach's alpha indices to determine reliability of the subset of items for the 2010 IM-MOC examination for diagnosis related questions and treatment questions.[1] Overall, 170 of the questions were categorized as treatment or diagnostic related with 71 items classified as treatment and 99 items classified as diagnosis related questions. Overall, reliability for the diagnosis related questions was high, 0.84, suggesting that these questions hung together and were related to one underlying construct. The reliability for treatment related questions was also high, 0.75. This index, however, is partly a function of the number of items included in the calculation, where more items typically result in higher reliability. Consequently, it is not surprising that the diagnostic related questions have higher reliability given there were 28 more items than the treatment scale. To make these indices more equal, we computed the Spearman-Brown prophecy formula, which indicates expected reliability if the treatment scale was 99 items instead of 71. That formula resulted in a value of 0.81 for the treatment items which suggests that treatment related questions also measure one underlying construct.

Section 4. Imputations for missing variables

Missing practice characteristics (1,432 or 2.94% of sample) were coded as "other unknown".
Missing HCC (86 or .18% of sample) were replace by in sample mean HCC.
Missing rural indicator (22 or .05% of sample) were assumed to be non-rural
Missing ZIP code median income (708 or 1.46% of sample) were replace by in sample mean median income

Section 5. Regression Sensitivity Analyses

In this section we describe the results of falsification and robustness sensitivities. Falsification sensitivities examine associations with diagnostic knowledge under scenarios where we expect the underlying associations to be weaker than in the base case. Robustness sensitivities examine the degree to which base case associations with diagnostic knowledge were robust to assumptions regarding index visit diagnoses eligibility, outcome variable construction, and regression control variables.

Falsification sensitivities

Results of falsification sensitivities are exhibited in eTable 5.1. These sensitivities include applying the index visit sample that did not meet any diagnoses eligibility criteria and applying elective hospitalizations as an outcome measure. Presumably diagnostic knowledge would not impact outcomes with the diagnostic error sensitive conditions after index visits where related diagnoses codes for these conditions were not present. That is, either because the underlying condition was not present or not detectable at the time of the index visit and therefore was not preventable. However, outcomes after these index visits could be associated with omitted variables that were both correlated with our outcome measures and exam performance. For example, it could be that physicians with low diagnostic knowledge also have less healthy patients in ways we do not control for and therefore would be more likely to experience adverse events more generally. We also assume that elective hospitalizations would be related to the overall propensity to hospitalize but would not be related to underlying diagnostic skill.

Overall the results of falsification sensitivities support the validity of our base case finding. For example, although the overall risk of each adverse outcome was comparable to the base case, all associations with diagnostic knowledge were very small in absolute terms and none were statistically significant (P>0.05). For example, applying for the sample of index visits without eligible diagnoses codes, scoring in the top versus bottom tertile of diagnostic knowledge was associated with a 0.0 (95% CI -1.3 to 1.3, p=0.99) difference in the risk of death within 90 days of the index visit or under one tenth of the statistically significant 2.9 (95% CI: -5.0 to -0.7, p=0.008) fewer death per 1,000 observed in the base case. Yet, the mean risk of death in the base case and this sensitivity was comparable (0.7% in the base case versus 0.4% in this sensitivity). This sensitivity also addressed another limitation of our study, that we did not have a direct measure of cause of death since if the associations we found were driven by reductions in death due to the 13 diagnostic error prone conditions applied in our study we would expect that the associations with death and diagnostic exam performance would be much smaller when estimated using the index sample without eligible diagnoses codes for these conditions. Similarly we found that the associations between diagnostic knowledge and risk of an elective hospitalization were statistically insignificant, top compared to bottom tertile association P was 0.63, and was wrong signed.

Robustness sensitivities

Results of robustness sensitivities are exhibited in eTables 5.2.1 (for death), 5.2.2 (hospitalization) to 6.2.3 (for emergency department visit).

For the first sensitivity we expanding the eligible diagnoses code groups to all 76 identified by physician authors versus 38 in the base case that also met the relative risk criteria.

For the third sensitivity we expand the index visit clean period to 97 days and contracted the index visit clean period to 83 days.

For the fourth sensitivity, we excluded physician in academic medical centers to consider the possibility that the unobserved physician characteristics related to where they worked or who they worked with could be were independently both related to the underlying physician diagnostic skill and our outcome measures.

For the fifth sensitivity we accounted for the possibility that adverse outcomes were avoided because the patient died by altering the ED and hospitalization measures to include all-cause mortality. For this sensitivity we added the following two outcome measures: base case hospitalization or death and base case ED or death.

Overall results of robustness sensitivity analysis suggests that our base case results were not highly sensitive to different underlying assumptions related to these factors (e.g., across all robustness sensitivities percent change in the outcome measures between top versus bottom diagnostic knowledge exam performers remained statistically significant ($P<0.05$)).

Table 5.1. Results of Falsification Sensitivity Analyses for All Adverse Outcomes

Adverse outcome measure / Sensitivity	Number of index visits	Regression adjusted outcomes per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Death										
Base	48,632	5.2 (4.1 to 6.3)	6.5 (5.4 to 7.6)	8.1 (6.5 to 9.7)	-35.3 (-52.8 to -11.2)	-2.9 (-5.0 to -0.7)	0.008	-20.2 (-38.3 to 3.2)	-1.6 (-3.6 to 0.3)	0.09
Falsification sensitivity										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	3.9 (3.0 to 4.7)	4.3 (3.5 to 5.0)	3.9 (3.1 to 4.7)	0.2 (-27.9 to 39.4)	0.0 (-1.3 to 1.3)	0.99	10.1 (-17.2 to 46.5)	0.4 (-0.8 to 1.5)	0.51
Hospitalization										
Base	48,632	9.2 (7.7 to 10.8)	11.0 (9.4 to 12.6)	13.3 (11.2 to 15.4)	-30.5 (-46.1 to -10.4)	-4.1 (-6.9 to -1.2)	0.006	-17.1 (-33.2 to 3.0)	-2.3 (-4.9 to 0.4)	0.09
Falsification sensitivities										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	13.8 (12.0 to 15.5)	13.1 (11.8 to 14.4)	14.0 (12.5 to 15.5)	-1.5 (-18.2 to 18.6)	-0.2 (-2.8 to 2.4)	0.87	-6.0 (-19.1 to 9.1)	-0.8 (-2.9 to 1.2)	0.42
Elective hospitalization	48,264	9.6 (7.7 to 11.5)	9.0 (7.6 to 10.3)	8.9 (7.4 to 10.5)	7.6 (-19.6 to 43.9)	0.7 (-2.0 to 3.4)	0.63	0.4 (-20.1 to 26.3)	0.0 (-2.0 to 2.1)	0.97
Emergency Department Visit										
Base	48,632	11.5 (9.8 to 13.2)	13.2 (11.5 to 15.0)	16.4 (14.0 to 18.7)	-29.8 (-44.4 to -11.4)	-4.9 (-8.1 to -1.6)	0.003	-19.0 (-33.8 to -1.0)	-3.1 (-6.1 to -0.1)	0.04
Falsification sensitivity										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	18.0 (16.0 to 20.0)	17.7 (16.1 to 19.2)	18.7 (17.0 to 20.4)	-3.8 (-17.8 to 12.6)	-0.7 (-3.6 to 2.2)	0.63	-5.5 (-16.9 to 7.3)	-1.0 (-3.4 to 1.3)	0.38

Table 5.2.1. Results of Robustness Sensitivity Analyses for the Death Adverse Outcome

	Number of index visits	Regression adjusted deaths per 1,000 index visits (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	48,632	5.2 (4.1 to 6.3)	6.5 (5.4 to 7.6)	8.1 (6.5 to 9.7)	-35.3 (-52.8 to -11.2)	-2.9 (-5.0 to -0.7)	0.008	-20.2 (-38.3 to 3.2)	-1.6 (-3.6 to 0.3)	0.09
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,749	4.9 (3.9 to 5.9)	5.7 (4.8 to 6.7)	7.0 (5.7 to 8.4)	-30.2 (-48.9 to -4.5)	-2.1 (-4.0 to -0.3)	0.03	-18.4 (-36.7 to 5.2)	-1.3 (-2.9 to 0.4)	0.13
97 day index visit clean period	40,417	7.5 (5.8 to 9.1)	6.8 (5.6 to 8.1)	4.9 (3.8 to 6.0)	-34.7 (-53.9 to -7.6)	-2.6 (-4.8 to -0.4)	0.02	-8.5 (-31.0 to 21.2)	-0.6 (-2.7 to 1.4)	0.54
83 day index visit clean period	54,169	5.5 (4.4 to 6.6)	6.8 (5.7 to 7.8)	8.4 (6.8 to 10.0)	-34.7 (-51.7 to -11.7)	-2.9 (-5.0 to -0.8)	0.007	-19.5 (-37.0 to 3.0)	-1.6 (-3.6 to 0.3)	0.09
Exclusion of visits with physicians working in academic medical centers	45,924	5.1 (4.0 to 6.3)	6.5 (5.4 to 7.6)	8.0 (6.4 to 9.5)	-35.5 (-53.1 to -11.2)	-2.8 (-4.9 to -0.8)	0.008	-18.2 (-36.7 to 5.7)	-1.5 (-3.3 to 0.4)	0.13

Table 5.2.2. Results of Robustness Sensitivity Analyses for the Hospitalization Adverse Outcome

	Number of index visits	Regression adjusted risk of emergency department hospitalization per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	48,632	9.2 (7.7 to 10.8)	11.0 (9.4 to 12.6)	13.3 (11.2 to 15.4)	-30.5 (-46.1 to -10.4)	-4.1 (-6.9 to -1.2)	0.006	-17.1 (-33.2 to 3.0)	-2.3 (-4.9 to 0.4)	0.09
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,749	11.3 (9.6 to 13.0)	9.7 (8.3 to 11.0)	8.3 (6.9 to 9.7)	-26.6 (-43.0 to -5.4)	-3.0 (-5.5 to -0.5)	0.02	-14.6 (-31.0 to 5.6)	-1.7 (-3.9 to 0.6)	0.15
97 day index visit clean period	40,417	8.3 (6.7 to 9.9)	10.4 (8.7 to 12.1)	13.4 (11.0 to 15.9)	-38.4 (-54.2 to -17.3)	-5.2 (-8.4 to -1.9)	0.002	-22.8 (-39.6 to -1.3)	-3.1 (-6.0 to -0.1)	0.04
83 day index visit clean period	54,169	9.3 (7.8 to 10.8)	11.2 (9.7 to 12.8)	13.2 (11.2 to 15.3)	-29.7 (-45.3 to -9.7)	-3.9 (-6.8 to -1.1)	0.007	-15.1 (-31.2 to 4.8)	-2.0 (-4.6 to 0.6)	0.13
Exclusion of visits with physicians working in academic medical centers	45,924	9.0 (7.4 to 10.7)	10.8 (9.2 to 12.4)	12.8 (10.8 to 14.9)	-29.4 (-45.9 to -7.9)	-3.8 (-6.7 to -0.9)	0.01	-15.9 (-32.7 to 5.1)	-2.0 (-4.7 to 0.6)	0.13
Hospitalization visit or death (hospitalization base case measure or death base case measure)	48,632	13.7 (11.9 to 15.4)	16.4 (14.5 to 18.2)	19.8 (17.4 to 22.2)	-30.9 (-43.3 to -15.8)	-6.1 (-9.4 to -2.8)	<.001	-17.4 (-30.5 to -1.9)	-3.4 (-6.6 to -0.3)	0.03
Shortening the outcome period from 90 day to 14 days	48,632	2.0 (1.3 to 2.7)	3.2 (2.4 to 4.1)	3.3 (2.4 to 4.3)	-40.3 (-63.3 to -3.0)	-1.4 (-2.6 to -0.1)	0.04	-3.7 (-35.2 to 43.2)	-0.1 (-1.4 to 1.2)	0.85

Table 5.2.3. Results of Robustness Sensitivity Analyses for the Emergency Department Visit Adverse Outcome

	Number of index visits	Regression adjusted risk of emergency department visit per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	48,632	11.5 (9.8 to 13.2)	13.2 (11.5 to 15.0)	16.4 (14.0 to 18.7)	-29.8 (-44.4 to -11.4)	-4.9 (-8.1 to -1.6)	0.003	-19.0 (-33.8 to -1.0)	-3.1 (-6.1 to -0.1)	0.04
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,740	10.4 (8.8 to 12.0)	11.7 (10.2 to 13.2)	13.9 (12.0 to 15.8)	-25.2 (-40.5 to -6.0)	-3.5 (-6.3 to -0.7)	0.01	-16.3 (-31.1 to 1.7)	-2.3 (-4.8 to 0.2)	0.08
97 day index visit clean period	40,417	10.5 (8.7 to 12.3)	12.6 (10.7 to 14.5)	16.7 (13.9 to 19.5)	-37.2 (-51.9 to -18.0)	-6.2 (-9.9 to -2.5)	<.001	-24.5 (-39.9 to -5.3)	-4.1 (-7.5 to -0.7)	0.02
83 day index visit clean period	54,169	11.6 (9.9 to 13.2)	13.4 (11.7 to 15.1)	16.4 (14.1 to 18.8)	-29.5 (-43.8 to -11.6)	-4.8 (-8.0 to -1.7)	0.003	-18.4 (-32.6 to -1.1)	-3.0 (-5.9 to -0.1)	0.04
Exclusion of visits with physicians working in academic medical centers	45,924	11.2 (9.4 to 13.0)	13.0 (11.2 to 14.8)	16.1 (13.7 to 18.4)	-30.5 (-45.4 to -11.4)	-4.9 (-8.2 to -1.6)	0.004	-19.3 (-34.3 to -0.7)	-3.1 (-6.1 to -0.1)	0.05
Emergency department visit or death (hospitalization base case measure or death base case measure)	48,632	15.7 (13.7 to 17.7)	18.5 (16.5 to 20.5)	22.6 (20.0 to 25.2)	-30.6 (-42.6 to -16.0)	-6.9 (-10.6 to -3.3)	<.001	-18.0 (-30.4 to -3.4)	-4.1 (-7.5 to -0.7)	0.02
Shortening the outcome period from 90 day to 14 days	48,632	2.7 (1.9 to 3.4)	3.7 (2.8 to 4.7)	4.0 (2.9 to 5.1)	-34.4 (-57.8 to 2.1)	-1.4 (-2.9 to 0.1)	0.07	-7.5 (-36.2 to 34.2)	-0.3 (-1.8 to 1.1)	0.68

Section 6. Full Regression Coefficient Estimates and Explanatory Variables List

eTables 6.1 lists the probit coefficient associations with outcome measures across all explanatory variables as well as regression descriptive statistics. See Section 7 for percentage point associations with physician characteristics.

eTable 6.1. Probit Coefficient Associations and Regression Descriptive Statistics

	Death		Hospitalization		Emergency Department Visit	
	Wald chi2(102): 815.36		Wald chi2(102): 1197.54		Wald chi2(102): 1201.10	
	Log pseudolikelihood -1588.8		Log pseudolikelihood = -2456.7		Log pseudolikelihood = -2989.0	
Label	Difference per 1,000 (SE)	P	Difference per 1,000 (SE)	P	Difference per 1,000 (SE)	P
Diagnosis question percent correct						
Diagnosis tertile 1	Reference		Reference		Reference	
Diagnosis tertile 2	-1.6 (1.0)	0.09	-2.3 (1.4)	0.09	-3.1 (1.5)	0.04
Diagnosis tertile 3	-2.9 (1.1)	0.008	-4.1 (1.5)	0.006	-4.9 (1.7)	0.003
Treatment question percent correct						
Treatment tertile 1	Reference		Reference		Reference	
Treatment tertile 2	0.7 (0.8)	0.41	-0.7 (1.2)	0.54	-0.3 (1.4)	0.82
Treatment tertile 3	1.6 (1.0)	0.13	1.6 (1.5)	0.29	1.6 (1.7)	0.33
Other question percent correct						
Other tertile 1	Reference		Reference		Reference	
Other tertile 2	1.3 (0.8)	0.12	0.3 (1.2)	0.78	0.1 (1.3)	0.95
Other tertile 3	2.5 (1.0)	0.01	-0.8 (1.3)	0.52	0.5 (1.5)	0.72
Female Physician	-1.2 (0.7)	0.08	-0.8 (1.0)	0.43	-0.7 (1.2)	0.54
Physician birth and medical school						
US born: US medical schools	Reference		Reference		Reference	
US born: Int'l medical schools	1.2 (1.8)	0.51	-1.9 (2.8)	0.50	-0.7 (2.8)	0.79
Int'l born: US medical schools	0.4 (1.1)	0.71	3.1 (1.5)	0.05	2.6 (1.9)	0.18
Int'l born: Int'l medical schools	0.6 (0.8)	0.43	0.2 (1.1)	0.86	0.5 (1.3)	0.70
Practice Type						
Academic practice	Reference		Reference		Reference	
Other practice, unknown[a]	3.5 (2.4)	0.14	-3.9 (2.7)	0.15	-3.9 (3.2)	0.22
Solo physician practice	-0.2 (1.8)	0.93	-5.0 (2.4)	0.04	-5.3 (2.7)	0.05
Small group practice (2 to 10)	-1.0 (1.7)	0.55	-5.6 (2.2)	0.01	-5.7 (2.5)	0.02
Medium physicians group practice (11 to 50)	1.7 (1.9)	0.37	-1.3 (2.4)	0.58	-3.3 (2.8)	0.25
Large physician group practice (>50 physicians)	-2.4 (1.8)	0.20	-1.4 (2.7)	0.62	-2.3 (3.1)	0.46
Female Beneficiaries	-3.6 (1.2)	0.002	-5.1 (1.5)	0.001	-6.2 (1.7)	<.001
Beneficiary Race						
White	Reference		Reference		Reference	
Black	0.5 (1.3)	0.73	4.9 (2.0)	0.01	3.6 (2.1)	0.09
Other	-3.1 (1.1)	0.004	-4.2 (1.5)	0.005	-5.5 (1.7)	0.001
Hierarchical Condition Category (HCC) score[b]	1.7 (0.4)	<.001	1.2 (0.5)	0.03	1.9 (0.6)	0.003
Medicaid Dual Eligible	0.1 (1.2)	0.91	2.3 (1.6)	0.16	1.9 (1.8)	0.27
Beneficiary age	0.7 (0.1)	<.001	0.4 (0.1)	<.001	0.5 (0.1)	<.001
Rural county residence[c]	-1.3 (0.9)	0.15	-1.3 (1.3)	0.31	0.5 (1.6)	0.76
Household medium income[d],	-3.1E-05 (1.6E-05)	0.05	8.7E-06 (2.2E-05)	0.69	-3.1E-06 (2.5E-05)	0.90
CCW chronic conditions						
Alzheimer's Disease and Related Disorders or Senile Dementia	1.7 (1.2)	0.18	3.0 (1.8)	0.09	3.7 (2.0)	0.07
Alzheimer's Disease	2.6 (1.7)	0.14	2.8 (2.5)	0.26	1.8 (2.6)	0.50
Acute Myocardial Infarction	2.7 (1.8)	0.14	2.3 (2.1)	0.27	2.5 (2.4)	0.29
Anemia	0.0 (0.8)	0.99	0.7 (1.1)	0.54	0.8 (1.2)	0.50

Asthma	-0.8 (1.1)	0.45	-0.2 (1.4)	0.88	0.1 (1.7)	0.95
Atrial Fibrillation	1.8 (1.1)	0.10	3.4 (1.5)	0.02	3.7 (1.7)	0.03
Breast Cancer	-2.0 (1.3)	0.13	-3.0 (1.8)	0.10	-2.0 (2.2)	0.35
Colorectal Cancer	-0.5 (1.7)	0.76	-3.4 (2.0)	0.10	-1.9 (2.5)	0.44
Endometrial Cancer	1.6 (4.2)	0.71	-1.1 (4.7)	0.82	-0.9 (5.5)	0.87
Lung Cancer	3.7 (3.4)	0.28	13.3 (6.2)	0.03	10.3 (6.2)	0.10
Prostate Cancer	-1.6 (1.4)	0.26	4.3 (2.5)	0.09	3.6 (2.8)	0.20
Cataract	-1.0 (0.9)	0.29	1.1 (1.0)	0.31	0.1 (1.2)	0.96
Heart Failure	1.8 (1.0)	0.08	2.9 (1.2)	0.02	3.3 (1.4)	0.02
Chronic Kidney Disease	-0.7 (0.8)	0.39	2.9 (1.2)	0.02	4.2 (1.4)	0.004
Chronic Obstructive Pulmonary Disease	1.1 (0.9)	0.26	1.3 (1.2)	0.27	0.9 (1.3)	0.50
Depression	0.2 (0.9)	0.79	0.9 (1.1)	0.43	0.7 (1.2)	0.59
Diabetes	0.0 (0.8)	0.99	3.3 (1.1)	0.003	2.4 (1.2)	0.04
Glaucoma	-0.9 (0.8)	0.29	0.0 (1.1)	1.00	-0.3 (1.2)	0.80
Hip/Pelvic Fracture	1.4 (1.6)	0.39	3.0 (2.4)	0.20	5.0 (2.8)	0.07
Hyperlipidemia	-1.8 (1.1)	0.09	-1.1 (1.3)	0.39	-0.7 (1.4)	0.63
Benign Prostatic Hyperplasia	-0.3 (1.1)	0.79	0.0 (1.5)	0.98	-0.8 (1.7)	0.63
Hypertension	0.8 (1.1)	0.46	2.4 (1.4)	0.09	1.2 (1.6)	0.44
Hypothyroidism	0.7 (0.8)	0.42	1.4 (1.1)	0.19	1.8 (1.2)	0.14
Ischemic Heart Disease	0.8 (0.9)	0.39	0.1 (1.1)	0.92	-1.3 (1.2)	0.29
Osteoporosis	-1.9 (0.8)	0.02	2.0 (1.2)	0.09	1.4 (1.3)	0.28
Rheumatoid Arthritis	-2.3 (0.8)	0.005	-0.2 (1.0)	0.87	0.3 (1.1)	0.81
Stroke	2.7 (1.1)	0.02	2.7 (1.3)	0.04	2.8 (1.5)	0.06
Visit with same doctor in last year	-0.9 (1.1)	0.40	-1.3 (1.4)	0.34	-2.3 (1.5)	0.13
Visit with any physician in last year	-8.4 (3.5)	0.02	-3.5 (3.2)	0.28	-2.5 (3.3)	0.44
Hospitalization in prior year	8.8 (5.4)	0.10	0.9 (4.1)	0.84	0.4 (4.5)	0.93
ED visit in prior year	1.0 (2.5)	0.69	7.3 (4.0)	0.07	8.4 (4.6)	0.07
Days since last visit with any physician (per 30 d)	0.3 (0.2)	0.11	0.0 (0.3)	0.94	0.1 (0.3)	0.64
Days since last hospitalization (per 30 d)	-0.6 (0.4)	0.13	0.2 (0.5)	0.72	0.3 (0.5)	0.55
Days since last ED visits (per 30 d)	-0.2 (0.3)	0.60	-0.5 (0.4)	0.21	-0.7 (0.4)	0.13
Index visit diagnosis group indicators						
Pulmonary embolism	-0.5 (1.3)	0.68	6.1 (1.4)	<.001	7.1 (1.6)	<.001
Acute coronary syndrome	-1.3 (1.1)	0.25	-3.0 (1.8)	0.11	-5.5 (2.0)	0.007
Stroke	-2.3 (1.4)	0.10	7.4 (1.5)	<.001	7.7 (1.7)	<.001
Congestive heart failure	0.2 (1.3)	0.88	10.1 (1.6)	<.001	12.1 (1.7)	<.001
Fracture	-1.3 (1.1)	0.22	3.2 (1.3)	0.02	5.1 (1.5)	<.001
Abscess	0.7 (2.3)	0.77	6.4 (3.3)	0.05	11.7 (3.3)	<.001
Pneumonia	2.3 (1.2)	0.05	5.6 (1.4)	<.001	6.7 (1.6)	<.001
Aortic aneurysm	1.0 (1.4)	0.50	-0.6 (2.0)	0.76	0.7 (2.2)	0.74
Appendicitis	2.0 (1.8)	0.28	5.9 (3.0)	0.05	9.6 (3.1)	0.002
Depression	0.0 (1.3)	0.99	3.0 (1.5)	0.05	2.4 (1.7)	0.15
Anemia	2.3 (1.1)	0.04	3.5 (1.8)	0.04	3.2 (2.0)	0.11
Bacteremia	0.5 (2.5)	0.85	-9.5 (3.0)	0.001	-8.3 (3.1)	0.008
Spinal cord compression	-0.5 (1.8)	0.79	-2.8 (2.8)	0.32	-7.0 (3.1)	0.02
Mental health visit	1.4 (1.2)	0.22	-0.9 (1.5)	0.53	0.1 (1.8)	0.97
HHS Region						
HHS Region 1	Reference		Reference		Reference	
HHS Region 2	1.6 (1.7)	0.35	-5.2 (2.2)	0.02	-6.7 (2.7)	0.01
HHS Region 3	2.7 (1.8)	0.12	2.1 (2.5)	0.40	1.3 (3.0)	0.66
HHS Region 4	0.4 (1.5)	0.77	-2.7 (2.2)	0.22	-4.9 (2.6)	0.07
HHS Region 5	0.3 (1.4)	0.81	0.8 (2.1)	0.69	-1.0 (2.6)	0.70
HHS Region 6	-0.9 (1.5)	0.53	-2.8 (2.2)	0.21	-4.4 (2.8)	0.11
HHS Region 7	0.0 (2.2)	0.99	3.2 (3.2)	0.31	0.9 (3.5)	0.79
HHS Region 8	-1.6 (2.2)	0.47	1.9 (3.8)	0.62	-2.0 (3.8)	0.61
HHS Region 9	0.0 (1.6)	0.99	-0.6 (2.5)	0.81	-3.2 (2.8)	0.26
HHS Region 10	-0.6 (2.2)	0.77	4.4 (3.5)	0.21	4.0 (4.3)	0.35
Study Year						
2009	-3.1 (3.0)	0.30	-2.5 (4.3)	0.56	-1.9 (5.9)	0.75

2010	-1.9 (2.9)	0.52	-2.1 (3.6)	0.55	-1.7 (5.2)	0.75
2011	1.1 (2.3)	0.63	1.4 (2.7)	0.60	-2.3 (4.2)	0.58
2012	Reference		Reference		Reference	
Yearly Quarter						
Q1	Reference		Reference		Reference	
Q2	-0.6 (0.9)	0.50	0.7 (1.2)	0.54	0.4 (1.4)	0.78
Q3	-0.7 (0.9)	0.43	-0.1 (1.2)	0.94	-0.8 (1.3)	0.55
Q4	0.6 (1.1)	0.55	1.9 (1.4)	0.18	1.2 (1.5)	0.42
Test Forms						
May 2008: A	3.7 (3.6)	0.30	-6.4 (4.2)	0.13	-5.5 (5.0)	0.27
May 2008: B	2.3 (4.3)	0.60	-4.1 (4.9)	0.41	-3.6 (6.1)	0.56
Nov. 2008: A	1.1 (3.1)	0.72	0.7 (4.2)	0.87	-2.7 (5.4)	0.62
Nov. 2008: B	Reference		Reference		Reference	
May 2009: A	5.1 (3.7)	0.16	3.6 (3.9)	0.36	-2.2 (5.0)	0.66
May 2009: B	0.2 (5.0)	0.96	-0.1 (5.0)	0.98	-6.0 (6.0)	0.31
Nov 2009: A	1.5 (3.1)	0.64	2.7 (3.4)	0.43	-1.5 (4.9)	0.75
Nov 2009: B	6.7 (3.9)	0.08	8.2 (3.9)	0.04	5.2 (5.2)	0.32
Nov 2009: C	Reference		Reference		Reference	
May 2010: A	0.9 (2.4)	0.69	-0.8 (2.6)	0.75	-4.6 (4.1)	0.26
May 2010: B	1.7 (2.4)	0.48	-0.2 (2.7)	0.94	-3.6 (4.3)	0.41
Nov. 2010: A	1.3 (2.4)	0.59	-1.2 (2.5)	0.63	-4.8 (4.1)	0.24
Nov. 2010: B	1.4 (2.3)	0.55	-0.5 (2.6)	0.85	-3.6 (4.1)	0.38
Nov. 2010: C	Reference		Reference		Reference	
May 2011: A	3.3 (3.2)	0.30	1.5 (3.7)	0.69	-1.3 (5.2)	0.80
May 2011: B	1.9 (3.4)	0.59	-1.4 (4.0)	0.74	-5.8 (5.3)	0.27
Nov. 2011: A	-1.8 (3.2)	0.57	-3.6 (4.5)	0.42	-3.2 (7.2)	0.65
Nov. 2011: B	0.2 (2.7)	0.94	-4.6 (3.7)	0.21	-8.0 (5.3)	0.13
Nov. 2011: C	Reference		Reference		Reference	

Note:
[a]Missing practice characteristics (1,432 or 2.94% of sample) were coded as “other unknown”.
[b]Missing HCC (86 or .18% of sample) were replace by in sample mean HCC.
[c]Missing rural indicator (22 or .05% of sample) were assumed to be non-rural
[b]Missing ZIP code median income (708 or 1.46% of sample) were replace by in sample mean median income.

References

1. Bandalos DL. *Measurement theory and applications for the social sciences*: Guilford Publications; 2018.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract [Done]
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found [See abstract starting on page 2]
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported [See first paragraph page 6]
Objectives	3	State specific objectives, including any prespecified hypotheses [See last paragraph of first paragraph page 6]
Methods		
Study design	4	Present key elements of study design early in the paper [See Methodology section starting on page 7]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection [See Physician and Index Visit sample subsections, (page 7)]
Participants	6	(*a*) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants [See Methodology section and Figure 1 for physician, patient and visit sample stats)]
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed [NA] *Case-control study*—For matched studies, give matching criteria and the number of controls per case [NA]
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable [See page 9 for outcome measures and page 9 for measures of knowledge]
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group [See page 10 for diagnostic knowledge measure]
Bias	9	Describe any efforts to address potential sources of bias [See Statistical Analyses page 11 first paragraph explanation for inclusion of other measures of knowledge and Sensitivity Analysis subsection page 12 and results of sensitivity analysis bottom page 13]
Study size	10	Explain how the study size was arrived at [See first and second paragraph page 6]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why [See Statistical Methods subsection starting on page 9]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding [See Statistical Methods first paragraph of page 12]
		(*b*) Describe any methods used to examine subgroups and interactions [NA]
		(*c*) Explain how missing data were addressed [See section 4 in the Supplement and reference to this in Table 3]

(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed
Case-control study—If applicable, explain how matching of cases and controls was addressed [NA]
Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy [Sensitivity Analysis subsection starting on page 12 top]

(*e*) Describe any sensitivity analyses [Sensitivity Analysis subsection starting on top of page 15]

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed [See Figure 1 and first paragraph page 12]
		(b) Give reasons for non-participation at each stage [See Figure 1, Table 1 and first paragraph page 11]
		(c) Consider use of a flow diagram [See Figure 1]
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders [See Page 13 second paragraph and Table 2]
		(b) Indicate number of participants with missing data for each variable of interest [NA]
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) [NA]
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time [NA]
		Case-control study—Report numbers in each exposure category, or summary measures of exposure [NA]
		Cross-sectional study—Report numbers of outcome events or summary measures [See Table 1]
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included [See Table 3 and Supplementary Material for full set of controls and coefficients (Section 6)
		(*b*) Report category boundaries when continuous variables were categorized [See Statistical Analysis Section and Supplementary Material Section 4]
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period [See Results section starting on top of page 13, Table 3]
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses [See Sensitivity Analysis subsection of Results section page top of Page 14 and Supplementary Material Section 5]
Discussion		
Key results	18	Summarise key results with reference to study objectives [See Discussion subsection last paragraph of page 14]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias [See first full paragraph starting on page 16]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence [No other study has addressed our research question, however, in terms of methodology we compare our study to other in the Discussion section starting on bottom of page 15]
Generalisability	21	Discuss the generalisability (external validity) of the study results [See paragraph starting on last paragraph page 16, line 328]
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based [See Funding section last paragraph on page 19]

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

The Association Between Primary Care Physician Diagnostic Knowledge and Death, Hospitalization and Emergency Department Visits Following an Outpatient Visit at Risk for Diagnostic Error: A Retrospective Cohort Study Using Medicare Claims

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The Association Between Primary Care Physician Diagnostic Knowledge and Death, Hospitalization and Emergency Department Visits Following an Outpatient Visit at Risk for Diagnostic Error: A Retrospective Cohort Study Using Medicare Claims

Bradley M. Gray, PhD, corresponding author

Email: bgray@abim.org, Phone: 202-213 6646, FAX 202-213 6646

American Board of Internal Medicine

510 Walnut Street, Suite 1700, Philadelphia, Pennsylvania 19106, USA

Jonathan L. Vandergrift, MS

American Board of Internal Medicine Philadelphia, Pennsylvania, USA

Rozalina, G. McCoy, MD

Mayo Clinic, Rochester, Minnesota, USA

Rebecca S. Lipner, PhD

American Board of Internal Medicine Philadelphia, Pennsylvania, USA

Bruce E. Landon, MD

Harvard Medical School, Boston, Massachusetts, USA

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Objective

Diagnostic error is a key health care concern and can result in substantial morbidity and mortality. Yet no study has investigated the relationship between adverse outcomes resulting from diagnostic errors and one potentially large contributor to these errors: deficiencies in diagnostic knowledge. Our objective was to measure that associations between diagnostic knowledge and adverse outcomes after visits to primary care physicians that were at risk for diagnostic errors.

Setting/Participants

1,410 US general internists who recently took their American Board of Internal Medicine Maintenance of Certification (ABIM-IM-MOC) exam treating 42,407 Medicare beneficiaries who experienced 48,632 "index" outpatient visits for new complaints at risk for diagnostic error because the presenting complaint (e.g., dizziness) was related to pre-specified diagnostic error sensitive conditions (e.g. stroke).

Outcome measures

90-day risk of all-cause death, and, for outcome conditions related to the index visits diagnosis, emergency department (ED) visits and hospitalizations.

Design

Using retrospective cohort study design, we related physician performance on ABIM-IM-MOC diagnostic exam questions to patient outcomes during the 90 day period following an "index" visit at risk for diagnostic error after controlling for practice characteristics, patient sociodemographic and baseline clinical characteristics.

Results

Rates of 90-day adverse outcomes per 1,000 index visits were 7 for death, 11 for hospitalizations, and 14 for ED visits. Being seen by a physician in the top versus bottom third of diagnostic knowledge during an index visit for a new complaint at risk for diagnostic error was associated with 2.9 fewer all-cause deaths (95% confidence interval (CI) -5.0 to -0.7, P=.008), 4.1 fewer hospitalizations (95% CI -6.9 to -1.2, P=0.006), and 4.9 fewer ED visits (95% CI -8.1% to -1.6%, P=0.003) per 1,000 visits.

Conclusion

Higher diagnostic knowledge was associated with lower risk of adverse outcomes after visits for complaints at heightened risk for diagnostic error.

Strengths and limitations of this study

- Unique diagnostic knowledge measure linking diagnostic knowledge with adverse outcomes
- Scalable adverse outcome measures and extensive sensitivity analyses
- Our assessment of diagnostic error is indirect (as indicated by adverse outcomes)
- Results are subject to selection bias if the mix of index visits or the severity of the patients or practice support differed for physicians with different levels of diagnostic knowledge.
- Results are only generalizable to physicians who elected to attempt ABIM's certification exam and were about 10 years past initial certification and patients older than 65.

Introduction

Diagnostic error has been identified as a key health care delivery concern and contributes to significant potentially preventable morbidity and mortality.(1-3) Ambulatory care, and especially primary care, is a practice setting with a particularly high risk for diagnostic error(4, 5) because of the wide variety of presentations encountered and the concomitant difficulty of distinguishing harmful conditions from routine self-limited complaints, compounded by the well-known time constraints faced by practitioners in that setting. It has been estimated that at least 5% of ambulatory visits are associated with diagnostic error, half of which may result in considerable patient harm. Diagnostic error is a common cause of malpractice suits and most frequently occurs in the ambulatory care settings.(6, 7)

Deficiencies in diagnostic knowledge are likely to be an important contributor to these diagnostic errors that could impact, for example, the breadth of diagnoses considered, appropriate ordering and interpretation of tests, and/or synthesis of data more generally.(8-11) Because of this, measuring physician diagnostic knowledge has become a major focus of organizations throughout the developed world that are tasked with licensing and certifying physicians with the underlying, although largely untested, hypothesis being that diagnostic knowledge will be a measurable and strong predictor of diagnostic error.(12-15) Testing this hypothesis and quantifying this relationship is therefore a critical public policy concern both in terms of the importance of board certification and other programs designed to enhance lifelong learning for physicians.

In the US, the American Board of Internal Medicine (ABIM) is a leading organization that certifies primary care physicians, most notably general internists. In fact, most general internists in the US are certified by the ABIM and these physicians represent about 45% of all adult primary care physicians in the US.(16) Unlike medical licensure, board certification is not a legal requirement to practice medicine in the US, though many hospitals require board certification as one criterion to obtain privileges and insurers often require board certification to be included in covered physician panels.(17, 18) To maintain their certification, general internists must pass an initial certifying exam and, periodically, pass a recertification exam thereafter (referred to as Maintenance of Certification (MOC) exams).(19, 20) Diagnostic knowledge is a major component of these exams representing about half of all exam questions for the Internal Medicine MOC (IM-MOC) exam.

One explanation for the lack of research on this topic is the difficulty in studying the relationship between general diagnostic knowledge and diagnostic error because of the inability to quantify diagnostic knowledge and identifying diagnostic errors at a population level, especially in the outpatient setting.(21) We address this gap in the literature by applying a unique measure of diagnostic knowledge, performance on diagnostic related questions on ABIM's IM-MOC exam, and relating this measure to deaths, hospitalizations, and emergency department visits that occurred after outpatient visits for new complaints at heightened risk for diagnostic error.

Methods

Physician and Index Visit Sample

Our physician sample included general internists who were initially ABIM board certified in 2000 and took their IM-MOC exam between 2008 and 2011 (Figure 1). We identified Medicare beneficiary outpatient Evaluation & Management (E&M) visits with these physicians using their National Provider Identifier (NPI) during the calendar year following their exam (2009 to 2012). These patients were age 65 or older and continuously enrolled in Medicare fee-for-service (Medicare insures most of the US population over 65) during the physician's one year follow-up period and the year prior. To ensure that any presenting complaints being evaluated were new (i.e., not follow up), we restricted these visits to those that were the first visit for a new complaint (the "*index visit*") because these visits were preceded by a 90-day clean period with no previous inpatient or outpatient visit. The 90-day clean period is consistent with the US government Centers for Medicare and Medicaid Services criteria used by its Bundled Payments for Care Improvement Program for defining new episodes of care and with the patterns of visits we observed (see Appendix Section 1 for related analysis).(22, 23)

We further restricted these index visits to those at heightened risk for diagnostic errors because the recorded diagnosis in the Medicare claims (the "*index visit diagnosis"*), which includes recording of symptom (e.g. loss of balance), could have been the initial presenting complaint for one or more of 13 pre-specified diagnostic error sensitive conditions such as congestive heart failure or bacteremia/sepsis (see Table 1). These 13 conditions (see Appendix Section 2 for a list

and applicable ICD-9 codes) were an acute non-cancerous subset of 20 conditions previously noted by Schiff et al. to be at high risk for serious diagnostic error.(24) For instance, index visits with diagnosis codes for chest pain, dyspepsia, shortness of breath, hypoxemia/hypoxia, respiratory distress, weakness/fatigue, edema or ascites could all be the initial presentation of congestive heart failure, which is one of the 13 diagnostic error sensitive conditions.

We used a three-step process to identify eligible index visit diagnoses. First, two physician authors (RGM and BEL) identified all diagnoses that could be presenting complaints for the 13 diagnostic error sensitive conditions: what complaints/diagnoses might someone who ultimately presented with a diagnostic-error sensitive condition have presented with initially? Second, because the original list of identified index visit diagnoses was large (76), we reduced this list to 38 by applying a relative risk (RR) criteria. For a specific index visit diagnosis to meet this criteria, all index visits with that diagnosis had to have a greater portion of later ED visits or hospitalizations with the related outcome condition discharge diagnosis than index visits where the specific at risk diagnosis was not present. For example, dizziness was chosen as an eligible index visit diagnosis for stroke, one of the diagnostic error sensitive conditions, both because it was identified as a potential presenting symptom of a stroke by physician authors and because index visits with that diagnosis had a greater proportion of later hospitalization or ED visits for stroke than visits without this diagnosis. Third, we also included index visits where the actual diagnosis was one of the 13 diagnostic error sensitive conditions because we wanted to include cases where diagnostic errors were and were not made. Therefore, we also included index visits with a diagnosis of congestive heart failure itself as being at risk for the underlying condition congestive heart failure.

Outcome Measures

We examined the risk of three serious adverse outcomes within 90 days of the index visit that we hypothesized would occur more frequently in cases of misdiagnosis: all-cause mortality, hospitalizations, and ED visits. We did not count these events as adverse outcomes if they occurred on the same day as the index visit because this may reflect a positive action (the physician correctly diagnosed a patient with stroke and referred/admitted them to the hospital) or be unavoidable regardless of the accuracy of the index visit diagnosis (the patient died despite immediately admitting the patient to the hospital who exhibited stroke symptoms). Based on Medicare billing codes, hospitalizations were limited to non-elective hospitalizations initiated through the ED or trauma center. The ED and hospitalization outcomes were also limited to cases where the discharge diagnosis was for one of the 13 diagnostic error sensitive conditions following an index visit with the applicable diagnosis. We therefore presumed that these discharge diagnoses were a reasonable representation of the underlying condition of the patient at the time of the index visit. For example, we would count a hospitalization with a discharge diagnosis of stroke as an adverse outcome if it occurred after an index visit for dizziness because dizziness was identified as being a potential presenting complaint for stroke. However, we did not count hospitalizations with a discharge diagnosis for acute coronary syndrome following an index visit for dizziness because dizziness was not identified as a presenting complaint for acute coronary syndrome. The rationale is that if there were no presenting complaints during the index visit related to coronary syndrome, either because the underlying condition was not present or could not be detected at the time of the index visit, then the index visit physician could not have prevented the hospitalization regardless of their diagnostic knowledge.

Measure of Diagnostic Knowledge

Our measure of diagnostic knowledge was calculated as the percent of correct answers on the IM-MOC exam for questions previously coded as "diagnosis-related" by ABIM's IM-MOC exam committee. In our study, these questions comprised 53% of all IM-MOC exam questions, with the remaining 42% addressing treatment and 5% related to other topics such as epidemiology or pathophysiology. More generally, exam questions are designed to replicate real world clinical scenarios and/or patient encounters and without reliance on rote memorization.(25, 26)

The ABIM exam committee coded each question based on the primary function tested to assure that the exam covers care typically rendered by outpatient primary care physicians. Questions coded as "diagnosis related" typically test knowledge and skills related to diagnostic inference, differential diagnosis, and diagnostic testing and therefore are measuring diagnostic knowledge and related decision-making. Psychometric analysis indicates that scores on diagnosis related exam questions were meaningfully correlated (i.e., Cronbach's alpha score of 0.84), and thereby represent an independent underlying construct that could be interpreted as diagnostic knowledge (see Appendix Section 3 for more details).(27) Similarly, this analysis indicated that questions coded as treatment related also represent an independent underlying construct (i.e., Cronbach's alpha score of 0.75). Although performance on diagnosis and treatment related questions were correlated (Pearson Correlation=0.62), 59.5% of the variation in diagnosis exam performance for the physician study sample was not explained by performance on other parts of the exam.

Statistical methods

Using Probit regression we estimated the associations with each adverse outcome, with standard errors adjusted for correlations resulting from the nesting of visits within patients within physicians.(28, 29) To measure associations with diagnostic knowledge we included categorical regression explanatory variables for top and middle third of percent correct scores on diagnosis related questions (bottom third was the reference category). Other exam level explanatory variables included tertile indicators for performance on treatment-related questions and performance on other question types. Since these variables measure knowledge unrelated to diagnosis, they account for correlations between factors such as unmeasured practice or patient characteristics that might be correlated with exam performance and our outcome measures (e.g., high scoring physicians may be more likely to practice in an academic setting or other such settings that might be independently related to diagnostic error). Exam form indicators accounted for differences in exam difficulty across exam administrations.

We also included physician, patient and visit level regression controls. Physician level controls included: practice size (indicators for solo practice and practices larger than 50 physicians), practice type (indicators for academic, group), demographic (gender), and training characteristics (medical school location interacted with country of birth). Patient level controls included: demographic characteristics (age and age squared, gender and race/ethnicity indicators) and a Medicaid eligibility indicator. Lagged patient risk adjusters included 27 indicators for chronic conditions and Medicare's Hierarchal Condition Category (HCC) risk adjustment score. We imputed values for a small number of missing values for controls (see Appendix Section 4). Patient index visit location level controls included: an indicator for residing in a rural ZIP code, ZIP code median household income, and indicators for 10 US Health and Human Services

regions. Index visit level controls included: indicators of any outpatient visit, hospitalization or ED visits within the prior year and number of days since the most recent of these events, visit year indicators to control for secular changes in quality. We also included an indicator for whether or not the patient had a previous contact with the index visit physician during the year prior to the index visit to account for differences in physician-patient continuity (see Appendix Section 5 for a full list of controls).

Sensitivity Analysis

We performed numerous sensitivity analyses to test the robustness of our results (detailed in Appendix Section 6). First, we expanded the index visit sample to include all index visits with the original 76 diagnoses identified by the physician authors regardless of whether they met the relative risk criteria. Second, we expanded and contracted the index visit clean period by seven days. Third, excluded hospitalizations or ED events occurring the day after the index visit, in addition to same day events, to consider the possibility that they might be triggered by a correct diagnosis and therefore should not have been considered adverse outcomes. Fourth, we considered the possibility that our results were biased due to omitted variables correlated with practice size. For example, it could be that physicians in large practices have greater access to specialists or other physicians for informal consultations than those is small practices and therefore outcomes for these physicians may be less sensitive to their knowledge. To examine this possibility, we estimated associations with knowledge and our two utilization measures across a sample of physicians in either small (<=10 physicians, 54.5% (768/1,410) of physicians) or large practices (>50 or in academic medical centers, 23.7% (334/1,410) of physicians). We did not conduct these sensitivities for death because there were too few deaths in the subgroups to allow us to reliably estimate the associations (e.g., 39 deaths for physicians in large

practices).Fifth, to consider the possibility that these outcomes were only avoided because the patient died, for the ED and hospitalization outcome, we also included instances where the patient died. Sixth, as a falsification test we limited the index visits to those that were unrelated to the 13 diagnostic error sensitive conditions. Under this sensitivity, we expected then that the associations with diagnostic knowledge would decline. The index visit physician's diagnostic knowledge cannot impact a future adverse outcome if the underlying condition that caused that outcome was not present or detectible at the time of index visit. Therefore, this reduction in association should be especially true for the hospitalization and ED measures where adverse outcomes were limited to the 13 diagnostic error conditions and so were unrelated to the index visit diagnoses in this sensitivity. Similarly, for the last sensitivity, we applied elective hospitalizations as an outcome measure to consider the possibility that there could be a correlation between the overall propensity to hospitalize in an area and physician knowledge.

The Advarra Institutional Review Board approved our study protocol and all analyses were performed using Stata version 15 (College Station, TX). Patients and the public were not involved in the design or execution of this study as the existing patient claims data used were de-identified by the Center for Medicaid and Medicare Services prior to analysis.

Patient and Public Involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Results

Of 2,492 general internists who initially certified in 2000 and who took an IM-MOC exam between 2009 and 2012, 1,722 had outpatient visits with a fee-for-service Medicare beneficiary during the study period. Those without visits generally practiced hospital medicine. Of these, 1,410 were included in the study because they had at least one outpatient index visit that met our study inclusion criteria during the year after they took their IM-MOC exam. In total, 48,632 index visits with 42,407 patients treated by 1,410 physicians met study inclusion criteria (Figure 1). Table 1 lists frequency of index visits and subsequent outcomes for each diagnostic error sensitivity condition.

The mean percent correct on diagnosis questions ranged from 84.3% among top third performers to 65.5% among bottom third performers (Table 2). Patient and visit characteristics were similar across tertiles of physician diagnostic knowledge. For example, there were no statistically significant differences in the HCC risk adjuster across tertiles (P=.19) However, there were differences in some physician and practice characteristics. When compared to physicians in the bottom tertile of diagnostic knowledge, physicians in the top were significantly less likely to be in solo practice (12.8% versus 24.4%, P=0.009), and more likely to be in academic practice (9.7% versus 3.4%, P<.001). However, the proportion graduating from a US medical school was similar across diagnostic knowledge tertiles (70.0% versus 63.3%, P=.30).

Associations between diagnostic knowledge and patient adverse outcomes

The overall rates of 90-day adverse outcomes per 1,000 index visits was 6.5 for death, 11.1 for hospitalizations, and 13.6 for ED visits (with the latter two directly associated with one of the

diagnostic error sensitive conditions whose antecedent was present in the applicable index visit). Being seen by a physician scoring in the top versus bottom third of diagnostic knowledge on the MOC exam was associated with 2.9 fewer deaths per 1,000 visits (95% confidence interval (CI) -5.0 to -0.7, P=.008) which reflects a 35.3% lower risk of death (95% CI -52.8 to -11.2, P=.008), (Table 3). Our finding also suggests that this difference in exam performance was associated with 4.1 fewer applicable hospitalizations (95% CI -6.9 to -1.2, P=0.006), and 4.9 fewer applicable ED visits (95% CI -8.1 to -1.6, P=0.003) per 1,000 visits (Table). These reductions correspond with about a 30% lower risk for these utilization measures (hospitalizations: -30.5%, 95% CI -46.1 to -10.4, P=.003, ED: -29.8%, 95% CI -44.4 to -11.4).

We also found a significant dose response relationship across all three regression adjusted relative risk measures (P-trends <0.008). For example, the regression-adjusted 90-day risk of death per 1,000 patients whose index visit physician scored in the top third of diagnostic knowledge was 5.2 (95% CI 4.1 to 6.3), compared to 6.5 (95% CI 5.4 to 7.6) for the middle third, and 8.1 (95% CI 6.5 to 9.7) for the bottom third (P-trend 0.008).

Sensitivity Analyses

Our sensitivity analyses (Appendix Section 6) confirmed that base case associations with diagnostic knowledge were robust to different index visit clean periods, and diagnosis code inclusion criteria and next day coding of outcome measures. Associations with diagnostic knowledge were also fairly robust to physician's practice size for both the ED and hospitalization measures when we limited the sample to either small or large or academic practices.

Suggesting that our results were not influenced by omitted variable bias, we found that associations with diagnostic knowledge and our outcome measures became small and statistically insignificant when we limited the sample to index visits with diagnoses unrelated to any of the 13 diagnostic sensitive error conditions, and so were at lower risk for diagnostic error (P>0.50 and associations were at most about a tenth of the base case percent difference between top and bottom third of diagnostic knowledge). We also found no significant association between lack of diagnostic knowledge and elective hospitalizations (P=0.63).

Discussion

We found that higher diagnostic knowledge among US outpatient internal medicine physicians was associated with significant reductions in subsequent adverse outcomes whose cause was at risk for diagnostic error. Indeed, for every 1,000 index visits for a new complaint at risk for diagnostic error, being seen by a physician in the top versus bottom third of diagnostic knowledge was associated with 2.9 fewer all-cause death and, for diagnostic error sensitive conditions, 4.1 fewer hospitalizations and 4.9 fewer ED visits within 90 days. These figures correspond to a reduction in risk for these adverse events by about a third. Although some prior studies have demonstrated the high morbidity and mortality of diagnostic error(1-3), this is the first study to demonstrate and quantify the direct association between serious adverse outcomes and the diagnostic knowledge of their first contact primary care physician. These finding support the notion that gaps in diagnostic knowledge between physicians may be an important contributor to the diagnostic error problem plaguing the healthcare system worldwide.

We measured the association between diagnostic knowledge and potential diagnostic error by using Medicare claims data to identify patients who presented for outpatient visits with complaints at heightened risk for serious diagnostic errors and examining the occurrence of clinically relevant adverse outcomes soon thereafter. Although this approach lacks the precision of individual chart audits(7), it is both clinically plausible and scalable in that it can be used to monitor the care of large numbers of patients, making the method itself an important contribution to the literature on diagnostic error. Although we did not directly measure diagnostic errors through chart audits, the fact that we found associations with diagnostic knowledge and the diagnostic error sensitive outcome conditions we studied coupled with the fact that we did not find associations with treatment knowledge, nor did we find associations when the underlying diagnostic error sensitive condition was likely not present during the outpatient index visit because no antecedent diagnoses recorded indicates that the associations we report in this study were likely driven by association with diagnostic errors that occurred during these visits. Furthermore, our approach builds on prior studies that used claims data to infer diagnostic error incidence for ED visits, in that we identified index visit diagnoses at risk for diagnostic error that were clinically plausible and verified empirically, and we assured that we were studying new problems by requiring that the patient not have had a visit over the previous 3 months contacts.(30-32) We expanded on these studies by focusing on outpatient care and by examining a much more comprehensive set of presenting complaints that may have been precursors to one of 13 diagnostic error prone conditions that we studied. This approach was necessary in order to study diagnostic error in the more low acuity setting of outpatient general internal medicine.

Our findings suggest an association between diagnostic knowledge and adverse outcomes. Yet, there are important limitations to consider. We did not directly determine whether a diagnostic error had occurred through such validated means as a chart review. Our findings cannot be interpreted as causal given the cross-sectional nature of our study so we cannot rule out the possibility that observed associations were the result of omitted variable bias related to either physician or patient characteristics, and do not reflect a causal relationship between diagnostic knowledge and adverse outcomes. That said, there is no reason to believe that these characteristics would be correlated with diagnostic knowledge independent of treatment knowledge which we were able to control for as both these knowledge measures should be similarly correlated with unobserved factors such as ability of consulting colleagues. Furthermore, had associations with diagnostic knowledge been driven by omitted variable bias then we would have expected them to be similar when estimated across index visits with lower or higher risk for diagnostic error, and they were not. We also found that diagnosis exam performance was not associated with elective hospitalizations, which are, presumably, unrelated to underlying diagnostic knowledge but may be related to the overall propensity to hospitalize. That said, the fact that practice size was found to be correlated with diagnostic exam performance is concerning. For example, as described above, practice size could be correlated with access to specialists that intern might be related to our outcome measures. However, sensitive analyses indicate that associations with knowledge and our utilization adverse outcome measures were fairly similar across physicians practice size/type (small, and large or academic). An additional limitation is that we studied select conditions among older patients enrolled in the Medicare program so we cannot extrapolate these findings to a younger population, other conditions we did not consider, or populations with no or different health insurance coverage.

Our findings might also not be applicable to older physicians who certified before 2000 or younger physicians who certified after 2000 as well as physicians who choose not to attempt an exam. While a physician's clinical knowledge might be related to their decision to not take the MOC exam therefore not maintaining their certification, other factors certainly play a role in this decision.

Another limitation of our study is that the IM-MOC exam was specifically designed to measure clinical knowledge in general, it was not designed to measure diagnostic knowledge specifically. That said, diagnostic knowledge is a major component of the exam and was found to meet the criteria for measuring this underlying construct. Also diagnostic error may have stemmed from factors outside of inadequate diagnostic knowledge, which are not covered by the exam but could be correlated with our exam based diagnostic knowledge measure (e.g., poor patient/physician communication skills and related system failures).(33, 34) That said, there is no reason to believe that these other contributors to diagnostic error would not also be correlated with the other aspects of the exam we do account for. Furthermore, based on an analysis of malpractice claims, Newman-Toker et al. (6) reported that clinical judgement played an important role in 86% of diagnostic errors, while poor patient/physician communication and system failures played a role in far fewer diagnostic errors that resulted in malpractice suits (35% and 22% respectively). Suggesting that improving communication will not reduce stroke related diagnostic error, Kerber et al. (35) reported that frontline providers rarely ask the right questions when patients present with dizziness. Communication ability is only valuable in terms of reducing diagnostic error if the physician knows what questions to ask and what the answers mean. Although we cannot say with certainty that our finding are driven by an underlying

association between diagnostic knowledge and diagnostic errors, at a minimum, our finding suggest that patients treated by physicians who scored well on diagnostic exam questions may be at lower risk for the adverse outcomes we studied. Finally, some might assert that a standardized exam without access to medical reference material might be more a reflection of a physician's rote memory and ability to recall medical facts than a test of their clinical knowledge and judgement. Although this is a fundamental limitation of our study, it should be noted that the exam is designed to mimic decision making in real life situations including have such things as lab values and reference material embedded in questions and past research indicates that an "open" book format that allows physicians access to reference material did not materially impact exam performance.(36) It should also be noted that the necessary rapidity of decision making by primary care physicians who have limited time per encounter might fairly be represented by an exam with time constraints.

In this exploratory analysis, we found evidence that diagnostic knowledge of primary care physicians seeing a patient for an index visit for a complaint that is at heightened risk of diagnostic error is associated with adverse outcomes. The fact that there exists a link between general diagnostic knowledge and diagnostic error may not be surprising, the magnitude of the associations we found suggests that interventions ignoring the role of physician knowledge may be inadequate to address the crisis of diagnostic error. Interventions targeted at improving diagnostic knowledge could include such things as a greater focus on diagnostic training during graduate medical education (i.e., medical school, residency, and fellowship). Knowledge-focused interventions could also include incentivizing broad-based learning as well as targeted learning pursued through continuing medical education (CME) activities.(30) During visits identified as

being at risk for diagnostic errors, physicians could be given related information at the point of care including suggestions for specialty consultation.

Our results are important for two additional reasons. First, these results provide evidence that board certification and maintenance of certification, which involves lifelong learning directed at maintaining medical knowledge, might, in fact, be a valid approach to assuring the delivery of high quality care. Many in the US complain about the time and expense of MOC and often point to the lack of rigorous assessment between aspects of MOC and outcomes of interest to patients. These findings suggest that processes such as MOC may translate into meaningful improvements in outcomes because they can provide incentives for meaningful learning. This learning also could be enhanced through exam feedback targeted at diagnostic knowledge. Second, the findings also suggest that interventions aimed at improving diagnostic skills, whether knowledge-based or through, for instance, delivery of relevant information at the point of care [this is in response to system changes] might be approaches that might be worthwhile if the findings of this study are validated with additional research. Yet more research is needed to better understand the link between diagnostic knowledge and diagnostic errors that are identified through chart review or other methods of direct ascertainment and the extent to which such errors result in adverse clinical outcomes.

In conclusion, gaps in diagnostic knowledge among first contact primary care physicians is associated with serious diagnostic error sensitive outcomes. If this finding is confirmed in future studies, diagnostic knowledge should be a target for interventions to reduce diagnostic errors.

Statements

A. Contribution statement: Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon met the ICMJE guidelines authorship criteria:

   a. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon substantially contributed to the conception and design of the work.

   b. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner contributed to the acquisition of the data.

   c. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon substantially contributed to analysis or interpretation of data.

   d. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon substantially contributed to the drafting the work and revising it critically for important intellectual content.

   e. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon gave final approval of the version published.

   f. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved.

B. Competing Interests: Bradley Gray, Jonathan Vandergrift, and Rebecca Lipner are paid employees of the American Board of Internal Medicine. Bruce Landon is a paid consultants for the American Board of Internal Medicine.

C. Funding Statement: This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

D. Data Sharing: Administrative data describing physician characteristics and exam performance can be obtained from the ABIM through a data sharing agreement that assures physician confidentiality and its use for legitimate research purposes. Access to de-identified Medicare claims data for this study were obtained through a special data use agreement with the Centers for Medicare and Medicaid services which is a process available to researchers in the US.

E. Dissemination to participants and related patient and public communities: As study data were pseudonymised, it is not possible to send findings directly to the study participants. ABIM's communication department in collaboration with the authors of this study will write a press release whose goal is to inform the public regarding the findings of the study.

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Table 1. Frequency of Index Visits Related to each Diagnostic Error Sensitive Condition

Thirteen diagnostic error sensitive conditions	Index visits with a diagnosis code related to a diagnostic error sensitive condition (percentages can add to greater than 100% because of antecedent index visit diagnoses related to more than one diagnostic error sensitive condition)	Hospitalization[a,b]	Emergency department visit[a]	Death[c]
	Number (percent of index visits)	Number (percent of hospitalizations with a diagnostic error sensitive condition)	Number (percent of emergency department visits with a diagnostic error sensitive condition)	Number (percent of deaths)
	48,632 (100.0)	541 (100)	663 (100)	316 (100)
Acute Coronary Syndrome	16,228 (33.4)	48 (8.9)	56 (8.4)	103 (32.6)
Fracture	13,409 (27.6)	60 (11.1)	100 (15.1)	60 (19.0)
Depression	12,637 (26.0)	Not Reported[d]	Not Reported[d]	121 (38.3)
Anemia	12,410 (25.5)	54 (10.0)	59 (8.9)	110 (34.8)
Pneumonia	12,183 (25.1)	91 (16.8)	107 (16.1)	107 (33.9)
Congestive Heart Failure	12,137 (25.0)	227 (42.0)	254 (38.3)	120 (38.0)
Aortic Aneurysm	11,491 (23.6)	17 (3.1)	23 (3.5)	79 (25.0)
Stroke	10,026 (20.6)	69 (12.8)	82 (12.4)	71 (22.5)
Pulmonary Embolism	8,534 (17.5)	12 (2.2)	13 (2.0)	89 (28.2)
Spinal Cord Compression	6,386 (13.1)	Not Reported[d]	Not Reported[d]	36 (11.4)
Bacteremia / Sepsis	5,567 (11.4)	19 (3.5)	21 (3.2)	46 (14.6)
Appendicitis	2,584 (5.3)	Not Reported[d]	Not Reported[d]	17 (5.4)
Abscess	1,005 (2.1)	Not Reported[d]	13 (2.0)	Not Reported[d]

[a]Condition specific outcomes for one of the 13 diagnostic error sensitive conditions within 90 days of an outpatient index visit at risk for that condition

[b]Hospitalizations include non-elective hospitalizations either initiated through the ED or a trauma center.

[c]All cause mortality within 90 days of the index visit.

[d]Not reported because observations were less than 11.

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	Total	Diagnosis question percent correct			P-value[a]
		Top (78.5 to 95.8)	Middle (71.4 to 78.4)	Bottom (42.9 to 71.3)	
Exam performance, Mean (standard deviation) [a]					
Diagnosis question percent correct	74.5 (0.4)	84.3 (0.3)	74.8 (0.1)	65.5 (0.3)	<.001
Other question percent correct	72.6 (0.7)	80.2 (1.0)	72.1 (1.1)	66.4 (1.5)	<.001
Treatment question percent correct	77.3 (0.3)	83.4 (0.4)	77.2 (0.4)	72.0 (0.5)	<.001
Physician Characteristics, count (%)					
Female Physician	19,428 (39.9)	6,546 (43.8)	6,357 (37.5)	6,525 (39.0)	0.37
US born physician	28,462 (58.5)	9,284 (62.1)	9,932 (58.6)	9,246 (55.3)	0.37
US medical school	31,960 (65.7)	10,471 (70.0)	10,900 (64.3)	10,589 (63.3)	0.30
Practice Type					
Solo physician practice	9,452 (19.4)	1,914 (12.8)	3,462 (20.4)	4,076 (24.4)	0.009
Small group practice (2 to 10)	20,563 (42.3)	5,543 (37.1)	7,529 (44.4)	7,491 (44.8)	0.19
Medium physicians group practice (11 to 50)	7,442 (15.3)	2,899 (19.4)	2,402 (14.2)	2,141 (12.8)	0.25
Large physician group practice (>50 physicians)	5,391 (11.1)	2,150 (14.4)	1,655 (9.8)	1,586 (9.5)	0.14
Academic practice	2,708 (5.6)	1,447 (9.7)	697 (4.1)	564 (3.4)	<.001
Other practice	3,076 (6.3)	1,005 (6.7)	1,211 (7.1)	860 (5.1)	0.59
Beneficiary characteristics					
Beneficiary Race, count (percent)					
White	40,086 (82.4)	12,652 (84.6)	13,778 (81.3)	13,656 (81.7)	0.13
Black	3,958 (8.1)	926 (6.2)	1,609 (9.5)	1,423 (8.5)	0.03
Other	4,588 (9.4)	1,380 (9.2)	1,569 (9.3)	1,639 (9.8)	0.88
Beneficiary age (per year), Mean (SD) [a]	76.6 (0.1)	76.8 (0.1)	76.5 (0.1)	76.6 (0.1)	0.23
CCW chronic conditions, count (percent)					
Alzheimer's Disease and Related Disorders or Senile Dementia	5,151 (10.6)	1,497 (10.0)	1,793 (10.6)	1,861 (11.1)	0.16
Alzheimer's Disease	2,061 (4.2)	627 (4.2)	704 (4.2)	730 (4.4)	0.82
Acute Myocardial Infarction	1,408 (2.9)	394 (2.6)	494 (2.9)	520 (3.1)	0.13
Anemia	22,450 (46.2)	6,706 (44.8)	7,766 (45.8)	7,978 (47.7)	0.11
Asthma	4,424 (9.1)	1,313 (8.8)	1,548 (9.1)	1,563 (9.3)	0.39
Atrial Fibrillation	4,225 (8.7)	1,265 (8.5)	1,478 (8.7)	1,482 (8.9)	0.69
Breast Cancer	2,485 (5.1)	779 (5.2)	831 (4.9)	875 (5.2)	0.48
Colorectal Cancer	1,139 (2.3)	357 (2.4)	406 (2.4)	376 (2.2)	0.68
Endometrial Cancer	352 (0.7)	113 (0.8)	109 (0.6)	130 (0.8)	0.39
Lung Cancer	435 (0.9)	151 (1.0)	152 (0.9)	132 (0.8)	0.19
Prostate Cancer	1,662 (3.4)	507 (3.4)	600 (3.5)	555 (3.3)	0.66
Cataract	31,095 (63.9)	9,601 (64.2)	10,773 (63.5)	10,721 (64.1)	0.74
Heart Failure	9,207 (18.9)	2,786 (18.6)	3,155 (18.6)	3,266 (19.5)	0.54
Chronic Kidney Disease	6,904 (14.2)	2,083 (13.9)	2,392 (14.1)	2,429 (14.5)	0.62
Chronic Obstructive Pulmonary Disease	9,108 (18.7)	2,635 (17.6)	3,165 (18.7)	3,308 (19.8)	0.02
Depression	12,042 (24.8)	3,728 (24.9)	4,145 (24.4)	4,169 (24.9)	0.83
Diabetes	13,296 (27.3)	3,947 (26.4)	4,590 (27.1)	4,759 (28.5)	0.16
Glaucoma	10,030 (20.6)	3,086 (20.6)	3,501 (20.6)	3,443 (20.6)	0.99
Hip/Pelvic Fracture	1,531 (3.1)	430 (2.9)	535 (3.2)	566 (3.4)	0.15
Hyperlipidemia	37,132 (76.4)	11,266 (75.3)	12,898 (76.1)	12,968 (77.6)	0.11
Benign Prostatic Hyperplasia	5,815 (12.0)	1,792 (12.0)	1,987 (11.7)	2,036 (12.2)	0.76
Hypertension	37,607 (77.3)	11,345 (75.8)	13,011 (76.7)	13,251 (79.3)	<.001
Hypothyroidism	11,425 (23.5)	3,490 (23.3)	3,862 (22.8)	4,073 (24.4)	0.25

Ischemic Heart Disease	18,713 (38.5)	5,616 (37.5)	6,393 (37.7)	6,704 (40.1)	0.06
Osteoporosis	14,171 (29.1)	4,372 (29.2)	4,794 (28.3)	5,005 (29.9)	0.34
Rheumatoid Arthritis	23,352 (48.0)	6,879 (46.0)	8,275 (48.8)	8,198 (49.0)	0.02
Stroke	6,255 (12.9)	1,880 (12.6)	2,212 (13.0)	2,163 (12.9)	0.70
Number of chronic conditions, count (percent)					
<=4	5,066 (10.4)	1,459 (9.8)	1,744 (10.3)	1,863 (11.1)	0.08
5 to 7	16,861 (34.7)	5,392 (36.0)	5,981 (35.3)	5,488 (32.8)	0.006
8 to 10	16,230 (33.4)	4,907 (32.8)	5,664 (33.4)	5,659 (33.8)	0.35
>=11	10,475 (21.5)	3,200 (21.4)	3,567 (21.0)	3,708 (22.2)	0.28
Mental health visit, count (percent)	6,347 (13.1)	2,040 (13.6)	2,119 (12.5)	2,188 (13.1)	0.46
Hierarchical Condition Category (HCC) score, Mean (SD)[a]	0.98 (0.01)	0.96 (0.01)	0.98 (0.01)	0.99 (0.01)	0.19
Household medium income, mean $ (SD)[a]	59,852 (643)	61,574 (1,106)	59,113 (1,144)	59,063 (1,075)	0.19
Medicaid dual eligible, count (percent)	6,392 (13.1)	1,793 (12.0)	2,411 (14.2)	2,188 (13.1)	0.28
Rural county residence, count (percent)	7,392 (15.2)	2,207 (14.8)	2,866 (16.9)	2,319 (13.9)	0.64
Visit characteristics					
Visit with same doctor in last year, Count (percent)	37,726 (77.6)	11,369 (76.0)	13,154 (77.6)	13,203 (79.0)	0.08
Visit with any physician in last year, count (percent)	44,852 (92.2)	13,711 (91.7)	15,647 (92.3)	15,494 (92.7)	0.08
Days since last visit with any physician (if any visit in last year), Mean (SD)[a]	144.2 (0.6)	147.1 (0.8)	144.4 (1.0)	141.4 (1.3)	<.001
ED visit in prior year, count (percent)	8,101 (16.7)	2,428 (16.2)	2,879 (17.0)	2,794 (16.7)	0.43
Days since last ED visits (if ED visit in last year), Mean (SD)[a]	222.8 (0.9)	221.2 (1.5)	223.5 (1.5)	223.4 (1.5)	0.47
Hospitalization in prior year, Count (percent)	4,227 (8.7)	1,280 (8.6)	1,489 (8.8)	1,458 (8.7)	0.85
Days since last hospitalization (if hospitalization in last year), Mean (SD)[a]	229.6 (1.2)	229.1 (2.1)	229.7 (2.1)	230.1 (1.9)	0.95
Index visit diagnosis groups, Count (percent)					
Abscess	1,005 (2.1)	268 (1.8)	394 (2.3)	343 (2.1)	0.21
Anemia	12,410 (25.5)	3,817 (25.5)	4,369 (25.8)	4,224 (25.3)	0.93
Aortic aneurysm	11,491 (23.6)	3,495 (23.4)	4,165 (24.6)	3,831 (22.9)	0.18
Appendicitis	2,584 (5.3)	845 (5.6)	949 (5.6)	790 (4.7)	0.01
Bacteremia	5,567 (11.4)	1,660 (11.1)	1,929 (11.4)	1,978 (11.8)	0.83
Congestive heart failure	12,137 (25.0)	3,633 (24.3)	4,221 (24.9)	4,283 (25.6)	0.67
Acute coronary syndrome	16,228 (33.4)	4,627 (30.9)	5,740 (33.9)	5,861 (35.1)	0.02
Depression	12,637 (26.0)	3,932 (26.3)	4,312 (25.4)	4,393 (26.3)	0.78
Fracture	13,409 (27.6)	4,324 (28.9)	4,364 (25.7)	4,721 (28.2)	0.11
Pulmonary embolism	8,534 (17.5)	2,683 (17.9)	2,984 (17.6)	2,867 (17.1)	0.71
Pneumonia	12,183 (25.1)	3,773 (25.2)	4,224 (24.9)	4,186 (25.0)	0.97
Spinal cord compression	6,386 (13.1)	1,985 (13.3)	2,218 (13.1)	2,183 (13.1)	0.94
Stroke	10,026 (20.6)	3,003 (20.1)	3,542 (20.9)	3,481 (20.8)	0.79

[a]P-values and standard deviation accounted for correlated errors within physicians

Table 3. Associations with diagnostic knowledge and adverse events per 1,000 index visits

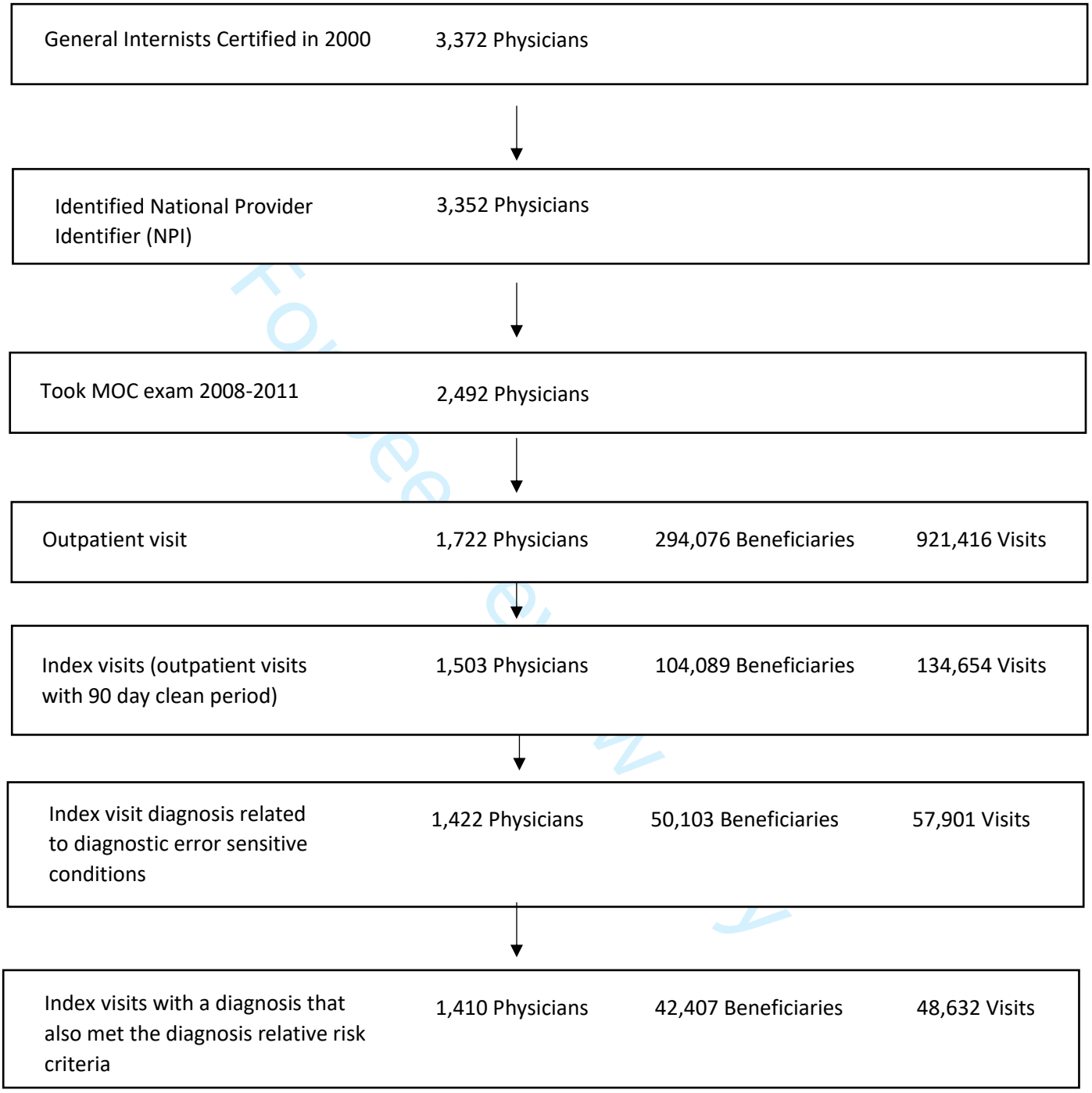
Diagnostic knowledge tertile	Death[a]				Emergency department visit[b]				Hospitalization[c]			
	Unadjusted[e]	Regression adjusted[d,e]			Unadjusted[e]	Regression adjusted[d,e]			Unadjusted[e]	Regression adjusted[d,e]		
	Events per 1,000 visits (95% CI interval)	Events per 1,000 visits (95% CI interval)	Difference (95% CI)	P-value	Events per 1,000 visits (95%CI)	Events per 1,000 visits (95%CI)	Difference (95% CI)	P-value	Events per 1,000 visits (95% CI)	Events per 1,000 visits (95% CI)	Difference (95% CI)	P-value
Top	6.2 (5.0 to 7.4)	5.2 (4.1 to 6.3)	-2.9 (-5.0 to -0.7)	0.008	13.0 (11.2 to 14.8)	11.5 (9.8 to 13.2)	-4.9 (-8.1 to -1.6)	0.003	10.4 (8.8 to 12.1)	9.2 (7.7 to 10.8)	-4.1 (-6.9 to -1.2)	0.006
Middle	6.6 (5.4 to 7.8)	6.5 (5.4 to 7.6)	-1.6 (-3.6 to 0.3)	0.09	13.0 (11.2 to 14.7)	13.2 (11.5 to 15.0)	-3.1 (-6.1 to -0.1)	0.04	10.8 (9.2 to 12.4)	11.0 (9.4 to 12.6)	-2.3 (-4.9 to 0.4)	0.09
Bottom	6.6 (5.5 to 7.8)	8.1 (6.5 to 9.7)	reference		14.9 (13.0 to 16.8)	16.4 (14.0 to 18.7)	reference		12.1 (10.4 to 13.8)	13.3 (11.2 to 15.4)	reference	

[a]All cause mortality within 90 days of an outpatient index visit with a diagnosis at risk for one of 3 diagnostic error sensitive conditions.
[b]Emergency department visit for one of the 13 diagnostic error sensitive conditions within 90 days of an outpatient index visit with a visit at risk for that condition.
[c]Hospitalizations were for non-elective hospitalizations either initiated through the ED or a trauma center with a discharge diagnosis for one of 13 diagnostic error sensitive conditions within 90 days of the index visit with a diagnosis at risk for that condition.

FIGURE LEGEND:

Figure 1. Sample Selection

Figure 1. Sample Selection



Appendix

The Association Between Primary Care Physician Diagnostic Knowledge and Death, Hospitalization and Emergency Department Visits Following an Outpatient Visit at Risk for Diagnostic Error: A Retrospective Cohort Study Using Medicare Claims

Bradley M. Gray, PhD, corresponding author
Email: bgray@abim.org 202-213 6646, FAX 202-213 6646
American Board of Internal Medicine
510 Walnut Street, Suite 1700, Philadelphia, Pennsylvania 19106, USA

Contents

Section 1: 90-day Index Visit Clean Period Derivation

Figure 1.1 displays the visit periodicity between each of the 921,416 visits to an internist in the sample and the most recent visit prior to that one.

To determine what the index visit clean period was we assumed that when two contacts happen "close" together they are more likely to be visits for the same acute episode of care. Therefore, if we exclude all but the first visit that happen "close" together then the remaining visits are highly likely to represent the first visit for a new episode of care (i.e., a new problem). However, the visit periodicity threshold that distinguishes visits that are "close" versus "not close" is unknown.

To help delineate this threshold, Figure 1.1 visit shows periodicity between each of the 921,416 visits to an internist in the sample and the most recent adjacent visit prior to that one. In Figure 1.1, you can see the slope of frequency curve is falling until about a 90 day gap between visits. This indicates that many of the visits prior to this point may be related to an existing episode of care. After 90 days, the periodicity slope begins to flatten out which indicates that the timing between visits is likely random and so it is less likely that the two visits are related to the same episode of care.

This flattening of the slope after 90 days is more clearly displayed in Figure 1.2 which displays the 15 day moving average of the change in visit counts per day (i.e., the changing slope). Here the slope stabilizes at about zero beginning around 90 days suggesting that a 90 day clean period for physician visits is likely to exclude most visits that are a follow-up to an ongoing episode of care from the index visit sample.

Figure 1.1. Visit Periodicity Plot for the 921,416 Outpatient Visits to Physicians in the Sample

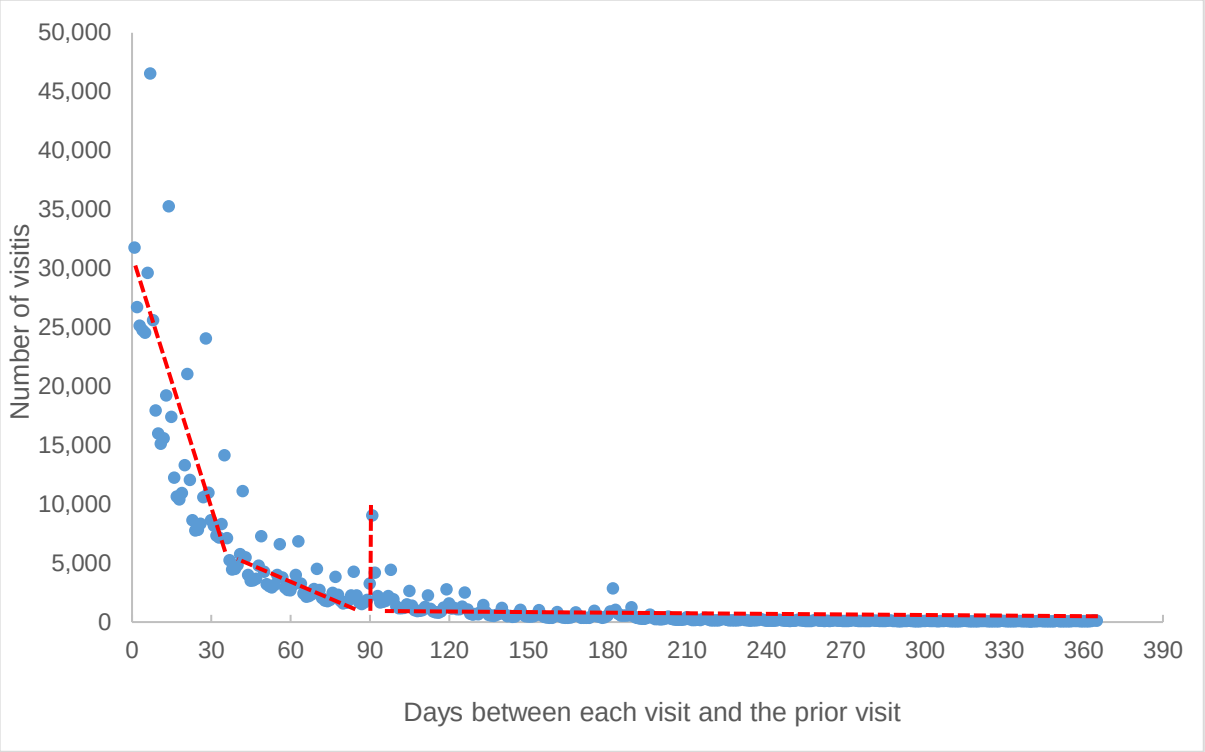
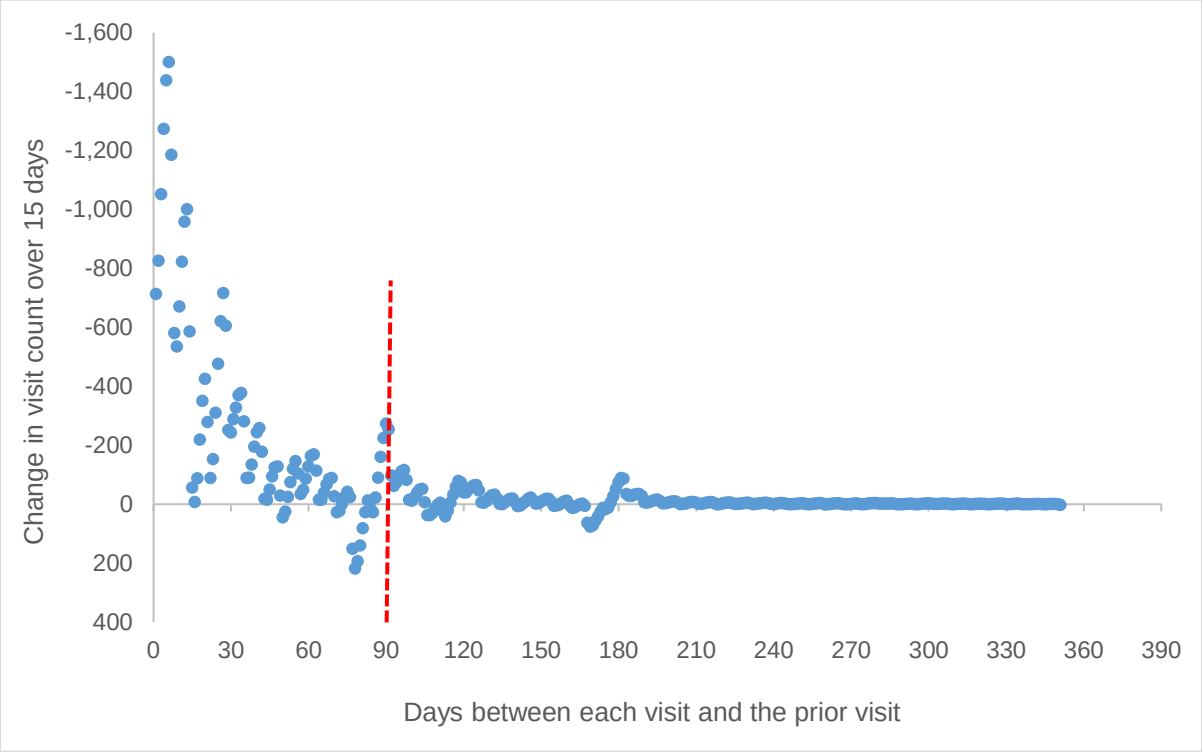


Figure 1.2. Average Change in Visit Count over the 15 days (15-day slope) Following each Data Point Listed in Figure 1



Section 2. ICD-9 Code Codes for Diagnostic Error sensitive Conditions and ICD-9 Code Groups for Index Visit Eligibility and Related Relative Risks

The Section includes a list the list of diagnostic error sensitive condition ICD-9 diagnoses (Table 2.1), index visit eligible ICD-9s diagnoses groups (Table 2.2), and relative risks for each index visit diagnosis group (Table 2.3).

eTable 2.1. ICD-9 Code Codes for Diagnostic Error Sensitive Conditions

Diagnostic Error Sensitive Conditions	ICD-9 groups
Abscess	681, 682
Acute Coronary Syndrome	410, 411.1
Anemia	280-284
Appendicitis	540-542, 543.0, 543.9
Aortic aneurysm	441
Bacteremia/Sepsis	038, 003.1, 020.2, 022.3, 036.2, 054.5, 449, 771.81, 790.7, 995.91, 995.92
Depression	296.2, 296.3
Fracture	800-829, 733.81
Congestive Heart failure	428
Pneumonia	480-486
Pulmonary embolism	415.1
Spinal cord compression	336.9
Stroke	430-437

eTable 2.2. ICD-9 Code Groups for Index Visit Eligibility

Index visit ICD-9 recorded diagnosis ICD-9 codes (76 different diagnoses)	ICD-9s	Met at least one diagnostic error sensitive relative risk criterion (38 met this criteria)
Abdominal pain	789.0	Yes
Abdominal tenderness	789.6	No
Abnormal respiration	786.0	Yes
Alcohol	291.0-291.5, 291.8, 291.9, 357.5, 425.5, 571.0-571.3, 303, 305.00-305.03, 535.30-535.31, E860.0	No
Amphetamines	304.4	No
Anxiety	300.0	Yes
Ascites	785.5	Yes
Back pain	724.5	Yes
Bronchitis	466.0, 466.1	Yes
Cannabis	304.3, 305.2	No
Celiac disease	579.0	No
Chest Pain	786.50, 786.51, 786.59	Yes
Chills	780.64	No
Cocaine	304.2, 305.6, E938.25	No
Confusion	298.2	Yes
Cough	786.2	Yes
Deep vein thrombosis	453.40	No
Delirium	293.0, 780.97	Yes
Diverticulitis	562.11	Yes
Dizziness	780.4	Yes
Drug Mental Disease	292	No
Dyspnea	786.09	Yes
Dysthymia	300.4	Yes
Edema	782.3	Yes
Elevated blood pressure	796.2	No
Esophageal disease	530.1, 530.3-530.9	Yes
Facial weakness	728.87	Yes
Falls	v15.88	No
Fatigue	780.7	Yes
Fever	780.60, 780.61	Yes
Gait instability	781.2	Yes
Gastritis	535	No
Gastrointestinal bleeding	578.9	Yes
Hallucinogens	304.5, 305.3, 969.6, E854.1, E939.6	No
Headache	339, 346, 784.0	Yes
Heart Burn	787.1	No
Hemoptysis	786.30, 786.39	Yes
Hyperparathyroidism	262.0	Yes
Hypoxemia/Hypoxia	799.02	Yes
Influenza	487.0, 487.1, 487.8, 488	No
Lack coordination	781.3	Yes
Lower respiratory disease	519.8	No
Lung cancer	162	Yes
Menorrhagia	626.2	No
Mood disorder	293.83, 293.84	No

Nausea	787.01, 787.02	Yes
Opioids	304.0, 304.7, 305.5, 965.0, E850.0-E850.2, E935.0-E935.2	No
Osteopenia	733.90	No
Osteoporosis	733.0	Yes
Other back pain	721.2-721.9, 722.1, 722.2, 722.5, 722.6, 722.70, 722.72, 722.73, 722.80, 722.82, 722.83, 722.90 722.92, 722.93, 724.0, 724.1	Yes
Other respiratory issue	786.00,786.01, 786.06, 786.07, 786.52, 786.1, 786.2	Yes
Otitis media	381-383, 387, 055.2, 384.2, 384.8, 384.9, 385.0-385.2	No
Personality disorder	301	No
Pain respiration	786.52	Yes
Peripheral neuropathy	337.9, 337.1	No
Reflux disease	530.81	Yes
related alcohol disease	291.9, 292, 304.0-304.6	No
Respiratory Distress	518.81	No
Sedatives	304.1	No
Shortness of breath	786.05	Yes
Sinusitis	473	Yes
Speech disturbance	784.5	Yes
Stress	308	No
Stress fracture	733.94-733.98	No
Tachycardia	785.0	Yes
Tension headache	307.81	No
Thunderclap headache	339.43	No
Transient ischemic attack	435.0-435.3, 435.8, 435.9	Yes
Upper respiratory disease	472, 476, 477, 478.8	No
Viral illness	079.99	No
Vitamin D deficiency	268	Yes
Vomiting	787.01, 787.03	Yes
Weakness/Fatigue	728.87, 708.7	Yes
Weight gain	783.1	No
Weight loss	783.2	Yes

eTable 2.3 Relative Risks for each Index Visit Diagnosis

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Abscess	Fever	2.65
	Chills	0.00
Anemia	Gastrointestinal bleeding	25.20
	Weight loss	4.09
	Shortness of breath	3.51
	Weakness/Fatigue	2.35
	Hypoxemia/Hypoxia	2.11
	Dyspnea	2.05
	Chest Pain	1.82
	Headache	1.29
	Menorrhagia	0.00
Aortic Aneurysm	Dyspnea	4.98
	Abdominal pain	4.93
	Shortness of breath	3.80
	Chest pain	2.42
	Other back pain	1.64
	Back pain	1.01
	Elevated blood pressure	0.00
Appendicitis	Vomiting	30.79
	Diverticulitis	30.45
	Nausea	16.81
	Abdominal pain	15.60
	Abdominal tenderness	0.00
	Fever	0.00
Bacteremia/Sepsis	Vomiting	6.99
	Fever	5.10
	Nausea	3.82
	Tachycardia	2.67
	Weakness/Fatigue	1.75
Heart failure	Hypoxemia/Hypoxia	9.99
	Shortness of breath	5.09
	Dyspnea	3.33
	Edema	3.27
	Chest Pain	2.46
	Weakness/Fatigue	1.42
	Ascites	0.00
	Respiratory Distress	0.00

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Acute Coronary Syndrome	Chest pain	8.38
	Dyspnea	7.29
	Shortness of breath	3.65
	Hypoxemia/hypoxia	2.01
	Reflux disease	1.23
	Esophageal disease	1.22
	Weakness/Fatigue	1.14
	Nausea	1.05
	Other respiratory issue	0.86
	Respiratory distress	0.00
	Gastritis	0.00
	Heart Burn	0.00
Depression	Delirium	32.76
	Heart failure	6.16
	Anxiety	5.04
	Dysthymia	4.99
	Weight loss	4.73
	Anemia	2.74
	Fatigue	1.06
	Alcohol	0.00
	Amphetamines	0.00
	Cannabis	0.00
	Cocaine	0.00
	Drug Mental Disease	0.00
	Hallucinogens	0.00
	Opioids	0.00
	Personality disorder	0.00
	related alcohol disease	0.00
	Sedatives	0.00
	Stress	0.00
	Weight gain	0.00
	Mood disorder	0.00
Fracture	Gait instability	2.53
	Edema	1.79
	Osteoporosis	1.66
	Hyperparathyroidism	1.09
	Vitamin D deficiency	1.08

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Fracture (con't)	Osteopenia	0.54
	Celiac disease	0.00
	Falls	0.00
	Stress fracture	0.00
Pulmonary embolism	Tachycardia	12.16
	Hypoxemia/hypoxia	10.98
	Shortness of breath	6.75
	Dyspnea	6.54
	Abnormal respiration	6.35
	Heart failure	4.51
	Chest pain	4.31
	Cough	1.48
	Other respiratory issue	1.34
	Deep vein thrombosis	0.00
	Respiratory distress	0.00
	Fever	0.00
	Heart burn	0.00
	Hemoptysis	0.00
Pneumonia	Hypoxemia/hypoxia	8.24
	Hemoptysis	7.57
	Lung cancer	7.53
	Fever	6.19
	Delirium	5.18
	Bronchitis	3.07
	Shortness of breath	2.99
	Cough	2.77
	Abnormal respiration	2.38
	Pain respiration	2.13
	Dyspnea	2.05
	Weakness/Fatigue	1.38
	Sinusitis	1.26
	Chest Pain	1.00
	Upper respiratory disease	0.71
	Otitis media	0.48
	Influenza	0.00
	Lower respiratory disease	0.00
	Viral illness	0.00

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Spinal cord compression	Abdominal pain	31.20
	Back pain	15.03
	Peripheral neuropathy	0.00
	Weakness/Fatigue	0.00
Stroke	Facial weakness	65.24
	Confusion	48.93
	Speech disturbance	19.60
	Transient ischemic attack	7.82
	Delirium	4.96
	Dizziness	3.20
	Lack coordination	2.92
	Gait instability	2.92
	Vomiting	2.15
	Weakness/Fatigue	1.54
	Headache	1.37
	Nausea	1.17
	Thunderclap headache	0.00
	Tension headache	0.00

[a]Outcomes include any hospitalization or emergency department visit for the diagnostic conditions within 90 days of the index visits including same day events

[b]Index visit diagnoses groups applied in the analysis include those with a relative risk greater than one. Relative risks were computed as the probability of an outcome if the index visit diagnosis group was recorded in the index visit divided by the probability of an outcome if the diagnosis group was not recorded.

Section 3. Psychometric Analysis of Whether Diagnosis Related Questions Reflect an Underlying Construct

To examine the degree to which treatment and diagnosis related questions represented an underlying construct, we calculated separate Cronbach's alpha indices to determine reliability of the subset of items for the 2010 IM-MOC examination for diagnosis related questions and treatment questions.[1] Overall, 170 of the questions were categorized as treatment or diagnostic related with 71 items classified as treatment and 99 items classified as diagnosis related questions. Overall, reliability for the diagnosis related questions was high, 0.84, suggesting that these questions hung together and were related to one underlying construct. The reliability for treatment related questions was also high, 0.75. This index, however, is partly a function of the number of items included in the calculation, where more items typically result in higher reliability. Consequently, it is not surprising that the diagnostic related questions have higher reliability given there were 28 more items than the treatment scale. To make these indices more equal, we computed the Spearman-Brown prophecy formula, which indicates expected reliability if the treatment scale was 99 items instead of 71. That formula resulted in a value of 0.81 for the treatment items which suggests that treatment related questions also measure one underlying construct.

Although performance on diagnosis and treatment related questions were correlated (Pearson Correlation=.62), 59.5% of the variation in diagnosis exam performance for the physician study sample was not explained by performance on other parts of the exam.

Section 4. Imputations for missing variables

Missing practice characteristics (1,432 or 2.94% of sample) were coded as “other unknown”.
Missing HCC (86 or .18% of sample) were replace by in sample mean HCC.
Missing rural indicator (22 or .05% of sample) were assumed to be non-rural
Missing ZIP code median income (708 or 1.46% of sample) were replace by in sample mean median income.

Section 5. Full Regression Coefficient Estimates and Explanatory Variables List

eTables 5.1 lists the probit coefficient associations with outcome measures across all explanatory variables as well as regression descriptive statistics. See Section 7 for percentage point associations with physician characteristics.

eTable 5.1. Probit Coefficient Associations and Regression Descriptive Statistics

	Death		Hospitalization		Emergency Department Visit	
	Wald chi2(102): 815.36		Wald chi2(102): 1197.54		Wald chi2(102): 1201.10	
	Log pseudolikelihood -1588.8		Log pseudolikelihood = -2456.7		Log pseudolikelihood = -2989.0	
Label	Difference per 1,000 (SE)	P	Difference per 1,000 (SE)	P	Difference per 1,000 (SE)	P
Diagnosis question percent correct						
Diagnosis tertile 1	Reference		Reference		Reference	
Diagnosis tertile 2	-1.6 (1.0)	0.09	-2.3 (1.4)	0.09	-3.1 (1.5)	0.04
Diagnosis tertile 3	-2.9 (1.1)	0.008	-4.1 (1.5)	0.006	-4.9 (1.7)	0.003
Treatment question percent correct						
Treatment tertile 1	Reference		Reference		Reference	
Treatment tertile 2	0.7 (0.8)	0.41	-0.7 (1.2)	0.54	-0.3 (1.4)	0.82
Treatment tertile 3	1.6 (1.0)	0.13	1.6 (1.5)	0.29	1.6 (1.7)	0.33
Other question percent correct						
Other tertile 1	Reference		Reference		Reference	
Other tertile 2	1.3 (0.8)	0.12	0.3 (1.2)	0.78	0.1 (1.3)	0.95
Other tertile 3	2.5 (1.0)	0.01	-0.8 (1.3)	0.52	0.5 (1.5)	0.72
Female Physician	-1.2 (0.7)	0.08	-0.8 (1.0)	0.43	-0.7 (1.2)	0.54
Physician birth and medical school						
US born: US medical schools	Reference		Reference		Reference	
US born: Int'l medical schools	1.2 (1.8)	0.51	-1.9 (2.8)	0.50	-0.7 (2.8)	0.79
Int'l born: US medical schools	0.4 (1.1)	0.71	3.1 (1.5)	0.05	2.6 (1.9)	0.18
Int'l born: Int'l medical schools	0.6 (0.8)	0.43	0.2 (1.1)	0.86	0.5 (1.3)	0.70
Practice Type						
Academic practice	Reference		Reference		Reference	
Other practice, unknown[a]	3.5 (2.4)	0.14	-3.9 (2.7)	0.15	-3.9 (3.2)	0.22
Solo physician practice	-0.2 (1.8)	0.93	-5.0 (2.4)	0.04	-5.3 (2.7)	0.05
Small group practice (2 to 10)	-1.0 (1.7)	0.55	-5.6 (2.2)	0.01	-5.7 (2.5)	0.02
Medium physicians group practice (11 to 50)	1.7 (1.9)	0.37	-1.3 (2.4)	0.58	-3.3 (2.8)	0.25
Large physician group practice (>50 physicians)	-2.4 (1.8)	0.20	-1.4 (2.7)	0.62	-2.3 (3.1)	0.46
Female Beneficiaries	-3.6 (1.2)	0.002	-5.1 (1.5)	0.001	-6.2 (1.7)	<.001
Beneficiary Race						
White	Reference		Reference		Reference	
Black	0.5 (1.3)	0.73	4.9 (2.0)	0.01	3.6 (2.1)	0.09
Other	-3.1 (1.1)	0.004	-4.2 (1.5)	0.005	-5.5 (1.7)	0.001
Hierarchical Condition Category (HCC) score[b]	1.7 (0.4)	<.001	1.2 (0.5)	0.03	1.9 (0.6)	0.003
Medicaid Dual Eligible	0.1 (1.2)	0.91	2.3 (1.6)	0.16	1.9 (1.8)	0.27
Beneficiary age	0.7 (0.1)	<.001	0.4 (0.1)	<.001	0.5 (0.1)	<.001
Rural county residence[c]	-1.3 (0.9)	0.15	-1.3 (1.3)	0.31	0.5 (1.6)	0.76
Household medium income[d],	-3.1E-05 (1.6E-05)	0.05	8.7E-06 (2.2E-05)	0.69	-3.1E-06 (2.5E-05)	0.90
CCW chronic conditions						
Alzheimer's Disease and Related Disorders or Senile Dementia	1.7 (1.2)	0.18	3.0 (1.8)	0.09	3.7 (2.0)	0.07
Alzheimer's Disease	2.6 (1.7)	0.14	2.8 (2.5)	0.26	1.8 (2.6)	0.50
Acute Myocardial Infarction	2.7 (1.8)	0.14	2.3 (2.1)	0.27	2.5 (2.4)	0.29
Anemia	0.0 (0.8)	0.99	0.7 (1.1)	0.54	0.8 (1.2)	0.50

Asthma	-0.8 (1.1)	0.45	-0.2 (1.4)	0.88	0.1 (1.7)	0.95
Atrial Fibrillation	1.8 (1.1)	0.10	3.4 (1.5)	0.02	3.7 (1.7)	0.03
Breast Cancer	-2.0 (1.3)	0.13	-3.0 (1.8)	0.10	-2.0 (2.2)	0.35
Colorectal Cancer	-0.5 (1.7)	0.76	-3.4 (2.0)	0.10	-1.9 (2.5)	0.44
Endometrial Cancer	1.6 (4.2)	0.71	-1.1 (4.7)	0.82	-0.9 (5.5)	0.87
Lung Cancer	3.7 (3.4)	0.28	13.3 (6.2)	0.03	10.3 (6.2)	0.10
Prostate Cancer	-1.6 (1.4)	0.26	4.3 (2.5)	0.09	3.6 (2.8)	0.20
Cataract	-1.0 (0.9)	0.29	1.1 (1.0)	0.31	0.1 (1.2)	0.96
Heart Failure	1.8 (1.0)	0.08	2.9 (1.2)	0.02	3.3 (1.4)	0.02
Chronic Kidney Disease	-0.7 (0.8)	0.39	2.9 (1.2)	0.02	4.2 (1.4)	0.004
Chronic Obstructive Pulmonary Disease	1.1 (0.9)	0.26	1.3 (1.2)	0.27	0.9 (1.3)	0.50
Depression	0.2 (0.9)	0.79	0.9 (1.1)	0.43	0.7 (1.2)	0.59
Diabetes	0.0 (0.8)	0.99	3.3 (1.1)	0.003	2.4 (1.2)	0.04
Glaucoma	-0.9 (0.8)	0.29	0.0 (1.1)	1.00	-0.3 (1.2)	0.80
Hip/Pelvic Fracture	1.4 (1.6)	0.39	3.0 (2.4)	0.20	5.0 (2.8)	0.07
Hyperlipidemia	-1.8 (1.1)	0.09	-1.1 (1.3)	0.39	-0.7 (1.4)	0.63
Benign Prostatic Hyperplasia	-0.3 (1.1)	0.79	0.0 (1.5)	0.98	-0.8 (1.7)	0.63
Hypertension	0.8 (1.1)	0.46	2.4 (1.4)	0.09	1.2 (1.6)	0.44
Hypothyroidism	0.7 (0.8)	0.42	1.4 (1.1)	0.19	1.8 (1.2)	0.14
Ischemic Heart Disease	0.8 (0.9)	0.39	0.1 (1.1)	0.92	-1.3 (1.2)	0.29
Osteoporosis	-1.9 (0.8)	0.02	2.0 (1.2)	0.09	1.4 (1.3)	0.28
Rheumatoid Arthritis	-2.3 (0.8)	0.005	-0.2 (1.0)	0.87	0.3 (1.1)	0.81
Stroke	2.7 (1.1)	0.02	2.7 (1.3)	0.04	2.8 (1.5)	0.06
Visit with same doctor in last year	-0.9 (1.1)	0.40	-1.3 (1.4)	0.34	-2.3 (1.5)	0.13
Visit with any physician in last year	-8.4 (3.5)	0.02	-3.5 (3.2)	0.28	-2.5 (3.3)	0.44
Hospitalization in prior year	8.8 (5.4)	0.10	0.9 (4.1)	0.84	0.4 (4.5)	0.93
ED visit in prior year	1.0 (2.5)	0.69	7.3 (4.0)	0.07	8.4 (4.6)	0.07
Days since last visit with any physician (per 30 d)	0.3 (0.2)	0.11	0.0 (0.3)	0.94	0.1 (0.3)	0.64
Days since last hospitalization (per 30 d)	-0.6 (0.4)	0.13	0.2 (0.5)	0.72	0.3 (0.5)	0.55
Days since last ED visits (per 30 d)	-0.2 (0.3)	0.60	-0.5 (0.4)	0.21	-0.7 (0.4)	0.13
Index visit diagnosis group indicators						
Pulmonary embolism	-0.5 (1.3)	0.68	6.1 (1.4)	<.001	7.1 (1.6)	<.001
Acute coronary syndrome	-1.3 (1.1)	0.25	-3.0 (1.8)	0.11	-5.5 (2.0)	0.007
Stroke	-2.3 (1.4)	0.10	7.4 (1.5)	<.001	7.7 (1.7)	<.001
Congestive heart failure	0.2 (1.3)	0.88	10.1 (1.6)	<.001	12.1 (1.7)	<.001
Fracture	-1.3 (1.1)	0.22	3.2 (1.3)	0.02	5.1 (1.5)	<.001
Abscess	0.7 (2.3)	0.77	6.4 (3.3)	0.05	11.7 (3.3)	<.001
Pneumonia	2.3 (1.2)	0.05	5.6 (1.4)	<.001	6.7 (1.6)	<.001
Aortic aneurysm	1.0 (1.4)	0.50	-0.6 (2.0)	0.76	0.7 (2.2)	0.74
Appendicitis	2.0 (1.8)	0.28	5.9 (3.0)	0.05	9.6 (3.1)	0.002
Depression	0.0 (1.3)	0.99	3.0 (1.5)	0.05	2.4 (1.7)	0.15
Anemia	2.3 (1.1)	0.04	3.5 (1.8)	0.04	3.2 (2.0)	0.11
Bacteremia	0.5 (2.5)	0.85	-9.5 (3.0)	0.001	-8.3 (3.1)	0.008
Spinal cord compression	-0.5 (1.8)	0.79	-2.8 (2.8)	0.32	-7.0 (3.1)	0.02
Mental health visit	1.4 (1.2)	0.22	-0.9 (1.5)	0.53	0.1 (1.8)	0.97
HHS Region						
HHS Region 1	Reference		Reference		Reference	
HHS Region 2	1.6 (1.7)	0.35	-5.2 (2.2)	0.02	-6.7 (2.7)	0.01
HHS Region 3	2.7 (1.8)	0.12	2.1 (2.5)	0.40	1.3 (3.0)	0.66
HHS Region 4	0.4 (1.5)	0.77	-2.7 (2.2)	0.22	-4.9 (2.6)	0.07
HHS Region 5	0.3 (1.4)	0.81	0.8 (2.1)	0.69	-1.0 (2.6)	0.70
HHS Region 6	-0.9 (1.5)	0.53	-2.8 (2.2)	0.21	-4.4 (2.8)	0.11
HHS Region 7	0.0 (2.2)	0.99	3.2 (3.2)	0.31	0.9 (3.5)	0.79
HHS Region 8	-1.6 (2.2)	0.47	1.9 (3.8)	0.62	-2.0 (3.8)	0.61
HHS Region 9	0.0 (1.6)	0.99	-0.6 (2.5)	0.81	-3.2 (2.8)	0.26
HHS Region 10	-0.6 (2.2)	0.77	4.4 (3.5)	0.21	4.0 (4.3)	0.35
Study Year						
2009	-3.1 (3.0)	0.30	-2.5 (4.3)	0.56	-1.9 (5.9)	0.75

2010	-1.9 (2.9)	0.52	-2.1 (3.6)	0.55	-1.7 (5.2)	0.75
2011	1.1 (2.3)	0.63	1.4 (2.7)	0.60	-2.3 (4.2)	0.58
2012	Reference		Reference		Reference	
Yearly Quarter						
Q1	Reference		Reference		Reference	
Q2	-0.6 (0.9)	0.50	0.7 (1.2)	0.54	0.4 (1.4)	0.78
Q3	-0.7 (0.9)	0.43	-0.1 (1.2)	0.94	-0.8 (1.3)	0.55
Q4	0.6 (1.1)	0.55	1.9 (1.4)	0.18	1.2 (1.5)	0.42
Test Forms						
May 2008: A	3.7 (3.6)	0.30	-6.4 (4.2)	0.13	-5.5 (5.0)	0.27
May 2008: B	2.3 (4.3)	0.60	-4.1 (4.9)	0.41	-3.6 (6.1)	0.56
Nov. 2008: A	1.1 (3.1)	0.72	0.7 (4.2)	0.87	-2.7 (5.4)	0.62
Nov. 2008: B	Reference		Reference		Reference	
May 2009: A	5.1 (3.7)	0.16	3.6 (3.9)	0.36	-2.2 (5.0)	0.66
May 2009: B	0.2 (5.0)	0.96	-0.1 (5.0)	0.98	-6.0 (6.0)	0.31
Nov 2009: A	1.5 (3.1)	0.64	2.7 (3.4)	0.43	-1.5 (4.9)	0.75
Nov 2009: B	6.7 (3.9)	0.08	8.2 (3.9)	0.04	5.2 (5.2)	0.32
Nov 2009: C	Reference		Reference		Reference	
May 2010: A	0.9 (2.4)	0.69	-0.8 (2.6)	0.75	-4.6 (4.1)	0.26
May 2010: B	1.7 (2.4)	0.48	-0.2 (2.7)	0.94	-3.6 (4.3)	0.41
Nov. 2010: A	1.3 (2.4)	0.59	-1.2 (2.5)	0.63	-4.8 (4.1)	0.24
Nov. 2010: B	1.4 (2.3)	0.55	-0.5 (2.6)	0.85	-3.6 (4.1)	0.38
Nov. 2010: C	Reference		Reference		Reference	
May 2011: A	3.3 (3.2)	0.30	1.5 (3.7)	0.69	-1.3 (5.2)	0.80
May 2011: B	1.9 (3.4)	0.59	-1.4 (4.0)	0.74	-5.8 (5.3)	0.27
Nov. 2011: A	-1.8 (3.2)	0.57	-3.6 (4.5)	0.42	-3.2 (7.2)	0.65
Nov. 2011: B	0.2 (2.7)	0.94	-4.6 (3.7)	0.21	-8.0 (5.3)	0.13
Nov. 2011: C	Reference		Reference		Reference	

Note:

[a]Missing practice characteristics (1,432 or 2.94% of sample) were coded as "other unknown".

[b]Missing HCC (86 or .18% of sample) were replace by in sample mean HCC.

[c]Missing rural indicator (22 or .05% of sample) were assumed to be non-rural

[b]Missing ZIP code median income (708 or 1.46% of sample) were replace by in sample mean median income.

Section 6. Regression Sensitivity Analyses

In this section we describe the results of falsification and robustness sensitivities. Falsification sensitivities examine associations with diagnostic knowledge under scenarios where we expect the underlying associations to be weaker than in the base case. Robustness sensitivities examine the degree to which base case associations with diagnostic knowledge were robust to assumptions regarding index visit diagnoses eligibility, outcome variable construction, and regression control variables.

Falsification sensitivities

Results of falsification sensitivities are exhibited in eTable 6.1. These sensitivities include applying the index visit sample that did not meet any diagnoses eligibility criteria and applying elective hospitalizations as an outcome measure. Presumably diagnostic knowledge would not impact outcomes with the diagnostic error sensitive conditions after index visits where related diagnoses codes for these conditions were not present. That is, either because the underlying condition was not present or not detectable at the time of the index visit and therefore was not preventable. However, outcomes after these index visits could be associated with omitted variables that were both correlated with our outcome measures and exam performance. For example, it could be that physicians with low diagnostic knowledge also have less healthy patients in ways we do not control for and therefore would be more likely to experience adverse events more generally. We also assume that elective hospitalizations would be related to the overall propensity to hospitalize but would not be related to underlying diagnostic skill.

Overall the results of falsification sensitivities support the validity of our base case finding. For example, although the overall risk of each adverse outcome was comparable to the base case, all associations with diagnostic knowledge were very small in absolute terms and none were statistically significant (P>0.05). For example, applying for the sample of index visits without eligible diagnoses codes, scoring in the top versus bottom tertile of diagnostic knowledge was associated with a 0.0 (95% CI -1.3 to 1.3, p=0.99) difference in the risk of death within 90 days of the index visit or under one tenth of the statistically significant 2.9 (95% CI: -5.0 to -0.7, p=0.008) fewer death per 1,000 observed in the base case. Yet, the mean risk of death in the base case and this sensitivity was comparable (0.7% in the base case versus 0.4% in this sensitivity). This sensitivity also addressed another limitation of our study, that we did not have a direct measure of cause of death since if the associations we found were driven by reductions in death due to the 13 diagnostic error prone conditions applied in our study we would expect that the associations with death and diagnostic exam performance would be much smaller when estimated using the index sample without eligible diagnoses codes for these conditions. Similarly we found that the associations between diagnostic knowledge and risk of an elective hospitalization were statistically insignificant, top compared to bottom tertile association P was 0.63, and was wrong signed.

Robustness sensitivities

Results of robustness sensitivities are exhibited in eTables 6.2.1 (for death), 6.2.2 (hospitalization) to 6.2.3 (for emergency department visit).

For the first sensitivity we expanding the eligible diagnoses code groups to all 76 identified by physician authors versus 38 in the base case that also met the relative risk criteria.

For the third sensitivity we expand the index visit clean period to 97 days and contracted the index visit clean period to 83 days.

For the fourth sensitivity, we excluded physician in academic medical centers to consider the possibility that the unobserved physician characteristics related to where they worked or who they worked with could be were independently both related to the underlying physician diagnostic skill and our outcome measures.

For the fifth sensitivity we accounted for the possibility that adverse outcomes were avoided because the patient died by altering the ED and hospitalization measures to include all-cause mortality. For this sensitivity we added the following two outcome measures: base case hospitalization or death and base case ED or death.

Overall results of robustness sensitivity analysis suggests that our base case results were not highly sensitive to different underlying assumptions related to these factors (e.g., across all robustness sensitivities percent change in the outcome measures between top versus bottom diagnostic knowledge exam performers remained statistically significant ($P<0.05$)).

Table 6.1. Results of Falsification Sensitivity Analyses for All Adverse Outcomes

Adverse outcome measure / Sensitivity	Number of index visits	Regression adjusted outcomes per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Death										
Base	48,632	5.2 (4.1 to 6.3)	6.5 (5.4 to 7.6)	8.1 (6.5 to 9.7)	-35.3 (-52.8 to -11.2)	-2.9 (-5.0 to -0.7)	0.008	-20.2 (-38.3 to 3.2)	-1.6 (-3.6 to 0.3)	0.09
Falsification sensitivity										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	3.9 (3.0 to 4.7)	4.3 (3.5 to 5.0)	3.9 (3.1 to 4.7)	0.2 (-27.9 to 39.4)	0.0 (-1.3 to 1.3)	0.99	10.1 (-17.2 to 46.5)	0.4 (-0.8 to 1.5)	0.51
Hospitalization										
Base	48,632	9.2 (7.7 to 10.8)	11.0 (9.4 to 12.6)	13.3 (11.2 to 15.4)	-30.5 (-46.1 to -10.4)	-4.1 (-6.9 to -1.2)	0.006	-17.1 (-33.2 to 3.0)	-2.3 (-4.9 to 0.4)	0.09
Falsification sensitivities										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	13.8 (12.0 to 15.5)	13.1 (11.8 to 14.4)	14.0 (12.5 to 15.5)	-1.5 (-18.2 to 18.6)	-0.2 (-2.8 to 2.4)	0.87	-6.0 (-19.1 to 9.1)	-0.8 (-2.9 to 1.2)	0.42
Elective hospitalization	48,264	9.6 (7.7 to 11.5)	9.0 (7.6 to 10.3)	8.9 (7.4 to 10.5)	7.6 (-19.6 to 43.9)	0.7 (-2.0 to 3.4)	0.63	0.4 (-20.1 to 26.3)	0.0 (-2.0 to 2.1)	0.97
Emergency Department Visit										
Base	48,632	11.5 (9.8 to 13.2)	13.2 (11.5 to 15.0)	16.4 (14.0 to 18.7)	-29.8 (-44.4 to -11.4)	-4.9 (-8.1 to -1.6)	0.003	-19.0 (-33.8 to -1.0)	-3.1 (-6.1 to -0.1)	0.04
Falsification sensitivity										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	18.0 (16.0 to 20.0)	17.7 (16.1 to 19.2)	18.7 (17.0 to 20.4)	-3.8 (-17.8 to 12.6)	-0.7 (-3.6 to 2.2)	0.63	-5.5 (-16.9 to 7.3)	-1.0 (-3.4 to 1.3)	0.38

Table 6.2.1. Results of Robustness Sensitivity Analyses for the Death Adverse Outcome

	Number of index visits	Regression adjusted deaths per 1,000 index visits (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	**48,632**	**5.2 (4.1 to 6.3)**	**6.5 (5.4 to 7.6)**	**8.1 (6.5 to 9.7)**	**-35.3 (-52.8 to -11.2)**	**-2.9 (-5.0 to -0.7)**	**0.008**	**-20.2 (-38.3 to 3.2)**	**-1.6 (-3.6 to 0.3)**	**0.09**
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,749	4.9 (3.9 to 5.9)	5.7 (4.8 to 6.7)	7.0 (5.7 to 8.4)	-30.2 (-48.9 to -4.5)	-2.1 (-4.0 to -0.3)	0.03	-18.4 (-36.7 to 5.2)	-1.3 (-2.9 to 0.4)	0.13
97 day index visit clean period	40,417	7.5 (5.8 to 9.1)	6.8 (5.6 to 8.1)	4.9 (3.8 to 6.0)	-34.7 (-53.9 to -7.6)	-2.6 (-4.8 to -0.4)	0.02	-8.5 (-31.0 to 21.2)	-0.6 (-2.7 to 1.4)	0.54
83 day index visit clean period	54,169	5.5 (4.4 to 6.6)	6.8 (5.7 to 7.8)	8.4 (6.8 to 10.0)	-34.7 (-51.7 to -11.7)	-2.9 (-5.0 to -0.8)	0.007	-19.5 (-37.0 to 3.0)	-1.6 (-3.6 to 0.3)	0.09
Small practices (visits with physicians with practices of 10 or less physicians)	29,242	4.5 (3.2 to 5.9)	5.9 (4.6 to 7.2)	8.2 (6.3 to 10.2)	-44.9 (-63.6 to -16.7)	-3.7 (-6.3 to -1.1)	.0047	-28.6 (-48.9 to .1)	-2.4 (-4.8 to 0.1)	.058
Large (>50 physicians)/academic medical center practices:	6,308[a]	6.4 (3.6 to 9.1)	6.4 (3.4 to 9.4)	5.7 (2.1 to 9.2)	12.9 (-50.8 to 159.0)	0.7 (-4.2 to 5.6)	.7714	13.3 (-43.0 to -125.1)	0.8 (-3.3 to 4.8)	0.72
Not counting next day death as an adverse outcome	48,632	5.2 (4.1 to 6.3)	6.4 (5.3 to 7.5)	8.1 (6.5 to 9.7)	-35.7 (-53.1 to -11.8)	-2.9 (-5.0 to -0.8)	.000729	-21.0 (-38.9 to 2.1)	-1.7 (-3.6 to 0.2)	.081

[a] 1,791 observations excluded due to lack of variation in outcomes within control test administrations or other controls

Table 6.2.2. Results of robustness sensitivity analyses for the hospitalization adverse outcome

	Number of index visits	Regression adjusted risk of emergency department hospitalization per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	**48,632**	**9.2 (7.7 to 10.8)**	**11.0 (9.4 to 12.6)**	**13.3 (11.2 to 15.4)**	**-30.5 (-46.1 to -10.4)**	**-4.1 (-6.9 to -1.2)**	**0.006**	**-17.1 (-33.2 to 3.0)**	**-2.3 (-4.9 to 0.4)**	**0.09**
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,749	11.3 (9.6 to 13.0)	9.7 (8.3 to 11.0)	8.3 (6.9 to 9.7)	-26.6 (-43.0 to -5.4)	-3.0 (-5.5 to -0.5)	0.02	-14.6 (-31.0 to 5.6)	-1.7 (-3.9 to 0.6)	0.15
97 day index visit clean period	40,417	8.3 (6.7 to 9.9)	10.4 (8.7 to 12.1)	13.4 (11.0 to 15.9)	-38.4 (-54.2 to -17.3)	-5.2 (-8.4 to -1.9)	0.002	-22.8 (-39.6 to -1.3)	-3.1 (-6.0 to -0.1)	0.04
83 day index visit clean period	54,169	9.3 (7.8 to 10.8)	11.2 (9.7 to 12.8)	13.2 (11.2 to 15.3)	-29.7 (-45.3 to -9.7)	-3.9 (-6.8 to -1.1)	0.007	-15.1 (-31.2 to 4.8)	-2.0 (-4.6 to 0.6)	0.13
Hospitalization visit or death (hospitalization base case measure or death base case measure)	48,632	13.7 (11.9 to 15.4)	16.4 (14.5 to 18.2)	19.8 (17.4 to 22.2)	-30.9 (-43.3 to -15.8)	-6.1 (-9.4 to -2.8)	<.001	-17.4 (-30.5 to -1.9)	-3.4 (-6.6 to -0.3)	0.03
Shortening the outcome period from 90 day to 14 days	48,632	2.0 (1.3 to 2.7)	3.2 (2.4 to 4.1)	3.3 (2.4 to 4.3)	-40.3 (-63.3 to -3.0)	-1.4 (-2.6 to -0.1)	0.04	-3.7 (-35.2 to 43.2)	-0.1 (-1.4 to 1.2)	0.85
Small practices (visits with physicians with practices of 10 or less physicians)	29,242	7.8 (5.8 to 9.8)	12.1 (10.0 to 14.2)	11.8 (9.5 to 14.0)	-33.4 (-53.0 to -5.6)	-3.9 (-7.2 to -0.6)	0.02	-18.8 (-39.3 to 8.5)	-2.2 (-5.3 to 0.9)	0.16
Large (>50 physicians)/academic medical center practices:	7,966a	10.4 (7.3 to 13.5)	12.0 (7.8 to 16.2)	22.5 (13.5 to 31.5)	-53.7 (-73.2 to -20.2)	-12.1 (-22.2 to -2.0)	0.02	-46.7 (-68.0 to -8.7)	-10.5 (-20.5 to -0.5)	0.04
Not counting next day hospitalizations as an adverse outcome	48,632	8.7 (7.2 to 10.2)	9.9 (8.4 to 11.5)	12.5 (10.4 to 14.5)	-30.0 (-46.1 to -9.0)	-3.7 (-6.5 to -0.9)	0.0087	-20.2 (36.3 to 0.0)	-2.5 (-5.1 to 0)	.054604

[a] 133 observations excluded due to lack of variation in outcomes within control test administrations or other controls

Table 6.2.3. Results of robustness sensitivity analyses for the emergency department visit adverse outcome

	Number of index visits	Regression adjusted risk of emergency department visit per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	**48,632**	**11.5 (9.8 to 13.2)**	**13.2 (11.5 to 15.0)**	**16.4 (14.0 to 18.7)**	**-29.8 (-44.4 to -11.4)**	**-4.9 (-8.1 to -1.6)**	**0.003**	**-19.0 (-33.8 to -1.0)**	**-3.1 (-6.1 to -0.1)**	**0.04**
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,740	10.4 (8.8 to 12.0)	11.7 (10.2 to 13.2)	13.9 (12.0 to 15.8)	-25.2 (-40.5 to -6.0)	-3.5 (-6.3 to -0.7)	0.01	-16.3 (-31.1 to 1.7)	-2.3 (-4.8 to 0.2)	0.08
97 day index visit clean period	40,417	10.5 (8.7 to 12.3)	12.6 (10.7 to 14.5)	16.7 (13.9 to 19.5)	-37.2 (-51.9 to -18.0)	-6.2 (-9.9 to -2.5)	<.001	-24.5 (-39.9 to -5.3)	-4.1 (-7.5 to -0.7)	0.02
83 day index visit clean period	54,169	11.6 (9.9 to 13.2)	13.4 (11.7 to 15.1)	16.4 (14.1 to 18.8)	-29.5 (-43.8 to -11.6)	-4.8 (-8.0 to -1.7)	0.003	-18.4 (-32.6 to -1.1)	-3.0 (-5.9 to -0.1)	0.04
Emergency department visit or death (hospitalization base case measure or death base case measure)	48,632	15.7 (13.7 to 17.7)	18.5 (16.5 to 20.5)	22.6 (20.0 to 25.2)	-30.6 (-42.6 to -16.0)	-6.9 (-10.6 to -3.3)	<.001	-18.0 (-30.4 to -3.4)	-4.1 (-7.5 to -0.7)	0.02
Shortening the outcome period from 90 day to 14 days	48,632	2.7 (1.9 to 3.4)	3.7 (2.8 to 4.7)	4.0 (2.9 to 5.1)	-34.4 (-57.8 to 2.1)	-1.4 (-2.9 to 0.1)	0.07	-7.5 (-36.2 to 34.2)	-0.3 (-1.8 to 1.1)	0.68
Small practices (visits with physicians with practices of 10 or less physicians)	29,242	10.3 (8.0 to 12.5)	12.1 (10.0 to 14.2)	14.7 (12.3 to 17.1)	-30.1 (-48.2 to -5.8)	-4.4 (-8.0 to -0.8)	.016	-17.7 (-36.2 to 6.3)	-2.6 (-6.0 to 0.8)	.138
Large (>50 physicians)/academic medical center practices:	7,966a	13.3 (9.3 to 17.2)	12.6 (8.4 to 16.8)	24.2 (15.2 to 33.2)	-45.3 (-67.8 to -6.9)	-11.0 (-21.7 to -0.3)	0.045	-48.1 (-68.3 to -14.8)	-11.6 (-21.5 to -1.8)	0.021
Not counting next day emergency department visits as an adverse outcome	48,632	10.6 (9.0 to 12.3)	12.0 (10.3 to 13.7)	15.0 (23.7 to 17.3)	-29.2 (44.2 to 10.2)	-4.4 (-7.5 to -1.3)	.0055	-20.1 (35.2 to 1.3)	-3.0 (-5.9 to -0.1)	.040

[a] **133 observations excluded due to lack of variation in outcomes within control test administrations or other controls**

References

1. Bandalos DL. *Measurement theory and applications for the social sciences*: Guilford Publications; 2018.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract [Done]
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found [See abstract starting on line 25]
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported [See Introduction section of the Manuscript first paragraph]
Objectives	3	State specific objectives, including any prespecified hypotheses [See last paragraph of first paragraph Introduction Section]
Methods		
Study design	4	Present key elements of study design early in the paper [See Methodology section]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection [See Physician and Index Visit sample subsections, (starting on line 122)]
Participants	6	(*a*) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants [See Methodology section and Figure 1 for physician, patient and visit sample stats)]
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed [NA] *Case-control study*—For matched studies, give matching criteria and the number of controls per case [NA]
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable [See Outcome Measures subsection of Mythology section starting on line 166 for Outcomes, starting on line 188 for diagnostic measure.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group [See line 188 for diagnostic knowledge measure]
Bias	9	Describe any efforts to address potential sources of bias [See Statistical Methodes starting on line 208 first paragraph explanation for inclusion of other measures of knowledge and Sensitivity Analysis subsection start on line 237 and results of sensitivity analysis starting on line 308]
Study size	10	Explain how the study size was arrived at [See first and second paragraph page 6]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why [See Statistical Methods section]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding [See Statistical Methods first paragraph]
		(*b*) Describe any methods used to examine subgroups and interactions [NA]
		(*c*) Explain how missing data were addressed [See section 4 in the Supplement and reference to this in Table 3]
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed

	Case-control study—If applicable, explain how matching of cases and controls was addressed [NA] *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy [Sensitivity Analysis subsection starting on line 238]
(*e*) Describe any sensitivity analyses [Sensitivity Analysis subsection starting on line 238]	

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed [See Figure 1 and first paragraph of the Results section]
		(b) Give reasons for non-participation at each stage [See Figure 1, Table 1 and first paragraph of the Results section]
		(c) Consider use of a flow diagram [See Figure 1]
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders [See Results section paragraph 2 and Table 2]
		(b) Indicate number of participants with missing data for each variable of interest [NA]
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) [NA]
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time [NA]
		Case-control study—Report numbers in each exposure category, or summary measures of exposure [NA]
		Cross-sectional study—Report numbers of outcome events or summary measures [See Table 1]
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included [See Table 3 and Supplementary Material for full set of controls and coefficients (Section 6)
		(*b*) Report category boundaries when continuous variables were categorized [See Statistical Analysis Section and Supplementary Material Section 4]
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period [See Results section and Table 3]
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses [See Sensitivity Analysis subsection of Results section and Supplementary Material Section 5]
Discussion		
Key results	18	Summarise key results with reference to study objectives [See Discussion subsection last paragraph of page 14]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias [See several paragraphs in the Discussion section starting on line 363 to 420]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence [No other study has addressed our research question, however, in terms of methodology we compare our study to other in the Discussion section starting on line 341]
Generalisability	21	Discuss the generalisability (external validity) of the study results [See study limitation bullet points after the abstract, lines 357 to 412 of the Discussion Section]
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based [See Funding section last paragraph]

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The Association Between Primary Care Physician Diagnostic Knowledge and Death, Hospitalization and Emergency Department Visits Following an Outpatient Visit at Risk for Diagnostic Error: A Retrospective Cohort Study Using Medicare Claims

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The Association Between Primary Care Physician Diagnostic Knowledge and Death, Hospitalization and Emergency Department Visits Following an Outpatient Visit at Risk for Diagnostic Error: A Retrospective Cohort Study Using Medicare Claims

Bradley M. Gray, PhD, corresponding author

Email: bgray@abim.org, Phone: 202-213 6646, FAX 202-213 6646

American Board of Internal Medicine

510 Walnut Street, Suite 1700, Philadelphia, Pennsylvania 19106, USA

Jonathan L. Vandergrift, MS

American Board of Internal Medicine Philadelphia, Pennsylvania, USA

Rozalina, G. McCoy, MD

Mayo Clinic, Rochester, Minnesota, USA

Rebecca S. Lipner, PhD

American Board of Internal Medicine Philadelphia, Pennsylvania, USA

Bruce E. Landon, MD

Harvard Medical School, Boston, Massachusetts, USA

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Objective

Diagnostic error is a key health care concern and can result in substantial morbidity and mortality. Yet no study has investigated the relationship between adverse outcomes resulting from diagnostic errors and one potentially large contributor to these errors: deficiencies in diagnostic knowledge. Our objective was to measure that associations between diagnostic knowledge and adverse outcomes after visits to primary care physicians that were at risk for diagnostic errors.

Setting/Participants

1,410 US general internists who recently took their American Board of Internal Medicine Maintenance of Certification (ABIM-IM-MOC) exam treating 42,407 Medicare beneficiaries who experienced 48,632 "index" outpatient visits for new complaints at risk for diagnostic error because the presenting complaint (e.g., dizziness) was related to pre-specified diagnostic error sensitive conditions (e.g. stroke).

Outcome measures

90-day risk of all-cause death, and, for outcome conditions related to the index visits diagnosis, emergency department (ED) visits and hospitalizations.

Design

Using retrospective cohort study design, we related physician performance on ABIM-IM-MOC diagnostic exam questions to patient outcomes during the 90 day period following an "index" visit at risk for diagnostic error after controlling for practice characteristics, patient sociodemographic and baseline clinical characteristics.

Results

Rates of 90-day adverse outcomes per 1,000 index visits were 7 for death, 11 for hospitalizations, and 14 for ED visits. Being seen by a physician in the top versus bottom third of diagnostic knowledge during an index visit for a new complaint at risk for diagnostic error was associated with 2.9 fewer all-cause deaths (95% confidence interval (CI) -5.0 to -0.7, P=.008), 4.1 fewer hospitalizations (95% CI -6.9 to -1.2, P=0.006), and 4.9 fewer ED visits (95% CI -8.1% to -1.6%, P=0.003) per 1,000 visits.

Conclusion

Higher diagnostic knowledge was associated with lower risk of adverse outcomes after visits for complaints at heightened risk for diagnostic error.

Strengths and limitations of this study

- Unique diagnostic knowledge measure linking diagnostic knowledge with adverse outcomes
- Scalable adverse outcome measures and extensive sensitivity analyses
- Our assessment of diagnostic error is indirect (as indicated by adverse outcomes)
- Results are subject to selection bias if the mix of index visits or the severity of the patients or practice support differed for physicians with different levels of diagnostic knowledge.
- Results are only generalizable to physicians who elected to attempt ABIM's certification exam and were about 10 years past initial certification and patients older than 65.

Introduction

Diagnostic error has been identified as a key health care delivery concern and contributes to significant potentially preventable morbidity and mortality.(1-3) Ambulatory care, and especially primary care, is a practice setting with a particularly high risk for diagnostic error(4, 5) because of the wide variety of presentations encountered and the concomitant difficulty of distinguishing harmful conditions from routine self-limited complaints, compounded by the well-known time constraints faced by practitioners in that setting. It has been estimated that at least 5% of ambulatory visits are associated with diagnostic error, half of which may result in considerable patient harm. Diagnostic error is a common cause of malpractice suits and most frequently occurs in the ambulatory care settings.(6, 7)

Deficiencies in diagnostic knowledge are likely to be an important contributor to these diagnostic errors that could impact, for example, the breadth of diagnoses considered, appropriate ordering and interpretation of tests, and/or synthesis of data more generally.(8-11) Because of this, measuring physician diagnostic knowledge has become a major focus of organizations throughout the developed world that are tasked with licensing and certifying physicians with the underlying, although largely untested, hypothesis being that diagnostic knowledge will be a measurable and strong predictor of diagnostic error.(12-15) Testing this hypothesis and quantifying this relationship is therefore a critical public policy concern both in terms of the importance of board certification and other programs designed to enhance lifelong learning for physicians.

In the US, the American Board of Internal Medicine (ABIM) is a leading organization that certifies primary care physicians, most notably general internists. In fact, most general internists in the US are certified by the ABIM and these physicians represent about 45% of all adult primary care physicians in the US.(16) Unlike medical licensure, board certification is not a legal requirement to practice medicine in the US, though many hospitals require board certification as one criterion to obtain privileges and insurers often require board certification to be included in covered physician panels.(17, 18) To maintain their certification, general internists must pass an initial certifying exam and, periodically, pass a recertification exam thereafter (referred to as Maintenance of Certification (MOC) exams).(19, 20) Diagnostic knowledge is a major component of these exams representing about half of all exam questions for the Internal Medicine MOC (IM-MOC) exam.

One explanation for the lack of research on this topic is the difficulty in studying the relationship between general diagnostic knowledge and diagnostic error because of the inability to quantify diagnostic knowledge and identifying diagnostic errors at a population level, especially in the outpatient setting.(21) We address this gap in the literature by applying a unique measure of diagnostic knowledge, performance on diagnostic related questions on ABIM's IM-MOC exam, and relating this measure to deaths, hospitalizations, and emergency department visits that occurred after outpatient visits for new complaints at heightened risk for diagnostic error.

Methods

Physician and Index Visit Sample

Our physician sample included general internists who were initially ABIM board certified in 2000 and took their IM-MOC exam between 2008 and 2011 (Figure 1). We identified Medicare beneficiary outpatient Evaluation & Management (E&M) visits with these physicians using their National Provider Identifier (NPI) during the calendar year following their exam (2009 to 2012). These patients were age 65 or older and continuously enrolled in Medicare fee-for-service (Medicare insures most of the US population over 65) during the physician's one year follow-up period and the year prior. To ensure that any presenting complaints being evaluated were new (i.e., not follow up), we restricted these visits to those that were the first visit for a new complaint (the "*index visit*") because these visits were preceded by a 90-day clean period with no previous inpatient or outpatient visit. The 90-day clean period is consistent with the US government Centers for Medicare and Medicaid Services criteria used by its Bundled Payments for Care Improvement Program for defining new episodes of care and with the patterns of visits we observed (see Appendix Section 1 for related analysis).(22, 23)

We further restricted these index visits to those at heightened risk for diagnostic errors because the recorded diagnosis in the Medicare claims (the "*index visit diagnosis"*), which includes recording of symptom (e.g. loss of balance), could have been the initial presenting complaint for one or more of 13 pre-specified diagnostic error sensitive conditions such as congestive heart failure or bacteremia/sepsis (see Table 1). These 13 conditions (see Appendix Section 2 for a list

and applicable ICD-9 codes) were an acute non-cancerous subset of 20 conditions previously noted by Schiff et al. to be at high risk for serious diagnostic error.(24) For instance, index visits with diagnosis codes for chest pain, dyspepsia, shortness of breath, hypoxemia/hypoxia, respiratory distress, weakness/fatigue, edema or ascites could all be the initial presentation of congestive heart failure, which is one of the 13 diagnostic error sensitive conditions.

We used a three-step process to identify eligible index visit diagnoses. First, two physician authors (RGM and BEL) identified all diagnoses that could be presenting complaints for the 13 diagnostic error sensitive conditions: what complaints/diagnoses might someone who ultimately presented with a diagnostic-error sensitive condition have presented with initially? Second, because the original list of identified index visit diagnoses was large (76), we reduced this list to 38 by applying a relative risk (RR) criteria. For a specific index visit diagnosis to meet this criteria, all index visits with that diagnosis had to have a greater portion of later ED visits or hospitalizations with the related outcome condition discharge diagnosis than index visits where the specific at risk diagnosis was not present. For example, dizziness was chosen as an eligible index visit diagnosis for stroke, one of the diagnostic error sensitive conditions, both because it was identified as a potential presenting symptom of a stroke by physician authors and because index visits with that diagnosis had a greater proportion of later hospitalization or ED visits for stroke than visits without this diagnosis. Third, we also included index visits where the actual diagnosis was one of the 13 diagnostic error sensitive conditions because we wanted to include cases where diagnostic errors were and were not made. Therefore, we also included index visits with a diagnosis of congestive heart failure itself as being at risk for the underlying condition congestive heart failure.

Outcome Measures

We examined the risk of three serious adverse outcomes within 90 days of the index visit that we hypothesized would occur more frequently in cases of misdiagnosis: all-cause mortality, hospitalizations, and ED visits. We did not count these events as adverse outcomes if they occurred on the same day as the index visit because this may reflect a positive action (the physician correctly diagnosed a patient with stroke and referred/admitted them to the hospital) or be unavoidable regardless of the accuracy of the index visit diagnosis (the patient died despite immediately admitting the patient to the hospital who exhibited stroke symptoms). Based on Medicare billing codes, hospitalizations were limited to non-elective hospitalizations initiated through the ED or trauma center. The ED and hospitalization outcomes were also limited to cases where the discharge diagnosis was for one of the 13 diagnostic error sensitive conditions following an index visit with the applicable diagnosis. We therefore presumed that these discharge diagnoses were a reasonable representation of the underlying condition of the patient at the time of the index visit. For example, we would count a hospitalization with a discharge diagnosis of stroke as an adverse outcome if it occurred after an index visit for dizziness because dizziness was identified as being a potential presenting complaint for stroke. However, we did not count hospitalizations with a discharge diagnosis for acute coronary syndrome following an index visit for dizziness because dizziness was not identified as a presenting complaint for acute coronary syndrome. The rationale is that if there were no presenting complaints during the index visit related to coronary syndrome, either because the underlying condition was not present or could not be detected at the time of the index visit, then the index visit physician could not have prevented the hospitalization regardless of their diagnostic knowledge.

Measure of Diagnostic Knowledge

Our measure of diagnostic knowledge was calculated as the percent of correct answers on the IM-MOC exam for questions previously coded as "diagnosis-related" by ABIM's IM-MOC exam committee. In our study, these questions comprised 53% of all IM-MOC exam questions, with the remaining 42% addressing treatment and 5% related to other topics such as epidemiology or pathophysiology. More generally, exam questions are designed to replicate real world clinical scenarios and/or patient encounters and without reliance on rote memorization.(25, 26)

The ABIM exam committee coded each question based on the primary function tested to assure that the exam covers care typically rendered by outpatient primary care physicians. Questions coded as "diagnosis related" typically test knowledge and skills related to diagnostic inference, differential diagnosis, and diagnostic testing and therefore are measuring diagnostic knowledge and related decision-making. Psychometric analysis indicates that scores on diagnosis related exam questions were meaningfully correlated (i.e., Cronbach's alpha score of 0.84), and thereby represent an independent underlying construct that could be interpreted as diagnostic knowledge (see Appendix Section 3 for more details).(27) Similarly, this analysis indicated that questions coded as treatment related also represent an independent underlying construct (i.e., Cronbach's alpha score of 0.75). Although performance on diagnosis and treatment related questions were correlated (Pearson Correlation=0.62), 59.5% of the variation in diagnosis exam performance for the physician study sample was not explained by performance on other parts of the exam.

Statistical methods

Using Probit regression we estimated the associations with each adverse outcome, with standard errors adjusted for correlations resulting from the nesting of visits within patients within physicians.(28, 29) To measure associations with diagnostic knowledge we included categorical regression explanatory variables for top and middle third of percent correct scores on diagnosis related questions (bottom third was the reference category). Other exam level explanatory variables included tertile indicators for performance on treatment-related questions and performance on other question types. Since these variables measure knowledge unrelated to diagnosis, they account for correlations between factors such as unmeasured practice or patient characteristics that might be correlated with exam performance and our outcome measures (e.g., high scoring physicians may be more likely to practice in an academic setting or other such settings that might be independently related to diagnostic error). Exam form indicators accounted for differences in exam difficulty across exam administrations.

We also included physician, patient and visit level regression controls. Physician level controls included: practice size (indicators for solo practice and practices larger than 50 physicians), practice type (indicators for academic, group), demographic (gender), and training characteristics (medical school location interacted with country of birth). Patient level controls included: demographic characteristics (age and age squared, gender and race/ethnicity indicators) and a Medicaid eligibility indicator. Lagged patient risk adjusters included 27 indicators for chronic conditions and Medicare's Hierarchal Condition Category (HCC) risk adjustment score. We imputed values for a small number of missing values for controls (see Appendix Section 4). Patient index visit location level controls included: an indicator for residing in a rural ZIP code, ZIP code median household income, and indicators for 10 US Health and Human Services

regions. Index visit level controls included: indicators of any outpatient visit, hospitalization or ED visits within the prior year and number of days since the most recent of these events, visit year indicators to control for secular changes in quality. We also included an indicator for whether or not the patient had a previous contact with the index visit physician during the year prior to the index visit to account for differences in physician-patient continuity (see Appendix Section 5 for a full list of controls).

Sensitivity Analysis

We performed numerous sensitivity analyses to test the robustness of our results (detailed in Appendix Section 6). First, we expanded the index visit sample to include all index visits with the original 76 diagnoses identified by the physician authors regardless of whether they met the relative risk criteria. Second, we expanded and contracted the index visit clean period by seven days. Third, excluded hospitalizations or ED events occurring the day after the index visit, in addition to same day events, to consider the possibility that they might be triggered by a correct diagnosis and therefore should not have been considered adverse outcomes. Fourth, we considered the possibility that our results were biased due to omitted variables correlated with practice size. For example, it could be that physicians in large practices have greater access to specialists or other physicians for informal consultations than those is small practices and therefore outcomes for these physicians may be less sensitive to their knowledge. To examine this possibility, we estimated associations with knowledge and our two utilization measures across a sample of physicians in either small (<=10 physicians, 54.5% (768/1,410) of physicians) or large practices (>50 or in academic medical centers, 23.7% (334/1,410) of physicians). We did not conduct these sensitivities for death because there were too few deaths in the subgroups to allow us to reliably estimate the associations (e.g., 39 deaths for physicians in large

practices).Fifth, to consider the possibility that these outcomes were only avoided because the patient died, for the ED and hospitalization outcome, we also included instances where the patient died. Sixth, as a falsification test we limited the index visits to those that were unrelated to the 13 diagnostic error sensitive conditions. Under this sensitivity, we expected then that the associations with diagnostic knowledge would decline. The index visit physician's diagnostic knowledge cannot impact a future adverse outcome if the underlying condition that caused that outcome was not present or detectible at the time of index visit. Therefore, this reduction in association should be especially true for the hospitalization and ED measures where adverse outcomes were limited to the 13 diagnostic error conditions and so were unrelated to the index visit diagnoses in this sensitivity. Similarly, for the last sensitivity, we applied elective hospitalizations as an outcome measure to consider the possibility that there could be a correlation between the overall propensity to hospitalize in an area and physician knowledge.

The Advarra Institutional Review Board approved our study protocol and all analyses were performed using Stata version 15 (College Station, TX).

Patient and Public Involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Results

Of 2,492 general internists who initially certified in 2000 and who took an IM-MOC exam between 2009 and 2012, 1,722 had outpatient visits with a fee-for-service Medicare beneficiary during the study period. Those without visits generally practiced hospital medicine. Of these, 1,410 were included in the study because they had at least one outpatient index visit that met our study inclusion criteria during the year after they took their IM-MOC exam. In total, 48,632 index visits with 42,407 patients treated by 1,410 physicians met study inclusion criteria (Figure 1). Table 1 lists frequency of index visits and subsequent outcomes for each diagnostic error sensitivity condition.

The mean percent correct on diagnosis questions ranged from 84.3% among top third performers to 65.5% among bottom third performers (Table 2). Patient and visit characteristics were similar across tertiles of physician diagnostic knowledge. For example, there were no statistically significant differences in the HCC risk adjuster across tertiles (P=.19) However, there were differences in some physician and practice characteristics. When compared to physicians in the bottom tertile of diagnostic knowledge, physicians in the top were significantly less likely to be in solo practice (12.8% versus 24.4%, P=0.009), and more likely to be in academic practice (9.7% versus 3.4%, P<.001). However, the proportion graduating from a US medical school was similar across diagnostic knowledge tertiles (70.0% versus 63.3%, P=.30).

Associations between diagnostic knowledge and patient adverse outcomes

The overall rates of 90-day adverse outcomes per 1,000 index visits was 6.5 for death, 11.1 for hospitalizations, and 13.6 for ED visits (with the latter two directly associated with one of the diagnostic error sensitive conditions whose antecedent was present in the applicable index visit).

Being seen by a physician scoring in the top versus bottom third of diagnostic knowledge on the MOC exam was associated with 2.9 fewer deaths per 1,000 visits (95% confidence interval (CI) -5.0 to -0.7, P=.008) which reflects a 35.3% lower risk of death (95% CI -52.8 to -11.2, P=.008), (Table 3). Our finding also suggests that this difference in exam performance was associated with 4.1 fewer applicable hospitalizations (95% CI -6.9 to -1.2, P=0.006), and 4.9 fewer applicable ED visits (95% CI -8.1 to -1.6, P=0.003) per 1,000 visits (Table). These reductions correspond with about a 30% lower risk for these utilization measures (hospitalizations: -30.5%, 95% CI -46.1 to -10.4, P=.003, ED: -29.8%, 95% CI -44.4 to -11.4).

We also found a significant dose response relationship across all three regression adjusted relative risk measures (P-trends <0.008). For example, the regression-adjusted 90-day risk of death per 1,000 patients whose index visit physician scored in the top third of diagnostic knowledge was 5.2 (95% CI 4.1 to 6.3), compared to 6.5 (95% CI 5.4 to 7.6) for the middle third, and 8.1 (95% CI 6.5 to 9.7) for the bottom third (P-trend 0.008).

Sensitivity Analyses

Our sensitivity analyses (Appendix Section 6) confirmed that base case associations with diagnostic knowledge were robust to different index visit clean periods, and diagnosis code inclusion criteria and next day coding of outcome measures. Associations with diagnostic knowledge were also fairly robust to physician's practice size for both the ED and hospitalization measures when we limited the sample to either small or large or academic practices.

Suggesting that our results were not influenced by omitted variable bias, we found that associations with diagnostic knowledge and our outcome measures became small and statistically insignificant when we limited the sample to index visits with diagnoses unrelated to any of the 13 diagnostic sensitive error conditions, and so were at lower risk for diagnostic error (P>0.50 and associations were at most about a tenth of the base case percent difference between top and bottom third of diagnostic knowledge). We also found no significant association between lack of diagnostic knowledge and elective hospitalizations (P=0.63).

Discussion

We found that higher diagnostic knowledge among US outpatient internal medicine physicians was associated with significant reductions in subsequent adverse outcomes whose cause was at risk for diagnostic error. Indeed, for every 1,000 index visits for a new complaint at risk for diagnostic error, being seen by a physician in the top versus bottom third of diagnostic knowledge was associated with 2.9 fewer all-cause death and, for diagnostic error sensitive conditions, 4.1 fewer hospitalizations and 4.9 fewer ED visits within 90 days. These figures correspond to a reduction in risk for these adverse events by about a third. Although some prior studies have demonstrated the high morbidity and mortality of diagnostic error(1-3), this is the first study to demonstrate and quantify the direct association between serious adverse outcomes and the diagnostic knowledge of their first contact primary care physician. These finding support the notion that gaps in diagnostic knowledge between physicians may be an important contributor to the diagnostic error problem plaguing the healthcare system worldwide.

We measured the association between diagnostic knowledge and potential diagnostic error by using Medicare claims data to identify patients who presented for outpatient visits with complaints at heightened risk for serious diagnostic errors and examining the occurrence of clinically relevant adverse outcomes soon thereafter. Although this approach lacks the precision of individual chart audits(7), it is both clinically plausible and scalable in that it can be used to monitor the care of large numbers of patients, making the method itself an important contribution to the literature on diagnostic error. Although we did not directly measure diagnostic errors through chart audits, the fact that we found associations with diagnostic knowledge and the diagnostic error sensitive outcome conditions we studied coupled with the fact that we did not find associations with treatment knowledge, nor did we find associations when the underlying diagnostic error sensitive condition was likely not present during the outpatient index visit because no antecedent diagnoses recorded indicates that the associations we report in this study were likely driven by association with diagnostic errors that occurred during these visits. Furthermore, our approach builds on prior studies that used claims data to infer diagnostic error incidence for ED visits, in that we identified index visit diagnoses at risk for diagnostic error that were clinically plausible and verified empirically, and we assured that we were studying new problems by requiring that the patient had not had an ED, hospital or outpatient visit over the previous 3 months.(30-32) We expanded on these studies by focusing on outpatient care and by examining a much more comprehensive set of presenting complaints that may have been precursors to one of 13 diagnostic error prone conditions that we studied. This approach was necessary in order to study diagnostic error in the more low acuity setting of outpatient general internal medicine.

Our findings suggest an association between diagnostic knowledge and adverse outcomes. Yet, there are important limitations to consider. We did not directly determine whether a diagnostic error had occurred through such validated means as a chart review. Our findings cannot be interpreted as causal given the cross-sectional nature of our study so we cannot rule out the possibility that observed associations were the result of omitted variable bias related to either physician or patient characteristics, and do not reflect a causal relationship between diagnostic knowledge and adverse outcomes. That said, there is no reason to believe that these characteristics would be correlated with diagnostic knowledge independent of treatment knowledge which we were able to control for as both these knowledge measures should be similarly correlated with unobserved factors such as ability of consulting colleagues. Furthermore, had associations with diagnostic knowledge been driven by omitted variable bias then we would have expected them to be similar when estimated across index visits with lower or higher risk for diagnostic error, and they were not. We also found that diagnosis exam performance was not associated with elective hospitalizations, which are, presumably, unrelated to underlying diagnostic knowledge but may be related to the overall propensity to hospitalize. That said, the fact that practice size was found to be correlated with diagnostic exam performance is concerning. For example, as described above, practice size could be correlated with access to specialists that in turn might be related to our outcome measures. However, sensitive analyses indicate that associations with knowledge and our utilization adverse outcome measures were fairly similar across physicians practice size/type (small, and large or academic). An additional limitation is that we studied select conditions among older patients enrolled in the Medicare program so we cannot extrapolate these findings to a younger population, other

conditions we did not consider, or populations with no or different health insurance coverage. Our findings might also not be applicable to older physicians who certified before 2000 or younger physicians who certified after 2000 as well as physicians who choose not to attempt an exam. While a physician's clinical knowledge might be related to their decision to not take the MOC exam therefore not maintaining their certification, other factors certainly play a role in this decision.

Another limitation of our study is that the IM-MOC exam was specifically designed to measure clinical knowledge in general, it was not designed to measure diagnostic knowledge specifically. That said, diagnostic knowledge is a major component of the exam and was found to meet the criteria for measuring this underlying construct. Also diagnostic error may have stemmed from factors outside of inadequate diagnostic knowledge, which are not covered by the exam but could be correlated with our exam based diagnostic knowledge measure (e.g., poor patient/physician communication skills and related system failures).(33, 34) That said, there is no reason to believe that these other contributors to diagnostic error would not also be correlated with the other aspects of the exam we do account for. Furthermore, based on an analysis of malpractice claims, Newman-Toker et al. (6) reported that clinical judgement played an important role in 86% of diagnostic errors, while poor patient/physician communication and system failures played a role in far fewer diagnostic errors that resulted in malpractice suits (35% and 22% respectively). Suggesting that improving communication will not reduce stroke related diagnostic error, Kerber et al. (35) reported that frontline providers rarely ask the right questions when patients present with dizziness. Communication ability is only valuable in terms of reducing diagnostic error if the physician knows what questions to ask and what the answers

mean. Although we cannot say with certainty that our finding are driven by an underlying association between diagnostic knowledge and diagnostic errors, at a minimum, our finding suggest that patients treated by physicians who scored well on diagnostic exam questions may be at lower risk for the adverse outcomes we studied. Finally, some might assert that a standardized exam without access to medical reference material might be more a reflection of a physician's rote memory and ability to recall medical facts than a test of their clinical knowledge and judgement. Although this is a fundamental limitation of our study, it should be noted that the exam is designed to mimic decision making in real life situations including such things as patient's laboratory results and reference material impeded in the exam and past research indicates that an "open" book format that allows physicians access to reference material did not materially impact exam performance.(36) It should also be noted that the necessary rapidity of decision making by primary care physicians who have limited time per encounter might fairly be represented by an exam with time constraints.

In this exploratory analysis, we found evidence that diagnostic knowledge of primary care physicians seeing a patient for an index visit for a complaint that is at heightened risk of diagnostic error is associated with adverse outcomes. The fact that there exists a link between general diagnostic knowledge and diagnostic error may not be surprising, the magnitude of the associations we found suggests that interventions ignoring the role of physician knowledge may be inadequate to address the crisis of diagnostic error. Interventions targeted at improving diagnostic knowledge could include such things as a greater focus on diagnostic training during graduate medical education (i.e., medical school, residency, and fellowship). Knowledge-focused interventions could also include incentivizing broad-based learning as well as targeted learning

pursued through continuing medical education (CME) activities.(30) During visits identified as being at risk for diagnostic errors, physicians could be given related information at the point of care including suggestions for specialty consultation.

Our results are important for two additional reasons. First, these results provide evidence that board certification and maintenance of certification, which involves lifelong learning directed at maintaining medical knowledge, might, in fact, be a valid approach to assuring the delivery of high quality care. Many in the US complain about the time and expense of MOC and often point to the lack of rigorous assessment between aspects of MOC and outcomes of interest to patients. These findings suggest that processes such as MOC may translate into meaningful improvements in outcomes because they can provide incentives for meaningful learning. This learning also could be enhanced through exam feedback targeted at diagnostic knowledge. Second, the findings also suggest that interventions aimed at improving diagnostic skills, whether knowledge-based or through, for instance, delivery of relevant information at the point of care [this is in response to system changes] might be approaches that might be worthwhile if the findings of this study are validated with additional research. Yet more research is needed to better understand the link between diagnostic knowledge and diagnostic errors that are identified through chart review or other methods of direct ascertainment and the extent to which such errors result in adverse clinical outcomes.

In conclusion, gaps in diagnostic knowledge among first contact primary care physicians is associated with serious diagnostic error sensitive outcomes. If this finding is confirmed in future studies, diagnostic knowledge should be a target for interventions to reduce diagnostic errors.

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Statements

A. Contribution statement: Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon met the ICMJE guidelines authorship criteria:

   a. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon substantially contributed to the conception and design of the work.

   b. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner contributed to the acquisition of the data.

   c. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon substantially contributed to analysis or interpretation of data.

   d. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon substantially contributed to the drafting the work and revising it critically for important intellectual content.

   e. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon gave final approval of the version published.

   f. Bradley Gray, Jonathan Vandergrift, Rebecca Lipner, Rozalina McCoy, and Bruce Landon agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved.

B. Competing Interests: Bradley Gray, Jonathan Vandergrift, and Rebecca Lipner are paid employees of the American Board of Internal Medicine. Bruce Landon is a paid consultants for the American Board of Internal Medicine.

C. Funding Statement: This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

D. Data Sharing: Administrative data describing physician characteristics and exam performance can be obtained from the ABIM through a data sharing agreement that assures physician confidentiality and its use for legitimate research purposes. Access to de-identified Medicare claims data for this study were obtained through a special data use agreement with the Centers for Medicare and Medicaid services which is a process available to researchers in the US.

E. Dissemination to participants and related patient and public communities: As study data were pseudonymised, it is not possible to send findings directly to the study participants. ABIM's communication department in collaboration with the authors of this study will write a press release whose goal is to inform the public regarding the findings of the study.

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Table 1. Frequency of Index Visits Related to each Diagnostic Error Sensitive Condition

Thirteen diagnostic error sensitive conditions	Index visits with a diagnosis code related to a diagnostic error sensitive condition (percentages can add to greater than 100% because of antecedent index visit diagnoses related to more than one diagnostic error sensitive condition)	Hospitalization[a,b]	Emergency department visit[a]	Death[c]
	Number (percent of index visits)	Number (percent of hospitalizations with a diagnostic error sensitive condition)	Number (percent of emergency department visits with a diagnostic error sensitive condition)	Number (percent of deaths)
	48,632 (100.0)	541 (100)	663 (100)	316 (100)
Acute Coronary Syndrome	16,228 (33.4)	48 (8.9)	56 (8.4)	103 (32.6)
Fracture	13,409 (27.6)	60 (11.1)	100 (15.1)	60 (19.0)
Depression	12,637 (26.0)	Not Reported[d]	Not Reported[d]	121 (38.3)
Anemia	12,410 (25.5)	54 (10.0)	59 (8.9)	110 (34.8)
Pneumonia	12,183 (25.1)	91 (16.8)	107 (16.1)	107 (33.9)
Congestive Heart Failure	12,137 (25.0)	227 (42.0)	254 (38.3)	120 (38.0)
Aortic Aneurysm	11,491 (23.6)	17 (3.1)	23 (3.5)	79 (25.0)
Stroke	10,026 (20.6)	69 (12.8)	82 (12.4)	71 (22.5)
Pulmonary Embolism	8,534 (17.5)	12 (2.2)	13 (2.0)	89 (28.2)
Spinal Cord Compression	6,386 (13.1)	Not Reported[d]	Not Reported[d]	36 (11.4)
Bacteremia / Sepsis	5,567 (11.4)	19 (3.5)	21 (3.2)	46 (14.6)
Appendicitis	2,584 (5.3)	Not Reported[d]	Not Reported[d]	17 (5.4)
Abscess	1,005 (2.1)	Not Reported[d]	13 (2.0)	Not Reported[d]

[a]Condition specific outcomes for one of the 13 diagnostic error sensitive conditions within 90 days of an outpatient index visit at risk for that condition

[b]Hospitalizations include non-elective hospitalizations either initiated through the ED or a trauma center.

[c]All cause mortality within 90 days of the index visit.

[d]Not reported because observations were less than 11.

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	Total	Diagnosis question percent correct			P-value[a]
		Top (78.5 to 95.8)	Middle (71.4 to 78.4)	Bottom (42.9 to 71.3)	
Exam performance, Mean (standard deviation) [a]					
Diagnosis question percent correct	74.5 (0.4)	84.3 (0.3)	74.8 (0.1)	65.5 (0.3)	<.001
Other question percent correct	72.6 (0.7)	80.2 (1.0)	72.1 (1.1)	66.4 (1.5)	<.001
Treatment question percent correct	77.3 (0.3)	83.4 (0.4)	77.2 (0.4)	72.0 (0.5)	<.001
Physician Characteristics, count (%)					
Female Physician	19,428 (39.9)	6,546 (43.8)	6,357 (37.5)	6,525 (39.0)	0.37
US born physician	28,462 (58.5)	9,284 (62.1)	9,932 (58.6)	9,246 (55.3)	0.37
US medical school	31,960 (65.7)	10,471 (70.0)	10,900 (64.3)	10,589 (63.3)	0.30
Practice Type					
Solo physician practice	9,452 (19.4)	1,914 (12.8)	3,462 (20.4)	4,076 (24.4)	0.009
Small group practice (2 to 10)	20,563 (42.3)	5,543 (37.1)	7,529 (44.4)	7,491 (44.8)	0.19
Medium physicians group practice (11 to 50)	7,442 (15.3)	2,899 (19.4)	2,402 (14.2)	2,141 (12.8)	0.25
Large physician group practice (>50 physicians)	5,391 (11.1)	2,150 (14.4)	1,655 (9.8)	1,586 (9.5)	0.14
Academic practice	2,708 (5.6)	1,447 (9.7)	697 (4.1)	564 (3.4)	<.001
Other practice	3,076 (6.3)	1,005 (6.7)	1,211 (7.1)	860 (5.1)	0.59
Beneficiary characteristics					
Beneficiary Race, count (percent)					
White	40,086 (82.4)	12,652 (84.6)	13,778 (81.3)	13,656 (81.7)	0.13
Black	3,958 (8.1)	926 (6.2)	1,609 (9.5)	1,423 (8.5)	0.03
Other	4,588 (9.4)	1,380 (9.2)	1,569 (9.3)	1,639 (9.8)	0.88
Beneficiary age (per year), Mean (SD) [a]	76.6 (0.1)	76.8 (0.1)	76.5 (0.1)	76.6 (0.1)	0.23
CCW chronic conditions, count (percent)					
Alzheimer's Disease and Related Disorders or Senile Dementia	5,151 (10.6)	1,497 (10.0)	1,793 (10.6)	1,861 (11.1)	0.16
Alzheimer's Disease	2,061 (4.2)	627 (4.2)	704 (4.2)	730 (4.4)	0.82
Acute Myocardial Infarction	1,408 (2.9)	394 (2.6)	494 (2.9)	520 (3.1)	0.13
Anemia	22,450 (46.2)	6,706 (44.8)	7,766 (45.8)	7,978 (47.7)	0.11
Asthma	4,424 (9.1)	1,313 (8.8)	1,548 (9.1)	1,563 (9.3)	0.39
Atrial Fibrillation	4,225 (8.7)	1,265 (8.5)	1,478 (8.7)	1,482 (8.9)	0.69
Breast Cancer	2,485 (5.1)	779 (5.2)	831 (4.9)	875 (5.2)	0.48
Colorectal Cancer	1,139 (2.3)	357 (2.4)	406 (2.4)	376 (2.2)	0.68
Endometrial Cancer	352 (0.7)	113 (0.8)	109 (0.6)	130 (0.8)	0.39
Lung Cancer	435 (0.9)	151 (1.0)	152 (0.9)	132 (0.8)	0.19
Prostate Cancer	1,662 (3.4)	507 (3.4)	600 (3.5)	555 (3.3)	0.66
Cataract	31,095 (63.9)	9,601 (64.2)	10,773 (63.5)	10,721 (64.1)	0.74
Heart Failure	9,207 (18.9)	2,786 (18.6)	3,155 (18.6)	3,266 (19.5)	0.54
Chronic Kidney Disease	6,904 (14.2)	2,083 (13.9)	2,392 (14.1)	2,429 (14.5)	0.62
Chronic Obstructive Pulmonary Disease	9,108 (18.7)	2,635 (17.6)	3,165 (18.7)	3,308 (19.8)	0.02
Depression	12,042 (24.8)	3,728 (24.9)	4,145 (24.4)	4,169 (24.9)	0.83
Diabetes	13,296 (27.3)	3,947 (26.4)	4,590 (27.1)	4,759 (28.5)	0.16
Glaucoma	10,030 (20.6)	3,086 (20.6)	3,501 (20.6)	3,443 (20.6)	0.99
Hip/Pelvic Fracture	1,531 (3.1)	430 (2.9)	535 (3.2)	566 (3.4)	0.15
Hyperlipidemia	37,132 (76.4)	11,266 (75.3)	12,898 (76.1)	12,968 (77.6)	0.11
Benign Prostatic Hyperplasia	5,815 (12.0)	1,792 (12.0)	1,987 (11.7)	2,036 (12.2)	0.76
Hypertension	37,607 (77.3)	11,345 (75.8)	13,011 (76.7)	13,251 (79.3)	<.001
Hypothyroidism	11,425 (23.5)	3,490 (23.3)	3,862 (22.8)	4,073 (24.4)	0.25

Ischemic Heart Disease	18,713 (38.5)	5,616 (37.5)	6,393 (37.7)	6,704 (40.1)	0.06
Osteoporosis	14,171 (29.1)	4,372 (29.2)	4,794 (28.3)	5,005 (29.9)	0.34
Rheumatoid Arthritis	23,352 (48.0)	6,879 (46.0)	8,275 (48.8)	8,198 (49.0)	0.02
Stroke	6,255 (12.9)	1,880 (12.6)	2,212 (13.0)	2,163 (12.9)	0.70
Number of chronic conditions, count (percent)					
<=4	5,066 (10.4)	1,459 (9.8)	1,744 (10.3)	1,863 (11.1)	0.08
5 to 7	16,861 (34.7)	5,392 (36.0)	5,981 (35.3)	5,488 (32.8)	0.006
8 to 10	16,230 (33.4)	4,907 (32.8)	5,664 (33.4)	5,659 (33.8)	0.35
>=11	10,475 (21.5)	3,200 (21.4)	3,567 (21.0)	3,708 (22.2)	0.28
Mental health visit, count (percent)	6,347 (13.1)	2,040 (13.6)	2,119 (12.5)	2,188 (13.1)	0.46
Hierarchical Condition Category (HCC) score, Mean (SD)[a]	0.98 (0.01)	0.96 (0.01)	0.98 (0.01)	0.99 (0.01)	0.19
Household medium income, mean $ (SD)[a]	59,852 (643)	61,574 (1,106)	59,113 (1,144)	59,063 (1,075)	0.19
Medicaid dual eligible, count (percent)	6,392 (13.1)	1,793 (12.0)	2,411 (14.2)	2,188 (13.1)	0.28
Rural county residence, count (percent)	7,392 (15.2)	2,207 (14.8)	2,866 (16.9)	2,319 (13.9)	0.64
Visit characteristics					
Visit with same doctor in last year, Count (percent)	37,726 (77.6)	11,369 (76.0)	13,154 (77.6)	13,203 (79.0)	0.08
Visit with any physician in last year, count (percent)	44,852 (92.2)	13,711 (91.7)	15,647 (92.3)	15,494 (92.7)	0.08
Days since last visit with any physician (if any visit in last year), Mean (SD)[a]	144.2 (0.6)	147.1 (0.8)	144.4 (1.0)	141.4 (1.3)	<.001
ED visit in prior year, count (percent)	8,101 (16.7)	2,428 (16.2)	2,879 (17.0)	2,794 (16.7)	0.43
Days since last ED visits (if ED visit in last year), Mean (SD)[a]	222.8 (0.9)	221.2 (1.5)	223.5 (1.5)	223.4 (1.5)	0.47
Hospitalization in prior year, Count (percent)	4,227 (8.7)	1,280 (8.6)	1,489 (8.8)	1,458 (8.7)	0.85
Days since last hospitalization (if hospitalization in last year), Mean (SD)[a]	229.6 (1.2)	229.1 (2.1)	229.7 (2.1)	230.1 (1.9)	0.95
Index visit diagnosis groups, Count (percent)					
Abscess	1,005 (2.1)	268 (1.8)	394 (2.3)	343 (2.1)	0.21
Anemia	12,410 (25.5)	3,817 (25.5)	4,369 (25.8)	4,224 (25.3)	0.93
Aortic aneurysm	11,491 (23.6)	3,495 (23.4)	4,165 (24.6)	3,831 (22.9)	0.18
Appendicitis	2,584 (5.3)	845 (5.6)	949 (5.6)	790 (4.7)	0.01
Bacteremia	5,567 (11.4)	1,660 (11.1)	1,929 (11.4)	1,978 (11.8)	0.83
Congestive heart failure	12,137 (25.0)	3,633 (24.3)	4,221 (24.9)	4,283 (25.6)	0.67
Acute coronary syndrome	16,228 (33.4)	4,627 (30.9)	5,740 (33.9)	5,861 (35.1)	0.02
Depression	12,637 (26.0)	3,932 (26.3)	4,312 (25.4)	4,393 (26.3)	0.78
Fracture	13,409 (27.6)	4,324 (28.9)	4,364 (25.7)	4,721 (28.2)	0.11
Pulmonary embolism	8,534 (17.5)	2,683 (17.9)	2,984 (17.6)	2,867 (17.1)	0.71
Pneumonia	12,183 (25.1)	3,773 (25.2)	4,224 (24.9)	4,186 (25.0)	0.97
Spinal cord compression	6,386 (13.1)	1,985 (13.3)	2,218 (13.1)	2,183 (13.1)	0.94
Stroke	10,026 (20.6)	3,003 (20.1)	3,542 (20.9)	3,481 (20.8)	0.79

[a]P-values and standard deviation accounted for correlated errors within physicians

Table 3. Associations with diagnostic knowledge and adverse events per 1,000 index visits

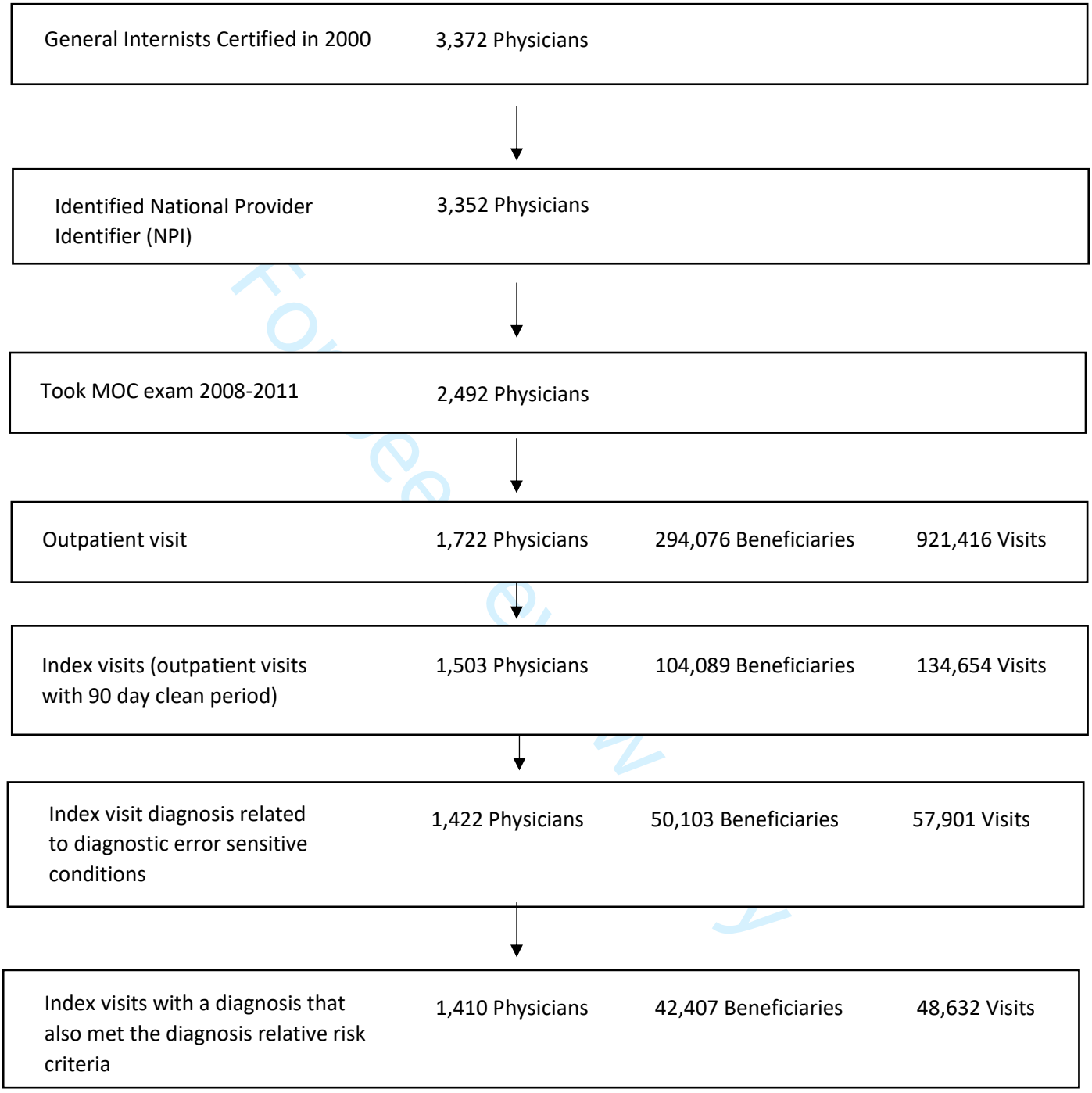
Diagnostic knowledge tertile	Death[a]				Emergency department visit[b]				Hospitalization[c]			
	Unadjusted[e]	Regression adjusted[d,e]			Unadjusted[e]	Regression adjusted[d,e]			Unadjusted[e]	Regression adjusted[d,e]		
	Events per 1,000 visits (95% CI interval)	Events per 1,000 visits (95% CI interval)	Difference (95% CI)	P-value	Events per 1,000 visits (95%CI)	Events per 1,000 visits (95%CI)	Difference (95% CI)	P-value	Events per 1,000 visits (95% CI)	Events per 1,000 visits (95% CI)	Difference (95% CI)	P-value
Top	6.2 (5.0 to 7.4)	5.2 (4.1 to 6.3)	-2.9 (-5.0 to -0.7)	0.008	13.0 (11.2 to 14.8)	11.5 (9.8 to 13.2)	-4.9 (-8.1 to -1.6)	0.003	10.4 (8.8 to 12.1)	9.2 (7.7 to 10.8)	-4.1 (-6.9 to -1.2)	0.006
Middle	6.6 (5.4 to 7.8)	6.5 (5.4 to 7.6)	-1.6 (-3.6 to 0.3)	0.09	13.0 (11.2 to 14.7)	13.2 (11.5 to 15.0)	-3.1 (-6.1 to -0.1)	0.04	10.8 (9.2 to 12.4)	11.0 (9.4 to 12.6)	-2.3 (-4.9 to 0.4)	0.09
Bottom	6.6 (5.5 to 7.8)	8.1 (6.5 to 9.7)	reference		14.9 (13.0 to 16.8)	16.4 (14.0 to 18.7)	reference		12.1 (10.4 to 13.8)	13.3 (11.2 to 15.4)	reference	

[a]All cause mortality within 90 days of an outpatient index visit with a diagnosis at risk for one of 3 diagnostic error sensitive conditions.
[b]Emergency department visit for one of the 13 diagnostic error sensitive conditions within 90 days of an outpatient index visit with a visit at risk for that condition.
[c]Hospitalizations were for non-elective hospitalizations either initiated through the ED or a trauma center with a discharge diagnosis for one of 13 diagnostic error sensitive conditions within 90 days of the index visit with a diagnosis at risk for that condition.

FIGURE LEGEND:

Figure 1. Sample Selection

Figure 1. Sample Selection



Appendix

The Association Between Primary Care Physician Diagnostic Knowledge and Death, Hospitalization and Emergency Department Visits Following an Outpatient Visit at Risk for Diagnostic Error: A Retrospective Cohort Study Using Medicare Claims

Bradley M. Gray, PhD, corresponding author
Email: bgray@abim.org 202-213 6646, FAX 202-213 6646
American Board of Internal Medicine
510 Walnut Street, Suite 1700, Philadelphia, Pennsylvania 19106, USA

Contents

Section 1: 90-day Index Visit Clean Period Derivation

Figure 1.1 displays the visit periodicity between each of the 921,416 visits to an internist in the sample and the most recent visit prior to that one.

To determine what the index visit clean period was we assumed that when two contacts happen "close" together they are more likely to be visits for the same acute episode of care. Therefore, if we exclude all but the first visit that happen "close" together then the remaining visits are highly likely to represent the first visit for a new episode of care (i.e., a new problem). However, the visit periodicity threshold that distinguishes visits that are "close" versus "not close" is unknown.

To help delineate this threshold, Figure 1.1 visit shows periodicity between each of the 921,416 visits to an internist in the sample and the most recent adjacent visit prior to that one. In Figure 1.1, you can see the slope of frequency curve is falling until about a 90 day gap between visits. This indicates that many of the visits prior to this point may be related to an existing episode of care. After 90 days, the periodicity slope begins to flatten out which indicates that the timing between visits is likely random and so it is less likely that the two visits are related to the same episode of care.

This flattening of the slope after 90 days is more clearly displayed in Figure 1.2 which displays the 15 day moving average of the change in visit counts per day (i.e., the changing slope). Here the slope stabilizes at about zero beginning around 90 days suggesting that a 90 day clean period for physician visits is likely to exclude most visits that are a follow-up to an ongoing episode of care from the index visit sample.

Figure 1.1. Visit Periodicity Plot for the 921,416 Outpatient Visits to Physicians in the Sample

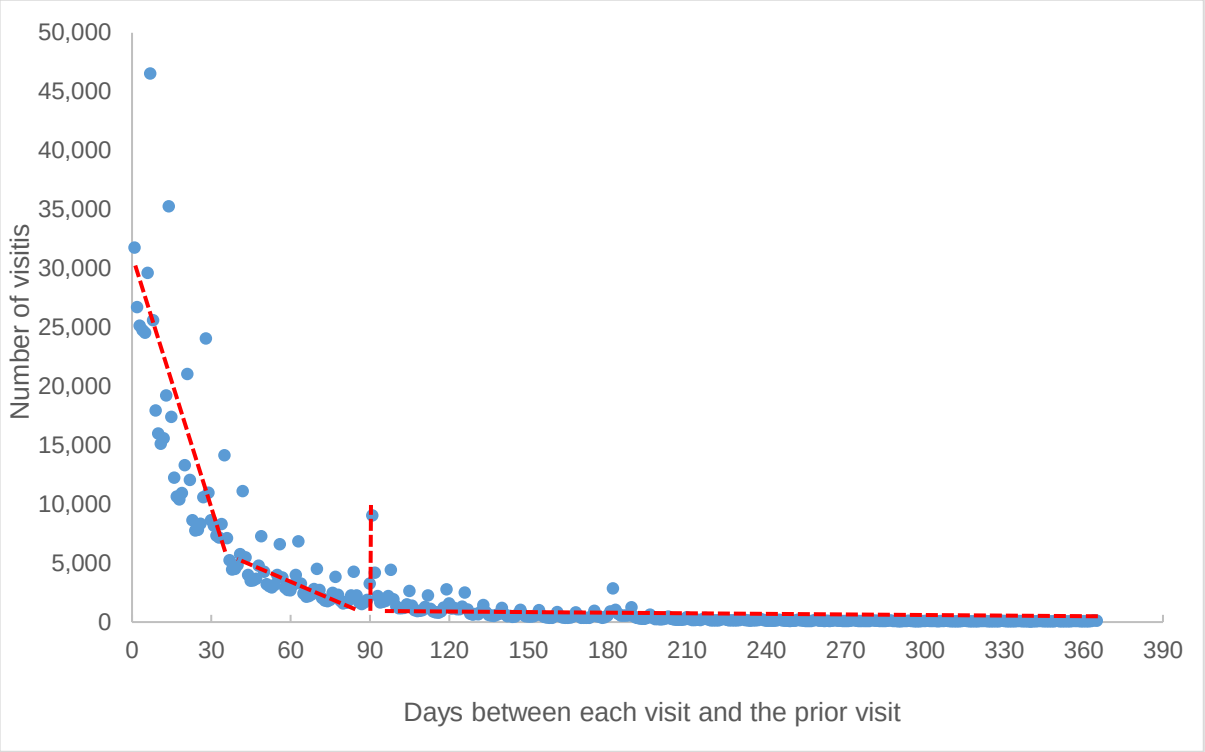
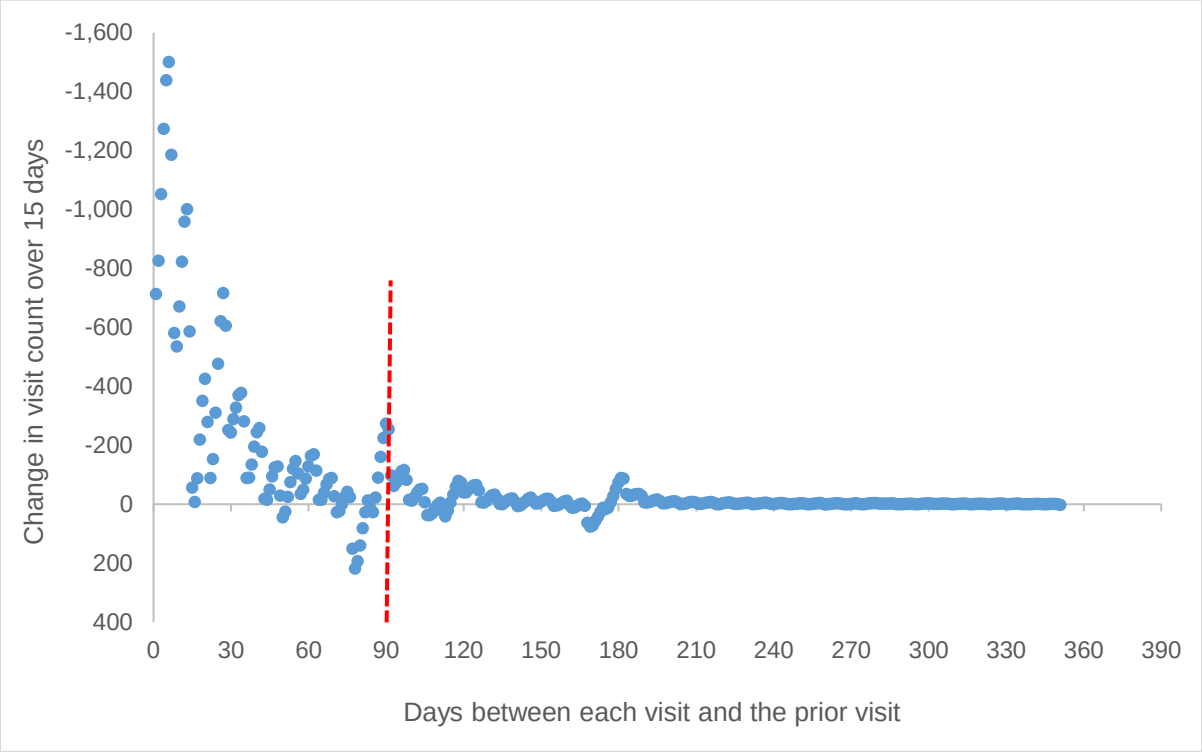


Figure 1.2. Average Change in Visit Count over the 15 days (15-day slope) Following each Data Point Listed in Figure 1



Section 2. ICD-9 Code Codes for Diagnostic Error sensitive Conditions and ICD-9 Code Groups for Index Visit Eligibility and Related Relative Risks

The Section includes a list the list of diagnostic error sensitive condition ICD-9 diagnoses (Table 2.1), index visit eligible ICD-9s diagnoses groups (Table 2.2), and relative risks for each index visit diagnosis group (Table 2.3).

eTable 2.1. ICD-9 Code Codes for Diagnostic Error Sensitive Conditions

Diagnostic Error Sensitive Conditions	ICD-9 groups
Abscess	681, 682
Acute Coronary Syndrome	410, 411.1
Anemia	280-284
Appendicitis	540-542, 543.0, 543.9
Aortic aneurysm	441
Bacteremia/Sepsis	038, 003.1, 020.2, 022.3, 036.2, 054.5, 449, 771.81, 790.7, 995.91, 995.92
Depression	296.2, 296.3
Fracture	800-829, 733.81
Congestive Heart failure	428
Pneumonia	480-486
Pulmonary embolism	415.1
Spinal cord compression	336.9
Stroke	430-437

eTable 2.2. ICD-9 Code Groups for Index Visit Eligibility

Index visit ICD-9 recorded diagnosis ICD-9 codes (76 different diagnoses)	ICD-9s	Met at least one diagnostic error sensitive relative risk criterion (38 met this criteria)
Abdominal pain	789.0	Yes
Abdominal tenderness	789.6	No
Abnormal respiration	786.0	Yes
Alcohol	291.0-291.5, 291.8, 291.9, 357.5, 425.5, 571.0-571.3, 303, 305.00-305.03, 535.30-535.31, E860.0	No
Amphetamines	304.4	No
Anxiety	300.0	Yes
Ascites	785.5	Yes
Back pain	724.5	Yes
Bronchitis	466.0, 466.1	Yes
Cannabis	304.3, 305.2	No
Celiac disease	579.0	No
Chest Pain	786.50, 786.51, 786.59	Yes
Chills	780.64	No
Cocaine	304.2, 305.6, E938.25	No
Confusion	298.2	Yes
Cough	786.2	Yes
Deep vein thrombosis	453.40	No
Delirium	293.0, 780.97	Yes
Diverticulitis	562.11	Yes
Dizziness	780.4	Yes
Drug Mental Disease	292	No
Dyspnea	786.09	Yes
Dysthymia	300.4	Yes
Edema	782.3	Yes
Elevated blood pressure	796.2	No
Esophageal disease	530.1, 530.3-530.9	Yes
Facial weakness	728.87	Yes
Falls	v15.88	No
Fatigue	780.7	Yes
Fever	780.60, 780.61	Yes
Gait instability	781.2	Yes
Gastritis	535	No
Gastrointestinal bleeding	578.9	Yes
Hallucinogens	304.5, 305.3, 969.6, E854.1, E939.6	No
Headache	339, 346, 784.0	Yes
Heart Burn	787.1	No
Hemoptysis	786.30, 786.39	Yes
Hyperparathyroidism	262.0	Yes
Hypoxemia/Hypoxia	799.02	Yes
Influenza	487.0, 487.1, 487.8, 488	No
Lack coordination	781.3	Yes
Lower respiratory disease	519.8	No
Lung cancer	162	Yes
Menorrhagia	626.2	No
Mood disorder	293.83, 293.84	No

Nausea	787.01, 787.02	Yes
Opioids	304.0, 304.7, 305.5, 965.0, E850.0-E850.2, E935.0-E935.2	No
Osteopenia	733.90	No
Osteoporosis	733.0	Yes
Other back pain	721.2-721.9, 722.1, 722.2, 722.5, 722.6, 722.70, 722.72, 722.73, 722.80, 722.82, 722.83, 722.90 722.92, 722.93, 724.0, 724.1	Yes
Other respiratory issue	786.00,786.01, 786.06, 786.07, 786.52, 786.1, 786.2	Yes
Otitis media	381-383, 387, 055.2, 384.2, 384.8, 384.9, 385.0-385.2	No
Personality disorder	301	No
Pain respiration	786.52	Yes
Peripheral neuropathy	337.9, 337.1	No
Reflux disease	530.81	Yes
related alcohol disease	291.9, 292, 304.0-304.6	No
Respiratory Distress	518.81	No
Sedatives	304.1	No
Shortness of breath	786.05	Yes
Sinusitis	473	Yes
Speech disturbance	784.5	Yes
Stress	308	No
Stress fracture	733.94-733.98	No
Tachycardia	785.0	Yes
Tension headache	307.81	No
Thunderclap headache	339.43	No
Transient ischemic attack	435.0-435.3, 435.8, 435.9	Yes
Upper respiratory disease	472, 476, 477, 478.8	No
Viral illness	079.99	No
Vitamin D deficiency	268	Yes
Vomiting	787.01, 787.03	Yes
Weakness/Fatigue	728.87, 708.7	Yes
Weight gain	783.1	No
Weight loss	783.2	Yes

eTable 2.3 Relative Risks for each Index Visit Diagnosis

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Abscess	Fever	2.65
	Chills	0.00
Anemia	Gastrointestinal bleeding	25.20
	Weight loss	4.09
	Shortness of breath	3.51
	Weakness/Fatigue	2.35
	Hypoxemia/Hypoxia	2.11
	Dyspnea	2.05
	Chest Pain	1.82
	Headache	1.29
	Menorrhagia	0.00
Aortic Aneurysm	Dyspnea	4.98
	Abdominal pain	4.93
	Shortness of breath	3.80
	Chest pain	2.42
	Other back pain	1.64
	Back pain	1.01
	Elevated blood pressure	0.00
Appendicitis	Vomiting	30.79
	Diverticulitis	30.45
	Nausea	16.81
	Abdominal pain	15.60
	Abdominal tenderness	0.00
	Fever	0.00
Bacteremia/Sepsis	Vomiting	6.99
	Fever	5.10
	Nausea	3.82
	Tachycardia	2.67
	Weakness/Fatigue	1.75
Heart failure	Hypoxemia/Hypoxia	9.99
	Shortness of breath	5.09
	Dyspnea	3.33
	Edema	3.27
	Chest Pain	2.46
	Weakness/Fatigue	1.42
	Ascites	0.00
	Respiratory Distress	0.00

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Acute Coronary Syndrome	Chest pain	8.38
	Dyspnea	7.29
	Shortness of breath	3.65
	Hypoxemia/hypoxia	2.01
	Reflux disease	1.23
	Esophageal disease	1.22
	Weakness/Fatigue	1.14
	Nausea	1.05
	Other respiratory issue	0.86
	Respiratory distress	0.00
	Gastritis	0.00
	Heart Burn	0.00
Depression	Delirium	32.76
	Heart failure	6.16
	Anxiety	5.04
	Dysthymia	4.99
	Weight loss	4.73
	Anemia	2.74
	Fatigue	1.06
	Alcohol	0.00
	Amphetamines	0.00
	Cannabis	0.00
	Cocaine	0.00
	Drug Mental Disease	0.00
	Hallucinogens	0.00
	Opioids	0.00
	Personality disorder	0.00
	related alcohol disease	0.00
	Sedatives	0.00
	Stress	0.00
	Weight gain	0.00
	Mood disorder	0.00
Fracture	Gait instability	2.53
	Edema	1.79
	Osteoporosis	1.66
	Hyperparathyroidism	1.09
	Vitamin D deficiency	1.08

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Fracture (con't)	Osteopenia	0.54
	Celiac disease	0.00
	Falls	0.00
	Stress fracture	0.00
Pulmonary embolism	Tachycardia	12.16
	Hypoxemia/hypoxia	10.98
	Shortness of breath	6.75
	Dyspnea	6.54
	Abnormal respiration	6.35
	Heart failure	4.51
	Chest pain	4.31
	Cough	1.48
	Other respiratory issue	1.34
	Deep vein thrombosis	0.00
	Respiratory distress	0.00
	Fever	0.00
	Heart burn	0.00
	Hemoptysis	0.00
Pneumonia	Hypoxemia/hypoxia	8.24
	Hemoptysis	7.57
	Lung cancer	7.53
	Fever	6.19
	Delirium	5.18
	Bronchitis	3.07
	Shortness of breath	2.99
	Cough	2.77
	Abnormal respiration	2.38
	Pain respiration	2.13
	Dyspnea	2.05
	Weakness/Fatigue	1.38
	Sinusitis	1.26
	Chest Pain	1.00
	Upper respiratory disease	0.71
	Otitis media	0.48
	Influenza	0.00
	Lower respiratory disease	0.00
	Viral illness	0.00

Outcome conditions[a]	Index visit eligibility diagnosis group	Relative Risk[b]
Spinal cord compression	Abdominal pain	31.20
	Back pain	15.03
	Peripheral neuropathy	0.00
	Weakness/Fatigue	0.00
Stroke	Facial weakness	65.24
	Confusion	48.93
	Speech disturbance	19.60
	Transient ischemic attack	7.82
	Delirium	4.96
	Dizziness	3.20
	Lack coordination	2.92
	Gait instability	2.92
	Vomiting	2.15
	Weakness/Fatigue	1.54
	Headache	1.37
	Nausea	1.17
	Thunderclap headache	0.00
	Tension headache	0.00

[a]Outcomes include any hospitalization or emergency department visit for the diagnostic conditions within 90 days of the index visits including same day events

[b]Index visit diagnoses groups applied in the analysis include those with a relative risk greater than one. Relative risks were computed as the probability of an outcome if the index visit diagnosis group was recorded in the index visit divided by the probability of an outcome if the diagnosis group was not recorded.

Section 3. Psychometric Analysis of Whether Diagnosis Related Questions Reflect an Underlying Construct

To examine the degree to which treatment and diagnosis related questions represented an underlying construct, we calculated separate Cronbach's alpha indices to determine reliability of the subset of items for the 2010 IM-MOC examination for diagnosis related questions and treatment questions.[1] Overall, 170 of the questions were categorized as treatment or diagnostic related with 71 items classified as treatment and 99 items classified as diagnosis related questions. Overall, reliability for the diagnosis related questions was high, 0.84, suggesting that these questions hung together and were related to one underlying construct. The reliability for treatment related questions was also high, 0.75. This index, however, is partly a function of the number of items included in the calculation, where more items typically result in higher reliability. Consequently, it is not surprising that the diagnostic related questions have higher reliability given there were 28 more items than the treatment scale. To make these indices more equal, we computed the Spearman-Brown prophecy formula, which indicates expected reliability if the treatment scale was 99 items instead of 71. That formula resulted in a value of 0.81 for the treatment items which suggests that treatment related questions also measure one underlying construct.

Although performance on diagnosis and treatment related questions were correlated (Pearson Correlation=.62), 59.5% of the variation in diagnosis exam performance for the physician study sample was not explained by performance on other parts of the exam.

Section 4. Imputations for missing variables

Missing practice characteristics (1,432 or 2.94% of sample) were coded as “other unknown”.
Missing HCC (86 or .18% of sample) were replace by in sample mean HCC.
Missing rural indicator (22 or .05% of sample) were assumed to be non-rural
Missing ZIP code median income (708 or 1.46% of sample) were replace by in sample mean median income.

Section 5. Full Regression Coefficient Estimates and Explanatory Variables List

eTables 5.1 lists the probit coefficient associations with outcome measures across all explanatory variables as well as regression descriptive statistics. See Section 7 for percentage point associations with physician characteristics.

eTable 5.1. Probit Coefficient Associations and Regression Descriptive Statistics

	Death		Hospitalization		Emergency Department Visit	
	Wald chi2(102): 815.36		Wald chi2(102): 1197.54		Wald chi2(102): 1201.10	
	Log pseudolikelihood -1588.8		Log pseudolikelihood = -2456.7		Log pseudolikelihood = -2989.0	
Label	Difference per 1,000 (SE)	P	Difference per 1,000 (SE)	P	Difference per 1,000 (SE)	P
Diagnosis question percent correct						
Diagnosis tertile 1	Reference		Reference		Reference	
Diagnosis tertile 2	-1.6 (1.0)	0.09	-2.3 (1.4)	0.09	-3.1 (1.5)	0.04
Diagnosis tertile 3	-2.9 (1.1)	0.008	-4.1 (1.5)	0.006	-4.9 (1.7)	0.003
Treatment question percent correct						
Treatment tertile 1	Reference		Reference		Reference	
Treatment tertile 2	0.7 (0.8)	0.41	-0.7 (1.2)	0.54	-0.3 (1.4)	0.82
Treatment tertile 3	1.6 (1.0)	0.13	1.6 (1.5)	0.29	1.6 (1.7)	0.33
Other question percent correct						
Other tertile 1	Reference		Reference		Reference	
Other tertile 2	1.3 (0.8)	0.12	0.3 (1.2)	0.78	0.1 (1.3)	0.95
Other tertile 3	2.5 (1.0)	0.01	-0.8 (1.3)	0.52	0.5 (1.5)	0.72
Female Physician	-1.2 (0.7)	0.08	-0.8 (1.0)	0.43	-0.7 (1.2)	0.54
Physician birth and medical school						
US born: US medical schools	Reference		Reference		Reference	
US born: Int'l medical schools	1.2 (1.8)	0.51	-1.9 (2.8)	0.50	-0.7 (2.8)	0.79
Int'l born: US medical schools	0.4 (1.1)	0.71	3.1 (1.5)	0.05	2.6 (1.9)	0.18
Int'l born: Int'l medical schools	0.6 (0.8)	0.43	0.2 (1.1)	0.86	0.5 (1.3)	0.70
Practice Type						
Academic practice	Reference		Reference		Reference	
Other practice, unknown[a]	3.5 (2.4)	0.14	-3.9 (2.7)	0.15	-3.9 (3.2)	0.22
Solo physician practice	-0.2 (1.8)	0.93	-5.0 (2.4)	0.04	-5.3 (2.7)	0.05
Small group practice (2 to 10)	-1.0 (1.7)	0.55	-5.6 (2.2)	0.01	-5.7 (2.5)	0.02
Medium physicians group practice (11 to 50)	1.7 (1.9)	0.37	-1.3 (2.4)	0.58	-3.3 (2.8)	0.25
Large physician group practice (>50 physicians)	-2.4 (1.8)	0.20	-1.4 (2.7)	0.62	-2.3 (3.1)	0.46
Female Beneficiaries	-3.6 (1.2)	0.002	-5.1 (1.5)	0.001	-6.2 (1.7)	<.001
Beneficiary Race						
White	Reference		Reference		Reference	
Black	0.5 (1.3)	0.73	4.9 (2.0)	0.01	3.6 (2.1)	0.09
Other	-3.1 (1.1)	0.004	-4.2 (1.5)	0.005	-5.5 (1.7)	0.001
Hierarchical Condition Category (HCC) score[b]	1.7 (0.4)	<.001	1.2 (0.5)	0.03	1.9 (0.6)	0.003
Medicaid Dual Eligible	0.1 (1.2)	0.91	2.3 (1.6)	0.16	1.9 (1.8)	0.27
Beneficiary age	0.7 (0.1)	<.001	0.4 (0.1)	<.001	0.5 (0.1)	<.001
Rural county residence[c]	-1.3 (0.9)	0.15	-1.3 (1.3)	0.31	0.5 (1.6)	0.76
Household medium income[d],	-3.1E-05 (1.6E-05)	0.05	8.7E-06 (2.2E-05)	0.69	-3.1E-06 (2.5E-05)	0.90
CCW chronic conditions						
Alzheimer's Disease and Related Disorders or Senile Dementia	1.7 (1.2)	0.18	3.0 (1.8)	0.09	3.7 (2.0)	0.07
Alzheimer's Disease	2.6 (1.7)	0.14	2.8 (2.5)	0.26	1.8 (2.6)	0.50
Acute Myocardial Infarction	2.7 (1.8)	0.14	2.3 (2.1)	0.27	2.5 (2.4)	0.29
Anemia	0.0 (0.8)	0.99	0.7 (1.1)	0.54	0.8 (1.2)	0.50

Asthma	-0.8 (1.1)	0.45	-0.2 (1.4)	0.88	0.1 (1.7)	0.95
Atrial Fibrillation	1.8 (1.1)	0.10	3.4 (1.5)	0.02	3.7 (1.7)	0.03
Breast Cancer	-2.0 (1.3)	0.13	-3.0 (1.8)	0.10	-2.0 (2.2)	0.35
Colorectal Cancer	-0.5 (1.7)	0.76	-3.4 (2.0)	0.10	-1.9 (2.5)	0.44
Endometrial Cancer	1.6 (4.2)	0.71	-1.1 (4.7)	0.82	-0.9 (5.5)	0.87
Lung Cancer	3.7 (3.4)	0.28	13.3 (6.2)	0.03	10.3 (6.2)	0.10
Prostate Cancer	-1.6 (1.4)	0.26	4.3 (2.5)	0.09	3.6 (2.8)	0.20
Cataract	-1.0 (0.9)	0.29	1.1 (1.0)	0.31	0.1 (1.2)	0.96
Heart Failure	1.8 (1.0)	0.08	2.9 (1.2)	0.02	3.3 (1.4)	0.02
Chronic Kidney Disease	-0.7 (0.8)	0.39	2.9 (1.2)	0.02	4.2 (1.4)	0.004
Chronic Obstructive Pulmonary Disease	1.1 (0.9)	0.26	1.3 (1.2)	0.27	0.9 (1.3)	0.50
Depression	0.2 (0.9)	0.79	0.9 (1.1)	0.43	0.7 (1.2)	0.59
Diabetes	0.0 (0.8)	0.99	3.3 (1.1)	0.003	2.4 (1.2)	0.04
Glaucoma	-0.9 (0.8)	0.29	0.0 (1.1)	1.00	-0.3 (1.2)	0.80
Hip/Pelvic Fracture	1.4 (1.6)	0.39	3.0 (2.4)	0.20	5.0 (2.8)	0.07
Hyperlipidemia	-1.8 (1.1)	0.09	-1.1 (1.3)	0.39	-0.7 (1.4)	0.63
Benign Prostatic Hyperplasia	-0.3 (1.1)	0.79	0.0 (1.5)	0.98	-0.8 (1.7)	0.63
Hypertension	0.8 (1.1)	0.46	2.4 (1.4)	0.09	1.2 (1.6)	0.44
Hypothyroidism	0.7 (0.8)	0.42	1.4 (1.1)	0.19	1.8 (1.2)	0.14
Ischemic Heart Disease	0.8 (0.9)	0.39	0.1 (1.1)	0.92	-1.3 (1.2)	0.29
Osteoporosis	-1.9 (0.8)	0.02	2.0 (1.2)	0.09	1.4 (1.3)	0.28
Rheumatoid Arthritis	-2.3 (0.8)	0.005	-0.2 (1.0)	0.87	0.3 (1.1)	0.81
Stroke	2.7 (1.1)	0.02	2.7 (1.3)	0.04	2.8 (1.5)	0.06
Visit with same doctor in last year	-0.9 (1.1)	0.40	-1.3 (1.4)	0.34	-2.3 (1.5)	0.13
Visit with any physician in last year	-8.4 (3.5)	0.02	-3.5 (3.2)	0.28	-2.5 (3.3)	0.44
Hospitalization in prior year	8.8 (5.4)	0.10	0.9 (4.1)	0.84	0.4 (4.5)	0.93
ED visit in prior year	1.0 (2.5)	0.69	7.3 (4.0)	0.07	8.4 (4.6)	0.07
Days since last visit with any physician (per 30 d)	0.3 (0.2)	0.11	0.0 (0.3)	0.94	0.1 (0.3)	0.64
Days since last hospitalization (per 30 d)	-0.6 (0.4)	0.13	0.2 (0.5)	0.72	0.3 (0.5)	0.55
Days since last ED visits (per 30 d)	-0.2 (0.3)	0.60	-0.5 (0.4)	0.21	-0.7 (0.4)	0.13
Index visit diagnosis group indicators						
Pulmonary embolism	-0.5 (1.3)	0.68	6.1 (1.4)	<.001	7.1 (1.6)	<.001
Acute coronary syndrome	-1.3 (1.1)	0.25	-3.0 (1.8)	0.11	-5.5 (2.0)	0.007
Stroke	-2.3 (1.4)	0.10	7.4 (1.5)	<.001	7.7 (1.7)	<.001
Congestive heart failure	0.2 (1.3)	0.88	10.1 (1.6)	<.001	12.1 (1.7)	<.001
Fracture	-1.3 (1.1)	0.22	3.2 (1.3)	0.02	5.1 (1.5)	<.001
Abscess	0.7 (2.3)	0.77	6.4 (3.3)	0.05	11.7 (3.3)	<.001
Pneumonia	2.3 (1.2)	0.05	5.6 (1.4)	<.001	6.7 (1.6)	<.001
Aortic aneurysm	1.0 (1.4)	0.50	-0.6 (2.0)	0.76	0.7 (2.2)	0.74
Appendicitis	2.0 (1.8)	0.28	5.9 (3.0)	0.05	9.6 (3.1)	0.002
Depression	0.0 (1.3)	0.99	3.0 (1.5)	0.05	2.4 (1.7)	0.15
Anemia	2.3 (1.1)	0.04	3.5 (1.8)	0.04	3.2 (2.0)	0.11
Bacteremia	0.5 (2.5)	0.85	-9.5 (3.0)	0.001	-8.3 (3.1)	0.008
Spinal cord compression	-0.5 (1.8)	0.79	-2.8 (2.8)	0.32	-7.0 (3.1)	0.02
Mental health visit	1.4 (1.2)	0.22	-0.9 (1.5)	0.53	0.1 (1.8)	0.97
HHS Region						
HHS Region 1	Reference		Reference		Reference	
HHS Region 2	1.6 (1.7)	0.35	-5.2 (2.2)	0.02	-6.7 (2.7)	0.01
HHS Region 3	2.7 (1.8)	0.12	2.1 (2.5)	0.40	1.3 (3.0)	0.66
HHS Region 4	0.4 (1.5)	0.77	-2.7 (2.2)	0.22	-4.9 (2.6)	0.07
HHS Region 5	0.3 (1.4)	0.81	0.8 (2.1)	0.69	-1.0 (2.6)	0.70
HHS Region 6	-0.9 (1.5)	0.53	-2.8 (2.2)	0.21	-4.4 (2.8)	0.11
HHS Region 7	0.0 (2.2)	0.99	3.2 (3.2)	0.31	0.9 (3.5)	0.79
HHS Region 8	-1.6 (2.2)	0.47	1.9 (3.8)	0.62	-2.0 (3.8)	0.61
HHS Region 9	0.0 (1.6)	0.99	-0.6 (2.5)	0.81	-3.2 (2.8)	0.26
HHS Region 10	-0.6 (2.2)	0.77	4.4 (3.5)	0.21	4.0 (4.3)	0.35
Study Year						
2009	-3.1 (3.0)	0.30	-2.5 (4.3)	0.56	-1.9 (5.9)	0.75

2010	-1.9 (2.9)	0.52	-2.1 (3.6)	0.55	-1.7 (5.2)	0.75
2011	1.1 (2.3)	0.63	1.4 (2.7)	0.60	-2.3 (4.2)	0.58
2012	Reference		Reference		Reference	
Yearly Quarter						
Q1	Reference		Reference		Reference	
Q2	-0.6 (0.9)	0.50	0.7 (1.2)	0.54	0.4 (1.4)	0.78
Q3	-0.7 (0.9)	0.43	-0.1 (1.2)	0.94	-0.8 (1.3)	0.55
Q4	0.6 (1.1)	0.55	1.9 (1.4)	0.18	1.2 (1.5)	0.42
Test Forms						
May 2008: A	3.7 (3.6)	0.30	-6.4 (4.2)	0.13	-5.5 (5.0)	0.27
May 2008: B	2.3 (4.3)	0.60	-4.1 (4.9)	0.41	-3.6 (6.1)	0.56
Nov. 2008: A	1.1 (3.1)	0.72	0.7 (4.2)	0.87	-2.7 (5.4)	0.62
Nov. 2008: B	Reference		Reference		Reference	
May 2009: A	5.1 (3.7)	0.16	3.6 (3.9)	0.36	-2.2 (5.0)	0.66
May 2009: B	0.2 (5.0)	0.96	-0.1 (5.0)	0.98	-6.0 (6.0)	0.31
Nov 2009: A	1.5 (3.1)	0.64	2.7 (3.4)	0.43	-1.5 (4.9)	0.75
Nov 2009: B	6.7 (3.9)	0.08	8.2 (3.9)	0.04	5.2 (5.2)	0.32
Nov 2009: C	Reference		Reference		Reference	
May 2010: A	0.9 (2.4)	0.69	-0.8 (2.6)	0.75	-4.6 (4.1)	0.26
May 2010: B	1.7 (2.4)	0.48	-0.2 (2.7)	0.94	-3.6 (4.3)	0.41
Nov. 2010: A	1.3 (2.4)	0.59	-1.2 (2.5)	0.63	-4.8 (4.1)	0.24
Nov. 2010: B	1.4 (2.3)	0.55	-0.5 (2.6)	0.85	-3.6 (4.1)	0.38
Nov. 2010: C	Reference		Reference		Reference	
May 2011: A	3.3 (3.2)	0.30	1.5 (3.7)	0.69	-1.3 (5.2)	0.80
May 2011: B	1.9 (3.4)	0.59	-1.4 (4.0)	0.74	-5.8 (5.3)	0.27
Nov. 2011: A	-1.8 (3.2)	0.57	-3.6 (4.5)	0.42	-3.2 (7.2)	0.65
Nov. 2011: B	0.2 (2.7)	0.94	-4.6 (3.7)	0.21	-8.0 (5.3)	0.13
Nov. 2011: C	Reference		Reference		Reference	

Note:
[a]Missing practice characteristics (1,432 or 2.94% of sample) were coded as "other unknown".
[b]Missing HCC (86 or .18% of sample) were replace by in sample mean HCC.
[c]Missing rural indicator (22 or .05% of sample) were assumed to be non-rural
[b]Missing ZIP code median income (708 or 1.46% of sample) were replace by in sample mean median income.

Section 6. Regression Sensitivity Analyses

In this section we describe the results of falsification and robustness sensitivities. Falsification sensitivities examine associations with diagnostic knowledge under scenarios where we expect the underlying associations to be weaker than in the base case. Robustness sensitivities examine the degree to which base case associations with diagnostic knowledge were robust to assumptions regarding index visit diagnoses eligibility, outcome variable construction, and regression control variables.

Falsification sensitivities

Results of falsification sensitivities are exhibited in eTable 6.1. These sensitivities include applying the index visit sample that did not meet any diagnoses eligibility criteria and applying elective hospitalizations as an outcome measure. Presumably diagnostic knowledge would not impact outcomes with the diagnostic error sensitive conditions after index visits where related diagnoses codes for these conditions were not present. That is, either because the underlying condition was not present or not detectable at the time of the index visit and therefore was not preventable. However, outcomes after these index visits could be associated with omitted variables that were both correlated with our outcome measures and exam performance. For example, it could be that physicians with low diagnostic knowledge also have less healthy patients in ways we do not control for and therefore would be more likely to experience adverse events more generally. We also assume that elective hospitalizations would be related to the overall propensity to hospitalize but would not be related to underlying diagnostic skill.

Overall the results of falsification sensitivities support the validity of our base case finding. For example, although the overall risk of each adverse outcome was comparable to the base case, all associations with diagnostic knowledge were very small in absolute terms and none were statistically significant (P>0.05). For example, applying for the sample of index visits without eligible diagnoses codes, scoring in the top versus bottom tertile of diagnostic knowledge was associated with a 0.0 (95% CI -1.3 to 1.3, p=0.99) difference in the risk of death within 90 days of the index visit or under one tenth of the statistically significant 2.9 (95% CI: -5.0 to -0.7, p=0.008) fewer death per 1,000 observed in the base case. Yet, the mean risk of death in the base case and this sensitivity was comparable (0.7% in the base case versus 0.4% in this sensitivity). This sensitivity also addressed another limitation of our study, that we did not have a direct measure of cause of death since if the associations we found were driven by reductions in death due to the 13 diagnostic error prone conditions applied in our study we would expect that the associations with death and diagnostic exam performance would be much smaller when estimated using the index sample without eligible diagnoses codes for these conditions. Similarly we found that the associations between diagnostic knowledge and risk of an elective hospitalization were statistically insignificant, top compared to bottom tertile association P was 0.63, and was wrong signed.

Robustness sensitivities

Results of robustness sensitivities are exhibited in eTables 6.2.1 (for death), 6.2.2 (hospitalization) to 6.2.3 (for emergency department visit).

For the first sensitivity we expanding the eligible diagnoses code groups to all 76 identified by physician authors versus 38 in the base case that also met the relative risk criteria.

For the third sensitivity we expand the index visit clean period to 97 days and contracted the index visit clean period to 83 days.

For the fourth sensitivity, we excluded physician in academic medical centers to consider the possibility that the unobserved physician characteristics related to where they worked or who they worked with could be were independently both related to the underlying physician diagnostic skill and our outcome measures.

For the fifth sensitivity we accounted for the possibility that adverse outcomes were avoided because the patient died by altering the ED and hospitalization measures to include all-cause mortality. For this sensitivity we added the following two outcome measures: base case hospitalization or death and base case ED or death.

Overall results of robustness sensitivity analysis suggests that our base case results were not highly sensitive to different underlying assumptions related to these factors (e.g., across all robustness sensitivities percent change in the outcome measures between top versus bottom diagnostic knowledge exam performers remained statistically significant ($P<0.05$)).

Table 6.1. Results of Falsification Sensitivity Analyses for All Adverse Outcomes

Adverse outcome measure / Sensitivity	Number of index visits	Regression adjusted outcomes per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Death										
Base	48,632	5.2 (4.1 to 6.3)	6.5 (5.4 to 7.6)	8.1 (6.5 to 9.7)	-35.3 (-52.8 to -11.2)	-2.9 (-5.0 to -0.7)	0.008	-20.2 (-38.3 to 3.2)	-1.6 (-3.6 to 0.3)	0.09
Falsification sensitivity										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	3.9 (3.0 to 4.7)	4.3 (3.5 to 5.0)	3.9 (3.1 to 4.7)	0.2 (-27.9 to 39.4)	0.0 (-1.3 to 1.3)	0.99	10.1 (-17.2 to 46.5)	0.4 (-0.8 to 1.5)	0.51
Hospitalization										
Base	48,632	9.2 (7.7 to 10.8)	11.0 (9.4 to 12.6)	13.3 (11.2 to 15.4)	-30.5 (-46.1 to -10.4)	-4.1 (-6.9 to -1.2)	0.006	-17.1 (-33.2 to 3.0)	-2.3 (-4.9 to 0.4)	0.09
Falsification sensitivities										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	13.8 (12.0 to 15.5)	13.1 (11.8 to 14.4)	14.0 (12.5 to 15.5)	-1.5 (-18.2 to 18.6)	-0.2 (-2.8 to 2.4)	0.87	-6.0 (-19.1 to 9.1)	-0.8 (-2.9 to 1.2)	0.42
Elective hospitalization	48,264	9.6 (7.7 to 11.5)	9.0 (7.6 to 10.3)	8.9 (7.4 to 10.5)	7.6 (-19.6 to 43.9)	0.7 (-2.0 to 3.4)	0.63	0.4 (-20.1 to 26.3)	0.0 (-2.0 to 2.1)	0.97
Emergency Department Visit										
Base	48,632	11.5 (9.8 to 13.2)	13.2 (11.5 to 15.0)	16.4 (14.0 to 18.7)	-29.8 (-44.4 to -11.4)	-4.9 (-8.1 to -1.6)	0.003	-19.0 (-33.8 to -1.0)	-3.1 (-6.1 to -0.1)	0.04
Falsification sensitivity										
Index visits sample that did not meet the diagnoses code eligibility criteria.	84,497	18.0 (16.0 to 20.0)	17.7 (16.1 to 19.2)	18.7 (17.0 to 20.4)	-3.8 (-17.8 to 12.6)	-0.7 (-3.6 to 2.2)	0.63	-5.5 (-16.9 to 7.3)	-1.0 (-3.4 to 1.3)	0.38

Table 6.2.1. Results of Robustness Sensitivity Analyses for the Death Adverse Outcome

	Number of index visits	Regression adjusted deaths per 1,000 index visits (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	**48,632**	**5.2 (4.1 to 6.3)**	**6.5 (5.4 to 7.6)**	**8.1 (6.5 to 9.7)**	**-35.3 (-52.8 to -11.2)**	**-2.9 (-5.0 to -0.7)**	**0.008**	**-20.2 (-38.3 to 3.2)**	**-1.6 (-3.6 to 0.3)**	**0.09**
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,749	4.9 (3.9 to 5.9)	5.7 (4.8 to 6.7)	7.0 (5.7 to 8.4)	-30.2 (-48.9 to -4.5)	-2.1 (-4.0 to -0.3)	0.03	-18.4 (-36.7 to 5.2)	-1.3 (-2.9 to 0.4)	0.13
97 day index visit clean period	40,417	7.5 (5.8 to 9.1)	6.8 (5.6 to 8.1)	4.9 (3.8 to 6.0)	-34.7 (-53.9 to -7.6)	-2.6 (-4.8 to -0.4)	0.02	-8.5 (-31.0 to 21.2)	-0.6 (-2.7 to 1.4)	0.54
83 day index visit clean period	54,169	5.5 (4.4 to 6.6)	6.8 (5.7 to 7.8)	8.4 (6.8 to 10.0)	-34.7 (-51.7 to -11.7)	-2.9 (-5.0 to -0.8)	0.007	-19.5 (-37.0 to 3.0)	-1.6 (-3.6 to 0.3)	0.09
Small practices (visits with physicians with practices of 10 or less physicians)	29,242	4.5 (3.2 to 5.9)	5.9 (4.6 to 7.2)	8.2 (6.3 to 10.2)	-44.9 (-63.6 to -16.7)	-3.7 (-6.3 to -1.1)	.0047	-28.6 (-48.9 to .1)	-2.4 (-4.8 to 0.1)	.058
Large (>50 physicians)/academic medical center practices:	6,308[a]	6.4 (3.6 to 9.1)	6.4 (3.4 to 9.4)	5.7 (2.1 to 9.2)	12.9 (-50.8 to 159.0)	0.7 (-4.2 to 5.6)	.7714	13.3 (-43.0 to -125.1)	0.8 (-3.3 to 4.8)	0.72
Not counting next day death as an adverse outcome	48,632	5.2 (4.1 to 6.3)	6.4 (5.3 to 7.5)	8.1 (6.5 to 9.7)	-35.7 (-53.1 to -11.8)	-2.9 (-5.0 to -0.8)	.000729	-21.0 (-38.9 to 2.1)	-1.7 (-3.6 to 0.2)	.081

[a] 1,791 observations excluded due to lack of variation in outcomes within control test administrations or other controls

Table 6.2.2. Results of robustness sensitivity analyses for the hospitalization adverse outcome

	Number of index visits	Regression adjusted risk of emergency department hospitalization per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	**48,632**	**9.2 (7.7 to 10.8)**	**11.0 (9.4 to 12.6)**	**13.3 (11.2 to 15.4)**	**-30.5 (-46.1 to -10.4)**	**-4.1 (-6.9 to -1.2)**	**0.006**	**-17.1 (-33.2 to 3.0)**	**-2.3 (-4.9 to 0.4)**	**0.09**
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,749	11.3 (9.6 to 13.0)	9.7 (8.3 to 11.0)	8.3 (6.9 to 9.7)	-26.6 (-43.0 to -5.4)	-3.0 (-5.5 to -0.5)	0.02	-14.6 (-31.0 to 5.6)	-1.7 (-3.9 to 0.6)	0.15
97 day index visit clean period	40,417	8.3 (6.7 to 9.9)	10.4 (8.7 to 12.1)	13.4 (11.0 to 15.9)	-38.4 (-54.2 to -17.3)	-5.2 (-8.4 to -1.9)	0.002	-22.8 (-39.6 to -1.3)	-3.1 (-6.0 to -0.1)	0.04
83 day index visit clean period	54,169	9.3 (7.8 to 10.8)	11.2 (9.7 to 12.8)	13.2 (11.2 to 15.3)	-29.7 (-45.3 to -9.7)	-3.9 (-6.8 to -1.1)	0.007	-15.1 (-31.2 to 4.8)	-2.0 (-4.6 to 0.6)	0.13
Hospitalization visit or death (hospitalization base case measure or death base case measure)	48,632	13.7 (11.9 to 15.4)	16.4 (14.5 to 18.2)	19.8 (17.4 to 22.2)	-30.9 (-43.3 to -15.8)	-6.1 (-9.4 to -2.8)	<.001	-17.4 (-30.5 to -1.9)	-3.4 (-6.6 to -0.3)	0.03
Shortening the outcome period from 90 day to 14 days	48,632	2.0 (1.3 to 2.7)	3.2 (2.4 to 4.1)	3.3 (2.4 to 4.3)	-40.3 (-63.3 to -3.0)	-1.4 (-2.6 to -0.1)	0.04	-3.7 (-35.2 to 43.2)	-0.1 (-1.4 to 1.2)	0.85
Small practices (visits with physicians with practices of 10 or less physicians)	29,242	7.8 (5.8 to 9.8)	12.1 (10.0 to 14.2)	11.8 (9.5 to 14.0)	-33.4 (-53.0 to -5.6)	-3.9 (-7.2 to -0.6)	0.02	-18.8 (-39.3 to 8.5)	-2.2 (-5.3 to 0.9)	0.16
Large (>50 physicians)/academic medical center practices:	7,966a	10.4 (7.3 to 13.5)	12.0 (7.8 to 16.2)	22.5 (13.5 to 31.5)	-53.7 (-73.2 to -20.2)	-12.1 (-22.2 to -2.0)	0.02	-46.7 (-68.0 to -8.7)	-10.5 (-20.5 to -0.5)	0.04
Not counting next day hospitalizations as an adverse outcome	48,632	8.7 (7.2 to 10.2)	9.9 (8.4 to 11.5)	12.5 (10.4 to 14.5)	-30.0 (-46.1 to -9.0)	-3.7 (-6.5 to -0.9)	0.0087	-20.2 (36.3 to 0.0)	-2.5 (-5.1 to 0)	.054604

[a] 133 observations excluded due to lack of variation in outcomes within control test administrations or other controls

Table 6.2.3. Results of robustness sensitivity analyses for the emergency department visit adverse outcome

	Number of index visits	Regression adjusted risk of emergency department visit per 1,000 index visits, (95% CI)			Top versus bottom tertile of diagnostic knowledge			Middle versus bottom tertile of diagnostic knowledge		
		Top	Middle	Bottom	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value	Percent difference (95% CI)	Difference per 1,000 index visits (95% CI)	P-value
Base	**48,632**	**11.5 (9.8 to 13.2)**	**13.2 (11.5 to 15.0)**	**16.4 (14.0 to 18.7)**	**-29.8 (-44.4 to -11.4)**	**-4.9 (-8.1 to -1.6)**	**0.003**	**-19.0 (-33.8 to -1.0)**	**-3.1 (-6.1 to -0.1)**	**0.04**
Sensitivities										
Applying larger list of index visit diagnoses eligibility (all 76 diagnoses identified by physician authors)	57,740	10.4 (8.8 to 12.0)	11.7 (10.2 to 13.2)	13.9 (12.0 to 15.8)	-25.2 (-40.5 to -6.0)	-3.5 (-6.3 to -0.7)	0.01	-16.3 (-31.1 to 1.7)	-2.3 (-4.8 to 0.2)	0.08
97 day index visit clean period	40,417	10.5 (8.7 to 12.3)	12.6 (10.7 to 14.5)	16.7 (13.9 to 19.5)	-37.2 (-51.9 to -18.0)	-6.2 (-9.9 to -2.5)	<.001	-24.5 (-39.9 to -5.3)	-4.1 (-7.5 to -0.7)	0.02
83 day index visit clean period	54,169	11.6 (9.9 to 13.2)	13.4 (11.7 to 15.1)	16.4 (14.1 to 18.8)	-29.5 (-43.8 to -11.6)	-4.8 (-8.0 to -1.7)	0.003	-18.4 (-32.6 to -1.1)	-3.0 (-5.9 to -0.1)	0.04
Emergency department visit or death (hospitalization base case measure or death base case measure)	48,632	15.7 (13.7 to 17.7)	18.5 (16.5 to 20.5)	22.6 (20.0 to 25.2)	-30.6 (-42.6 to -16.0)	-6.9 (-10.6 to -3.3)	<.001	-18.0 (-30.4 to -3.4)	-4.1 (-7.5 to -0.7)	0.02
Shortening the outcome period from 90 day to 14 days	48,632	2.7 (1.9 to 3.4)	3.7 (2.8 to 4.7)	4.0 (2.9 to 5.1)	-34.4 (-57.8 to 2.1)	-1.4 (-2.9 to 0.1)	0.07	-7.5 (-36.2 to 34.2)	-0.3 (-1.8 to 1.1)	0.68
Small practices (visits with physicians with practices of 10 or less physicians)	29,242	10.3 (8.0 to 12.5)	12.1 (10.0 to 14.2)	14.7 (12.3 to 17.1)	-30.1 (-48.2 to -5.8)	-4.4 (-8.0 to -0.8)	.016	-17.7 (-36.2 to 6.3)	-2.6 (-6.0 to 0.8)	.138
Large (>50 physicians)/academic medical center practices:	7,966a	13.3 (9.3 to 17.2)	12.6 (8.4 to 16.8)	24.2 (15.2 to 33.2)	-45.3 (-67.8 to -6.9)	-11.0 (-21.7 to -0.3)	0.045	-48.1 (-68.3 to -14.8)	-11.6 (-21.5 to -1.8)	0.021
Not counting next day emergency department visits as an adverse outcome	48,632	10.6 (9.0 to 12.3)	12.0 (10.3 to 13.7)	15.0 (23.7 to 17.3)	-29.2 (44.2 to 10.2)	-4.4 (-7.5 to -1.3)	.0055	-20.1 (35.2 to 1.3)	-3.0 (-5.9 to -0.1)	.040

[a] **133 observations excluded due to lack of variation in outcomes within control test administrations or other controls**

References

1. Bandalos DL. *Measurement theory and applications for the social sciences*: Guilford Publications; 2018.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract [See page 3, last paragraph]
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found [See Abstract page 3 Design section]
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported [See page 6, Introduction section of the Manuscript first and second paragraph]
Objectives	3	State specific objectives, including any prespecified hypotheses [See page 7, last paragraph]
Methods		
Study design	4	Present key elements of study design early in the paper [See last sentence on page 7 and Methods section starting on page 8]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection [See Physician and Index Visit sample subsections starting on page 7]
Participants	6	(*a*) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants [See Methods section page 8 and Figure 1 for physician, patient and visit sample stats, page 33)]
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed [NA] *Case-control study*—For matched studies, give matching criteria and the number of controls per case [NA]
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable [See Outcome Measures subsection of Methods section, first paragraph of page 10 for outcomes. See paragraph starting on page 11 for diagnostic knowledge measure.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group [See paragraph starting on page 11 for diagnostic knowledge measure].
Bias	9	Describe any efforts to address potential sources of bias [See Statistical Methodes starting first paragraph of page 11, explanation for inclusion of other measures of knowledge and Sensitivity Analysis subsection on page 12]
Study size	10	Explain how the study size was arrived at [See first and second paragraph page 7]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why [See Statistical Methods an page 12 for description for specification of regression explanatory variables]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding [See Statistical Methods page 12 first paragraph]
		(*b*) Describe any methods used to examine subgroups and interactions [NA]
		(*c*) Explain how missing data were addressed [See second to last sentence page 12

	and Appendix page 44]
	(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed [NA] *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy [Sensitivity Analysis subsection page 13]
	(*e*) Describe any sensitivity analyses [Sensitivity Analysis subsection page 13]

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed [See first paragraph of the Results section page 15]
		(b) Give reasons for non-participation at each stage [See page 15 first paragraph as well as Figure 1 (page 33) and Table 1 (page 28)]
		(c) Consider use of a flow diagram [See Figure 1 (page 33)]
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders [See Results section paragraph 2 (page 14) and Table 2 (page 28)]
		(b) Indicate number of participants with missing data for each variable of interest [See second to last sentence page 12 and Appendix Section 4, page 44]
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) [NA]
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time [NA]
		Case-control study—Report numbers in each exposure category, or summary measures of exposure [NA]
		Cross-sectional study—Report numbers of outcome events or summary measures [See Table 1 page 28]
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included [See Table 3 page 30 for adjusted and unadjusted estimates and page 12 first a second paragraph controls and Appendix Section 5, page 45, for coefficient estimates listed as absolute differences)
		(*b*) Report category boundaries when continuous variables were categorized [See Statistical Analysis Section page 16, Results page 16 and Table 3, page 30]
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period [See Results starting on the last paragraph of page 15]
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses [See Sensitivity Analysis subsection of Results section last paragraph page 15 and Appendix Section 5, page 45]
Discussion		
Key results	18	Summarise key results with reference to study objectives [See first paragraph of Discussion section page subsection last paragraph of page 16]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias [See page Discussion section page 18 to page 20]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence [No other study has addressed our research question, however, in terms of methodology we compare our study to other in the Discussion section page 17]
Generalisability	21	Discuss the generalisability (external validity) of the study results [See Discussion section starting on the bottom of page 18 and continuing on page 19]
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based [See Funding bullet on page 23]

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.