Adjustment for Atherosclerosis Diagnosis Distorts the Effects of Percutaneous Coronary Intervention and the Ranking of Hospital Performance

Bijan A. Niknam, BS; Alexander F. Arriaga, MD, MPH, ScD; Paul R. Rosenbaum, PhD; Alexander S. Hill, BS; Richard N. Ross, MS; Orit Even-Shoshan, MS; Patrick S. Romano, MD, MPH; Jeffrey H. Silber, MD, PhD

Background—Coronary atherosclerosis raises the risk of acute myocardial infarction (AMI), and is usually included in AMI risk-adjustment models. Percutaneous coronary intervention (PCI) does not cause atherosclerosis, but may contribute to the notation of atherosclerosis in administrative claims. We investigated how adjustment for atherosclerosis affects rankings of hospitals that perform PCI.

Methods and Results—This was a retrospective cohort study of 414 715 Medicare beneficiaries hospitalized for AMI between 2009 and 2011. The outcome was 30-day mortality. Regression models determined the association between patient characteristics and mortality. Rankings of the 100 largest PCI and non-PCI hospitals were assessed with and without atherosclerosis adjustment. Patients admitted to PCI hospitals or receiving interventional cardiology more frequently had an atherosclerosis diagnosis. In adjustment models, atherosclerosis was associated, implausibly, with a 42% reduction in odds of mortality (odds ratio=0.58, *P*<0.0001). Without adjustment for atherosclerosis, the number of expected lives saved by PCI hospitals increased by 62% (*P*<0.001). Hospital rankings also changed: 72 of the 100 largest PCI hospitals had better ranks without atherosclerosis adjustment, while 77 of the largest non-PCI hospitals had worse ranks (*P*<0.001).

Conclusions—Atherosclerosis is almost always noted in patients with AMI who undergo interventional cardiology but less often in medically managed patients, so adjustment for its notation likely removes part of the effect of interventional treatment. Therefore, hospitals performing more extensive imaging and more PCIs have higher atherosclerosis diagnosis rates, making their patients appear healthier and artificially reducing the expected mortality rate against which they are benchmarked. Thus, atherosclerosis adjustment is detrimental to hospitals providing more thorough AMI care. (***J Am Heart Assoc***. 2018;7:e008366. DOI: 10.1161/JAHA.117.008366.)

Key Words: atherosclerosis • percutaneous coronary intervention • quality and outcomes

Coronary heart disease affects >15 million adults and is a leading cause of mortality, responsible for ≈1 in 7 US deaths in 2013.[1] Coronary atherosclerosis is the most common cause of myocardial ischemia,[2] which can lead to acute myocardial infarction (AMI). In 2011, MI ($11.5 billion) and coronary atherosclerosis ($10.4 billion) were 2 of the 10 most expensive US hospital principal discharge diagnoses.[1,3] As a dominant source of morbidity and cost in the healthcare system, AMI has long been a focus of hospital quality measurement.

Percutaneous coronary interventions (PCI), such as percutaneous transluminal coronary angioplasty, are commonly

Clinical Perspective

What Is New?

- While coronary atherosclerosis is a risk factor for acute myocardial infarction (AMI), its notation on an administrative claim may be affected by hospital practice patterns.
- Although biologically implausible, adjustment models used by the Centers for Medicare & Medicaid Services suggest that a diagnosis of atherosclerosis is associated with an ≈40% reduction in the odds of 30-day mortality in older Medicare beneficiaries hospitalized for AMI.
- Adjusted comparisons of hospital AMI outcomes that include atherosclerosis in the risk-adjustment model may underestimate the quality of percutaneous coronary intervention hospitals and overestimate the quality of non–percutaneous coronary intervention hospitals.

What Are the Clinical Implications?

- Hospitals that more frequently use interventional cardiology for treatment of AMI may be adversely affected by AMI mortality models that adjust for atherosclerosis.
- The notation of atherosclerosis on an administrative claim in the context of performing a percutaneous coronary intervention could introduce bias to comparisons of hospital quality of AMI care.

used in the elective workup[4] and urgent management[5] of coronary artery disease, including severe types of AMI such as ST-elevation MI. Percutaneous transluminal coronary angioplasty has been described as among the definitive medical advances of modern cardiology.[6] Current guidelines note coronary angioplasty to be the treatment of choice for management of ST-elevation MI if performed within certain parameters.[5]

Atherosclerosis can begin early in life and exist asymptomatically for decades. Atherosclerosis of the coronary arteries has been described in autopsy studies of young individuals, as well as in US soldiers killed in various conflicts.[7–11] While coronary atherosclerosis may frequently be present in older patients with coronary heart disease, its presence might not be noted as frequently in the absence of coronary arteriography or PCI.

In adjustment models used by the Centers for Medicare & Medicaid Services (CMS), a diagnosis of coronary atherosclerosis or angina is implausibly associated with a ≈40% reduction in the odds of 30-day mortality in older Medicare beneficiaries.[12] Is it conceivable for atherosclerosis to cut risk of death from AMI by almost half? If not, what is the mechanism by which such an association is produced?

To be valid, a risk factor or covariate must describe the condition of the patient before treatment, and its value must not be changed by the treatment a patient subsequently

receives.[13] As a biological condition, atherosclerosis upon admission is a valid risk factor, but if its notation in a medical chart or in administrative claims is affected by PCI, then its notation is not a risk factor but rather a consequence of treatment. If models adjust for consequences of a treatment, they remove or distort the effects of that treatment. This study explores the implications of adjustment for atherosclerosis when auditing hospitals for quality of AMI care.

Methods

Data use agreements with the CMS do not permit data sharing, but the corresponding author may be contacted for additional details on analytic methods.

Data Set

This research protocol was approved by the institutional review board of Children's Hospital of Philadelphia; informed consent was not required because the institutional review board determined this was not human subjects research. We studied older Medicare beneficiaries admitted to short-term acute-care hospitals nationwide with a principal diagnosis of AMI between July 1, 2009 and November 30, 2011 in the Medicare Provider Analysis and Review file, with additional data drawn from the Outpatient, Carrier/Part B, and Hospice files. We followed methods established by Krumholz et al for application to Medicare administrative claims data.[14–17] Using the master beneficiary summary file, we excluded patients <65.5 years of age at admission, who had missing sex, who were admitted from hospice, whose date of death preceded the admission date, or who lacked Part B coverage or were in a Health Maintenance Organization at any point in the 6 months before admission. As is done for CMS AMI quality assessment, outcomes for transferred patients were assigned to the first admitting hospital[14–17] (Table S1). If a patient had multiple qualifying admissions, we chose a random one.

Patient Characteristics

We defined each patient's age at admission, sex, category of AMI principal diagnosis, and comorbidities validated for AMI risk-adjustment using the inpatient record, any bills from other files in the 6 months before admission, or both, as indicated in established methods in use by Medicare.[14–17] *International Classification of Diseases Ninth Revision* (*ICD-9*) diagnosis codes in the 412 to 414 groups or *ICD-9* code 74685 indicated a diagnosis of coronary atherosclerosis or angina.[14–17] We determined history of percutaneous transluminal coronary angioplasty or coronary artery bypass grafting (CABG) via the same process as was used for ascertaining comorbidities. Using the index inpatient

bill, we also established whether each patient underwent PCI or CABG during the admission.

Hospital Characteristics

We defined a hospital as providing PCI services if they had a minimum of 10 inpatient bills per year noting a PCI in the procedure code fields, using *ICD-9* procedure codes 00.66, 17.55, 36.01, 36.02, and 36.05 to 36.07. We also defined other hospital characteristics using the Medicare Provider of Services file[18]: teaching status, size in beds, nurse-to-bed ratio, nurse-mix, and the availability of comprehensive cardiac technology (the presence of a coronary care unit and catheterization laboratory, and provision of cardiothoracic surgery services).

Outcomes

We examined all-location mortality within 30 days of admission.

Statistical Analysis

Mortality was modeled using LOGISTIC and GLIMMIX proce-dures in SAS Version 9.3 for UNIX.[19] Models adjusted for age, sex, AMI principal diagnosis type, history of percutaneous transluminal coronary angioplasty or CABG, and comorbidi-ties, following as closely as possible the established methods in use by Medicare for hospital quality assessment.[12,14–16] Hierarchical models added hospitals as random effects. The 2 types of models were each fit with and without atheroscle-rosis in the comorbidity set.

In each logit model, we calculated the risk-adjusted number of expected deaths had all patients been treated at PCI hospitals versus non-PCI hospitals, a form of direct standardization.[20,21]

In analyses that ranked hospitals, rather than use the logit models to calculate observed-to-expected (O/E) mortality rates for each hospital, we used the CMS hierarchical model to calculate predicted-to-expected (P/E) mortality ratios. The P/E mortality rate differs from the O/E mortality rate in that, unlike the O/E ratio, which uses a hospital's own actual death rate as the numerator, the CMS hierarchical model yields a predicted mortality rate ("P") that is based partially on a hospital's own death rate and partially on the national death rate. In the CMS hierarchical model, the weighting of P/E toward the hospital's own outcome rate versus the national outcome rate is contingent, in part, upon the hospital's volume, with lower-volume hospitals' P/E weighted more toward the national outcome rate. The CMS model has been criticized for shrinking to a national mean rather than a mean more appropriate to a hospital's specific characteristics[22–24];

regardless, P/E is believed to yield a more stabilized hospital estimate for smaller hospitals, and is the measure used by CMS. We likewise calculated and reported hospital ranks using P/E mortality ratios from CMS hierarchical models generated by the GLIMMIX procedure in SAS.[19]

Adjusted 30-day mortality rates for PCI hospitals and non-PCI hospitals were calculated by summing the predicted mortality and expected mortality from the hierarchical models for all patients at PCI hospitals and for all patients at non-PCI hospitals, then dividing them to form a P/E mortality ratio for each type of hospital. We then multiplied the national mortality rate by these P/E mortality ratios to obtain adjusted mortality rates for PCI hospitals and non-PCI hospitals.

In each hierarchical model, we calculated P/E mortality for the 100 largest PCI hospitals and 100 largest non-PCI hospitals, and ranked them from smallest to largest, with a rank of 1 signifying the smallest (best) P/E ratio. We then determined how their ranks among all hospitals were affected by removing atherosclerosis by subtracting each hospital's rank in the first model from its rank in the second. Inferences that compare pairs of 2 models, 1 with and 1 without atherosclerosis, used the bootstrap.[25]

A 2-tailed *P* value was significant if ≤0.05.

Role of the Funding Source

The Agency for Healthcare Research and Quality had no role in the design and conduct of the study; collection, manage-ment, analysis, and interpretation of the data; and prepara-tion, review, or approval of the article.

Results

Patient Characteristics by Hospital PCI Status

Table 1 shows patient and hospital characteristics split by whether patients were admitted to PCI hospitals or non-PCI hospitals. Important differences can be observed between patients at PCI hospitals and non-PCI hospitals. Patients at PCI hospitals were younger on admission. Also, patients at PCI hospitals more frequently had ST-elevation MIs amenable to treatment with PCI than patients at non-PCI hospitals (just >25% in PCI hospitals, compared with <10% at non-PCI hospitals).

In comparison to non-PCI hospitals, PCI hospitals were more often teaching hospitals, with larger bed size and better technology and nursing characteristics. For example, 35% of patients in the PCI hospital group were treated at teaching hospitals, compared with 16.9% of patients in the non-PCI hospital group. Similarly, 38.7% of PCI hospital patients were seen at hospitals with comprehensive cardiac technology, compared with just 3.2% of patients at non-PCI hospitals.

Table 1. Differences in Patient Demographics, MI Types, and Hospital Characteristics Between PCI and Non-PCI Hospitals

Covariate	All Patients	Patients at PCI Hospitals	Patients at Non-PCI Hospitals
Number of patients	414 715	359 685	55 030
Age at admission, y (mean)	78.2	77.9	80.6
Sex (% male)	52.0	53.1	44.9
Anterior or anterolateral MI (principal diagnoses 410.00–410.11)	9.6	10.5	4.0
Other ST-elevation MI of specified sites (principal diagnoses 410.20–410.61)	13.7	15.2	4.6
History of PTCA	5.6	5.8	4.2
History of CABG	7.2	7.2	6.7
Hospital characteristics			
% at teaching hospitals	32.6	35.1	16.9
% at large hospitals (size >250 beds)	71.1	77.9	26.5
% at hospitals with comprehensive cardiac technology*	33.9	38.7	3.2
Nurse-to-bed ratio (mean)	1.34	1.36	1.20
Nurse mix (% RNs, mean)	0.90	0.90	0.86

CABG indicates coronary artery bypass graft; MI, myocardial infarction; PCI, percutaneous coronary intervention; PTCA, percutaneous transluminal coronary angioplasty; RN, registered nurse.
*Presence of a cardiac catheterization laboratory and a coronary care unit, and provision of cardiothoracic surgery services.

Comorbidities by Hospital PCI Status

Table 2 shows comorbidity rates split by hospital PCI status. Patients at PCI hospitals had lower rates of all comorbidities except for coronary atherosclerosis or angina, which was diagnosed in 86.5% of patients at PCI hospitals, compared with 70.1% of patients at non-PCI hospitals. When directly comparing patients by treatment status rather than hospital type, patients who received PCI or underwent CABG had a rate of atherosclerosis diagnosis of 93.9%, compared with 75.4% among those who were managed medically (Table S2).

Atherosclerosis in Mortality Models

Although biologically implausible, the hierarchical model suggested that a diagnosis of atherosclerosis was associated with a reduction in the risk of death, the odds of death being reduced by a factor of 0.58 (95% confidence interval [CI], 0.55–0.61, $P<0.0001$) when compared with patients without a diagnosis of atherosclerosis. The logit model reached similar conclusions. See Tables S3 and S4 for hierarchical and logistic model results, respectively.

Atherosclerosis and Hospital Quality Assessment

The logit model with atherosclerosis estimated 4311 lives saved had all patients been treated at PCI hospitals (95% CI, 3111–5566). Removing atherosclerosis changed that estimate to 7296 lives saved had all patients been treated at PCI

hospitals (95% CI, 6048–8553), an increase of 2985, or 62% (95% CI, 2781–3173, $P<0.001$) (Table S5).

The bottom of Table 2 reports unadjusted mortality rates as well as adjusted mortality rates given by the hierarchical models. Unadjusted mortality rates at PCI hospitals and non-PCI hospitals were 13.7% and 18.1%, respectively, a difference of 4.4% between PCI hospitals and non-PCI hospitals. Adjusted mortality with atherosclerosis in the model was 14.1% at PCI hospitals and 14.4% at non-PCI hospitals, a difference of 0.3% between PCI hospitals and non-PCI hospitals. After removing atherosclerosis from the model, adjusted mortality at PCI hospitals declined to 14.0%, while adjusted mortality at non-PCI hospitals increased to 14.6%, a difference of 0.6% between PCI hospitals and non-PCI hospitals (Table S6).

Does adjustment for atherosclerosis affect the ranking of hospitals? The Figure shows that it does. After removing atherosclerosis from the hierarchical model, 72 of the 100 largest PCI hospitals had better rankings (95% CI, 70–81), while 77 of the 100 largest non-PCI hospitals had worse rankings (95% CI, 69–80). The alteration of the model had a significantly different effect on the 100 largest PCI hospitals relative to the 100 largest non-PCI hospitals ($P<0.001$). See Table S7 for details of hospital rank changes and bootstrap results.

Discussion

The biological condition of atherosclerosis is a known risk factor for cardiovascular disease and AMI. Its presence in a

Table 2. Excess Rate of Atherosclerosis Diagnosis Among Patients at PCI Hospitals

Comorbidity	Patients at PCI Hospitals	Patients at Non-PCI Hospitals	Difference
Number of patients	359 685	55 030	
Congestive heart failure	26.9	37.7	−10.8
Past myocardial infarction	15.0	20.4	−5.4
Unstable angina	14.4	18.7	−4.4
Coronary atherosclerosis or angina	86.5	70.1	*+16.4*
Cardiorespiratory failure or shock	9.3	12.4	−3.1
Valvular or rheumatic heart disease	29.7	31.4	−1.7
Hypertension	84.9	85.5	−0.6
Stroke	5.8	7.9	−2.1
Cerebrovascular disease	14.2	16.7	−2.4
Renal failure	19.5	24.9	−5.4
Chronic obstructive pulmonary disease	27.2	32.5	−5.3
Pneumonia	23.2	30.5	−7.3
Diabetes mellitus	42.7	45.7	−3.0
Malnutrition	5.2	6.4	−1.3
Dementia	16.2	25.0	−8.8
Paraplegia	4.7	6.2	−1.5
Peripheral vascular disease	21.0	25.0	−4.0
Cancer	3.5	4.0	−0.5
Trauma	21.9	26.4	−4.5
Major psychiatric disorders	6.5	9.1	−2.6
Chronic liver disease	1.1	1.3	−0.2
Outcomes			
Unadjusted 30-d mortality, %	13.7	18.1	−4.4
Adjusted 30-d mortality* including atherosclerosis, %	14.1	14.4	−0.3
Adjusted 30-d mortality* omitting atherosclerosis, %	14.0	14.6	−0.6

PCI indicates percutaneous coronary intervention; P/E, predicted-to-expected mortality ratios.

*Adjusted 30-day mortality rates are computed by multiplying the national mortality rate by the P/E mortality ratio for each type of hospital given by the 2 models with and without atherosclerosis.

patient with AMI should not lower the patient's risk of death, but adjustment models presently in use suggest that it does. We found that the diagnosis of atherosclerosis was more prevalent in patients who were admitted to PCI hospitals or who underwent PCI. Possibly, the mere notation of atherosclerosis in a hospital chart or administrative claim may be a consequence of PCI or admission to hospitals that provide more thorough cardiac workup. While another possibility is that patients with atherosclerosis are more likely to be admitted to PCI hospitals, it must be remembered that all these patients were admitted for AMI, so it would be unlikely that the chronic condition of atherosclerosis would determine which hospital a patient should be brought to. Rather than the presence of atherosclerosis driving the type

of hospital a patient is admitted to in the context of an AMI, it is far more plausible that diagnosis of this common medical condition is more frequently detected via interventions that can discover it. Adjusting for a consequence of treatment can, and typically does, distort the estimate of the effect caused by the treatment: it may, and typically does, remove part of the actual effect.[13] In this case, some of the effect of interventional treatment for AMI may instead be misleadingly transferred to the diagnosis of atherosclerosis. Thus, adjusting for atherosclerosis can potentially be harmful to the ranking of hospitals that treat AMI patients more thoroughly.

How does this distortion occur? Table 3 shows 1 hypothetical patient who is 75 years old, male, and at the onset of a MI, may be admitted to 2 nearby hospitals A and B. Hospital
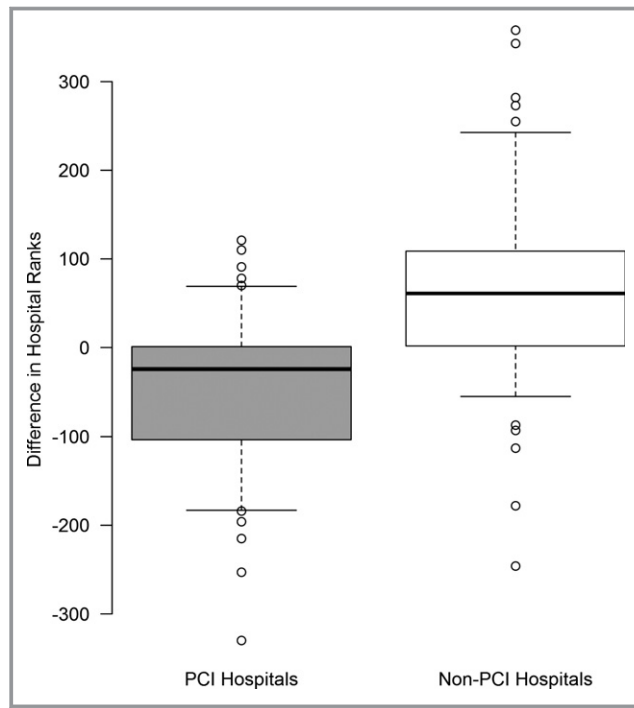
Figure. Boxplots of changes in P/E mortality rank for the 100 largest PCI hospitals and 100 largest non-PCI hospitals after removing atherosclerosis from the model. After ranking each hospital by P/E in the first model with atherosclerosis and the second model without atherosclerosis (with rank 1 assigned to the smallest (best) P/E), we subtracted each hospital's rank in the second model from its rank in the first; thus, a negative difference implies an improved ranking in the second model. The thick horizontal line represents the median, while the box represents the interquartile ranges. Whiskers extend to the 5th and 95th percentiles, with dots beyond the whiskers representing outlier hospitals. PCI indicates percutaneous coronary intervention; P/E, predicted-to-expected mortality ratios.

B has a catheterization laboratory, while hospital A does not. By applying coefficients reported in the Medicare AMI model, we will examine what would follow should this same patient with a specific medical history have gone to either hospital.

Upon presentation to hospital A, the patient is given aspirin at arrival, diagnosed with an inferior MI, and managed medically. In the absence of angiography or PCI, coronary atherosclerosis is not identified or noted on the claim. The

Table 3. Admission, Treatment, and Diagnosis Process for the Same Hypothetical Patient Admitted to a PCI Hospital or a Non-PCI Hospital

Patient History	*Same* Hypothetical 75-Year-Old Male Patient With an Inferior AMI	
Admitting Hospital	Hospital A	Hospital B
Treatment status	Hospital A does not have catheterization laboratory; patient does not receive angiography or PCI	Hospital B has a catheterization laboratory; patient receives angiography and PCI
Atherosclerosis diagnosis	History of atherosclerosis is not diagnosed or noted on inpatient bill at Hospital A	History of atherosclerosis is diagnosed and noted on inpatient bill at Hospital B
Expected risk of death at each hospital	Based on medical history and AMI type, patient is expected to have a probability of death of 19.3% *on admission* to Hospital A	Based on the *same* medical history and AMI type, but adding the diagnosis of atherosclerosis, the *same* patient is expected to have a probability of death of 11.2% *on admission* to Hospital B
Effect on quality assessment	Hospital A's P/E mortality ratio is spuriously *lower* because of an artificially elevated "E" because of the absence of an atherosclerosis diagnosis. Its adjusted rank is *better* than it would have been, had there not been adjustment for atherosclerosis	Hospital B's P/E mortality ratio is spuriously *higher* because of a depressed "E" that is reduced because of a diagnosis noted via treatment. Its adjusted rank is *worse* than it would have been, had there not been adjustment for atherosclerosis

AMI indicates acute myocardial infarction; P/E, predicted-to-expected mortality ratios; PCI, percutaneous coronary intervention.

model would assign the patient an expected probability of 30-day mortality of 19.3%.

Now suppose the same patient instead went to Hospital B. Hospital B sends the patient to its catheterization laboratory, and performs coronary angiography and a PCI. The patient's coronary atherosclerosis is noted on the chart and the administrative claim. Crucially, this 1 patient's baseline risk factors seem, misleadingly, to have changed, not because the patient changed, but because the diagnostic workup is more complete. Models do not understand cardiology; they understand what predicts what. The risk adjustment model does not see the PCI—it is not a baseline risk factor, so it does not go into risk adjustment—and so the model cannot use the PCI to adjust the patient's risk, but the model does see the notation of coronary atherosclerosis, so it misleadingly attributes a reduced risk to patients with a diagnosis of coronary atherosclerosis. From a cardiologist's perspective, that is silly, but from a model's perspective, it improves prediction. When the model assigns this patient's expected chance of dying based only on patient characteristics, it will now account for this diagnosis of atherosclerosis from the inpatient claim. Adding this diagnosis to the patient's other characteristics, the model would assign an expected probability of 30-day mortality of 11.2%.

A risk-adjustment model is only intended to account for a patient's risk factors *on admission*. If that is the case, how can the same patient be assigned such disparate probabilities of death solely because of choice of hospital? It is conceivable that, as described above, the presence of atherosclerosis diagnosis on an inpatient claim is not a risk factor, but rather a proxy for a hospital's quality of diagnosis and treatment. The finding that the rate of atherosclerosis diagnosis is highest among patients who did receive PCI or underwent CABG may be further evidence of this proxy effect.

What does this portend for quality measurement? When comparing hospitals, risk adjustment models are used to determine the expected number of deaths based on their patients' characteristics on admission. Once the expected number of deaths is given by the model, the observed number of deaths is divided by it to form an "O/E" ratio (or in the case of Medicare's Hospital Compare, a stabilized observed number of deaths "P" to form a "P/E" mortality ratio[12]). A hospital with a lower O/E ratio is considered better than a hospital with a higher ratio. An accurate count of expected deaths is essential to this calculation, because an underestimation spuriously inflates the hospital's ratio.

PCI hospitals appear to code more patients as having atherosclerosis because they perform more PCI, and because the risk adjustment model says, *implausibly*, that the presence of atherosclerosis *reduces risk*, then the risk model underestimates the expected number of deaths at PCI hospitals and therefore inflates their O/E ratio compared with non-PCI

hospitals. It is implausible that atherosclerosis reduces risk, as the models suggest. More plausible is that an atherosclerosis diagnosis simply indicates subsequent performance of a PCI or a more thorough diagnostic examination, either or both of which may help reduce mortality. We would suggest removing atherosclerosis from these risk-adjustment models.

There are important limitations to our study. This analysis was restricted to retrospective review of administrative claims for older fee-for-service Medicare beneficiaries, and therefore may not be generalizable to hospital benchmarking that includes younger patients. Moreover, the admissions spanned 2009 to 2011, and it is possible that with changes in coding practices and the use of diagnostic tests and treatments in intervening years, a more recent analysis could yield different findings. However, more recently reported Medicare models for 2013 to 2016 admissions still show that diagnosis of coronary atherosclerosis or angina is associated with a 0.65 odds of mortality.[12]

Although biologically implausible, risk-adjustment for the notation of atherosclerosis finds it to be associated with a greatly reduced risk of death in the models used to provide a hospital's expected number of deaths against which it is benchmarked. It would appear that present adjusted comparisons of hospital AMI outcomes that include atherosclerosis in the risk-adjustment model are underestimating the quality of PCI hospitals and overestimating the quality of non-PCI hospitals. Risk-adjustment models must not include a patient characteristic (such as atherosclerosis) whose notation may reflect the style of practice of a hospital (the availability and use of PCI), and not an implausible biological effect of a patient characteristic, such as the implied beneficial effect of atherosclerosis.

Acknowledgments

Sources of Funding

Disclosures

None.

References

1. Writing Group Members, Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, Das SR, de Ferranti S, Despres JP, Fullerton HJ, Howard VJ, Huffman MD, Isasi CR, Jimenez MC, Judd SE, Kissela BM, Lichtman JH, Lisabeth LD, Liu S, Mackey RH, Magid DJ, McGuire DK, Mohler ER III, Moy CS, Muntner P, Mussolino ME, Nasir K, Neumar RW, Nichol G, Palaniappan L,

Pandey DK, Reeves MJ, Rodriguez CJ, Rosamond W, Sorlie PD, Stein J, Towfighi A, Turan TN, Virani SS, Woo D, Yeh RW, Turner MB; American Heart Association Statistics Committee, Stroke Statistics Subcommittee. Heart disease and stroke statistics—2016 update: a report from the American Heart Association. *Circulation*. 2016;133:e38–e360.

2. Antman EM, Selwyn AP, Loscalzo J. Chapter 243: ischemic heart disease. In: Longo DL, Fauci AS, Kasper DL, Hauser SL, Jameson JL, Loscalzo J, eds. *Harrison's Principles of Internal Medicine*. 18th ed. New York: The McGraw-Hill Companies, Inc.; 2012:1998–2014.

3. Pfuntner A, Wier LM, Steiner C. Costs for hospital stays in the United States, 2011. HCUP Statistical Brief #168. Agency for Healthcare Research and Quality: December 2013. Available at: http://www.hcup-us.ahrq.gov/re ports/statbriefs/sb168-Hospital-Costs-United-States-2011.pdf. Accessed November 29, 2016.

4. Fleisher LA, Fleischmann KE, Auerbach AD, Barnason SA, Beckman JA, Bozkurt B, Davila-Roman VG, Gerhard-Herman MD, Holly TA, Kane GC, Marine JE, Nelson MT, Spencer CC, Thompson A, Ting HH, Uretsky BF, Wijeysundera DN. 2014 ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2014;130:e278–e333.

5. O'Connor RE, Al Ali AS, Brady WJ, Ghaemmaghami CA, Menon V, Welsford M, Shuster M. Part 9: acute coronary syndromes: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2015;132:S483–S500.

6. Braunwald E. The ten advances that have defined modern cardiology. *Trends Cardiovasc Med*. 2014;24:179–183.

7. Enos WF, Holmes RH, Beyer J. Coronary disease among United States soldiers killed in action in Korea. Preliminary report. *J Am Med Assoc*. 1953;152:1090–1093.

8. McNamara JJ, Molot MA, Stremple JF, Cutting RT. Coronary artery disease in combat casualties in Vietnam. *JAMA*. 1971;216:1185–1187.

9. Webber BJ, Seguin PG, Burnett DG, Clark LL, Otto JL. Prevalence of and risk factors for autopsy-determined atherosclerosis among US service members, 2001–2011. *JAMA*. 2012;308:2577–2583.

10. McGill HC Jr, McMahan CA, Zieske AW, Tracy RE, Malcom GT, Herderick EE, Strong JP. Association of coronary heart disease risk factors with microscopic qualities of coronary atherosclerosis in youth. *Circulation*. 2000;102:374–379.

11. Strong JP, Malcom GT, McMahan CA, Tracy RE, Newman WP III, Herderick EE, Cornhill JF. Prevalence and extent of atherosclerosis in adolescents and young adults: implications for prevention from the Pathobiological Determinants of Atherosclerosis in Youth Study. *JAMA*. 1999;281:727–735.

12. Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation. 2017 condition-specific measures updates and specifications report: hospital-level 30-day risk-standardized mortality measures. Acute myocardial infarction, Version 11.0. Prepared for Centers for Medicare &

Medicaid Services. Available at: https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/HospitalQualityInits/Measure-Me thodology.html. Accessed November 1, 2017.

13. Rosenbaum PR. The consequences of adjustment for a concomitant variable that has been affected by the treatment. *J R Stat Soc Series A*. 1984;147:656–666.

14. Krumholz HM, Wang Y, Mattera JA, Wang Y, Han LF, Ingber MJ, Roman S, Normand S-LT. An administrative claims model suitable for profiling hospital performance based on 30-day mortality rates among patients with an acute myocardial infarction. *Circulation*. 2006;113:1683–1692.

15. Krumholz HM, Normand S-LT, Galusha DH, Mattera JA, Rich AS, Wang Y, Ward MM. *Risk-Adjustment Models for AMI and HF 30-Day Mortality*. Baltimore, MD: Centers for Medicare and Medicaid Services; 2006, Subcontract #8908-03-02.

16. Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation. 2013 measure updates and specifications. Acute myocardial infarction, heart failure, and pneumonia 30-day risk-standardized mortality measure Version 7.0. Available at: https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/HospitalQualityInits/Measure-Me thodology.html. Accessed February 7, 2017.

17. U.S. Department of Health & Human Services, Centers for Medicare & Medicaid Services. Hospital compare—a quality tool for adults, including people with Medicare. Available at: http://www.medicare.gov/hospitalcompa re/search.html. Accessed February 21, 2017.

18. CMS.gov. Provider of services current files. Centers for Medicare & Medicaid Services. Available at: https://www.cms.gov/Research-Statistics-Data-and-Systems/Downloadable-Public-Use-Files/Provider-of-Services/. Accessed June 9, 2017.

19. SAS Institute Inc. *Version 9.3 of the Statistical Analytic Software System for UNIX*. Cary, NC: SAS Institute Inc.; 2014.

20. Bishop YMM, Fienberg SE, Holland PW. *Discrete Multivariate Analysis: Theory and Practice*. Cambridge, MA: The MIT Press; 1975.

21. Silber JH, Rosenbaum PR, Romano PS, Rosen AK, Wang Y, Teng Y, Halenar MJ, Even-Shoshan O, Volpp KG. Hospital teaching intensity, patient race, and surgical outcomes. *Arch Surg*. 2009;144:113–121.

22. Silber JH, Rosenbaum PR, Brachet TJ, Ross RN, Bressler LJ, Even-Shoshan O, Lorch SA, Volpp KG. The Hospital Compare mortality model and the volume-outcome relationship. *Health Serv Res*. 2010;45:1148–1167.

23. Silber JH, Satopää VA, Mukherjee N, Rockova V, Wang W, Hill AS, Even-Shoshan O, Rosenbaum PR, George EI. Improving Medicare's Hospital Compare mortality model. *Health Serv Res*. 2016;51:1229–1247.

24. George EI, Rockova V, Rosenbaum PR, Satopää VA, Silber JH. Mortality rate estimation and standardization for public reporting: Medicare's Hospital Compare. *J Am Stat Assoc*. 2017;112:933–947.

25. Efron B, Tibshirani R. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Stat Sci*. 1986;1:54–75.

SUPPLEMENTAL MATERIAL

SUPPLEMENTAL TABLES

SUPPLEMENTAL REFERENCES

SUPPLEMENTAL TABLES
S1. Creation of Study Cohort

Step	N Retained	N Excluded at Step	% Excluded at Step	Cumulative N Excluded	Cumulative % Excluded
All MedPAR admissions with a principal diagnosis of acute myocardial infarction	1,139,302				
Exclude admissions where patients were under 65 at admission, who were in HMO in the 6 months before admission, or who were not treated at short-term acute-care hospitals	743,520	395,782	34.7%	395,782	34.7%
Exclude admissions where patients who were in hospice in the 6 months before admission	737,069	6,451	0.9%	402,233	35.3%
Combine transfers into single admissions and assign to first hospital	626,146	110,923	15.0%	513,156	45.0%
Exclude admissions where patients had a length of stay under 2 days, invalid age, sex, length of stay, or date of death	623,161	2,985	0.5%	516,141	45.3%
Choose one random admission per patient over 2009-2011	550,272	72,889	11.7%	589,030	51.7%
Exclude admissions before July 1, 2009 to facilitate minimum 6-month look-back for risk-adjustment	450,156	100,116	18.2%	689,146	60.5%
Remove low-volume hospitals with under 25 admissions in the study period	414,715	35,441	7.9%	724,587	63.6%

S2. Characteristics of the Study Cohort

Covariate (all in percent unless noted)	N	%	Comparison by Hospital Type			Comparison by Patient Treatment		
			PCI Hospitals	Non-PCI Hospitals	Difference	PCI/ CABG Patients	Medically Managed Patients	Difference
Number of Patients	414,715		359,685	55,030		199,501	215,214	
Number of Hospitals	2,051		1,459	592		2,051	2,051	
Age at admission (years, mean)		78.2	77.9	80.6	-2.7	75.2	81.0	-5.8
Sex (% male)	215,699	52.0	53.1	44.9	+8.2	59.8	44.8	+15.1
Anterior myocardial infarction (principal diagnosis)	39,806	9.6	10.5	4.0	+6.5	14.8	4.8	+10.1
Other ST-elevation myocardial infarction (principal diagnosis)	57,022	13.7	15.2	4.6	+10.5	22.8	5.3	+17.5
History of PTCA	23,099	5.6	5.8	4.2	+1.5	5.8	5.4	+0.5
History of CABG	29,759	7.2	7.2	6.7	+0.5	5.3	8.9	-3.7
Comorbidities								
Congestive heart failure	117,357	28.3	26.9	37.7	-10.8	16.7	39.1	-22.4
Past myocardial infarction	65,339	15.8	15.0	20.4	-5.4	13.9	17.4	-3.5
Unstable angina	61,903	14.9	14.4	18.7	-4.4	13.7	16.1	-2.4
Coronary atherosclerosis or angina	349,573	84.3	86.5	70.1	+16.4	93.9	75.4	+18.6
Cardio-respiratory failure or shock	40,172	9.7	9.3	12.4	-3.1	6.1	13.0	-6.9
Valvular or rheumatic heart disease	123,896	29.9	29.7	31.4	-1.7	23.9	35.4	-11.5
Hypertension	352,421	85.0	84.9	85.5	-0.6	83.1	86.8	-3.7
Stroke	25,204	6.1	5.8	7.9	-2.1	3.5	8.4	-4.9
Cerebrovascular disease	60,351	14.6	14.2	16.7	-2.4	10.6	18.2	-7.7
Renal failure	83,636	20.2	19.5	24.9	-5.4	12.7	27.1	-14.5
Chronic obstructive pulmonary disease	115,763	27.9	27.2	32.5	-5.3	22.9	32.5	-9.6
Pneumonia	100,121	24.1	23.2	30.5	-7.3	15.4	32.3	-16.9
Diabetes	178,859	43.1	42.7	45.7	-3.0	40.3	45.8	-5.5
Malnutrition	22,139	5.3	5.2	6.4	-1.3	2.9	7.6	-4.6
Dementia	72,134	17.4	16.2	25.0	-8.8	7.6	26.5	-19.0
Paraplegia	20,212	4.9	4.7	6.2	-1.5	2.7	6.9	-4.2
Peripheral vascular disease	89,373	21.6	21.0	25.0	-4.0	15.5	27.1	-11.6
Cancer	14,870	3.6	3.5	4.0	-0.5	2.3	4.8	-2.5
Trauma	93,146	22.5	21.9	26.4	-4.5	16.2	28.3	-12.1
Major psychiatric disorders	28,479	6.9	6.5	9.1	-2.6	3.9	9.7	-5.8
Chronic liver disease	4,706	1.1	1.1	1.3	-0.2	0.8	1.5	-0.7

S3. Hierarchical Models with and without Atherosclerosis

S3.a. Hierarchical Model with Atherosclerosis							
Covariate	Estimate	Standard Error	Odds Ratio	Lower 95% CL	Upper 95% CL	Chi-Square	P-value
Intercept	-2.655	0.020	--	--	--	-133.1	<.0001
Age in years minus 65	0.055	0.001	1.057	1.056	1.058	89.2	<.0001
Sex (male)	0.121	0.010	1.129	1.108	1.151	12.5	<.0001
Anterior MI 1 (410.00-410.11)	0.719	0.015	2.052	1.992	2.114	47.6	<.0001
Anterior MI 2 (410.20-410.61)	0.488	0.014	1.629	1.584	1.676	33.9	<.0001
Non-ST-Elevation MI or Unspecified MI (410.70-410.91) (reference)	--	--	--	--	--	--	--
History of PTCA	-0.119	0.022	0.888	0.850	0.927	-5.3	<.0001
History of CABG	0.094	0.019	1.099	1.059	1.140	5.1	<.0001
Congestive heart failure	0.221	0.012	1.247	1.219	1.276	19.0	<.0001
Past myocardial infarction	-0.310	0.014	0.733	0.713	0.754	-21.6	<.0001
Unstable angina	-0.225	0.015	0.799	0.776	0.822	-15.2	<.0001
Coronary atherosclerosis or angina	-0.542	0.012	0.582	0.568	0.595	-45.6	<.0001
Cardio-respiratory failure or shock	0.234	0.015	1.264	1.227	1.302	15.5	<.0001
Valvular or rheumatic heart disease	0.107	0.010	1.113	1.091	1.136	10.4	<.0001
Hypertension	-0.362	0.013	0.697	0.679	0.715	-27.7	<.0001
Stroke	0.068	0.019	1.071	1.032	1.112	3.6	0.0003
Cerebrovascular disease	0.025	0.014	1.025	0.998	1.053	1.8	0.0687
Renal failure	0.268	0.012	1.307	1.277	1.338	22.6	<.0001
Chronic obstructive pulmonary disease	0.071	0.011	1.073	1.051	1.096	6.6	<.0001
Pneumonia	0.567	0.011	1.763	1.726	1.800	53.3	<.0001
Diabetes	0.126	0.010	1.135	1.113	1.157	12.7	<.0001
Malnutrition	0.525	0.017	1.691	1.636	1.748	31.0	<.0001
Dementia	0.399	0.012	1.490	1.457	1.525	34.1	<.0001
Paraplegia	0.206	0.020	1.229	1.182	1.279	10.2	<.0001
Peripheral vascular disease	0.137	0.011	1.147	1.122	1.173	12.1	<.0001
Cancer	0.731	0.020	2.078	1.996	2.162	35.8	<.0001
Trauma	0.070	0.011	1.072	1.050	1.095	6.4	<.0001
Major psychiatric disorders	0.110	0.017	1.116	1.079	1.153	6.5	<.0001
Chronic liver disease	0.518	0.037	1.679	1.560	1.807	13.8	<.0001
N Patients	414,715						
N Deaths	59,220						
Hospital Random Effects	2,051						

S3.b. Hierarchical Model without Atherosclerosis							
Covariate	Estimate	Standard Error	Odds Ratio	Lower 95% CL	Upper 95% CL	Chi-Square	P-value
Intercept	-3.033	0.018	--	--	--	-164.8	<.0001
Age in years minus 65	0.058	0.001	1.060	1.059	1.061	94.3	<.0001
Sex (male)	0.079	0.010	1.082	1.062	1.103	8.2	<.0001
Anterior MI 1 (410.00-410.11)	0.669	0.015	1.951	1.895	2.009	44.6	<.0001
Anterior MI 2 (410.20-410.61)	0.432	0.014	1.540	1.498	1.584	30.2	<.0001
Non-ST-Elevation MI or Unspecified MI (410.70-410.91) (reference)	--	--	--	--	--	--	--
History of PTCA	-0.182	0.022	0.834	0.798	0.871	-8.2	<.0001
History of CABG	0.021	0.019	1.021	0.984	1.059	1.1	0.2669
Congestive heart failure	0.186	0.012	1.204	1.177	1.232	16.1	<.0001
Past myocardial infarction	-0.312	0.014	0.732	0.712	0.753	-21.8	<.0001
Unstable angina	-0.255	0.015	0.775	0.753	0.797	-17.3	<.0001
Cardio-respiratory failure or shock	0.238	0.015	1.269	1.232	1.307	15.8	<.0001
Valvular or rheumatic heart disease	0.088	0.010	1.092	1.070	1.114	8.5	<.0001
Hypertension	-0.401	0.013	0.669	0.653	0.687	-31.0	<.0001
Stroke	0.064	0.019	1.066	1.027	1.107	3.4	0.0008
Cerebrovascular disease	0.013	0.014	1.013	0.987	1.040	1.0	0.332
Renal failure	0.263	0.012	1.301	1.271	1.331	22.2	<.0001
Chronic obstructive pulmonary disease	0.062	0.011	1.064	1.042	1.086	5.8	<.0001
Pneumonia	0.589	0.011	1.802	1.765	1.840	55.5	<.0001
Diabetes	0.109	0.010	1.116	1.094	1.137	11.1	<.0001
Malnutrition	0.555	0.017	1.742	1.685	1.801	32.8	<.0001
Dementia	0.430	0.012	1.537	1.502	1.572	36.9	<.0001
Paraplegia	0.215	0.020	1.239	1.191	1.289	10.7	<.0001
Peripheral vascular disease	0.122	0.011	1.129	1.104	1.155	10.7	<.0001
Cancer	0.765	0.020	2.148	2.064	2.235	37.5	<.0001
Trauma	0.079	0.011	1.083	1.060	1.106	7.3	<.0001
Major psychiatric disorders	0.120	0.017	1.128	1.091	1.166	7.1	<.0001
Chronic liver disease	0.536	0.037	1.710	1.589	1.840	14.3	<.0001
N Patients	414,715						
N Deaths	59,220						
N Hospitals	2,051						

S4. Logistic Models Predicting 30-day Mortality

S4.a. Model with Atherosclerosis							
Covariate	Estimate	Standard Error	Odds Ratio	Lower 95% CL	Upper 95% CL	Chi-Square	P-value
Intercept	-2.682	0.020	--	--	--	18,836.1	<.0001
Age in years minus 65	0.055	0.001	1.056	1.055	1.058	7,968.5	<.0001
Sex (male)	0.120	0.010	1.127	1.106	1.149	152.4	<.0001
Anterior MI 1 (410.00-410.11)	0.716	0.015	2.046	1.986	2.107	2,281.1	<.0001
Anterior MI 2 (410.20-410.61)	0.486	0.014	1.626	1.581	1.673	1,154.5	<.0001
Non-ST-Elevation MI or Unspecified MI (410.70-410.91) (reference)	--	--	--	--	--	--	--
History of PTCA	-0.120	0.022	0.887	0.849	0.926	29.3	<.0001
History of CABG	0.097	0.019	1.102	1.062	1.143	27.1	<.0001
Congestive heart failure	0.220	0.012	1.246	1.218	1.274	359.4	<.0001
Past myocardial infarction	-0.307	0.014	0.736	0.716	0.757	463.6	<.0001
Unstable angina	-0.227	0.015	0.797	0.774	0.820	238.3	<.0001
Coronary atherosclerosis or angina	-0.546	0.012	0.579	0.566	0.593	2,152.2	<.0001
Cardio-respiratory failure or shock	0.237	0.015	1.267	1.230	1.305	246.7	<.0001
Valvular or rheumatic heart disease	0.101	0.010	1.107	1.085	1.129	98.7	<.0001
Hypertension	-0.360	0.013	0.698	0.680	0.716	767.9	<.0001
Stroke	0.068	0.019	1.070	1.031	1.111	12.8	0.0004
Cerebrovascular disease	0.025	0.014	1.025	0.998	1.052	3.3	0.0695
Renal failure	0.268	0.012	1.307	1.277	1.337	515.5	<.0001
Chronic obstructive pulmonary disease	0.076	0.011	1.079	1.057	1.102	51.3	<.0001
Pneumonia	0.564	0.011	1.758	1.722	1.795	2,847.2	<.0001
Diabetes	0.126	0.010	1.135	1.113	1.157	162.6	<.0001
Malnutrition	0.519	0.017	1.681	1.627	1.737	955.1	<.0001
Dementia	0.401	0.012	1.493	1.459	1.528	1,185.4	<.0001
Paraplegia	0.209	0.020	1.232	1.185	1.282	108.1	<.0001
Peripheral vascular disease	0.131	0.011	1.140	1.115	1.165	133.5	<.0001
Cancer	0.723	0.020	2.059	1.979	2.143	1,258.0	<.0001
Trauma	0.068	0.011	1.070	1.048	1.093	38.8	<.0001
Major psychiatric disorders	0.106	0.017	1.112	1.076	1.150	40.0	<.0001
Chronic liver disease	0.516	0.037	1.676	1.558	1.803	191.2	<.0001
N Patients	414,715						
N Deaths	59,220						
C-statistic	0.733						

S4.b. Model without Atherosclerosis							
Covariate	Estimate	Standard Error	Odds Ratio	Lower 95% CL	Upper 95% CL	Chi-Square	P-value
Intercept	-3.069	0.018	--	--	--	29,486.7	<.0001
Age in years minus 65	0.058	0.001	1.059	1.058	1.061	8,942.2	<.0001
Sex (male)	0.076	0.010	1.079	1.059	1.100	62.8	<.0001
Anterior MI 1 (410.00-410.11)	0.661	0.015	1.937	1.882	1.994	1,978.3	<.0001
Anterior MI 2 (410.20-410.61)	0.426	0.014	1.531	1.489	1.575	901.7	<.0001
Non-ST-Elevation MI or Unspecified MI (410.70-410.91) (reference)	--	--	--	--	--	--	--
History of PTCA	-0.185	0.022	0.831	0.796	0.868	70.1	<.0001
History of CABG	0.021	0.019	1.022	0.985	1.059	1.3	0.2479
Congestive heart failure	0.185	0.012	1.203	1.176	1.231	257.6	<.0001
Past myocardial infarction	-0.307	0.014	0.735	0.715	0.756	466.0	<.0001
Unstable angina	-0.258	0.015	0.773	0.751	0.796	308.3	<.0001
Cardio-respiratory failure or shock	0.241	0.015	1.273	1.236	1.311	256.5	<.0001
Valvular or rheumatic heart disease	0.081	0.010	1.084	1.063	1.106	63.0	<.0001
Hypertension	-0.401	0.013	0.669	0.653	0.687	967.6	<.0001
Stroke	0.064	0.019	1.066	1.027	1.107	11.3	0.0008
Cerebrovascular disease	0.012	0.014	1.012	0.986	1.039	0.8	0.3595
Renal failure	0.263	0.012	1.301	1.271	1.331	500.5	<.0001
Chronic obstructive pulmonary disease	0.068	0.011	1.071	1.049	1.093	41.2	<.0001
Pneumonia	0.587	0.011	1.799	1.762	1.836	3,100.0	<.0001
Diabetes	0.109	0.010	1.115	1.094	1.137	122.8	<.0001
Malnutrition	0.549	0.017	1.731	1.675	1.789	1,070.8	<.0001
Dementia	0.433	0.012	1.542	1.508	1.578	1,398.3	<.0001
Paraplegia	0.218	0.020	1.243	1.195	1.293	117.9	<.0001
Peripheral vascular disease	0.114	0.011	1.121	1.096	1.146	101.8	<.0001
Cancer	0.756	0.020	2.130	2.047	2.216	1,387.4	<.0001
Trauma	0.078	0.011	1.081	1.058	1.104	51.1	<.0001
Major psychiatric disorders	0.117	0.017	1.124	1.088	1.162	48.7	<.0001
Chronic liver disease	0.535	0.037	1.707	1.586	1.836	205.3	<.0001
N Patients	414,715						
N Deaths	59,220						
C-statistic	0.726						

S5. Directly Standardized Analysis of Logistic Models Comparing Outcomes at PCI Hospitals and Non-PCI Hospitals

First, we re-fit each of the two logistic models described in III, adding to each a covariate indicating whether the patient was treated at a PCI hospital. Then, we calculated the number of expected deaths had all patients been treated at non-PCI hospitals, had all patients been treated at a PCI hospital, or at a non-PCI hospital. The difference between the two values represented the number of lives saved by one type of hospital versus another. Direct adjustment using the model with atherosclerosis estimated 4,311 lives would be saved had all patients were treated at PCI hospitals, but in the model without atherosclerosis, the number of lives saved increased to 7,296, a difference of 2,985.

Model	Observed Deaths	Expected Deaths had All Patients been Treated at PCI Hospitals	Expected Deaths had All Patients been Treated at Non-PCI Hospitals	Lives Saved by PCI Hospitals (Non-PCI Deaths minus PCI Deaths)	Difference in Lives Saved between Models and P-value using Bootstrapping
With Atherosclerosis	59,220	58,564 (58,091, 59,038)	62,875 (61,818, 64,077)	4,311 (3,111, 5,566)	2,985 (2,781, 3,173) $P < 0.001$
Without Atherosclerosis	59,220	58,151 (57,674, 58,622)	65,447 (64,303, 66,665)	7,296 (6,048, 8,553)	

To determine whether there was a significant difference in the number of expected lives saved by PCI hospitals between the first model with atherosclerosis and the second without atherosclerosis, we used the bootstrap method.[1] We generated 1,000 samples, and in each, we calculated the expected deaths had all patients been treated at PCI hospitals, or at non-PCI hospitals, and the difference (the number of lives saved by one type of hospital versus another), as described above. The 2.5% and 97.5% values across the 1,000 bootstrap samples yield the 95% confidence intervals. No samples showed fewer lives saved by PCI hospitals in the model without atherosclerosis relative to the model with atherosclerosis, therefore the model without atherosclerosis showed significantly more lived saved by PCI hospitals relative to the model with atherosclerosis ($P < 0.001$).

S6. Adjusted Outcome Rates Using Hierarchical and Logistic Models

The table below shows unadjusted and adjusted outcome rates using the hierarchical and logistic models, each run once with adjustment atherosclerosis, and once without. Adjusted rates were calculated by multiplying the predicted-to-expected mortality ratio or observed-to-expected mortality ratio for each type of hospital by the national AMI mortality rate in the complete dataset. As can be seen, PCI hospitals are shown to outperform non-PCI hospitals to a larger degree when atherosclerosis is not included in either the hierarchical or logistic adjustment models. Moreover, the results show that the hierarchical models shrink the mean for non-PCI hospitals closer to the national mean of 14.3%.

Outcome Rate	PCI Hospitals	Non-PCI Hospitals	Difference
N	359,685	55,030	
Unadjusted 30-day Mortality	13.7%	18.1%	-4.4%
Adjusted 30-day Mortality Using Hierarchical (P/E) Model with Atherosclerosis	14.1%	14.4%	-0.3%
Adjusted 30-day Mortality Using Hierarchical (P/E) Model without Atherosclerosis	14.0%	14.6%	-0.6%
Adjusted 30-day Mortality Using Logistic (O/E) Model with Atherosclerosis	14.1%	15.1%	-1.0%
Adjusted 30-day Mortality Using Logistic (O/E) Model without Atherosclerosis	14.0%	15.7%	-1.6%

S7. The Effect of Removal of Atherosclerosis from Hierarchical Models between 100 Largest PCI Hospitals and 100 Largest Non-PCI Hospitals

100 Largest PCI Hospitals					100 Largest Non-PCI Hospitals				
Model 1 with Atherosclerosis P/E	Model 2 without Atherosclerosis P/E	Model 1 Rank	Model 2 Rank	Change in Rank (2 minus 1)	Model 1 with Atherosclerosis P/E	Model 2 without Atherosclerosis P/E	Model 1 Rank	Model 2 Rank	Change in Rank (2 minus 1)
0.981	0.974	838	777	-61	1.061	1.085	1570	1671	101
0.916	0.907	286	277	-9	1.014	1.037	1172	1346	174
0.928	0.931	361	430	69	0.960	0.978	618	811	193
1.012	0.995	1153	975	-178	0.971	0.976	727	796	69
0.966	0.940	688	504	-184	1.064	1.086	1599	1681	82
0.951	0.943	543	523	-20	1.071	1.077	1633	1632	-1
0.871	0.861	110	114	4	0.946	0.949	499	571	72
0.984	0.966	861	707	-154	1.008	1.050	1104	1447	343
1.123	1.104	1895	1762	-133	0.830	0.840	40	64	24
0.832	0.844	43	73	30	0.862	0.878	83	163	80
0.998	0.969	986	733	-253	0.862	0.858	84	105	21
0.959	0.949	614	564	-50	0.954	0.935	571	458	-113
0.918	0.903	294	254	-40	0.912	0.908	261	282	21
0.935	0.923	418	373	-45	1.037	1.041	1383	1387	4
0.847	0.836	59	58	-1	0.929	0.927	375	401	26
0.927	0.923	353	376	23	1.045	1.059	1449	1515	66
0.836	0.806	49	30	-19	1.038	1.045	1396	1418	22
1.004	1.006	1059	1072	13	0.909	0.889	247	201	-46
1.003	0.985	1045	878	-167	0.962	0.979	648	823	175
0.953	0.921	558	362	-196	0.950	0.975	529	784	255
0.782	0.765	6	11	5	0.879	0.887	132	193	61
0.877	0.850	122	84	-38	0.927	0.967	355	713	358
1.018	1.029	1205	1275	70	0.975	0.972	765	766	1
0.964	0.960	671	657	-14	0.966	0.990	685	927	242
0.902	0.892	210	210	0	1.237	1.291	2040	2047	7
0.890	0.861	167	115	-52	1.113	1.155	1866	1949	83
1.047	1.033	1458	1315	-143	1.014	1.030	1166	1292	126
0.949	0.939	523	495	-28	0.897	0.905	194	272	78
1.094	1.091	1767	1699	-68	0.932	0.951	397	593	196
0.956	0.945	582	539	-43	0.894	0.910	189	293	104
0.913	0.895	264	223	-41	0.939	0.946	453	545	92
0.962	0.931	642	427	-215	0.923	0.916	327	334	7
0.813	0.807	25	35	10	0.876	0.887	118	194	76
0.888	0.871	159	142	-17	0.922	0.942	322	521	199
0.855	0.835	73	56	-17	1.001	0.992	1029	942	-87
0.931	0.914	385	319	-66	1.023	1.031	1253	1299	46
0.987	0.965	885	702	-183	1.056	1.071	1537	1592	55
0.973	0.955	741	621	-120	0.836	0.842	47	70	23
1.082	1.088	1697	1687	-10	0.935	0.923	413	377	-36
0.745	0.722	3	3	0	1.021	1.002	1228	1050	-178
0.923	0.914	329	318	-11	1.275	1.270	2047	2042	-5
0.956	0.942	581	516	-65	0.762	0.744	4	4	0
1.019	1.036	1217	1338	121	1.034	1.056	1352	1495	143
1.259	1.240	2043	2035	-8	0.960	0.975	617	788	171
1.048	1.044	1468	1411	-57	0.994	1.009	953	1104	151
0.991	0.973	925	770	-155	0.930	0.935	379	455	76

100 Largest PCI Hospitals					100 Largest Non-PCI Hospitals				
Model 1 with Atherosclerosis P/E	Model 2 without Atherosclerosis P/E	Model 1 Rank	Model 2 Rank	Change in Rank (2 minus 1)	Model 1 with Atherosclerosis P/E	Model 2 without Atherosclerosis P/E	Model 1 Rank	Model 2 Rank	Change in Rank (2 minus 1)
0.860	0.850	80	86	6	1.082	1.114	1699	1815	116
0.959	0.944	611	528	-83	0.891	0.904	177	260	83
0.822	0.804	30	27	-3	0.918	0.920	298	355	57
0.869	0.854	108	96	-12	1.058	1.074	1555	1615	60
0.868	0.874	104	151	47	1.159	1.168	1974	1974	0
1.004	0.996	1066	988	-78	1.119	1.149	1883	1938	55
0.939	0.937	456	471	15	1.150	1.159	1964	1956	-8
0.921	0.913	314	306	-8	0.890	0.890	171	205	34
0.976	0.982	776	854	78	1.022	1.021	1246	1217	-29
1.023	1.019	1259	1204	-55	0.959	0.948	616	563	-53
0.783	0.761	9	8	-1	1.125	1.137	1900	1900	0
0.885	0.859	145	108	-37	0.891	0.876	176	156	-20
0.961	0.968	641	732	91	1.076	1.067	1662	1569	-93
1.077	1.058	1667	1513	-154	0.946	0.942	496	519	23
0.965	0.942	682	517	-165	1.073	1.103	1645	1757	112
1.028	1.036	1295	1339	44	0.906	0.914	226	311	85
1.031	0.997	1329	999	-330	0.983	0.977	856	803	-53
0.888	0.869	156	136	-20	1.056	1.074	1531	1617	86
1.022	1.029	1245	1279	34	1.026	1.028	1273	1271	-2
1.017	1.024	1195	1235	40	0.906	0.901	229	244	15
0.947	0.925	505	387	-118	0.878	0.888	123	198	75
1.005	0.991	1077	934	-143	0.971	0.977	725	802	77
0.776	0.747	5	5	0	0.937	0.939	432	493	61
1.014	0.997	1169	992	-177	1.034	1.076	1354	1627	273
1.145	1.138	1956	1902	-54	1.087	1.116	1731	1828	97
0.986	0.974	874	781	-93	1.019	1.035	1214	1326	112
1.062	1.050	1583	1446	-137	1.078	1.096	1677	1724	47
0.883	0.850	139	88	-51	0.960	0.950	623	577	-46
1.000	1.005	1012	1064	52	0.854	0.870	70	140	70
1.083	1.103	1707	1755	48	1.033	1.036	1342	1336	-6
1.070	1.083	1632	1661	29	1.018	0.993	1204	958	-246
0.988	0.997	898	1008	110	1.193	1.168	2021	1972	-49
0.913	0.903	263	258	-5	0.993	1.003	938	1053	115
0.941	0.918	465	345	-120	0.928	0.935	364	457	93
0.786	0.760	10	7	-3	1.131	1.143	1920	1921	1
0.968	0.956	703	625	-78	0.910	0.912	249	302	53
0.826	0.807	33	32	-1	1.045	1.065	1444	1552	108
1.058	1.072	1550	1598	48	1.164	1.202	1979	2008	29
0.791	0.765	12	9	-3	1.230	1.263	2037	2040	3
1.019	1.010	1215	1107	-108	0.918	0.912	292	303	11
1.079	1.068	1685	1575	-110	1.005	1.018	1073	1197	124
1.069	1.063	1626	1538	-88	0.971	0.986	726	883	157
0.938	0.918	449	349	-100	0.916	0.905	285	267	-18
0.925	0.916	337	332	-5	0.954	0.982	570	852	282
0.989	0.971	900	757	-143	0.945	0.961	490	661	171
0.819	0.797	28	26	-2	1.134	1.184	1927	1990	63
0.782	0.775	8	13	5	0.976	0.970	781	751	-30
1.180	1.207	2003	2013	10	1.015	1.020	1181	1211	30
0.968	0.951	704	587	-117	1.024	1.039	1262	1361	99

100 Largest PCI Hospitals					100 Largest Non-PCI Hospitals				
Model 1 with Atherosclerosis P/E	Model 2 without Atherosclerosis P/E	Model 1 Rank	Model 2 Rank	Change in Rank (2 minus 1)	Model 1 with Atherosclerosis P/E	Model 2 without Atherosclerosis P/E	Model 1 Rank	Model 2 Rank	Change in Rank (2 minus 1)
1.125	1.132	1902	1886	-16	0.938	0.948	447	558	111
1.016	1.007	1184	1082	-102	1.115	1.130	1874	1876	2
1.129	1.118	1917	1836	-81	1.014	1.043	1165	1398	233
0.864	0.860	92	111	19	1.106	1.142	1840	1920	80
0.987	0.968	881	725	-156	0.989	1.009	901	1106	205
Number Improving Rank				72	Number Improving Rank				20
Number Maintaining Rank				3	Number Maintaining Rank				3
Number Declining Rank				25	Number Declining Rank				77
Bootstrapped 95% CI for Number Improving Rank				70-81	Bootstrapped 95% CI for Number Improving Rank				20-31
Bootstrapped 95% CI for Number Declining Rank				21-30	Bootstrapped 95% CI for Number Declining Rank				69-80
Bootstrap P-value: P < 0.001									

After fitting the two models, we ranked all 2,051 hospitals on their predicted-to-expected (P/E) mortality ratio in each model, assigning a rank of 1 to the hospital with the smallest P/E ratio. Then we identified the 100 largest PCI hospitals and the 100 largest non-PCI hospitals, and for each, we calculated the difference in their rank between the two models (the second model without atherosclerosis minus the first model that included it). A negative difference implied an improved ranking. We found that 72 of the 100 largest PCI hospitals had a better rank in the model without atherosclerosis, 3 had the same rank, and 25 had a worse rank. Among the 100 largest non-PCI hospitals, we found that only 20 had a better rank in the model without atherosclerosis, 3 had the same rank, and 77 had a worse rank.

To determine whether the change to the model of removing atherosclerosis had a significantly different effect on the 100 largest PCI hospitals and the 100 largest non-PCI hospitals, we used the bootstrap method.[1] 1,000 samples were generated, and for each, we fit the two hierarchical models and performed the same ranking process described above. This yielded 1,000 calculations of the number of PCI hospitals improving or declining in rank. The 2.5% and 97.5% values across the 1,000 bootstrap samples yield the 95% confidence intervals. None of the 1,000 samples showed more non-PCI hospitals with improved ranks than PCI hospitals, therefore the removal of atherosclerosis from the model had a significantly different effect on the 100 largest PCI hospitals than the 100 largest non-PCI hospitals, with more PCI hospitals having better ranks, and more non-PCI hospitals having worse ranks.

SUPPLEMENTAL REFERENCES

1.   Efron B, Tibshirani R. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Stat Sci*. 1986;1:54-75.