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Patterns of Stress Testing and Diagnostic Catheterization after Coronary Stenting in 250,350 Medicare Beneficiaries

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Abstract

Background—Patterns of non-invasive stress test (ST) and invasive coronary angiography (CA) utilization after percutaneous coronary intervention (PCI) are not well described in older populations.

Methods and Results—We linked National Cardiovascular Data Registry® CathPCI Registry® data with longitudinal Medicare claims data for 250,350 patients undergoing PCI from 2005 to 2007 and described subsequent testing and outcomes. Between 60 days post-PCI and end of follow-up (median 24 months), 49% (n=122,894) received stress testing first, 10% (n=25,512) underwent invasive CA first, and 41% (n=101,944) had no testing (NT). A number of clinical risk factors at time of index PCI were associated with decreased likelihood of downstream testing (ST or CA, $p<0.05$ for all), including older age (HR 0.784 per 10 year increase), male sex (HR 0.946), heart failure (HR 0.925), diabetes (HR 0.954), smoking (HR 0.804), and renal failure (HR 0.880). Fifteen percent of patients with ST first proceeded to subsequent CA within 90 days of testing (n=18,472/101,884); of these, 48% (n=8831) underwent revascularization within 90 days, compared to 53% (n=13,316) of CA first patients ($p<0.0001$).

Conclusions—In this descriptive analysis, stress testing and invasive CA were common in older patients after PCI. Paradoxically, patients with higher-risk features at baseline were less likely to undergo post-PCI testing. The revascularization yield was low on patients referred for ST after PCI, with only 9% undergoing revascularization within 90 days.

Keywords

non-invasive stress test; coronary angiography; percutaneous coronary intervention; clinical outcomes

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Diagnostic testing is commonplace following the 1.4 million percutaneous coronary intervention (PCI) procedures performed annually in the United States[1,2] and is addressed in the American College of Cardiology/American Heart Association (ACC/AHA) guidelines[3-5] and the American College of Cardiology Foundation (ACCF) Appropriate Use Criteria (AUC).[6,7] There has been accumulating scrutiny regarding the overall increased use of cardiac diagnostic testing in recent decades[8] with studies suggesting high testing rates in patients after PCI,[9] as well as significant geographic variability[10] and financial influences on testing rates.[11] Yet despite these concerns, limited data exist on current patterns of post-PCI cardiac testing and the subsequent need for repeat revascularization or other associated outcomes.

A better understanding of the predictors and downstream impact of imaging after PCI requires both rich clinical characteristics and longitudinal outcomes data. Therefore, we examined patterns of stress testing (ST) and invasive coronary angiography (CA) after PCI in a large, contemporary cohort using a unique dataset, which combined the Centers for Medicare & Medicaid Services (CMS) and the National Cardiovascular Data Registry® (NCDR) CathPCI Registry®.

Methods

Study Population

All patients >65 years receiving PCI with stenting, admitted and discharged between January 1, 2004 and December 31, 2008, and enrolled in the CathPCI Registry (with subsequent date restrictions, described below, for the final study population) were included. The CathPCI Registry is a large, national, clinical registry of patients undergoing cardiac catheterization or PCI.[12,13] The first PCI with a stent procedure for each admission was considered the index event and was the initial unit of analysis; there were 672,617 eligible index events.

CathPCI Registry index events were matched to Medicare inpatient claims data using indirect identifiers to link unique admissions.[14] Index CathPCI Registry events lacking Medicare inpatient claims (including procedures performed in the outpatient setting or at Veterans Affairs Administration hospitals, and procedures paid through Medicare managed care plans, employer-sponsored plans, or private insurance plans) could not be matched. Even so, using this methodology we successfully linked 443,922 index events to an admission in the Medicare data, or 67% of all eligible index events. After matching, only the first PCI for each patient was considered. Due to changes in the CathPCI Registry data collection form, and to allow for >1 year of potential follow-up for included patients, the final population for this study was limited to patients with index PCI events between January 1, 2004 and December 31, 2008. Patients who did not have fee-for-service Medicare coverage for the entire follow-up period were censored at the end of coverage. Additional exclusion criteria were applied (Figure 1).

A 60-day blackout period after PCI was defined for each patient, since diagnostic tests during this period may be performed for the purposes of cardiac rehabilitation, staging of procedures, or functional capacity assessments, and were not considered as post-revascularization stress tests or outcome events.

Data Definitions

Inpatient and outpatient stress test procedures, CA, coronary revascularization (PCI and coronary artery bypass graft surgery), and acute myocardial infarction (MI) after PCI were

identified by Healthcare Common Procedure Coding System (HCPCS) Current Procedural Terminology (CPT) and International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes, as described in Appendix 1. Date of death was obtained from the CMS beneficiary claim files.

Statistical Analysis

Patients were stratified by type of first follow-up test (no testing [NT] compared to any testing [AT], and ST first compared to CA first among those with testing) between the 60-day post-PCI blackout period and end of follow-up. Given our intended focus on diagnostic testing patterns outside of the acute setting, patients were classified only according to testing status prior to any MI admission or death; patients with first post-PCI testing during or after an MI admission were therefore counted in the NT group. Patients with ST and CA on the same day were included in the ST first group.

All statistical tests were two-sided with a significance level of 0.05. P-values were based on either Pearson chi-square tests for categorical variables or Kruskal-Wallis tests for continuous or ordinal variables. Due to variable follow-up time between groups, p-values were not reported for between-group comparisons, as in Table 1. We set a threshold of greater than 2% absolute difference between groups for reporting.

Time-to-first test (ST or CA) occurring between 60 days and one year after the index PCI were computed and plotted using cumulative incidence functions that accounted for administrative censoring and included MI hospitalization and death as competing risks.[15] One-year cumulative incidence of ST first or CA first was compared to NT using an unadjusted Poisson regression stratified by calendar quarter of index PCI, to determine if testing patterns changed over the study period.

To evaluate the association of baseline variables with type of first downstream test, if any, we developed cause-specific Cox proportional hazards models[16,17] to estimate hazard ratios of AT vs. NT, and ST first vs. CA first among those with testing, for a panel of baseline variables from available NCDR variables selected *a priori*, listed in Appendix 2. In each model, patients were censored at date of testing, MI admission, death, end of follow-up, or at 12 months after PCI.

Patterns of layered testing and procedures after PCI were evaluated by identifying the first test (ST first, CA first, or NT) at least 60 days after the index PCI procedure and prior to MI, and calculating rates of subsequent procedures (repeat ST, CA, and revascularization) between 0 and 90 days from that first post-PCI test, but prior to MI hospitalization or death. “Catheterization yield” rates were computed by dividing the revascularization rate by the CA rate (either CA first or CA within 90 days of first test).

In an exploratory observational analysis, we examined clinical outcomes following different first test types using the composite endpoint of death or MI admission. We fit an adjusted Cox model with a time-varying covariate indicating first testing status (no test/pre-testing, STF, or CAF) to account for differences in timing of testing and death or MI.[18] For this analysis only, following the 60-day blackout period after PCI all patients started in the NT/pre-testing group and remained in that group until undergoing a first test, at which time they moved to the ST first or CA first group, as appropriate. If an MI occurred during the same hospitalization as a CA first, we assumed that the CA was a diagnostic or therapeutic intervention for that MI, and the MI was attributed as an event to the “NT/pre-testing” group. We censored at the end of follow-up, first MI, or death, adjusting for the same baseline variables as in the Cox model for testing status. For ease of discussion, the “NT/pre-testing” group is referred to as the NT group in the Results and Discussion sections of

this paper. All statistical analyses were performed using SAS version 9.2 or higher (SAS Institute Inc., Cary, NC) and Stata Statistical Software: Release 11 (StataCorp, College Station, TX). The Duke University Medical Center Institutional Review Board granted a waiver of the informed consent and authorization for this study.

Results

The study population included 250,350 Medicare patients with qualifying PCI entered in the CathPCI Registry and matched to Medicare claims data between January 1, 2005 and December 31, 2007, with follow-up data through December 31, 2008 (Figures 1a and 1b). Median age at time of index PCI was 74 years, 43% were female, and median follow-up time was 728 days (inter-quartile range [IQR]: 491-1028 days). Among these PCI patients, 122,894 (48.9%) underwent ST first, 25,512 (10.2%) received CA first, and 101,944 (40.7%) had NT between 60 days after PCI and end of follow-up, and before any MI admission or death.

Patient and Hospital Characteristics by Follow-up Testing Status

"Any Testing" vs. "No Testing"—Patients who underwent either ST or CA at any time during follow-up differed at the time of index PCI from those who did not have subsequent testing (NT patients) (Table 1). No testing patients were older with a greater proportion aged at least 75 years, had higher rates of major comorbidities, including prior CHF diagnosis, diabetes, renal failure, cerebrovascular disease, chronic lung disease and current smoking. No testing patients were less likely to have had previous PCI or to have presented with angina, but more likely to have had acute MI and/or congestive heart failure (CHF) at the time of PCI. Any testing patients underwent PCI at centers with higher median annual PCI volume, were more likely to have received drug-eluting stents, and were less likely to have been treated at academic centers.

Rates of pre-PCI testing were clinically similar for patients with any testing post-PCI compared to no testing (78% vs. 77%, respectively), with very similar distribution of positive, negative, and equivocal results. Stress testing during the blackout period did not appear to preclude the use of testing after the blackout period, as AT patients were more likely to have had ST during the blackout period than NT patients, 14% vs. 9%. In contrast, there was no difference in ST use in the blackout period between post-blackout ST and CA patients, 14% in each group.

"Stress Test First" vs. "Coronary Angiography First"—Among patients with post-PCI testing at any time during follow-up (prior to MI hospitalization), ST first patients had lower baseline rates of most risk factors and comorbidities than CA first patients. Stress test first patients were less likely to have comorbid conditions, and were less likely to have had unstable angina or CHF at time of index PCI, but received drug-eluting stents more frequently. The time from PCI to testing was shorter for CA first patients, and they were treated at centers with higher median PCI volumes.

Patterns of Testing and Procedures within One Year after PCI

The cumulative incidences of CA first, ST first, and death or MI first between 60 days and one year after index PCI were examined to compare overall temporal trends (Figure 2) and 30-day incremental incidences (i.e., the incidence of testing or death/MI in patients not previously having an event; Figure 3). Accounting for censoring and competing risks, the cumulative incidence from 60-365 days after index PCI of CA first was 7.6%, of ST first was 32.8%, and of death or MI first was 6.0%. The remaining patients (55.6%) were alive without testing one year after PCI. For both ST first and CA first, the incremental 30-day

incidence of testing declined gradually over the first year after PCI. However, there are notable upticks in ST incidence in the 180-209 day range and the 330-359 day range, suggesting an increase in testing at 6-month and 1-year, possibly related to the time of routine follow-up visits. No similar pattern is apparent for 30-day incremental incidence of CA or death/MI.

The cumulative incidence of AT (ST or CA) within one year of index PCI declined from 41.9% in Q1 2005 to 38.0% in Q4 2007 (date of PCI). This decline was driven by a fall in ST incidence from 34.3% to 30.5% ($p<0.0001$) with decreases primarily in nuclear stress testing, 28.9% to 25.5%, $p<0.0001$. The incidence of CA was stable such that the likelihood of ST first relative to CA first decreased over time (Table 2).

Predictors of Testing after PCI

Cause-specific Cox models (with censoring at death, MI, end of follow-up, or 12 months) were used to calculate hazard ratios for AT (ST or CA) compared to NT within one year of index PCI (after the 60-day "blackout" period and prior to MI) for 30 baseline variables (Figure 4). Predictors of AT included female sex, non-white race, prior PCI, and receipt of bare metal stent(s). Most comorbidities and cardiac risk factors were associated with lower hazard ratios for AT, including: increasing age, prior CHF or MI, presentation with CHF at time of index PCI, diabetes, smoking, renal failure (dialysis or glomerular filtration rate less than 30 ml/min), cerebrovascular disease, and chronic lung disease.

Among patients with AT between 60 days and 12 months after PCI, a lower hazard of ST first and a higher likelihood of CA first was associated with prior CHF, prior PCI, prior CABG, diabetes, and chronic lung disease, but not sex or race. Acute coronary syndrome at time of index PCI and receipt of bare metal stents were both associated with a higher likelihood of ST first. The likelihood of ST first compared to CA first decreased over time.

Subsequent Testing and Clinical Outcomes

We examined downstream testing patterns within a 90-day episode of care period after the first post-PCI test, censoring for MI (Table 3). Among ST first patients (n=122,894), 2% (n=3016) had a second ST next, 83% (n=101,884) had no further cardiac testing, and 15% (n=18,472) proceeded to CA, of whom 48% (n=8831; 7% of the ST first group) had coronary revascularization. Repeat stress testing was not associated with an increased likelihood of revascularization.

For CA first patients (n=25,512), 4% (n=953) had ST next within 90 days, 44% (n=11,210) had no further testing, and 53% (n=13,316) proceeded to revascularization. Of patients referred to ST next after CA first who then returned to CA, 78% (n=96; 10% of the CA first patients with ST next) received revascularization.

In an unadjusted model treating testing status as a time-varying covariate, the hazard of either death or MI was higher after CA first (hazard ratio [HR] 1.20, 95% confidence interval [CI] 1.16-1.25, $p<0.0001$) and lower after ST first (HR 0.65, 95% CI 0.63-0.66, $p<0.0001$), relative to NT. After adjusting for baseline covariates (but without information about clinical presentation at time of post-PCI testing unavailable in this database), the results were similar: CA first vs. NT was associated with a 27% increase in likelihood of death or MI (HR 1.27, 95% CI, 1.23-1.32, $p<0.0001$) and ST first vs. NT was associated with a 19% reduced likelihood of death or MI (HR 0.81, 95% CI 0.79-0.83, $p<0.0001$).

Discussion

In this detailed analysis of contemporary patterns of cardiac testing among over 250,000 Medicare patients, we found that ST and CA were common within the first two years after PCI. Patterns of use suggest that patients with higher risk were less likely to undergo any post-PCI testing, and revascularization yield was low after post-PCI testing.

Our findings extend Shah et al.'s observation that 61% of privately insured patients <65 years old undergo ST within 2 years of PCI.[9] In the current study, 59% of elderly patients underwent cardiac testing between 60 days after PCI and end of follow-up, with ST first in 49% of patients and CA first in 10% of patients. In both studies, these rates greatly exceed the 15% one-year rates of angina symptoms in previous registry reports.[19] As in Shah et al.'s younger, commercially-insured cohort, we noted increased incremental ST rates at 6-months and 12-months post-PCI that may reflect a pattern of routine surveillance testing contrary to guidelines and AUC (though it is also possible that patients do not report concerning symptoms until scheduled visits, at which time symptom-driven testing may be ordered). The consistencies across these two studies, despite substantial differences in age and reimbursement mechanisms, demonstrate that testing is common after PCI across a broad range of patients, and these findings likely represents general patterns of care nationwide.

In aggregate, these observations suggest that there may be opportunities to improve the selection of patients for ST and CA after PCI. Over the time period studied we did see a modest but significant decline in testing rates after PCI driven by declines in ST rates, especially nuclear stress tests. This finding is consistent with reports of slowing growth in the setting of decreasing reimbursement rates following passage of the Deficit Reduction Act of 2005, the introduction of the ACC AUC standards,[6,7] and a growing focus on ensuring appropriate indications for testing over the years of the study period.[20]

Unlike other studies we were able to examine the implications of baseline clinical characteristics on subsequent care, finding that increasing age, male sex, and most comorbidities were associated with a lower likelihood of AT after PCI. Previous research has shown that ACS patients at highest baseline risk, and potentially with the most to gain from treatment, are often less likely to receive evidence-based therapies than healthier counterparts.[21-23] The current study suggests there may be a similar "paradoxical care" dynamic in testing after PCI, with lower testing rates among those most at risk; however, whether more testing would lead to better or worse outcomes cannot be determined in this observational study.

Among patients who did receive testing after PCI, comorbidities and risk factors were generally more common among CA first patients compared to ST first patients. This finding presumably reflects the guideline-supported tendency to refer higher risk patients directly to CA. Yet surprisingly, ACS presentation at the time of index PCI increased the likelihood of ST first rather than CA first—the reasons for this association are unclear.

Our study also highlights opportunities for identifying optimal testing strategies after PCI. We found that patients referred to ST first had only a 15% rate of subsequent cardiac catheterization, but the "catheterization yield" (i.e., rate of revascularization following catheterization) was clinically similar, though statistically different, between ST first and CA first patients (48% vs. 53%, $p<0.0001$). Though the ideal yield is impossible to determine, these "coin flip" rates underscore the challenges inherent in the contemporary evaluation of suspected ischemia, even in patients with known CAD and a history of revascularization. These findings highlight the need for improved methods to assess pre-test risk before and in addition to non-invasive or invasive testing.

Although we did not have clinical data at time of repeat testing, an exploratory analysis to evaluate clinical outcomes after post-PCI testing showed diametric differences in the hazard of death or acute MI with different post-PCI testing patterns. Invasive coronary angiography first patients had a 20% higher unadjusted hazard (27% adjusted) of the combined endpoint relative to NT, despite attribution of MIs that occurred during the same hospitalization as the initial CA to the NT group. In contrast, following ST first, there was a 35% lower unadjusted hazard of death or MI, relative to NT. After adjustment, the hazard decrement was lower, but still significant at 19%.

In this observational study, we cannot address causality, nor can we determine the extent to which observed differences in associated outcomes reflect unmeasured baseline differences, variations in clinical presentation or status at time of testing (confounding by indication), or differential effectiveness of testing strategies. Therefore, we do not intend to imply that test selection after PCI is a primary driver of clinical outcomes. Even so, the antipodal associations of CA first and ST first with clinical outcomes are notable and deserving of further research attention, potentially through randomized studies or the use of "natural experiments" in observational datasets.

Strengths and Limitations

Using a unique data set linking detailed baseline clinical information from the CathPCI Registry with longitudinal inpatient and outpatient Medicare fee-for-service claims data, we have analyzed testing patterns after PCI in a large, nationwide cohort of patients receiving care in "real world" clinical practice. We are not aware of any prior similar study of this magnitude. Nevertheless, data are limited to fee-for-service Medicare patients who underwent index PCI with inpatient Medicare billing at CathPCI Registry sites, and may not be generalizable to other populations. Only 67% of index NCDR PCI events were linked to longitudinal Medicare billing data; however, in a cohort of elderly PCI patients from 2004-2006 developed using the same methodology, linked and unlinked patients shared similar demographic and clinical features.[24] Data on symptoms, clinical presentation, and findings at the time of retesting were unavailable and surely differed between groups. The indications for and goals of testing were not available. Our dataset allowed only evaluation of medium-term testing patterns and outcomes, and longer-term results may diverge.

Conclusions

In contemporary practice, ST and CA are utilized frequently after PCI, with patterns of use suggesting that patients with higher risk are less likely to undergo post-PCI testing. Further research is warranted to identify ideal testing indications and strategies after PCI, and to determine the impact of testing strategies on clinical outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Role of the Sponsor

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References

1. Roger VL, Go AS, Lloyd-Jones DM, Adams RJ, Berry JD, Brown TM, Carnethon MR, Dai S, de Simone G, Ford ES, Fox CS, Fullerton HJ, Gillespie C, Greenlund KJ, Hailpern SM, Heit JA, Ho PM, Howard VJ, Kissela BM, Kittner SJ, Lackland DT, Lichtman JH, Lisabeth LD, Makuc DM, Marcus GM, Marelli A, Matchar DB, McDermott MM, Meigs JB, Moy CS, Mozaffarian D, Mussolino ME, Nichol G, Paynter NP, Rosamond WD, Sorlie PD, Stafford RS, Turan TN, Turner MB, Wong ND, Wylie-Rosett J. American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics--2011 update: a report from the American Heart Association. Circulation. 2011; 123:e18–e209. [PubMed: 21160056]
2. Epstein AJ, Polsky D, Yang F, Yang L, Groeneveld PW. Coronary revascularization trends in the United States, 2001-2008. JAMA. 2011; 305:1769–1776. [PubMed: 21540420]
3. Cheitlin MD, Armstrong WF, Aurigemma GP, Beller GA, Bierman FZ, Davis JL, Douglas PS, Faxon DP, Gillam LD, Kimball TR, Kussmaul WG, Pearlman AS, Philbrick JT, Rakowski H, Thys DM, Antman EM, Smith SC Jr, Alpert JS, Gregoratos G, Anderson JL, Hiratzka LF, Hunt SA, Fuster V, Jacobs AK, Gibbons RJ. Russell RO; American College of Cardiology; American Heart Association; American Society of Echocardiography. ACC/AHA/ASE 2003 guideline update for the clinical application of echocardiography: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASE Committee to Update the 1997 Guidelines for the Clinical Application of Echocardiography). Circulation. 2003; 108:1146–1162. [PubMed: 12952829]
4. Gibbons RJ, Balady GJ, Bricker JT, Chaitman BR, Fletcher GF, Froelicher VF, Mark DB, McCallister BD, Mooss AN, O'Reilly MG, Winters WL Jr, Gibbons RJ, Antman EM, Alpert JS, Faxon DP, Fuster V, Gregoratos G, Hiratzka LF, Jacobs AK, Russell RO, Smith SC Jr. American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). ACC/AHA 2002 guideline update for exercise testing: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). Circulation. 2002; 106:1883–1892. [PubMed: 12356646]
5. Klocke FJ, Baird MG, Lorell BH, Bateman TM, Messer JV, Berman DS, O'Gara PT, Carabello BA, Russell RO Jr, Cerqueira MD, St John Sutton MG, DeMaria AN, Udelson JE, Kennedy JW, Verani MS, Williams KA, Antman EM, Smith SC Jr, Alpert JS, Gregoratos G, Anderson JL, Hiratzka LF, Faxon DP, Hunt SA, Fuster V, Jacobs AK, Gibbons RJ, Russell RO. American College of Cardiology; American Heart Association Task Force on Practice Guidelines; American Society for Nuclear Cardiology. ACC/AHA/ASNC guidelines for the clinical use of cardiac radionuclide imaging--executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASNC Committee to Revise the 1995 Guidelines for the Clinical Use of Cardiac Radionuclide Imaging). Circulation. 2003; 108:1404–1418. [PubMed: 12975245]
6. Douglas PS, Khandheria B, Stainback RF, Weissman NJ, Peterson ED, Hendel RC, Stainback RF, Blaivas M, Des Prez RD, Gillam LD, Golash T, Hiratzka LF, Kussmaul WG, Labovitz AJ, Lindenfeld J, Masoudi FA, Mayo PH, Porembka D, Spertus JA, Wann LS, Wiegers SE, Brindis RG, Douglas PS, Hendel RC, Patel MR, Peterson ED, Wolk MJ, Allen JM. American College of Cardiology Foundation; American Society of Echocardiography; American College of Emergency

Physicians; American Heart Association; American Society of Nuclear Cardiology; Society for Cardiovascular Angiography and Interventions; Society of Cardiovascular Computed Tomography; Society for Cardiovascular Magnetic Resonance. ACCF/ASE/ACEP/AHA/ASNC/SCAI/SCCT/SCMR 2008 appropriateness criteria for stress echocardiography: a report of the American College of Cardiology Foundation Appropriateness Criteria Task Force, American Society of Echocardiography, American College of Emergency Physicians, American Heart Association, American Society of Nuclear Cardiology, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, and Society for Cardiovascular Magnetic Resonance endorsed by the Heart Rhythm Society and the Society of Critical Care Medicine. J Am Coll Cardiol. 2008; 51:1127–1147. [PubMed: 18342240]

7. Hendel RC, Berman DS, Di Carli MF, Heidenreich PA, Henkin RE, Pellikka PA, Pohost GM, Williams KA. American College of Cardiology Foundation Appropriate Use Criteria Task Force; American Society of Nuclear Cardiology; American College of Radiology; American Heart Association; American Society of Echocardiography; Society of Cardiovascular Computed Tomography; Society for Cardiovascular Magnetic Resonance; Society of Nuclear Medicine. ACCF/ASNC/ACR/AHA/ASE/SCCT/SCMR/SNM 2009 appropriate use criteria for cardiac radionuclide imaging: a report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the American Society of Nuclear Cardiology, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the Society of Cardiovascular Computed Tomography, the Society for Cardiovascular Magnetic Resonance, and the Society of Nuclear Medicine. Circulation. 2009; 119:561–587.
8. Medicare Part B imaging services: rapid spending growth and shift to physicians offices indicate need for CMS to consider additional management practices. U.S. Government Accountability Office web site. 2011; 20 http://www.gao.gov/products/GAO-08-452.
9. Shah BR, Cowper PA, O'Brien SM, Jensen N, Drawz M, Patel MR, Douglas PS, Peterson ED. Patterns of cardiac stress testing after revascularization in community practice. J Am Coll Cardiol. 2010; 56:1328–1334. [PubMed: 20888523]
10. Lucas FL, Siewers AE, Malenka DJ, Wennberg DE. Diagnostic-therapeutic cascade revisited: coronary angiography, coronary artery bypass graft surgery, and percutaneous coronary intervention in the modern era. Circulation. 2008; 118:2797–2802. [PubMed: 19064681]
11. Shah BR, Cowper PA, O'Brien SM, Jensen N, Patel MR, Douglas PS, Peterson ED. Association between physician billing and cardiac stress testing patterns following coronary revascularization. JAMA. 2011; 306:1993–2000. [PubMed: 22068991]
12. CathPCI Registry. American College of Cardiology National Cardiovascular Data CathPCI Registry web site. 20:2011. https://www.ncdr.com/webncdr/DefaultCathPCI.aspx.
13. Brindis RG, Fitzgerald S, Anderson HV, Shaw RE, Weintraub WS, Williams JF. The American College of Cardiology-National Cardiovascular Data Registry (ACC-NCDR): building a national clinical data repository. J Am Coll Cardiol. 2001; 37:2240–2245. [PubMed: 11419906]
14. Hammill BG, Hernandez AF, Peterson ED, Fonarow GC, Schulman KA, Curtis LH. Linking inpatient clinical registry data to Medicare claims data using indirect identifiers. Am Heart J. 2009; 157:995–1000. [PubMed: 19464409]
15. Kalbfleisch, JD.; Prentice, RL. The Statistical Analysis of Failure Time Data. John Wiley & Sons, Inc; New York: 1980.
16. Cox, DR.; Oakes, D. Analysis of Survival Data. Chapman and Hall; London: 1984.
17. Therneau, TM.; Grambsch, PM. Modeling Survival Data: Extending the Cox Model. Springer; New York: 2000.
18. Altman DG, De Stavola BL. Practical problems in fitting a proportional hazards model to data with updated measurements of the covariates. Stat Med. 1994; 13:301–341. [PubMed: 8177984]
19. Venkitachalam L, Kip KE, Mulukutla SR, Selzer F, Laskey W, Slater J, Cohen HA, Wilensky RL, Williams DO, Marroquin OC, Sutton-Tyrrell K, Bunker CH, Kelsey SF. NHLBI-Sponsored Dynamic Registry Investigators. Temporal trends in patient-reported angina at 1 year after percutaneous coronary revascularization in the stent era: a report from the National Heart, Lung, and Blood Institute-sponsored 1997-2006 dynamic registry. Circ Cardiovasc Qual Outcomes. 2009; 2:607–615. [PubMed: 20031899]

20. Shaw LJ, Min JK, Hachamovitch R, Peterson ED, Hendel RC, Woodard PK, Berman DS, Douglas PS. Cardiovascular imaging research at the crossroads. JACC Cardiovasc Imaging. 2010; 3:316–324. [PubMed: 20223430]

21. Motivala AA, Cannon CP, Srinivas VS, Dai D, Hernandez AF, Peterson ED, Bhatt DL, Fonarow GC. Changes in myocardial infarction guideline adherence as a function of patient risk an end to paradoxical care? J Am Coll Cardiol. 2011; 58:1760–1765. [PubMed: 21996387]

22. Mudrick DW, Chen AY, Roe MT, Newby LK, Gibler WB, Ohman EM, Peterson ED, Alexander KP. Changes in glycoprotein IIb/IIIa inhibitor excess dosing with site-specific safety feedback in the Can Rapid risk stratification of Unstable angina patients Suppress ADverse outcomes with Early implementation of the ACC/AHA guidelines (CRUSADE) initiative. Am Heart J. 2010; 160:1072–1078. [PubMed: 21146660]

23. Roe MT, Peterson ED, Newby LK, Chen AY, Pollack CV Jr, Brindis RG, Harrington RA, Christenson RH, Smith SC Jr, Califf RM, Braunwald E, Gibler WB, Ohman EM. The influence of risk status on guideline adherence for patients with non-ST-segment elevation acute coronary syndromes. Am Heart J. 2006; 151:1205–1213. [PubMed: 16781220]

24. Brennan JM, Peterson ED, Messenger JC, Rumsfeld JS, Weintraub WS, Anstrom KJ, Eisenstein EL, Milford-Beland S, Grau-Sepulveda MV, Booth ME, Dokholyan RS, Douglas PS. on behalf of the Duke Clinical Research Institute DEcIDE Team. Linking the National Cardiovascular Data Registry CathPCI Registry with Medicare claims data: validation of a longitudinal cohort of elderly patients undergoing cardiac catheterization. Circ Cardiovasc Qual Outcomes. 2012; 5:134–140. [PubMed: 22253370]

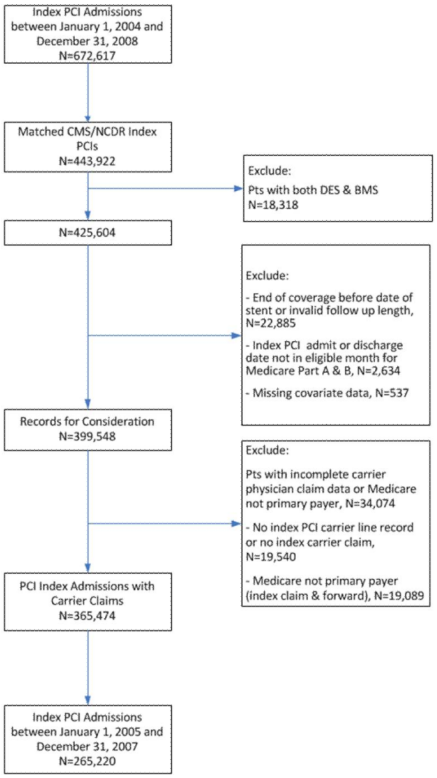

Figure 1a. Linked dataset population description
This figure displays the linked dataset population (CathPCI and CMS), exclusions included.

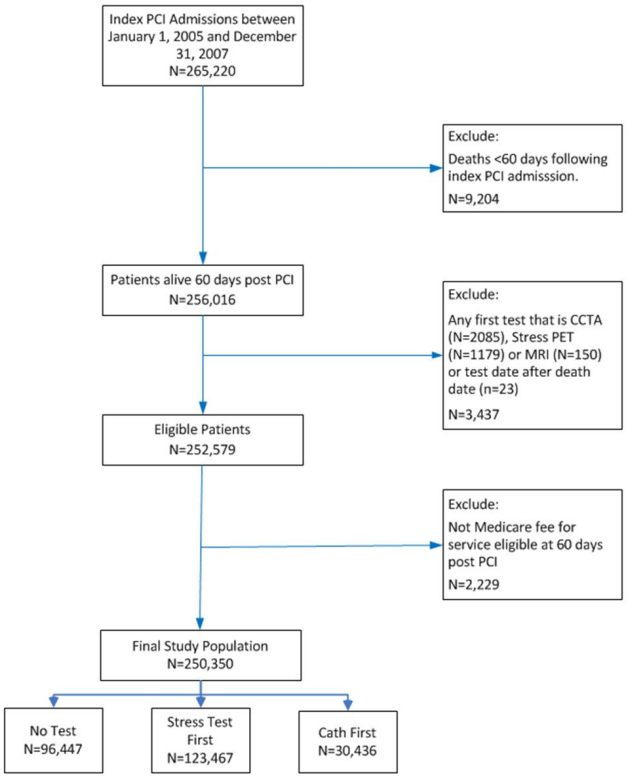

Figure 1b. Study population description

This figure displays initial patient cohort, through the final study population, exclusions included.

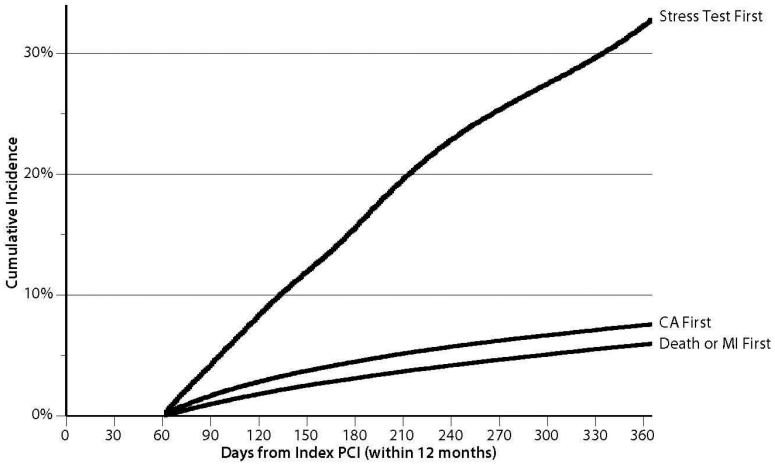

Figure 2. Cumulative incidence of stress test first, coronary angiography first, or death/ myocardial infarction within 1 year and at least 60 days after index PCI

This figure displays the cumulative incidence of stress testing, coronary angiography or death/myocardial infarction in patients without a previous event, treating each type of event as a competing risk for the other types.

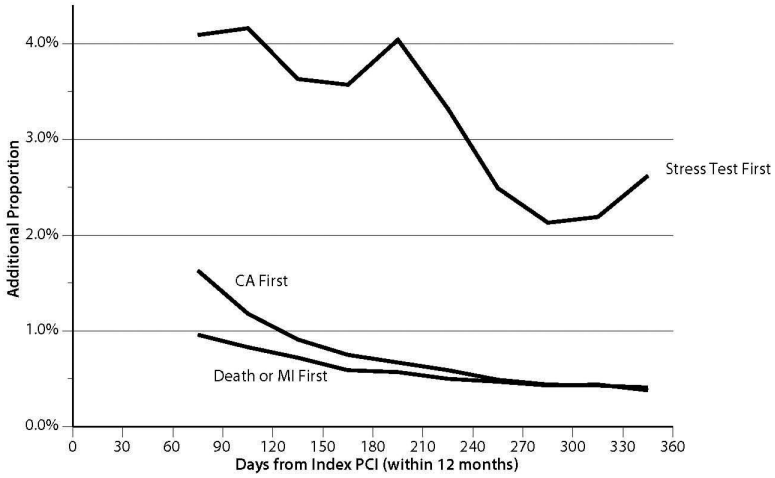

Figure 3. 30-day incremental incidence of stress test first, coronary angiography first, or death/myocardial infarction between 60 days and 1 year after index PCI

This figure displays the incremental incidence of stress testing, coronary angiography, or death/myocardial infarction per 30 day period in patients without a previous event, treating each type of event as a competing risk for the other types.

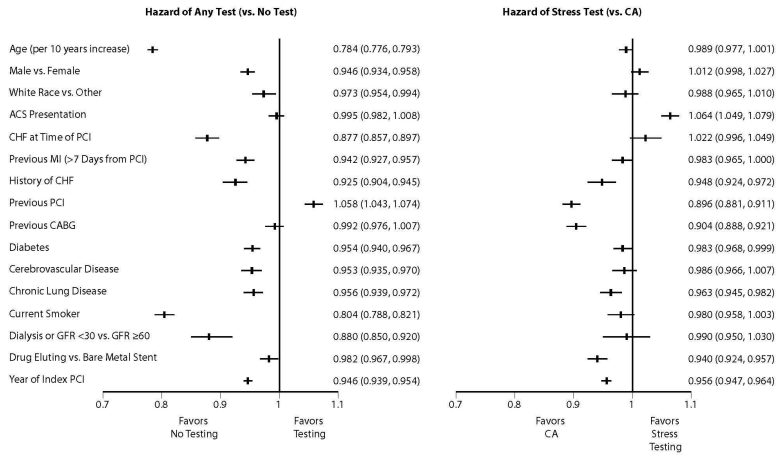

Figure 4. Hazard ratios associated with a risk of any test

Hazard ratios associated with a risk of stress test or coronary angiography compared to no test and risk of stress test first compared to coronary angiography first between 60 days and 12 months after PCI by baseline characteristics determined at time of index percutaneous coronary intervention.

Table 1

Baseline and Descriptive Characteristics at Time of Index Coronary Stenting, by Stress Test First or Coronary Angiography First (if any, between 60 Days after Index PCI and end of follow up, and prior to Death or Myocardial Infarction Admission)

	Overall (n=250,350)	No testing (n=101,944)	Any testing (n=148,406)	Among patients with testing (n=148,406)	
				STF (n=122,894)	CAF (n=25,512)
Baseline demographics					
Age (years)(median, Q1, Q3)	74 (69, 80)	76 (70, 81)	73 (69, 78)	73 (69, 78)	74 (69, 79)
≥75,%	49	56	45	44	46
Female, %	43	43	42	42	45
Caucasian, %	89	89	90	89	90
Baseline comorbid conditions					
BMI (median, Q1, Q3)	28 (25, 31)	27 (24, 31)	28 (25, 32)	28 (25, 32)	28 (25, 32)
≥30, %	33	32	34	34	35
Previous MI (>7 days), %	25	26	24	23	29
Previous CHF, %	13	16	11	10	16
Family history CAD, %	20	18	21	21	23
Hypertension, %	81	81	81	80	83
Diabetes, %	32	34	31	30	35
Renal failure (GFR <30), %	4	6	3	3	4
Cerebrovascular disease, %	16	18	14	14	17
PVD, %	15	16	14	13	17
Chronic lung disease, %	18	21	17	16	21
Dyslipidemia, %	74	71	76	75	77
Current smoker, %	12	14	11	11	12
Previous PCI, %	27	25	28	27	36
Previous CABG, %	22	22	22	21	30
Cardiac status					
No angina, %	14	14	14	15	11
Atypical chest pain,%	7	7	8	8	7
Stable angina, %	17	14	18	18	17
Unstable angina, %	34	32	36	35	43
Non-ST segment MI,%	17	20	14	14	13

	Overall (n=250,350)	No testing (n=101,944)	Any testing (n=148,406)	Among patients with testing (n=148,406)	
				STF (n=122,894)	CAF (n=25,512)
ST-segment MI, %	11	13	10	10	8
CHF on presentation,%	12	15	9	9	12
Procedural characteristics					
DES used, %	77	73	81	81	78
Time to 1st test (days), (median, Q1, Q3)	253 (145, 413)	N/A	253 (145, 413)	264 (154, 418)	210 (113, 380)
Duration of follow-up (days), (median, Q1, Q3)	728 (491, 1028)	586 (393, 861)	838 (593, 1108)	848 (602, 1115)	786 (540, 1069)
Hospital features					
# of CMS certified beds (median, Q1, Q3)	424 (300, 571)	426 (304, 572)	423 (300, 571)	421 (300, 585)	424 (300, 568)
Urban location, %	60	61	60	59	61
Region, %					
Northeast	11	11	11	11	9
Midwest	37	37	36	36	38
South	38	38	38	37	41
West	14	13	14	15	12
Community/private,%	89	88	90	90	89
Academic, %	52	54	51	51	52
Annual PCI volume (median, Q1, Q3)	881 (565, 1517)	877 (558, 1478)	889 (567, 1550)	881 (565, 1532)	946 (603, 1647)

BMI indicates body mass index; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CAF, coronary angiography first; CHF, congestive heart failure; CMS, Centers for Medicare & Medicaid Services; DES, drug-eluting stent; GFR, glomerular filtration rate; MI, myocardial infarction; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; STF, stress test first

Table 2

Time Trends in First Stress Test or Invasive Coronary Angiography within 1 Year and at Least 60 Days after Index PCI and prior to Death or Myocardial Infarction Admission, by Date (Quarter) of Initial PCI

Total population (n=250,350)	2005				2006				2007				Rate ratio per Q	P-value
	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)		
No testing (n=150,914)	58.1	57.4	59.1	58.4	60.2	59.3	61.1	60.8	62.3	61.1	61.7	62.0	1.007	<0.0001
Stress test or CA first (n=99,436)	41.9	42.6	40.9	41.6	39.8	40.7	38.9	39.2	37.7	38.9	38.3	38.0	0.990	<0.0001
Stress test first (n=80,747)	34.3	34.8	33.4	34.1	32.5	33.3	31.8	31.8	30.2	31.3	30.8	30.5	0.988	<0.0001
CA first (n=18,689)	7.6	7.8	7.5	7.5	7.3	7.4	7.1	7.4	7.5	7.6	7.5	7.5	0.999	0.77

CA indicates coronary angiography (invasive)

Table 3

Rates of Stress Testing, Coronary Angiography, and Revascularization after First Test Post-PCI (if any, within 90 Days of first Test after Index PCI and prior to Death or Myocardial Infarction Admission)

	First test after index PCI	
	STF (n=122,894)	**CAF (n=25,512)**
No subsequent test	83%	44%
Stress test next	2%	4%
Catheterization within 90 days	15%	N/A
Revascularization within 90 days	7%	53%
Catheterization yield*	48%	53%

All p-values <0.0001 for all comparisons

All abbreviations can be found in Table 1.

*Catheterization yield = revascularizations within 90 days divided by catheterizations within 90 days