ORIGINAL RESEARCH

Consistency of Hemoglobin A1c Testing and Cardiovascular Outcomes in Medicare Patients With Diabetes

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Background—Annual hemoglobin A1c testing is recommended for patients with diabetes mellitus. However, it is unknown how consistently patients with diabetes mellitus receive hemoglobin A1c testing over time, or whether testing consistency is associated with adverse cardiovascular outcomes.

Methods and Results—We identified 1 574 415 Medicare patients (2002–2012) with diabetes mellitus over the age of 65. We followed each patient for a minimum of 3 years to determine their consistency in hemoglobin A1C testing, using 3 categories: low (testing in 0 or 1 of 3 years), medium (testing in 2 of 3 years), and high (testing in all 3 years). In unweighted and inverse propensity-weighted cohorts, we examined associations between testing consistency and major adverse cardiovascular events, defined as death, myocardial infarction, stroke, amputation, or the need for leg revascularization. Overall, 70.2% of patients received high-consistency testing, 17.6% of patients received medium-consistency testing, and 12.2% of patients received low-consistency testing. When compared to high-consistency testing, low-consistency testing was associated with a higher risk of adverse cardiovascular events or death in unweighted analyses (hazard ratio [HR]=1.21; 95% CI, 1.20–1.23; $P<0.001$), inverse propensity-weighted analyses (HR=1.16; 95% CI, 1.15–1.17; $P<0.001$), and weighted analyses limited to patients who had at least 4 physician visits annually (HR=1.15; 95% CI, 1.15–1.16; $P<0.001$). Less-consistent testing was associated with worse results for each cardiovascular outcome and in analyses using all years as the exposure.

Conclusions—Consistent annual hemoglobin A1c testing is associated with fewer adverse cardiovascular outcomes in this observational cohort of Medicare patients of diabetes mellitus. **(*J Am Heart Assoc*. 2016;5:e003566 doi: 10.1161/JAHA.116.003566)**

Key Words: cardiovascular outcomes • diabetes mellitus • health disparities • health outcomes • hemoglobin A1c

The Diabetes Control and Complications Trial demonstrated that lower hemoglobin A1C levels were associated with fewer cardiovascular complications, especially microvascular complications, in patients with diabetes mellitus.[1] Based on this study and others,[2–6] the American Diabetes Association,[7,8] the National Quality Forum,[9] and the National Committee for Quality Assurance[10] all broadly endorse frequent hemoglobin A1c testing as an important tool in monitoring diabetic care. Each of these organizations recommend testing at least once a year, and many endorse testing at even closer intervals. Because of these recommendations, annual hemoglobin A1c testing rates are commonly used as a measure of provider and health-system quality of care for patients with diabetes mellitus.[11–14]

However, few have examined how consistently a patient receives hemoglobin A1c testing over a period longer than a single year. The consistency of hemoglobin A1c testing, which we define as the proportion of years in which a patient with diabetes mellitus receives at least 1 hemoglobin A1c test, has not been well characterized in large cohorts in the United States.[15] Furthermore, though a modest relationship has been observed between annual hemoglobin A1c testing use and cardiovascular outcomes,[2,4–6,16] the longitudinal relationship between consistency of hemoglobin A1c testing and cardiovascular outcomes, such as myocardial infarction, stroke, and amputation, has not been established in real-world practice.

To examine the consistency of hemoglobin A1c testing for patients with diabetes mellitus, we created a large

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An accompanying Data S1 is available at http://jaha.ahajournals.org/content/5/8/e003566/DC1/embed/inline-supplementary-material-1.pdf

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national cohort of Medicare patients with diabetes mellitus and followed each patient for a minimum of 3 years to determine the consistency with which they received hemoglobin A1c testing. We then examined associations between testing consistency and cardiovascular outcomes in subsequent years, using unweighted and inverse propensity-weighted analyses, as well as analyses targeting patients observed at least 4 times per year, to allow adequate opportunities for physicians to order hemoglobin A1c testing.

Methods

Creating a Cohort of Medicare Patients With Diabetes Mellitus

We used the Medicare Physician and Supplier file as well as the Medicare Denominator file, in the years 2002–2009, to identify all patients with diagnosis codes indicative of the presence of diabetes mellitus during that time period. Each patient was followed forward in time for a minimum of 3 calendar years, through the year 2012. Patients were required to have a diagnosis codes for diabetes mellitus in 2 of 3 consecutive years for inclusion in the cohort. We used the year in which the patient entered our cohort to establish the patient's comorbidities using the Charlson score. Because having diabetes mellitus was a requirement for cohort inclusion, we did not include diabetes mellitus with or without end organ damage within the overall Charlson score calculation.[17]

We excluded patients less than 65 years of age, greater than 99 years of age, and those not enrolled in fee-for-service Medicare plans. Further information was obtained using the denominator file, which contains information about Medicare and Medicaid eligibility, age, sex, race, and disability. We recorded patient ZIP code and the hospital referral region of residence, as described by the Dartmouth Atlas of Health Care.[18] We also linked zip code to the American Community Survey (2006–2010 aggregation) to identify local area median income and poverty status. We used county-level data from countyhealthrankings.org to obtain measures of area level health: healthy days, smoking, and obesity as described in previous work.[19] Patients left the cohort when they died or ceased enrollment in Medicare's Part A or Part B programs, such as in those who joined a Medicare HMO program such as Medicare Advantage.

Measuring Consistency in Hemoglobin A1c Testing

Hemoglobin A1c testing is recommended at least annually for patients with diabetes mellitus.[20] Within our cohort, we examined whether or not patients had ever undergone hemoglobin A1c testing. We used the CPT codes available for this laboratory test (Data S1). This variable has been used in previous studies using administrative datasets.[20–22]

To determine our exposure variable, consistency in hemoglobin A1c testing, we examined how consistently hemoglobin A1c testing was performed for each patient during the first 3 years they were followed in our cohort. Testing consistency was categorized as low (testing in none or 1 year of the first 3 years), medium (testing in any 2 years of the first 3 years), and high (testing in all 3 of the first 3 years). Our analysis considered only patients who had at least 1 physician visit per year during the first 3 years, given that a physician visit would allow for an opportunity for patients to receive hemoglobin A1C testing. Sensitivity analyses where none or 1 test during the first 3 years were analyzed independently were performed, and our findings were similar to those presented herein.

We excluded any patients who died within the first 3 years. Sensitivity analysis were performed, which required a minimum of 4 physician visits per year during the first 3 years. We also performed analyses that considered testing consistency during the entire time each patients appeared in fee-for-service Medicare, rather than using the first 3 years of testing as an exposure variable and examining outcomes using survival analysis thereafter. Because findings were similar between these analyses and our outcomes reported herein, we present only the latter strategy in this article.

Measuring Cardiovascular Outcomes, by Consistency Category

After using the first 3 years in the cohort to measure the exposure variable, we used all remaining years patients appeared in Medicare claims to measure major adverse cardiovascular events, beginning on the first day of the fourth year. We searched for evidence of death, as well as any of the following cardiovascular events: myocardial infarction, stroke, amputation, and need for a lower-extremity vascular procedure (codes are shown in Data S1). Death was assessed using the Denominator file. Myocardial infarction was defined using International Classification of Diseases, Ninth Revision (ICD-9) diagnosis codes as in previous reports.[23] Stroke was defined using ICD-9 codes, as published previously. We used a 1-year look back to exclude patients in whom any of the cardiovascular events occurred in the past year.[23,24] We recorded the occurrence of a major lower-extremity amputation at the patient level, using current procedural terminology codes indicative of above- or below-knee amputation. We excluded toe and forefoot amputations, and traumatic amputations, although in sensitivity analyses, our results remained similar

when we included toe or forefoot amputations in our analysis. Leg revascularization procedures were also measured using diagnosis and procedure codes reported in our previous work[20,25] A composite outcome of a major adverse cardiac event (MACE) was analyzed as well, defined as the occurrence of any of the following: death, myocardial infarction, stroke, major leg amputation, or need for lower-extremity revascularization.

All cardiovascular outcomes were assessed using time-to-event analyses, with the initial time period beginning on the first day of the fourth year; the first 3 years in the cohort were used to assign the exposure. Death was allowed in the fourth in the cohort and thereafter. Any major adverse cardiovascular events occurring in the first 3 years were excluded. If patients left fee-for-service Medicare claims for Medicare Advantage or other non-fee-for-service programs during this interval, they were censored on the date they ceased to appear in the fee-for-service Medicare program.

Statistical Analyses

We began by examining the consistency in hemoglobin A1c testing among Medicare patients with diabetes mellitus between 2002 and 2012. We created Cox survival models to understand associations between the consistency of testing and cardiovascular outcomes. These models were adjusted for age, sex, race, Medicaid eligibility, disability status, and Charlson score as well as regional variables indicative of health status, income, and poverty.

Crude results were examined using linear analyses before examining our 3 consistency categories and over time. Because patient characteristics differed across the categories of consistency in hemoglobin A1c testing (Table 1), we used multilevel inverse propensity weighting to develop a matched cohort of patients, based on the patient's likelihood to receive low-, medium-, and high-consistency testing.[26,27] We developed multinomial logistic models that identified patient and structural factors associated with each category of consistency in hemoglobin A1c testing. We then used the inverse of these probabilities to weight patients and balance the testing groups. Models were run using both baseline information only, as well as allowing covariates, including the year of testing, to change annually as the patient progressed through each year in the study. Both efforts produced similar results, and therefore the baseline-adjusted models are presented herein. *P* values are reported across all three categories.

All analyses were performed using SAS (SAS Institute Inc., Cary, NC) and STATA software (StataCorp LP, College Station, TX). The Geisel School of Medicine's Center for the Protection of Human Subjects approved our study. Informed consent was waived as part of the study, because it involved only secondary data-set analyses.

Results

Patient Characteristics and Unadjusted Outcomes, by Testing Consistency

Between 2002 and 2009, we identified 1 574 415 individual Medicare patients with diabetes mellitus. These patients were followed for a mean of 6.3 years in our cohort, with a range from 3 to 11 years. Overall, 70.2% of patients received high-consistency testing, 17.6% of patients received medium-consistency testing, and 12.2% of patients received low-consistency testing. Testing consistency in the first 3 years was reflected in testing in later years. For example, those with high-consistency testing in the first 3 years had testing in 88% of later years, and those with low-consistency testing during the first 3 years had testing in 49% of later years.

Patients were who received low-consistency testing were older than patients receiving high-consistency testing when they entered the cohort; the mean age was nearly 2 years older for those receiving low-consistency testing when compared to those receiving high-consistency testing (76.3 vs 74.6 years; $P<0.001$; Table 1). Differences by race were evident as well, as 14.3% of low-consistency testing patients were black, whereas 10.0% of high-consistency testing patients were black ($P<0.0001$). Finally, a larger proportion of patients getting low-consistency testing were on disability when compared to high-consistency testing (15.5% vs 11.9%; $P<0.0001$).

Because a patient clinic visit is an opportunity for a physician to order hemoglobin A1c testing, we examined patient visit patterns in our cohort. Overall, patients had an average of 17 physician visits in each year during the study period. Of these visits, an average of 8 were with a primary care physician. Patients were seen often by physicians; only 9% of Medicare enrollees in the cohort had fewer than 4 physician visits annually. Differences in the number of visits were evident across categories of testing consistency (Table 1). For example, patients who received low-consistency testing had a higher number of physician visits than those receiving high-consistency testing (19.7 vs 16.3 visits; $P<0.001$), but were also more likely to have fewer than 4 physician visits per year (11.1% vs 8.6%; $P<0.001$).

Cardiovascular Outcomes, by Testing Consistency

In unweighted analyses, we found 62.3% of patients treated with low-consistency testing experienced death or a major adverse cardiovascular event within 7 years of follow-up (Figure A). The rate of death or an adverse cardiovascular event was 13.2% lower, in absolute terms, for patients treated with high-consistency testing (49.0%), a difference that was highly significant across testing consistency categories (log

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Table 1. Patient Characteristics, by Consistency Category, in Both Crude and Inverse Propensity Weighted Cohorts

	Unweighted					Inverse Propensity Weighted				
		Low Consistency Testing	Medium Consistency Testing	High Consistency Testing			Low Consistency Testing	Medium Consistency Testing	High Consistency Testing	
All Patients	All Patients	Testing in 0 to 1 of 3 Years	Testing in 2 of 3 Years	Testing in 3 of 3 Years	*P* Value	All Patients	Testing in 0 to 1 of 3 Years	Testing in 2 of 3 Years	Testing in 3 of 3 Years	*P* Value
Person-years (percent of total)	1 051 072 (100.0)	128 000 (12.2)	185 514 (17.6)	737 558 (70.2)		3 132 810 (100.0)	1 032 290 (33.0)	1 044 699 (33.3)	1 055 821 (33.7)	
No. of years in cohort	7.5	7.1	7.4	7.6	<0.0001	7.4	7.1	7.4	7.7	<0.0001
Age at entry into cohort	75.0	76.3	75.6	74.6	<0.0001	75.0	75.1	75.0	74.9	<0.0001
Percent black	10.9	14.3	12.5	10.0	<0.0001	11.0	11.1	11.0	11.0	0.0429
Percent female	55.3	51.0	54.8	56.2	0.0002	55.3	55.4	55.4	55.2	<0.0001
Percent disabled at entry into cohort	12.7	15.5	13.6	11.9	<0.0001	12.7	12.8	12.7	12.7	<0.0001
Percent Hispanic	2.2	2.9	2.7	1.9	<0.0001	2.2	2.2	2.2	2.2	0.8734
Percent not Hispanic or black	0.9	0.8	0.9	0.9	<0.0001	0.9	0.9	0.9	0.9	0.0418
Percent Medicaid	18.4	24.8	21.7	16.4	<0.0001	18.6	19.0	18.6	18.3	0.6847
Regional surgical intensity quintile (1=lowest, 5=highest)	3.3	3.3	3.3	3.3	<0.0001	3.3	3.3	3.3	3.3	<0.0001
Percent of patients at <150% of poverty level	23.5	25.5	24.2	22.9	<0.0001	23.6	23.7	23.5	23.4	<0.0001
Charlson score (mean)	1.5	1.9	1.6	1.3	<0.0001	1.5	1.5	1.5	1.4	<0.0001
Regional mean number of unhealthy days per month	3.6	3.7	3.7	3.6	<0.0001	3.6	3.6	3.6	3.6	<0.0001
Mean number of adults with a BMI >30 (county level)	28.5	28.7	28.5	28.4	<0.0001	28.5	28.5	28.5	28.4	<0.0001
Percent of adults who smoke (county level)	19.8	20.0	19.8	19.8	<0.0001	19.8	19.9	19.8	19.8	<0.0001
Median household income in 2011 (in thousands of dollars)	53.5	51.2	52.8	54.1	<0.0001	53.5	53.5	53.6	53.4	0.0297

Continued

Table 1. Continued

	Unweighted					Inverse Propensity Weighted				
		Low Consistency Testing	Medium Consistency Testing	High Consistency Testing			Low Consistency Testing	Medium Consistency Testing	High Consistency Testing	
All Patients	All Patients	Testing in 0 to 1 of 3 Years	Testing in 2 of 3 Years	Testing in 3 of 3 Years	*P* Value	All Patients	Testing in 0 to 1 of 3 Years	Testing in 2 of 3 Years	Testing in 3 of 3 Years	*P* Value
No. of primary care provider visits per year	7.8	9.1	8.2	7.5	<0.0001	7.9	8.2	7.9	7.7	<0.0001
No. of physicians visits of any type, per year	17.0	19.7	17.7	16.3	<0.0001	17.3	18.0	17.1	16.7	<0.0001
Percent of patients with fewer than 4 physician visits per year (after having a visit in each of the 3 years during the period used to define testing categories)	9.2	11.1	10.1	8.6	<0.0001	10.3	12.0	10.5	8.5	<0.0001
Percent of patients with no physician visits in any year in the analysis (after having a visit in each of the 3 years during the period used to define testing categories)	7.8	11.9	8.3	7.0	<0.0001	9.2	12.4	8.4	7.0	<0.0001

BMI indicates body mass index.

From the American Community Survey of the US Census (https://www.census.gov/programs-surveys/acs/).

**Source:* 2012 county health rankings (all county level). Smoking is % of adults currently smoking. Unhealthy days is the mean number of physically unhealthy days per month.

†2006–2010 aggregated American community survey. Derived from census-tract-level data.

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rank, $P<0.001$). Similar trends were observed for all individual components of our adverse cardiovascular outcomes, including death, myocardial infarction, stroke, lower-extremity vascular procedures, and leg amputation (FigureB througF). We calculated unweighted hazard ratios, with surrounding 95% CIs, for each outcome, across consistency categories. These demonstrated an inverse relationship between testing consistency and the risk of death or a major adverse cardiovascular event, as well as each of its individual components (Table 2).

Cardiovascular Outcomes, by Testing Consistency in Inverse Propensity-Weighted Analyses

Because of the differences in patient characteristics across categories of testing consistency, we used inverse propensity weighting to generate 3 groups, which were similar across patient characteristics (Table 1). Many of these differences remained statistically significant given our large sample size, but all patient demographic characteristics in the inverse propensity weighted analyses varied by less than 1% across testing consistency categories.

As with our unweighted findings, Cox proportional hazards models derived from the inverse propensity-weighted cohort again demonstrated that low-consistency testing remained associated with worse cardiovascular outcomes, both in our composite outcome (MACE) and its individual components (Table 2). For example, patients receiving low-consistency testing were 16% more likely to experience a cardiovascular adverse event than those who had high-consistency testing (adjusted hazard ratio [HR]=1.16; 95% CI, 1.15–1.17; $P<0.001$). These findings were again similar for each of the components of our composite outcome.

Last, to ensure we accounted for differences in patient visit type and frequency, we repeated these analyses, but limited to patients who were seen by physicians at least 4 times per year to ensure that physicians had several opportunities to order hemoglobin A1c testing. As with our unweighted and inverse propensity-weighted analyses, we again found that low-consistency testing was associated with a higher risk of death and major adverse cardiovascular events (Table 2), with little change in the effect size evident in this sensitivity analysis.

Discussion

Hemoglobin A1c testing has been shown to be an important tool in guiding the care of patients with diabetes mellitus. Because of this, hemoglobin A1c testing has been established as an important quality measure for both physicians and health care systems. Success toward this effort is evident in our analysis, given that two thirds of patients received high-consistency testing. However, for one third of patients with diabetes mellitus in our analysis, testing did not occur in each year, and for 1 in 9, testing occurred in fewer than half of the years. These "missed opportunities" for hemoglobin A1c testing were associated with significant disparities in cardiovascular outcomes. Patients who received the least-consistent testing had the most cardiovascular complications, including significantly higher rates of myocardial infarction, stroke, amputation, and death.

These results are undoubtedly subject to the limitations of observational analyses using administrative data sets, wherein clinical details, such as the absolute value of the hemoglobin A1c test and its changes over time, are not available. However, our findings were remarkably similar and consistent across multiple endpoints and in several sensitivity analyses, suggesting that a simple confounding variable is unlikely to explain these findings directly.

Broad support for annual hemoglobin A1c testing, and for the use of annual testing as a quality metric, exists in national society guidelines, physician groups, and quality improvement organizations. However, our study, as well as others, suggests that translating these recommendations into practice has met with varying success. For example, a recent report from the US National Ambulatory Medical Care Survey suggested that more than 25% of patients followed for diabetes mellitus have missed testing opportunities.[15] These results are consistent with our observational findings in this large, national analysis of diabetic care provided to Medicare patients in the last decade.

Our results suggest that the consistency of hemoglobin A1c testing could be an important way to measure of the quality of care provided to patients with diabetes mellitus. Despite widespread endorsement and adoption, using annual hemoglobin A1c testing rates as a quality measure has little, if any, direct relationship to better cardiovascular outcomes.[28] Our work, though observational in nature, suggests that more-consistent testing over time is associated with better cardiovascular outcomes.

Is this relationship plausible, especially given that administrative data sets that allow examination of testing patterns do not current allow actual measurement of A1c testing results? A theoretical framework proposing an explanatory mechanism has been described by Presseau et al.,[29] wherein they hypothesized that highly consistent hemoglobin A1c testing is a derivative of the consistent patient and physician interactions that occur in the setting of clinical trials. Our results are consistent with this view. Whereas Presseau et al. strike a cautionary note—that raising consistency alone will not necessarily improve the quality of patient-physician interactions—testing consistency allows a determination of

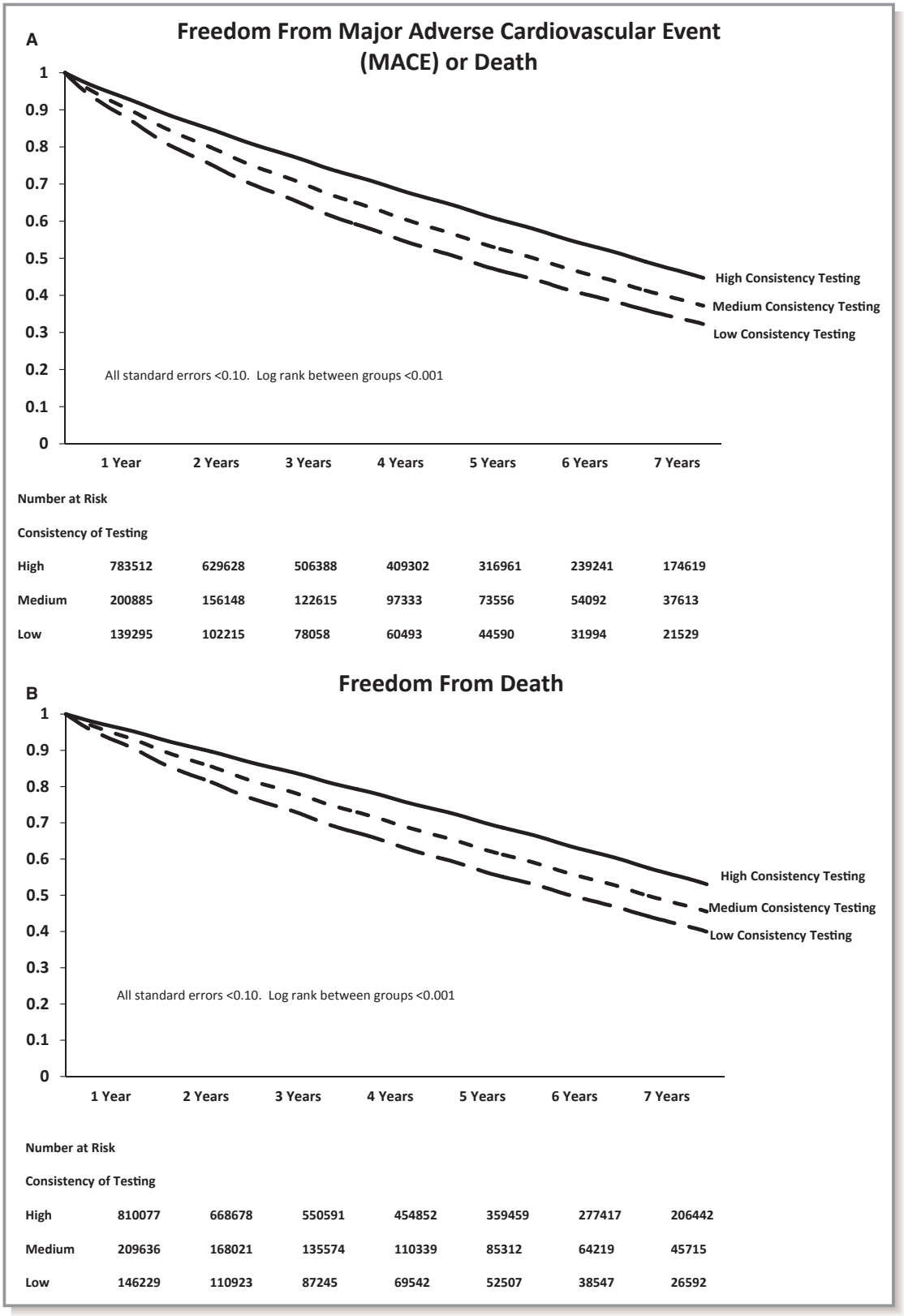
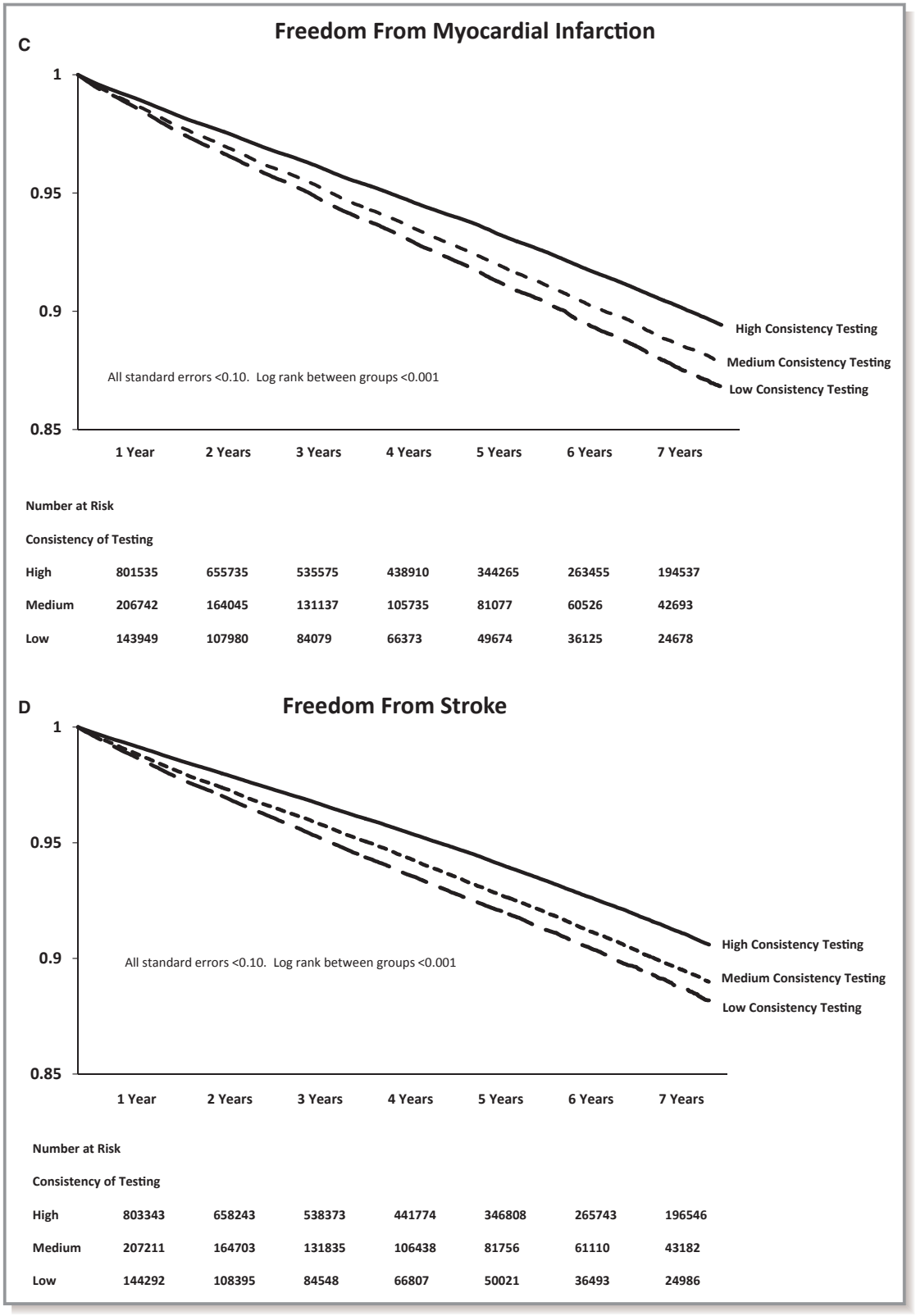


Figure. A, Freedom from major adverse cardiac events, by testing consistency category. B, Freedom from death, by testing consistency category. C, Freedom from myocardial infarction, by testing consistency category. D, Freedom from stroke, by testing consistency category. E, Freedom from leg vascular procedure, by testing consistency category. F, Freedom from amputation, by testing consistency category.



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which patients were most commonly engaged with their health care providers and are thereby likely to achieve stronger relationships with their health care team over time. These stronger relationships could potentially manifest in better outcomes, an increasingly common theme in cardiovascular care.[30,31]

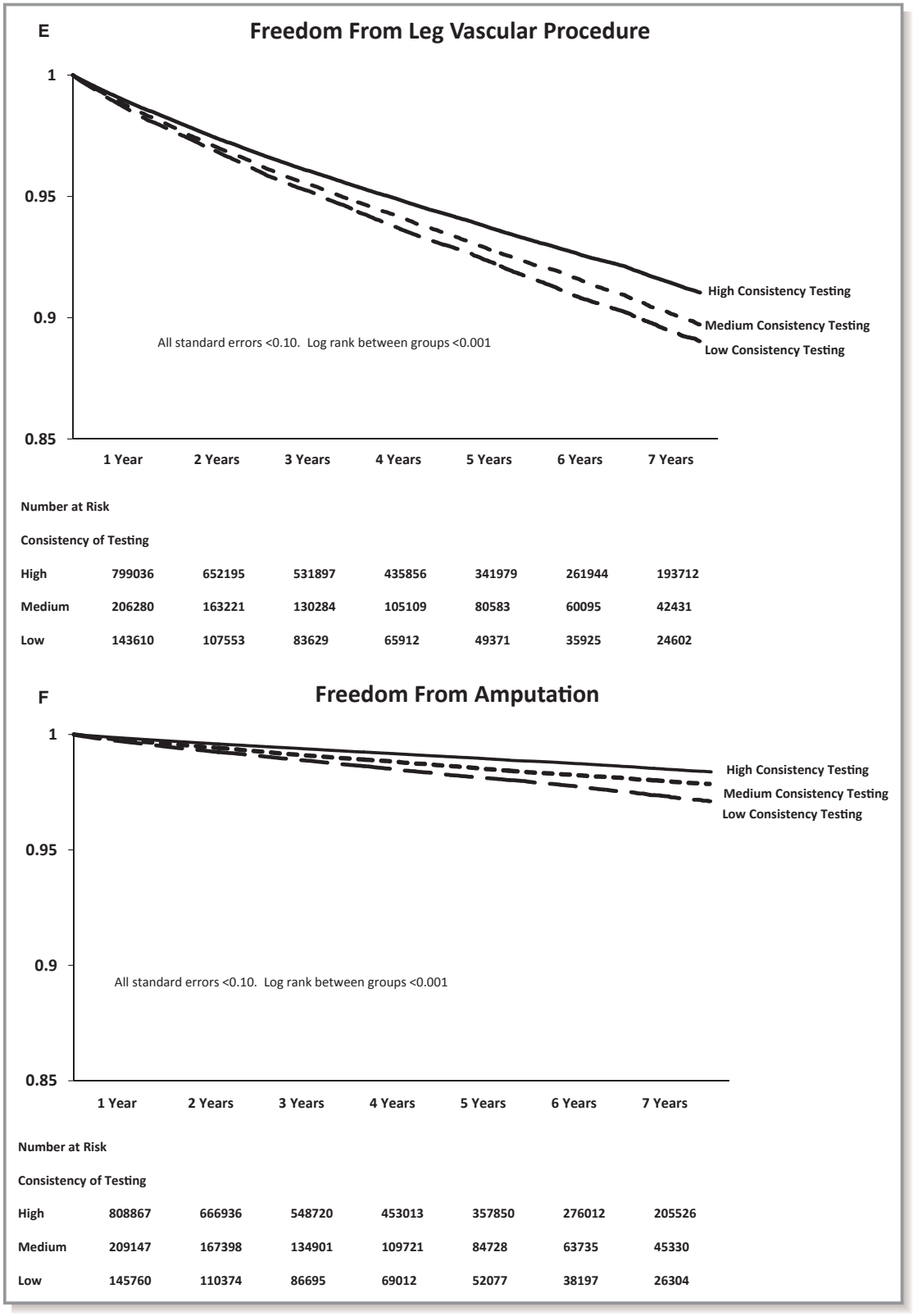

Figure. Continued

Quality metrics for providers and health care systems who care for patients with diabetes mellitus could be designed to help reach this goal. At present, only annual rates are reported in most care settings, and the longitudinal nature of hemoglobin A1C testing is not emphasized.[16,32,33] The direct association between higher-consistency testing and fewer

Table 2. Hazard Ratios for Adverse Outcomes, by Hemoglobin A1C Testing Category

	Low Consistency Testing	95% Confidence Intervals		Medium Consistency Testing	95% CIs	
Unweighted, all patients						
Any leg vascular procedure	1.12	1.08	1.15	1.09	1.06	1.11
Myocardial infarction	1.19	1.15	1.22	1.14	1.12	1.17
Death	1.21	1.20	1.23	1.12	1.11	1.13
Amputation	1.31	1.23	1.39	1.12	1.06	1.19
Stroke	1.20	1.16	1.23	1.14	1.11	1.16
Major adverse cardiovascular event	1.21	1.20	1.23	1.13	1.12	1.14
Inverse propensity weighted, all patients						
Any leg vascular procedure	1.08	1.07	1.10	1.06	1.05	1.08
Myocardial infarction	1.12	1.11	1.13	1.10	1.09	1.12
Death	1.16	1.15	1.17	1.08	1.08	1.09
Amputation	1.26	1.22	1.30	1.09	1.06	1.13
Stroke	1.16	1.14	1.17	1.11	1.09	1.12
Major adverse cardiovascular event	1.16	1.15	1.17	1.09	1.09	1.10
Inverse propensity weighted, with all patients having at least four physician visits per year						
Any leg vascular procedure	1.05	1.04	1.07	1.06	1.05	1.08
Myocardial infarction	1.08	1.06	1.09	1.09	1.08	1.11
Death	1.17	1.16	1.17	1.09	1.08	1.09
Amputation	1.23	1.19	1.27	1.08	1.05	1.12
Stroke	1.13	1.12	1.15	1.09	1.08	1.11
Major adverse cardiovascular event	1.15	1.15	1.16	1.09	1.08	1.10

deaths, myocardial infarctions, strokes, and amputations—all outcomes of significant importance to patients—makes this an important opportunity.

Building longitudinal quality measures for patients with diabetes mellitus will have obvious challenges. These metrics will measure engagement from patients as well as providers. Success would require patient compliance over time, just as much as physician compliance. These challenges, however, would also bring opportunities. For example, the clarity offered to patients from metrics emphasizing consistent testing may be easier to for patients to understand (eg, get your flu shot every year, a common Centers for Disease Control and Prevention public health message[34]) than guidelines emphasizing targeting A1c levels, which often are poorly understood by patients.[35,36] This could help patients and physicians achieve better adherence and health care engagement as they manage this challenging chronic disease. And finally, though a longitudinal "consistency" metric may be difficult to collect, new information technology systems will likely make measures of this nature easier to design and implement in future years.

As mentioned previously, our study has several important limitations. First, testing the value of testing, especially in a longitudinal sense, requires not just the evidence that hemoglobin A1C testing has been performed, but also the actual testing results. Current efforts to use "enriched" claims-based data sets that have the actual values, rather than just the use of testing for just this purpose, will help us to attain this goal.[37] Second, the main "preventive measure" we studied was hemoglobin A1C testing, which is a valuable tool for measuring diabetic care, but certainly not the only tool available for prevention of diabetic complications. Third, though our study closely examined the cardiovascular complications that occur with diabetes mellitus, we were prevented by data limitations from analyzing other types of complications, such as nephropathy and retinopathy. Fourth, hemoglobin A1c targeted diabetes mellitus management has shown variable effectiveness in limiting cardiovascular complications in randomized trials[38–40] and has shown the most efficacy in trials of patients with type 1 diabetes mellitus, a population unlikely to be specifically reflected in our population of older Medicare patients.

In summary, though more than two thirds of Medicare patients with diabetes mellitus receive hemoglobin A1c testing every year, nearly one third of these patients were not tested each year. For nearly 1 in 9 diabetic patients, hemoglobin A1c testing occurred in fewer than half of the

years in which we studied their care. Given that differences in testing consistency are associated with poorer cardiovascular outcomes, multiyear quality metrics for hemoglobin A1c testing may help improve cardiovascular care for patients with diabetes mellitus. Future efforts to limit cardiovascular complications for patients with diabetes mellitus should consider quality metrics that incentivize longitudinal approaches toward ensuring high-quality diabetic care.

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Disclosures

None.

References

1. Lachin JM, Orchard TJ, Nathan DM; Group DER. Update on cardiovascular outcomes at 30 years of the diabetes control and complications trial/epidemiology of diabetes interventions and complications study. *Diabetes Care*. 2014;37:39–43.
2. The effect of intensive treatment of diabetes on the development and progression of long-term complications in insulin-deppendent diabetes mellitus. The Diabetes Control and Complications Trial Research Group. *N Engl J Med*. 1993;329:977–986.
3. McKinlay J, Marceau L. US public health and the 21st century: diabetes mellitus. *Lancet*. 2000;356:757–761.
4. Tricco AC, Ivers NM, Grimshaw JM, Moher D, Turner L, Galipeau J, Halperin I, Vachon B, Ramsay T, Manns B, Tonelli M, Shojania K. Effectiveness of quality improvement strategies on the management of diabetes: a systematic review and meta-analysis. *Lancet*. 2012;379:2252–2261.
5. Bierman AS, Lurie N, Collins KS, Eisenberg JM. Addressing racial and ethnic barriers to effective health care: the need for better data. *Health Aff*. 2002;21:91–102.
6. Khaw KT, Wareham N, Bingham S, Luben R, Welch A, Day N. Association of hemoglobin A1c with cardiovascular disease and mortality in adults: the European prospective investigation into cancer in Norfolk. *Ann Intern Med*. 2004;141:413–420.
7. Grant RW, Kirkman MS. Trends in the evidence level for the American Diabetes Association's "Standards of Medical Care in Diabetes" from 2005 to 2014. *Diabetes Care*. 2015;38:6–8.
8. Standards of medical care in diabetes—2015: summary of revisions. *Diabetes Care*. 2015;38(suppl):S4.
9. O'Connor PJ. National quality forum white paper: towards a comprehensive diabetes quality measurement set: new measurement opportunities and methodologic challenges. Washington, DC: National Quality Forum; 2008.
10. National Committee for Quality Assurance. Healthcare effectiveness data and information set (HEDIS). Available at: www.ncqa.org. Accessed July 1, 2015.
11. Healthy people 2020 website. Available at: https://www.healthypeople.gov/. Accessed July 1, 2015.
12. Aligning forces for quality—the Robert Wood Johnson Foundation Report. Available at: http://forces4quality.org/. Accessed July 1, 2015.
13. Full and partial after care. ADA guidelines. *N Y State Dent J*. 1977;43:274.
14. Executive summary: standards of medical care in diabetes—2013. *Diabetes Care*. 2013;36(suppl 1):S4–S10.
15. Taylor C. The adherence of primary care providers to the Americans for Diabetes Association guideline for frequency of A1c testing. Amherst, MA: University of Massachusetts Scholarworks; 2014.
16. Managing diabetes complications: recommendations from the national committee on quality assurance. Available at: http://www.ncqa.org/Publications Products/OtherProducts/QualityProfiles/FocusonDiabetes/ManagingDiabetesComplications.aspx. Accessed July 1, 2015.
17. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. *J Clin Epidemiol*. 1992;45:613–619.
18. The Dartmouth Atlas of Healthcare. Hanover, NH: Dartmouth College Press; 2015.
19. Wennberg DE, Sharp SM, Bevan G, Skinner JS, Gottlieb DJ, Wennberg JE. A population health approach to reducing observational intensity bias in health risk adjustment: cross sectional analysis of insurance claims. *BMJ*. 2014;348:g2392.
20. Goodney PP, McClurg A, Spangler EL, Brooke BS, DeMartino RR, Stone DH, Nolan BW. Preventive measures for patients at risk for amputation from diabetes and peripheral arterial disease. *Diabetes Care*. 2014;37:e139–e140.
21. Yasaitis LC, Bubolz T, Skinner JS, Chandra A. Local population characteristics and hemoglobin A1c testing rates among diabetic Medicare beneficiaries. *PLoS One*. 2014;9:e111119.
22. Yasaitis LC, Bynum JP, Skinner JS. Association between physician supply, local practice norms, and outpatient visit rates. *Med Care*. 2013;51:524–531.
23. Colla CH, Goodney PP, Lewis VA, Nallamothu BK, Gottlieb DJ, Meara E. Implementation of a pilot accountable care organization payment model and the use of discretionary and nondiscretionary cardiovascular care. *Circulation*. 2014;130:1954–1961.
24. Goodney PP, Travis LL, Malenka D, Bronner KK, Lucas FL, Cronenwett JL, Goodman DC, Fisher ES. Regional variation in carotid artery stenting and endarterectomy in the Medicare population. *Circ Cardiovasc Qual Outcomes*. 2010;3:15–24.
25. Goodney PP, Holman K, Henke PK, Travis LL, Dimick JB, Stukel TA, Fisher ES, Birkmeyer JD. Regional intensity of vascular care and lower extremity amputation rates. *J Vasc Surg*. 2013;57:1471–1479, 1480.e1471-1473; discussion 1479-1480
26. Lunceford JK, Davidian M. Stratification and weighting via the propensity score in estimation of causal treatment effects: a comparative study. *Stat Med*. 2004;23:2937–2960.
27. Li F, Zaslavsky AM, Landrum MB. Propensity score weighting with multilevel data. *Stat Med*. 2013;32:3373–3387.
28. Lyon AW, Higgins T, Wesenberg JC, Tran DV, Cembrowski GS. Variation in the frequency of hemoglobin A1c (HbA1c) testing: population studies used to assess compliance with clinical practice guidelines and use of HbA1c to screen for diabetes. *J Diabetes Sci Technol*. 2009;3:411–417.
29. Presseau J, Hawthorne G, Sniehotta FF, Steen N, Francis JJ, Johnston M, Mackintosh J, Grimshaw JM, Kaner E, Elovainio M, Deverill M, Coulthard T, Brown H, Hunter M, Eccles MP. Improving diabetes care through examining, advising, and prescribing (IDEA): protocol for a theory-based cluster randomised controlled trial of a multiple behaviour change intervention aimed at primary healthcare professionals. *Implement Sci*. 2014;9:61.
30. Ho PM, Bryson CL, Rumsfeld JS. Medication adherence: its importance in cardiovascular outcomes. *Circulation*. 2009;119:3028–3035.
31. Brooke BS, Goodney PP, Kraiss LW, Gottlieb DJ, Samore MH, Finlayson SR. Readmission destination and risk of mortality after major surgery: an observational cohort study. *Lancet*. 2015;386:884–895.
32. Jencks SF, Huff ED, Cuerdon T. Change in the quality of care delivered to Medicare beneficiaries, 1998–1999 to 2000–2001. *JAMA*. 2003;289:305–312.
33. The national committe for quality assurance. Available at: www.ncqa.org. Accessed July 1, 2015.
34. Centers for disease control website: key facts about seasonal flu vaccine Available at: www.cdc.gov. Accessed January 1, 2016.
35. Hewitt J, Smeeth L, Chaturvedi N, Bulpitt CJ, Fletcher AE. Self management and patient understanding of diabetes in the older person. *Diabet Med*. 2011;28:117–122.
36. Delamater AM. Improving patient adherence. *Clin Diabetes*. 2006;24:71–77.
37. Tomek IM, Sabel AL, Froimson MI, Muschler G, Jevsevar DS, Koenig KM, Lewallen DG, Naessens JM, Savitz LA, Westrich JL, Weeks WB, Weinstein JN. A collaborative of leading health systems finds wide variations in total knee replacement delivery and takes steps to improve value. *Health Aff*. 2012;31:1329–1338.

38. Intensive blood-glucose control with sulphonylureas or insulin compared with conventional treatment and risk of complications in patients with type 2 diabetes (UKPDS 33). UK Prospective Diabetes Study (UKPDS) Group. *Lancet*. 1998;352:837–853.

39. Action to Control Cardiovascular Risk in Diabetes Study G, Gerstein HC, Miller ME, Byington RP, Goff DC Jr, Bigger JT, Buse JB, Cushman WC, Genuth S, Ismail-Beigi F, Grimm RH Jr, Probstfield JL, Simons-Morton DG, Friedewald WT. Effects of intensive glucose lowering in type 2 diabetes. *N Engl J Med*. 2008;358:2545–2559.

40. Group AC, Patel A, MacMahon S, Chalmers J, Neal B, Billot L, Woodward M, Marre M, Cooper M, Glasziou P, Grobbee D, Hamet P, Harrap S, Heller S, Liu L, Mancia G, Mogensen CE, Pan C, Poulter N, Rodgers A, Williams B, Bompoint S, de Galan BE, Joshi R, Travert F. Intensive blood glucose control and vascular outcomes in patients with type 2 diabetes. *N Engl J Med*. 2008;358:2560–2572.

SUPPLEMENTAL MATERIAL

Data S1: ICD9 and CPT codes used to identify patients with diabetes, as well as major adverse cardiovascular outcomes in our analysis.

Diabetes Diagnosis Codes:		
249.xx	Secondary diabetes mellitus	
250.xx	Diabetes mellitus	
Myocardial Infarction Diagnosis Codes:		
410.xx: Acute myocardial infarction		
411.xx: Other acute and subacute forms of ischemic heart disease		
412.xx: Old myocardial infarction		
413.xx: Angina pectoris		
414.xx: Other forms of chronic ischemic heart disease		
Stroke Diagnosis Codes:		
433.00 to 433.91: occlusion/stenosis, precerebral artery		
342 or 438: history of previous stroke		
435 or 781.4: transient ischemic attack		
362.34 or 368.12: amaurosis fugax		
997.0, 997.00, 997.01, and 997.09: In-hopsital stroke.		
Amputation Procedure Codes		
27590	AMPUTATION THIGH THROUGH FEMUR ANY LEVEL	
27591	AMP THI THRU FEMUR LVL IMMT FITG TQ W/1ST CST	
27592	AMPUTATION THIGH THRU FEMUR OPEN CIRCULAR	
27880	AMPUTATION LEG THROUGH TIBIA&FIBULA	
27881	AMP LEG THRU TIBFIB W/IMMT FITG TQ W/1ST CST	
27882	AMPUTATION LEG THRU TIBIA&FIBULA OPEN CIRCULAR	
Leg Vascular Procedure Codes		
36200	INTRODUCTION CATHETER AORTA	
36245	SLCTV CATHJ EA 1ST ORD ABDL PEL/LXTR ART BRNCH	
36246	SLCTV CATHJ 2ND ORDER ABDL PEL/LXTR ART BRNCH	
36247	SLCTV CATHJ 3RD+ ORD SLCTV ABDL PEL/LXTR	

	BRNCH
36248	SLCTV CATHJ EA 2ND+ ORD ABDL PEL/LXTR ART BRNCH
0238T	TRLUML PERIPHERAL ATHERECTOMY ILIAC ARTERY EA
35452	TRLUML BALLOON ANGIOPLASTY OPEN AORTIC
35454	TRLUML BALO ANGIOP OPN ILIAC
35456	TRLUML BALO ANGIOP OPN FEM-POP
35459	TRLUML BALO ANGIOP OPN TIBIOPRONEAL TRNK&BRNCH
35470	TRLUML BALO ANGIOP PRQ TIBPRNL TRNK/BRNCH EA
35472	TRLUML BALLOON ANGIOPLASTY PERCUTANEOUS AORTIC
35473	TRLUML BALO ANGIOP PRQ ILIAC
35474	TRLUML BALO ANGIOP PRQ FEMPOP
35481	TRLUML PRPH ATHRC OPN AORTIC
35482	TRLUML PRPH ATHRC OPN ILIAC
35483	TRLUML PRPH ATHRC OPN FEMPOP
35485	TRLUML PRPH ATHRC OPN TIBPRNL TRNK&BRNCH
35491	TRLUML PRPH ATHRC PRQ AORTIC
35492	TRLUML PRPH ATHRC PRQ ILIAC
35493	TRLUML PRPH ATHRC PRQ FEMPOP
35495	TRLUML PRPH ATHRC PRQ TIBPRNL TRNK&BRNCH
37205	TCAT PLMT IV STENT PERCUTANEOUS 1ST VESSEL
37206	TCAT PLMT IV STENT PERCUTANEOUS EACH ADDL VESSEL
37207	TCAT PLMT IV STENT OPEN 1ST VESSEL
37208	TCAT PLMT IV STENT OPEN EACH ADDL VESSEL
37220	REVASCULARIZATION ILIAC ARTERY ANGIOP 1ST VSL
37221	REVSC OPN/PRQ ILIAC ART W/STNT PLMT & ANGIOPLSTY
37222	REVASCULARIZATION ILIAC ART ANGIOP EA IPSI VSL
37223	REVSC OPN/PRQ ILIAC ART W/STNT & ANGIOP IPSILATL
37224	REVSC OPN/PRG FEM/POP W/ANGIOPLASTY UNI
37225	REVSC OPN/PRQ FEM/POP W/ATHRC/ANGIOP SM VSL
37226	REVSC OPN/PRQ FEM/POP W/STNT/ANGIOP

	SM VSL
37227	REVSC OPN/PRQ FEM/POP W/STNT/ATHRC/ANGIOP SM VSL
37228	REVSC OPN/PRQ TIB/PERO W/ANGIOPLASTY UNI
37229	REVSC OPN/PRQ TIB/PERO W/ATHRC/ANGIOP SM VSL
37230	REVSC OPN/PRQ TIB/PERO W/STNT/ANGIOP SM VSL
37231	REVSC OPN/PRQ TIB/PERO W/STNT/ATHR/ANGIOP SM VSL
37232	REVSC OPN/PRQ TIB/PERO W/ANGIOPLASTY UNI EA VSL
37233	REVSC OPN/PRQ TIB/PERO W/ATHRC/ANGIOP UNI EA VSL
37234	REVSC OPN/PRQ TIB/PERO W/STNT/ANGIOP UNI EA VSL
37235	REVSC OPN/PRQ TIB/PERO W/STNT/ATHR/ANGIOP EA VSL
35302	TEAEC W/GRAFT SUPERFICIAL FEMORAL ARTERY
35303	TEAEC W/GRAFT POPLITEAL ARTERY
35304	TEAEC W/GRAFT TIBIOPERONEAL TRUNK ARTERY
35305	TEAEC W/GRAFT TIBIAL/PERONEAL ART 1ST VESSEL
35306	TEAEC W/GRAFT EA ADDL TIBIAL/PERONEAL ART
35351	TEAEC W/WO PATCH GRAFT ILIAC
35355	TEAEC W/WO PATCH GRAFT ILIOFEMORAL
35361	TEAEC W/WO PATCH GRAFT COMBINED AORTOILIAC
35363	TEAEC W/WO PATCH GRAFT COMBINED AORTOILIOFEMORAL
35371	TEAEC W/WO PATCH GRAFT COMMON FEMORAL
35372	TEAEC W/WO PATCH GRAFT DEEP PROFUNDA FEMORAL
35521	BYPASS W/VEIN AXILLARY-FEMORAL
35533	BYPASS W/VEIN AXILLARY-FEMORAL-FEMORAL
35538	BYPASS W/VEIN AORTOBI-ILIAC
35539	BYPASS W/VEIN AORTOFEMORAL
35540	BYPASS W/VEIN AORTOBIFEMORAL
35541	BYP W/VEIN AORTOILIAC/BI-ILIAC
35546	BYP W/VEIN AORTOFEM/BIFEM

35548	BYP W/VEIN AORTOILIOFEM UNI
35549	BYP W/VEIN AORTOILIOFEM BI
35551	BYP W/VEIN AORTOFEMPOP
35556	BYPASS W/VEIN FEMORAL-POPLITEAL
35558	BYPASS W/VEIN FEMORAL-FEMORAL
35563	BYPASS W/VEIN ILIOILIAC
35565	BYPASS W/VEIN ILIOFEMORAL
35566	BYP FEM-ANT TIBL PST TIBL PRONEAL ART/OTH DSTL
35571	BYP W/VEIN POP-TIBL-PRONEAL ART/OTH DSTL VSL
35583	IN-SITU VEIN BYPASS FEMORAL-POPLITEAL
35585	IN-SITU FEM-ANT TIBL PST TIBL/PRONEAL ART
35587	IN-SITU VEIN BYP POP-TIBL PRONEAL
35621	BYP OTH/THN VEIN AXILLARY-FEMORAL
35623	BYP OTH/THN VEIN AXILLARY-POPLITEAL/-TIBIAL
35637	BYP OTH/THN VEIN AORTOILIAC
35638	BYP OTH/THN VEIN AORTOBI-ILIAC
35646	BYP OTH/THN VEIN AORTOBIFEMORAL
35647	BYP OTH/THN VEIN AORTOFEMORAL
35651	BYP OTH/THN VEIN AORTOFEMPOP
35654	BYP OTH/THN VEIN AXILLARY-FEMORAL-FEMORAL
35656	BYP OTH/THN VEIN FEMORAL-POPLITEAL
35661	BYP OTH/THN VEIN FEMORAL-FEMORAL
35663	BYP OTH/THN VEIN ILIOILIAC
35665	BYP OTH/THN VEIN ILIOFEMORAL
35666	BYP OTH/THN VEIN FEM-ANT TIBL PST TIBL/PRONEAL
35671	BYP OTH/THN VEIN POPLITEAL-TIBIAL/-PERONEAL ART
35681	BYPASS COMPOSITE GRAFT PROSTHETIC & VEIN
35682	BYP AUTOG COMPOSIT 2 SEG VEINS FROM 2 LOCATIONS
35683	BYP AUTOG COMPOSIT 3/> SEG FROM 2/> LOCATION
35879	REVJ LXTR ARTL BYP OPN VEIN PATCH ANGIOP
35881	REVJ LXTR ARTL BYP OPN W/SGMTL VEIN INTERPOS
35883	REVISION FEMORAL ANAST OPEN NONAUTOG GRAFT
35884	REVISION FEMORAL ANAST OPEN W/AUTOG GRAFT