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

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Background—Patterns of noninvasive 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 ST first, 10% (n=25,512) underwent invasive CA first, and 41% (n=101,944) had no testing. Several 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 (hazard ratio [HR] 0.784 per 10-year increase), male sex (HR 0.946), heart failure (HR 0.925), diabetes mellitus (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=8,831) underwent revascularization within 90 days, compared with 53% (n=13,316) of CA first patients (P<0.0001).

Conclusions—In this descriptive analysis, ST and invasive CA were common in older patients after PCI. Paradoxically, patients with higher risk factors 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. (Circ Cardiovasc Imaging. 2013;6:11-19.)

Key Words: clinical outcomes ▪ coronary angiography ▪ noninvasive stress test ▪ percutaneous coronary intervention

DiagnostiC testing is commonplace following the 1.4 million percutaneous coronary intervention (PCI) procedures performed annually in the United States and is addressed in the American College of Cardiology/American Heart Association guidelines and the American College of Cardiology Foundation Appropriate Use Criteria. There has been accumulating scrutiny regarding the overall increased use of cardiac diagnostic testing in recent decades, with studies suggesting high testing rates in patients after PCI, as well as significant geographic variability and financial influences on testing rates. 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 data set, which combined the Centers for Medicare & Medicaid Services and the National Cardiovascular Data Registry 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. 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.

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. Because of 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, because 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 postrevascularization STs or outcome events.

Data Definitions
Inpatient and outpatient ST 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 Current Procedural Terminology and International Classification of Diseases, Ninth Revision, Clinical Modification codes, as described in Online-Only Data Supplement Appendix 1. Date of death was obtained from the Centers for Medicare & Medicaid Services beneficiary claim files.

Statistical Analysis
Patients were stratified by type of first follow-up test (no testing [NT] compared with any testing [AT] and ST first compared with 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 the acute setting, patients were classified only according to testing status before 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 2-sided with a significance level of 0.05. P values were based on either Pearson χ² tests for categorical variables or Kruskal-Wallis tests for continuous or ordinal variables. As a result of variable follow-up time between groups, P values were not reported for between-group comparisons, as in Table 1. We set a threshold >2% absolute difference between groups for reporting.

Time-to-first test (ST or CA) occurring between 60 days and 1 year after the index PCI was computed and plotted using cumulative incidence functions that accounted for administrative censoring and included MI hospitalization and death as competing risks. One-year cumulative incidence of ST first or CA first was compared with NT using an unadjusted Poisson regression stratified by calendar quarter of index PCI to determine whether testing patterns changed during 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 to estimate hazard ratios (HRs) of AT versus NT and ST first versus CA first among those with testing, for a
Table 1. Baseline and Descriptive Characteristics at Time of Index Coronary Stenting, by STF or CAF (If Any, Between 60 Days After Index PCI and End of Follow-up and After Death or Myocardial Infarction Admission)

<table>
<thead>
<tr>
<th>Overall (n=250 350)</th>
<th>No Testing (n=101 944)</th>
<th>Any Testing (n=148 406)</th>
<th>Among Patients With Testing (n=148 406)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STF (n=122 894)</td>
<td>CAF (n=25 512)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Baseline demographics**

- **Age (y) (median, Q1, Q3)**: 74 (69, 80) 76 (70,81) 73 (69,78) 73 (69, 78) 74 (69,79)
- **≥75, %**: 49 56 45 44 46
- **Women, %**: 43 43 42 42 45
- **White, %**: 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 mellitus, %**: 4 6 3 3 3
- **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
- **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 first test (d) (median, Q1, Q3)**: 253 (145, 413) N/A 253 (145,413) 264 (154, 418) 210 (113, 380)
- **Duration of follow-up (d) (median, Q1, Q3)**: 728 (491, 1028) 586 (393, 861) 838 (593, 1108) 848 (602, 1115) 786 (540, 1069)

**Hospital features**

- **No. 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, %**: 11 11 11 11 9
- **Northeast**: 37 37 36 36 38
- **Midwest**: 38 38 38 37 41
- **South**: 14 13 14 15 12
- **West**: 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; CABS, 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; and STF, stress test first.
Panel of baseline variables from available National Cardiovascular Data Registry variables selected a priori, listed in Online-Only Data Supplement 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 before MI and calculating rates of subsequent procedures (repeat ST, CA, and revascularization) between 0 and 90 days from that first post-PCI test, but before 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/pretesting, ST first, or CA first) to account for differences in timing of testing and death or MI. For this analysis only, following the 60-day blackout period after PCI, all patients started in the NT/pretesting 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/pretesting 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/pretesting group is referred to as the NT group in the Results and Discussion sections of this article. 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 (Figure 1A and 1B). Median age at time of index PCI was 74 years, 43% were women, and median follow-up time was 728 days (interquartile range, 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 Versus 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 and had higher rates of major comorbidities, including prior congestive heart failure (CHF) diagnosis, diabetes mellitus, 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 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 with no testing (78% versus 77%, respectively), with very similar distribution of positive, negative, and equivocal results. ST during the blackout period did not seem 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% versus 9%. In contrast, there was no difference in ST use in the blackout period between postblackout ST and CA patients, 14% in each group.

ST First Versus CA First

Among patients with post-PCI testing at any time during follow-up (before MI hospitalization), ST first patients had lower baseline rates of most risk factors and comorbidities than CA first patients. ST 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 1 Year After PCI

The cumulative incidences of CA first, ST first, and death or MI first between 60 days and 1 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 to 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 1 year after PCI. For both ST first and CA first, the incremental 30-day incidence of testing declined gradually during the first year after PCI. However, there are notable upticks in ST incidence in the 180 to 209 day range and the 330 to 359 day range, suggesting an increase in testing at 6 months 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 1 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% (<0.0001) with decreases primarily in nuclear ST, 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 HRs for AT (ST or CA) compared with NT within 1 year of index PCI (after the 60-day blackout period and before MI) for 30 baseline variables (Figure 4). Predictors of AT included female sex, nonwhite race, prior PCI, and receipt of bare metal stents. Most comorbidities and cardiac risk factors were associated
with lower HRs for AT, including increasing age, prior CHF or MI, presentation with CHF at time of index PCI, diabetes mellitus, smoking, renal failure (dialysis or glomerular filtration rate <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 were associated with prior CHF, prior PCI, prior coronary artery bypass grafting, diabetes mellitus, 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 with 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 ST 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 (HR 1.20, 95% 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 versus 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 versus 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 more than 250,000 Medicare patients, we found that ST and CA were common within the first 2 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 the observation by Shah et al9 that 61% of privately insured patients aged <65 years undergo ST within 2 years of PCI. 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% 1-year rates of angina symptoms in previous registry reports.19 As in the younger, commercially insured cohort by Shah et al, we noted increased ST rates at 6 months and 12 months post-PCI, which may reflect a pattern of routine surveillance testing contrary to guidelines and Appropriate Use Criteria (although 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 2 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 represent 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. During 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 STs. 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 American College of Cardiology Appropriate Use Criteria standards,6,7 and a growing focus on ensuring appropriate indications for testing during the years of the study period.20

Table 2. Time Trends in First Stress Test or Invasive CA Within 1 Year and at Least 60 Days After Index PCI and Before Death or Myocardial Infarction Admission, by Date (Quarter) of Initial PCI

<table>
<thead>
<tr>
<th></th>
<th>Total Population (n=250,350)</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>Rate Ratio per Q P Value Q1, %</th>
<th>Q2, %</th>
<th>Q3, %</th>
<th>Q4, %</th>
<th>Rate Ratio per Q P Value Q1, %</th>
<th>Q2, %</th>
<th>Q3, %</th>
<th>Q4, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No testing (n=150,914)</td>
<td>58.1</td>
<td>57.4</td>
<td>59.1</td>
<td>58.4</td>
<td>60.2</td>
<td>59.3</td>
<td>61.1</td>
<td>60.8</td>
<td>62.3</td>
<td>61.1</td>
<td>61.7</td>
<td>62.0</td>
</tr>
<tr>
<td>Stress test or CA first (n=99,436)</td>
<td>41.9</td>
<td>42.6</td>
<td>40.9</td>
<td>41.6</td>
<td>39.8</td>
<td>40.7</td>
<td>38.9</td>
<td>39.2</td>
<td>37.7</td>
<td>38.9</td>
<td>38.3</td>
<td>38.0</td>
</tr>
<tr>
<td>Stress test first (n=80,747)</td>
<td>34.3</td>
<td>34.8</td>
<td>33.4</td>
<td>34.1</td>
<td>32.5</td>
<td>33.3</td>
<td>31.8</td>
<td>31.8</td>
<td>30.2</td>
<td>31.3</td>
<td>30.8</td>
<td>30.5</td>
</tr>
<tr>
<td>CA first (n=18,689)</td>
<td>7.6</td>
<td>7.8</td>
<td>7.5</td>
<td>7.5</td>
<td>7.3</td>
<td>7.4</td>
<td>7.1</td>
<td>7.4</td>
<td>7.5</td>
<td>7.6</td>
<td>7.5</td>
<td>7.5</td>
</tr>
</tbody>
</table>

CA indicates coronary angiography (invasive); and PCI, percutaneous coronary intervention.

Figure 4. Hazard ratios (HRs) associated with a risk of any test. HRs associated with a risk of stress test or coronary angiography compared with no test, and risk of stress test first compared with coronary angiography first, between 60 days and 12 months after percutaneous coronary intervention (PCI) by baseline characteristics determined at time of index PCI. ACS indicates acute coronary syndrome; CABG, coronary artery bypass grafting; CHF, congestive heart failure; and GFR, glomerular filtration rate.
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 Before Death or Myocardial Infarction Admission)

<table>
<thead>
<tr>
<th>First Test After Index PCI</th>
<th>CAF (n=25 512)</th>
<th>STF (n=122 894)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No subsequent test, %</td>
<td>83</td>
<td>44</td>
</tr>
<tr>
<td>Stress test next, %</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Catheterization within 90 days, %</td>
<td>N/A</td>
<td>15</td>
</tr>
<tr>
<td>Revascularization within 90 days, %</td>
<td>7</td>
<td>53</td>
</tr>
<tr>
<td>Catheterization yield, %*</td>
<td>48</td>
<td>53</td>
</tr>
</tbody>
</table>

All P values < 0.0001 for all comparisons. CAF indicates coronary angiography first; PCI, percutaneous coronary intervention; and STF, stress test first.

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

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 acute coronary syndrome 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. 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 with ST first patients. This finding presumably reflects the guideline-supported tendency to refer higher risk patients directly to CA. Yet surprisingly, acute coronary syndrome 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 (ie, rate of revascularization after catheterization) was clinically similar, although statistically different, between ST first and CA first patients (48% versus 53%, P < 0.0001). Although 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 pretest risk before and in addition to noninvasive 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 CA 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, after 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 data sets.

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 National Cardiovascular Data Registry PCI events were linked to longitudinal Medicare billing data; however, in a cohort of elderly PCI patients from 2004 to 2006 developed using the same methodology, linked and unlinked patients shared similar demographic and clinical features. 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 data set allowed only evaluation of medium-term testing patterns and outcomes, and longer-term results may diverge.

Conclusions
In contemporary practice, ST and CA are used 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.

Acknowledgments
We thank Sarah Milford-Beland, MS, for her assistance with database development and statistical methods. She did not receive funding for her assistance, apart from her employment at the institution where this study was conducted.

Sources of Funding
This project was sponsored by the Agency for Healthcare Research and Quality, US Department of Health and Human Services, Rockville, MD, as part of the Cardiovascular Consortium, and funded under Project ID 24-DKE-3 and Work Assignment Number HHSAA290-2005-0032-I-TO4-WA3 as part of the Developing Evidence to Inform Decisions about Effectiveness (DEcIDE) program. The authors of this report are responsible for its content. Statements in the report should not be construed as endorsement by the Agency for

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Disclosures

None.

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**CLINICAL PERSPECTIVE**

Diagnostic cardiac testing is commonplace following the 1.4 million percutaneous coronary intervention (PCI) procedures performed annually in the United States, but limited data exist on current patterns of post-PCI testing. Therefore, this study examined patterns of stress testing and invasive coronary angiography in a large, contemporary cohort of 250,350 elderly PCI patients using a unique data set combining longitudinal Medicare inpatient and outpatient claims with baseline clinical data from the National Cardiovascular Data Registry CathPCI Registry. Between 60 days post-PCI and end of follow-up (median, 24 months), 49% of patients received stress testing first, 10% underwent invasive coronary angiography first, and 41% had no testing. These testing rates are significantly higher than reported rates of recurrent angina after PCI in large registry studies. Paradoxically, several clinical risk factors at time of index PCI were associated with lower, rather than higher, likelihood of downstream testing, including older age, male sex, heart failure, diabetes mellitus, smoking, and renal failure. Fifteen percent of patients with stress testing first after PCI proceeded to subsequent invasive coronary angiography within 90 days of testing; of these, 48% underwent revascularization, compared with 53% of patients referred to catheterization first after PCI. Overall, the revascularization yield was low on patients referred for stress testing after PCI, with only 9% undergoing revascularization within 90 days. In aggregate, these results shed light on patterns of cardiac testing after PCI, and suggest further examination of these data incorporating reason for stress test referral and more insights into patient characteristics, particularly symptoms, after recent PCI.
Patterns of Stress Testing and Diagnostic Catheterization After Coronary Stenting in 250 Medicare Beneficiaries
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Circ Cardiovasc Imaging. 2013;6:11-19; originally published online October 16, 2012; doi: 10.1161/CIRCIMAGING.112.974121
Circulation: Cardiovascular Imaging is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-9651. Online ISSN: 1942-0080

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circimaging.ahajournals.org/content/6/1/11

An erratum has been published regarding this article. Please see the attached page for:
/content/6/3/e21.full.pdf

Data Supplement (unedited) at:
http://circimaging.ahajournals.org/content/suppl/2012/10/16/CIRCIMAGING.112.974121.DC1

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As stated in the results section on page 15 and in Table 3, the correct revascularization rate for patients referred for stress testing first after percutaneous intervention was 7% (122,894 stress tested and 8,831 revascularized). The 9% figure reported in the conclusions of the abstract represents a typographical error and should also read 7%; the number 101,884 in the last sentence of the abstract’s Methods and Results section should read 122,894.

The errors have been corrected in the current online version of the article which is available at: http://circimaging.ahajournals.org/content/6/1/11.full. The authors regret the errors.
SUPPLEMENTAL MATERIAL


1. Electrocardiogram stress*: 93015-93018
2. Stress nuclear: 78460-78461, 78464-78465, 78472-78473, 78481, 78483
3. Stress echocardiography: 93350
4. Diagnostic cardiac catheterization: 93508, 93539, 93540, 93545
5. Percutaneous coronary intervention**: 92980-92982, 92984, 92995, 92996, G0290, G0291, 36.01, 36.02, 36.05, 36.06, 36.07, 00.66
6. Coronary artery bypass grafting: 33510-33514, 33516-33519, 33521-33523, 33533-33536, 36.1x, 36.2, S2205-S2209
7. Acute myocardial infarction (inpatient): 410.x1

*Electrocardiogram stress and nuclear imaging procedures performed within one day of each other were considered a single stress nuclear event. Electrocardiogram stress and echocardiographic testing performed on the same day were considered a single stress echocardiography event.

**Multiple revascularization procedures within a single hospitalization were considered a single revascularization event.
Appendix 2. Baseline NCDR CathPCI variables included in Cox hazard models of post-PCI testing and outcomes

Variables examined were: age, race, gender, body mass index (BMI), acute coronary syndrome (ACS) at time of index PCI, peripheral vascular disease, history of congestive heart failure (CHF), diabetes, hypertension, dyslipidemia, current smoking status, cerebrovascular disease, family history of coronary artery disease before age 55, previous MI more than 7 days before index PCI, chronic lung disease, drug-eluting stent versus bare metal stent, glomerular filtration rate <30 ml/min or receiving dialysis, previous PCI, previous CABG, current CHF status, year of index PCI, hospital type (government, private and teaching, private and non-teaching, versus university), average annual PCI volume, number of CMS-certified beds, and region.