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Patterns and Predictors of Stress Testing Modality After Percutaneous Coronary Stenting

Data From the NCDR®

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OBJECTIVES We evaluated temporal trends and geographic variation in choice of stress testing modality after percutaneous coronary intervention (PCI), as well as associations between modality and procedure use after testing.

BACKGROUND Stress testing is frequently performed post-PCI, but the choices among available modalities (electrocardiography only, nuclear, or echocardiography; pharmacological or exercise stress) and consequences of such choices are not well characterized.

METHODS CathPCI Registry® data were linked with identifiable Medicare claims to capture stress testing use between 60 and 365 days post-PCI and procedures within 90 days after testing. Testing rates and modality used were modeled on the basis of patient, procedure, and PCI facility factors, calendar quarter, and Census Divisions using Poisson and logistic regression. Post-test procedure use was assessed using Gray's test.

RESULTS Among 284,971 patients, the overall stress testing rate after PCI was 53.1 per 100 person-years. Testing rates declined from 59.3 in quarter 1 (2006) to 47.1 in quarter 4 (2008), but the relative use of modalities changed little. Among exercise testing recipients, adjusted proportions receiving electrocardiography-only testing varied from 6.8% to 22.8% across Census Divisions; and among exercise testing recipients having an imaging test, the proportion receiving echocardiography (versus nuclear) varied from 9.4% to 34.1%. Post-test procedure use varied among modalities; exercise electrocardiography-only testing was associated with more subsequent stress testing (13.7% vs. 2.9%; $p < 0.001$), but less catheterization (7.4% vs. 14.1%; $p < 0.001$) than imaging-based tests.

CONCLUSIONS Modest reductions in stress testing after PCI occurring between 2006 and 2008 cannot be ascribed to trends in use of any single modality. Additional research should assess whether this trend represents better patient selection for testing or administrative policies (e.g., restricted access for patients with legitimate testing needs). Geographic variation in utilization of stress modalities and differences in downstream procedure use among modalities suggest a need to identify optimal use of the different test modalities in individual patients. (J Am Coll Cardiol Img 2012;5:969–80) © 2012 by the American College of Cardiology Foundation

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Over the past 20 years, dramatic growth in the utilization of cardiac stress testing has led to multiple efforts to control utilization (1–3). Commercial insurers have attempted to reduce use through reimbursement cuts and utilization management, including requiring prior authorization or forcing test substitution (4,5). Contemporaneously, professional societies led by the American College of Cardiology Foundation (ACCF) have responded to concerns about the growth in utilization by defining appropriate use criteria (AUC) for stress testing, including stress echocardiography and nuclear imaging (6,7).

Perhaps due to these efforts, contemporary evidence suggests that stress testing rates have stabilized since 2005 (8); however, few data exist on trends in the utilization of stress testing in specific populations. One such population is patients with recent percutaneous coronary intervention (PCI)—a group that commonly receives stress testing (9). Whether trends also exist in the rates of use of different stress testing modalities (e.g., nuclear versus echocardiography, and pharmacological versus exercise stress) in this population is similarly unclear. Finally, among patients with a recent history of PCI, predictors of different test modality use, and the associations between testing modality and subsequent procedures, are unknown. To address these issues, we used detailed clinical data provided by the CathPCI (Catheterization and Percutaneous Coronary Intervention) Registry® and longitudinal data from the Centers for Medicare and Medicaid Services (CMS) to describe current patterns in stress testing modalities after PCI.

ABBREVIATIONS AND ACRONYMS

ACCF = American College of Cardiology Foundation

AUC = appropriate use criteria

CABG = coronary artery bypass grafting

CathPCI = Catheterization and Percutaneous Coronary Intervention

CMS = Centers for Medicare and Medicaid Services

CTA = computed tomography angiography

ECG = electrocardiogram

FFS = fee-for-service

HCPCS = Healthcare Common Procedure Coding System

ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification

NCDR = National Cardiovascular Data Registry

OR = odds ratio

PCI = percutaneous coronary intervention

METHODS

Data sources and CathPCI-Medicare data matching. Percutaneous coronary intervention cases were identified from the CathPCI Registry, a national registry of patients undergoing cardiac catheterization or PCI within the United States (10,11). Included patients were those who received PCI with stent insertion, were at least 65 years of age, and were admitted and discharged between January 2005 and December 2008. Using the CathPCI Registry records, the first PCI procedure with stent insertion for each patient was considered to be their index event and was treated as the unit of analysis. Because the CathPCI Registry does not include direct patient identifiers, events from the registry were matched to Medicare inpatient claims using indirect methods (12). We successfully linked 443,922 (66.0%) of all eligible index events to an admission in the CMS database. For matched records, the CMS data allowed identification of subsequent resource use from inpatient, outpatient, and physician claims, as well as enrollment and mortality data from the Medicare denominator file. The linked population has been shown to be representative of the Medicare and CathPCI Registry populations (13).

The linked CathPCI Registry-Medicare sample was restricted to patients receiving 1 type of coronary stent (bare metal or drug eluting) to facilitate comparisons. Initial exclusion criteria were applied to ensure complete resource use measurement. Patients were excluded if they did not have both Part A and Part B Medicare coverage at the time of their index admission, if physician claims for their index event were missing, and if Medicare was serving as a secondary payer. Next, we defined a 60-day "blackout period" after each patient's index event,

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since diagnostic tests during this period may be performed for cardiac rehabilitation, procedure staging, or functional capacity assessments. Stress testing use during this period was ignored, and patients who ceased fee-for-service (FFS) Medicare enrollment, died, underwent a repeat revascularization or repeat catheterization, or were readmitted for myocardial infarction (MI) during the blackout period were excluded from analysis. Finally, patients who had a stress test, a competing event (death, repeat catheterization, revascularization, MI-related readmission), or were lost to follow-up before January 1, 2006, were excluded; this restriction was necessary to ensure that the incomplete cohort of patients receiving testing available for analysis during the 2005 calendar year did not confound trend assessments.

Stress test population. Among the remaining 284,971 patients, we identified those who received stress testing between 61 and 365 days after their index event, not preceded by repeat revascularization, catheterization, readmission for MI, or computed tomography angiography (CTA). Only each patient's first eligible stress test was included in the analysis. Because Healthcare Common Procedure Coding System (HCPCS) codes are not provided on inpatient claims, the use of pharmacological stress could not be identified. Consequently, comparisons of test modality were limited to outpatient stress testing as documented by place of service codes on physician claims. Patients receiving stress positron emission tomography or magnetic resonance imaging were excluded because these tests were rarely performed, precluding evaluation. We also excluded patients who were coded as having received both stress nuclear and stress echocardiography procedures on the same day, as well as those patients who were coded as having an electrocardiogram (ECG)-only stress test with use of pharmacological stress, as these may represent coding errors.

Data definitions. Use of cardiac stress testing after PCI was assessed by examining testing patterns overall and by type of test, as identified by HCPCS codes (ECG stress, 93015–93018; nuclear, 78460–78461, 78464–78465, 78472–78473, 78481, 78483; positron emission tomography, 78491–78492; stress echocardiography, 93350). Electrocardiogram stress and nuclear imaging procedures performed within 1 day of each other were considered a stress nuclear test, whereas ECG stress and echocardiographic testing performed on the same day were considered a stress echocardiography test. Pharmacological stress was identified using HCPCS codes J0152 (adenosine), J1245 (dipyridamole), J1250 (dobutamine), and the temporary codes for regadenoson used in 2008 (J3490, C9399, C9244); stress tests occurring on the same day (or in the case of nuclear stress testing, within 1 day) as pharmacological stress codes were considered pharmacological stress tests.

The number and dates of repeat catheterizations and revascularization (either PCI or coronary artery bypass graft [CABG] surgery) after stress testing were identified using International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM), and HCPCS codes (catheterization, 93508, 93539–93540, 93545; PCI, 92980–92982, 92984, 92995–92996, G0290, G0291, 36.01–36.02, 36.05–36.07, 00.66; CABG, 33510–33514, 33516–33519, 33521–33523, 33533–33536, 36.1x, 36.2, S2205–S2209).

Statistical analysis. Temporal trends in the utilization of stress testing within a year after PCI, excluding the 60-day "blackout period," were assessed by calculating the rate of stress testing per 100 person-years and testing, based on calendar quarter, using Poisson regression. The utilization of stress testing after PCI was also measured using cumulative incidence functions, treating catheterization, revascularization, readmission for MI, use of CTA, and death as competing risks, and loss to follow-up as censoring. For patients who underwent stress testing, quarterly time trends in the use of testing modalities relative to other modalities were assessed using logistic regression models. We used 3 binary comparisons of modality: 1) exercise ECG versus exercise imaging (nuclear or echocardiography); 2) pharmacological stress testing with imaging versus exercise stress testing with imaging; and 3) exercise echocardiography versus exercise nuclear testing. Patient and hospital characteristics were provided overall and stratified by test modality using descriptive statistics (number of observations, mean, standard deviation, median, 25th and 75th percentiles, minimum, and maximum) for continuous variables and with frequency and percentage for categorical variables. Bivariate tests of association were conducted using chi-square tests for categorical variables and Kruskal-Wallis tests for continuous variables. To identify adjusted predictors of imaging modality, we performed logistic regression for the 3 binary comparisons outlined above. Models were adjusted for demographic, clinical, and procedural characteristics, facility characteristics, time between PCI and stress test, calendar

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quarter of testing, and Census Division of patient's residence.

Associations between test modality and use of coronary procedures within the 90 days after the initial stress test, including additional stress testing, cardiac catheterization, or repeat revascularization, was measured using cumulative incidence functions where loss to follow-up was considered a censoring event and death a competing risk. For patients who received a cardiac catheterization after their initial stress test, the short-term revascularization rate after catheterization was computed as the cumulative incidence of a repeat revascularization procedure within 90 days of catheterization, treating loss to follow-up as censoring and death a competing risk. Tests of association were conducted using Gray's test (14).

Analyses were conducted using SAS version 9.2 (SAS Institute, Cary, North Carolina), R version 2.11.1 (R Foundation, Vienna, Austria), and Stata/IC version 12.0 (StataCorp, College Station, Texas). The Duke University Medical Center institutional review board granted a waiver of informed consent and authorization for this study, and analyses were conducted at the Duke Clinical Research Institute.

RESULTS

The study population included 284,971 patients who received PCI between 2005 and 2008, for whom it was possible to link the procedural and claims data sets, and survived without repeat catheterization, revascularization, MI, or CTA for 60 days after the initial PCI date (Fig. 1). Median follow-up time was 584 days (interquartile range: 612 days). Among these 284,971 patients, the incidence of stress testing that was not preceded by a repeat catheterization or revascularization, MI, or CTA was 32.5%.

The test modalities of 68,292 stress test recipients were evaluated. Among these patients, 5,034 (7.4%) received exercise ECG testing as their first stress test; 26,679 (39.1%) exercise nuclear testing; 5,286 (7.7%) exercise echocardiography; 30,604 (44.8%) pharmacological nuclear test; and 689 (1.0%) pharmacological echocardiography. Because of the infre-

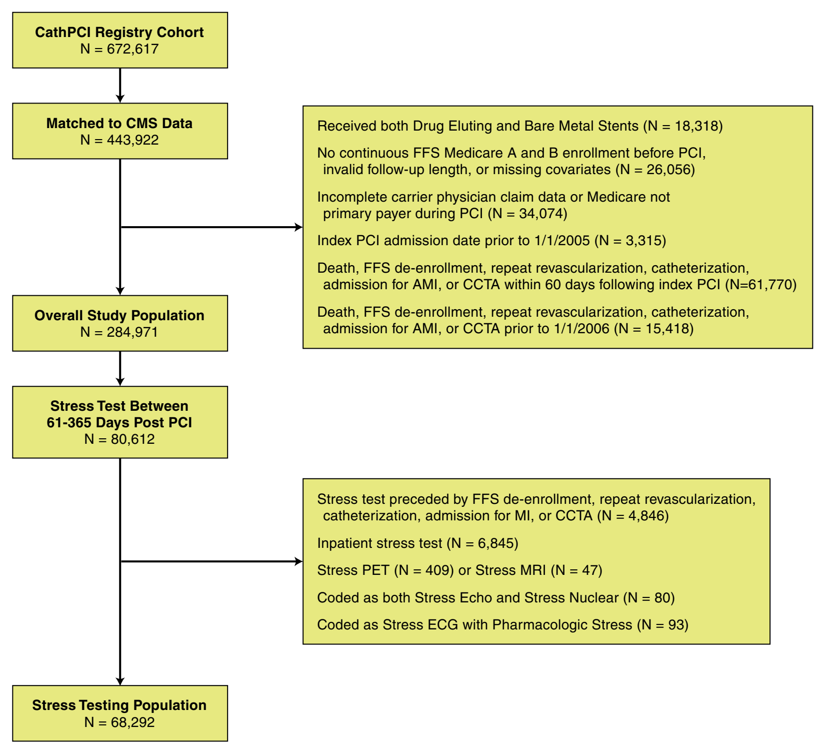

Figure 1. Population Flow Diagram

Flow diagram showing the process used to define the study population. AMI = acute myocardial infarction; CMS = Centers for Medicare and Medicaid Services; CTA = computed tomography angiography; ECG = electrocardiogram; FFS = fee-for-service; MRI = magnetic resonance imaging; PCI = percutaneous coronary intervention; PET = positron emission tomography.

quency of pharmacological echocardiography, pharmacological tests were combined.

Temporal trends in overall stress testing utilization and in test modalities. The stress test incidence rate after PCI fell from 59.3 per 100 person-years in the first quarter of 2006 to 47.1 in the fourth quarter of 2008 (Fig. 2); the unadjusted incidence rate ratio was 0.984 per quarter ($p < 0.001$). This trend corresponds to a decline of 17% in incidence from 35.2% in the first quarter of 2006 to 29.4% in the fourth quarter of 2008. Adjustment did not alter the findings (adjusted incidence rate ratio: 0.983, $p < 0.001$).

Among patients receiving exercise testing, the probability of ECG-only testing compared to exercise stress with imaging increased slightly over time (Fig. 3). This increase was not significant in unadjusted analyses (odds ratio [OR]: 1.009 per quarter, $p = 0.052$), but became significant after adjustment (OR: 1.020, $p < 0.001$). In contrast, among patients receiving a stress test with imaging (nuclear or echocardiography), the probability of pharmacological stress in unadjusted analysis (OR: 1.010, $p < 0.001$) increased slightly with time. However, this difference was diminished after adjustment (OR: 1.003, $p = 0.24$). Among patients receiving an exercise test with imaging, the change in probability of receiving echocardiography versus nuclear imaging was not statistically significant in unadjusted analysis (OR: 0.992, $p = 0.06$), but was in adjusted analyses (OR: 0.990, $p = 0.04$).

Predictors of stress test modality. In general, patients receiving exercise ECG were clinically similar to patients receiving an exercise stress test with imaging (Table 1). Exceptions included ECG-only testing recipients being older, more likely to have a history of heart failure and diabetes mellitus, and less likely to have a history of revascularization before the index procedure. They were also more likely to have received their index PCI in response to an MI. Patients who received stress testing further from their date of index PCI were substantially less likely to have an exercise ECG test (Fig. 4). After adjustment (Table 2), few clinical characteristics were strongly associated with receipt of exercise ECG versus exercise imaging. Geographic variation was present in the use of exercise stress with (versus without) imaging—a variation that persisted after adjustment (Fig. 5). The adjusted probability a patient would receive an exercise ECG test rather than exercise imaging ranged from 6.8% in the West North Central Census Division to 22.8% in the East South Central Census Division.

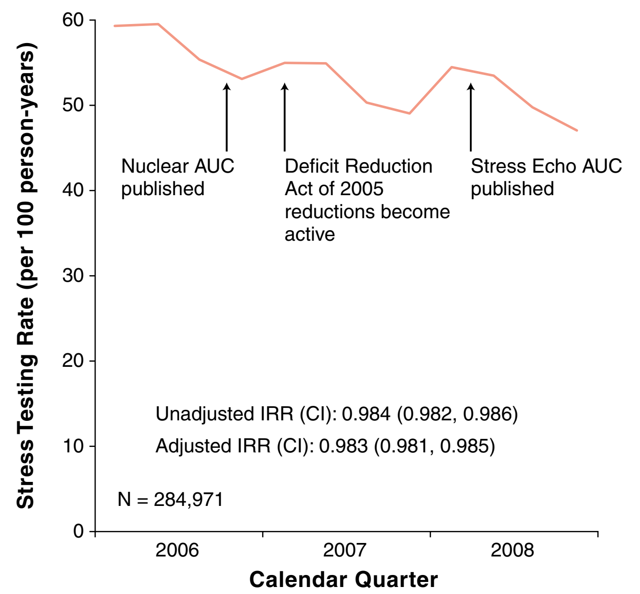

Figure 2. Temporal Trend in Stress Testing Rate

Temporal trend in incidence of stress testing between 61 and 365 days after percutaneous coronary intervention (PCI) not preceded by repeat revascularization or catheterization. Incidence rates ratios (IRR) are calculated both unadjusted and adjusted for patient, procedural, facility, and geographic characteristics using Poisson regression models; they refer to the relative rate of stress testing among patients alive during the calendar quarter who have not yet received a stress test. AUC = appropriate use criteria; CI = confidence interval.

Marked differences were evident in characteristics between patients receiving pharmacological tests versus exercise tests with imaging, with pharmacological stress testing patients having a higher burden of cardiovascular risk factors. Pharmacological stress test patients were older (52.5% were 75 years or older vs. 36.0% in the exercise imaging group, $p < 0.001$) and were more likely to have had a history of heart failure at the time of their index PCI (13.0% vs. 5.7%, $p < 0.001$). In addition, pharmacological stress recipients reported higher rates of virtually all other comorbidities. After multivariable adjustment (Table 2), increasing age and most comorbidities remained strong predictors of pharmacological testing with imaging rather than exercise testing with imaging. Minimal geographic variation was observed in the use of exercise stress as compared to pharmacological stress when performing an imaging stress test—even after statistical adjustment (Fig. 5). The notable exception was New England, where relatively few pharmacological tests were performed.

Patients receiving exercise echocardiography had a lower burden of cardiovascular risk factors compared to patients receiving exercise nuclear testing,

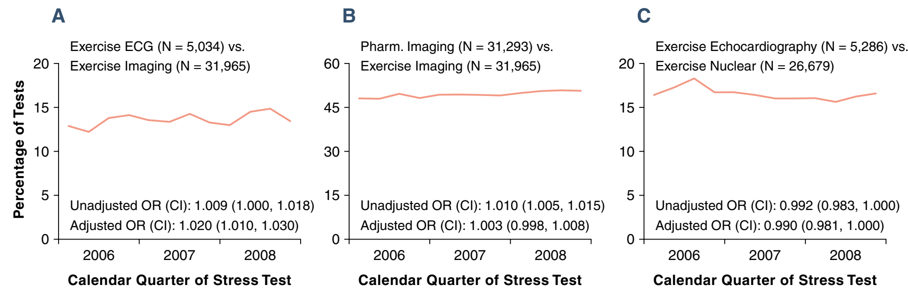

Figure 3. Temporal Trends in Stress Testing Modality

Trends in percentage of stress tests performed with **(A)** exercise electrocardiography (ECG) versus exercise imaging, **(B)** pharmacological (Pharm.) stress with imaging versus exercise stress with imaging, and **(C)** exercise echocardiography versus exercise nuclear testing, based on calendar quarter in which stress test was performed. Odds ratios (OR) were calculated, both unadjusted and adjusted, for patient, procedural, facility, and geographic characteristics using logistic regression. CI = confidence interval.

with echocardiography patients having lower rates of most comorbidities. Patients receiving echocardiography were also less likely to have had diagnosed multivessel disease at the time of PCI (46.5% vs. 51.1%, $p < 0.001$); however, after adjustment (Table 2), few clinical characteristics were strongly associated with receipt of echocardiography versus nuclear testing. Geographic variation existed in the use of exercise echocardiography compared with exercise nuclear testing, with rates varying from 9.4% in the South Atlantic Census Division to 34.1% in the Pacific Division.

Downstream procedures after stress testing. The incidence of repeat stress testing within 90 days of the initial stress test varied markedly depending on the type of first test, from 2.1% (pharmacological imaging) to 13.7% (exercise ECG) (Table 3). The incidence of repeat stress testing was higher after nonimaging tests compared to imaging exercise tests, exercise echocardiography compared with exercise nuclear imaging tests, and exercise imaging versus pharmacological stress imaging (all $p < 0.001$). The incidence of catheterization within 90 days after stress testing also varied substantially, being lowest for exercise ECG (7.4%) and highest for the pharmacological tests (15.8%). The incidence was lower in nonimaging tests compared to imaging exercise tests, exercise tests versus pharmacological tests, and exercise echocardiography compared to exercise nuclear imaging ($p < 0.001$ for all). The incidence of repeat revascularization after stress testing was somewhat less variable, ranging from 3.8% (exercise ECG) to 7.6% (pharmacological testing). The incidence was lower after nonimaging tests compared with exercise imaging tests, and exercise echocardiography compared with exercise nuclear testing ($p < 0.001$ and $p = 0.02$, respectively); rates were similar for exercise and pharmacological imaging tests ($p = 0.13$). Despite varying use of additional diagnostic procedures, the revascularization rate after catheterization (the incidence of a repeat revascularization within 90 days of a post-stress test catheterization) varied little across imaging modality. The only statistically significant difference noted was a slightly lower rate among pharmacological imaging tests compared with exercise imaging (47.8% vs. 51.0%, $p = 0.002$).

DISCUSSION

Creation of a data set linking detailed clinical information from the CathPCI Registry with inpatient and ambulatory Medicare claims enabled an evaluation of processes of care related to stress testing among a broad cohort of patients ages 65 years and older. We found that between 2006 and 2008, stress testing utilization declined roughly equally across testing modalities. Geographic region was strongly associated with the modality patients received and notable differences occurred in the downstream procedure use associated with each modality.

Consistent with previous reports on stress test use among Medicare beneficiaries, the overall rate of stress testing after PCI declined modestly over time (8). With the exception of a slight increase in the proportion of tests performed without imaging, the decline was uniform across imaging modalities. The explanation for these trends is unclear, but they temporally coincide with reductions in test reimbursement associated with the Deficit Reduction Act of 2005, the introduction of ACCF AUC for imaging, and an increasing concern regarding

Table 1. Baseline and Descriptive Characteristics of Patients Receiving Stress Testing Between 61 and 365 Days Post-Percutaneous Coronary Revascularization

	Total (N = 68,292)	(1) Exercise ECG (n = 5,034)	(2) Exercise Nuclear or Echo (n = 31,965)	p Value 1 vs. 2	(3) Exercise Nuclear (n = 26,679)	(4) Exercise Echo (n = 5,286)	p Value 3 vs. 4	(5) Pharm Imaging* (n = 31,293)	p Value 2 vs. 5
Demographic and clinical characteristics at time of index PCI									
Age, yrs, median (Q1–Q3)	73 (68–78)	73 (68–78)	72 (68–77)	<0.001	72 (68–77)	72 (68–77)	0.98	75 (70–80)	<0.001
75 years or older	43.8	40.0	36.0	<0.001	36.0	35.8	0.79	52.5	<0.001
Female	41.1	34.6	34.1	0.46	34.0	34.7	0.29	49.4	<0.001
White race	88.9	88.0	89.5	0.002	89.6	89.2	0.40	88.5	<0.001
BMI, median (Q1–Q3), kg/m^2	28 (25–31)	28 (25–31)	27 (25–31)	0.08	27 (25–31)	27 (25–30)	0.007	28 (25–32)	<0.001
Previous MI (>7 days)	21.6	18.9	19.7	0.17	20.0	18.2	0.002	24.0	<0.001
History of heart failure	9.1	6.7	5.7	0.004	5.8	4.8	0.002	13.0	<0.001
Family history of CAD	20.4	20.1	20.9	0.18	21.2	19.2	0.001	20.0	0.003
Hypertension	80.4	77.3	77.0	0.64	77.5	74.9	<0.001	84.4	<0.001
Diabetes mellitus	29.8	27.4	24.7	<0.001	24.9	23.5	0.03	35.5	<0.001
GFR <30 ml/min/1.73m^2 or dialysis dependent	2.7	1.7	1.6	0.03	1.6	1.4	0.30	4.0	<0.001
PVD	12.4	9.0	9.1	0.79	9.2	8.3	0.03	16.4	<0.001
Statin use	75.7	75.1	75.5	0.61	75.9	73.3	<0.001	76.1	0.06
Current smoker	10.9	9.6	10.5	0.06	10.4	10.4	0.67	11.4	<0.001
Previous revascularization	38.2	32.1	35.6	<0.001	36.0	33.6	0.001	41.8	<0.001
Cardiac status at time of PCI presentation				<0.001			0.007		<0.001
Asymptomatic	15.0	12.0	14.5		14.8	13.5		16.0	
Atypical chest pain	8.1	7.5	8.0		8.2	7.1		8.3	
Stable angina	18.3	16.9	18.7		18.5	19.5		18.1	
Unstable angina	33.5	30.9	33.1		33.1	33.4		34.3	
NSTEMI	14.4	17.2	13.8		13.7	14.1		14.6	
STEMI	10.7	15.6	11.8		11.7	12.4		8.7	
Multivessel disease	52.6	52.0	50.4	0.03	51.1	46.5	<0.001	55.0	<0.001
PCI procedure and facility characteristics									
PCI status				<0.001			<0.001		<0.001
Elective	53.4	47.3	53.1		53.7	50.4		54.7	
Urgent	34.7	36.2	34.1		36.1	36.1		35.0	
Emergency	11.8	16.5	12.7		12.5	13.5		10.2	
Salvage	0.1	0.1	0.1		0.1	0.1		0.1	
Drug-eluting stent used	75.7	75.6	77.4	0.004	77.5	76.9	0.36	73.9	<0.001
Census Division				<0.001			<0.001		<0.001
New England	5.1	10.9	5.9		6.2	4.8		3.3	
Middle Atlantic	7.0	4.8	7.2		7.6	5.1		7.0	
East North Central	23.4	22.0	22.4		22.8	20.5		24.6	
West North Central	9.8	4.5	10.0		9.7	11.3		10.4	
South Atlantic	24.0	20.6	24.7		27.0	13.2		23.9	
East South Central	7.0	11.8	6.7		7.0	5.1		6.7	
West South Central	7.8	6.9	7.0		6.8	7.8		8.8	
Mountain	5.7	7.1	5.6		4.6	10.4		5.5	
Pacific	10.3	11.3	10.6		8.4	21.9		9.8	
Testing characteristics									
Time from index PCI to stress test, median days (Q1–Q3)	186 (119–260)	122 (89–178)	186 (119–258)	<0.001	188 (122–261)	174 (109–245)	<0.001	196 (128–271)	<0.001

Values are median (Q1–Q3) or %. *Pharmacological (Pharm) nuclear and echocardiography (Echo) tests were combined because of small sample size in pharmacological echocardiography arm (n = 711).
BMI = body mass index; CABG = coronary artery bypass graft; CAD = coronary artery disease; CMS = Centers for Medicare and Medicaid Services; ECG = electrocardiography; GFR = glomerular filtration rate; MI = myocardial infarction; NSTEMI = non–ST-segment elevation myocardial infarction; PCI = percutaneous coronary intervention; PVD = peripheral vascular disease; Q = quartile; STEMI = ST-segment elevation myocardial infarction.

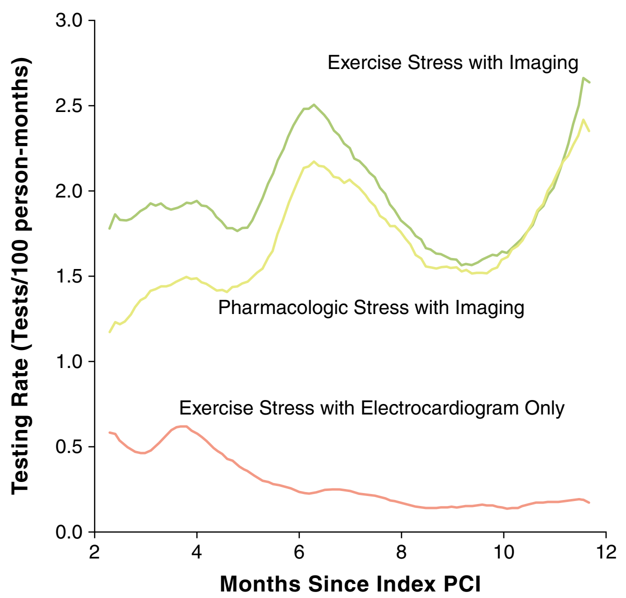

Figure 4. Relationship Between Imaging Modality and Time Since PCI

Trends in the percentage of stress tests performed with exercise electrocardiography **(red line)**, exercise imaging **(green line)**, or pharmacological imaging **(yellow line)**, based on number of months between patient's index percutaneous coronary intervention (PCI) procedure and stress test.

possible overuse. If related, perhaps greater attention to testing utilization spearheaded by the new standards or a diminishing financial return may be an underlying cause. Because all included patients were enrolled in FFS Medicare at the time of testing, none were subject to radiology benefit management. While it is possible that benefit management in privately insured patients may have a spillover effect in the FFS population, the direction of the effect cannot be predicted with certainty. Use would decline if providers perceive the burdens of testing not to be worth the effort or if providers are educated by encounters with radiology benefit management regarding appropriate use (15), but use would increase among FFS patients if pressure to maintain testing volume causes providers to increase testing in marginally appropriate patients.

There were few strong clinical or demographic predictors of receipt of exercise ECG versus exercise imaging stress testing. This result may be in part due to the absence of detailed electrocardiographic data indicating contraindications to ECG-only testing, such as left bundle branch block, electronic pacing, or left ventricular hypertrophy with repolarization abnormalities (16). Similarly, there were few strong clinical or demographic predictors of receipt of exercise echocardiography versus exercise nuclear imaging. Particularly surprising was the absence of a relationship for body mass index (OR: 0.99 per unit, $p = 0.64$), despite evidence that nuclear imaging may be (with appropriate attenuation adjustment) more feasible than echocardiography for patients with higher body mass index (17,18). In contrast, age (OR: 2.12 per decade) and comorbidities were strong predictors of pharmacological stress testing versus exercise testing with imaging. Although the data do not provide direct measures of exercise tolerance or frailty, age and comorbidities are indirect measures of these phenomena. In aggregate, these results suggest providers actively weigh these considerations when selecting pharmacological agents as the stress protocol.

In contrast to patient characteristics, geographic variation was strongly associated with the addition of imaging to exercise, and in the type of imaging used among patients receiving an imaging-based exercise test. These large-area patterns are consistent with previous, small-area studies demonstrating large, idiosyncratic variation in stress testing rates and the use of imaging with stress testing (19). The reasons for large-scale variation in imaging use and modality are unclear, but may be due to diffusion of practice preferences from regional "thought leaders," differences in population-level preferences for high technology care, or spillover effects from differences in the private insurance marketplace. Less geographic variability occurred in pharmacological versus exercise imaging. Although our data cannot directly address adherence to national guidelines recommending the use of pharmacological stress only among those patients unable to exercise, it does suggest that physician judgment about which patients are able to exercise is relatively uniform nationwide.

In general, subsequent procedures were uncommon, suggesting that stress tests are employed in the post-PCI population for low-risk indications—a result consistent with findings using a private insurer's database (9). Compared with those receiving exercise imaging, patients receiving ECG-only testing experienced higher rates of additional stress testing, with more than 1 in 7 patients receiving a subsequent stress test within 90 days—most of which (73.2%) were performed with imaging. In contrast, exercise ECG patients had lower rates of catheterization compared with patients tested initially with imaging. While our findings are limited by their observational nature, they suggest that a strategy of using exercise ECG first, reserving imaging for use after an equivocal study or in those patients with contradictions to ECG-only test-

Table 2. Selected Adjusted Predictors of Stress Testing Modality

	Exercise ECG (n = 5,034) vs. Exercise Imaging (n = 31,965)		Pharm Imaging (n = 31,293) vs. Exercise Imaging (n = 31,965)		Exercise Echo (n = 5,286) vs. Exercise Nuclear (n = 26,679)	
	OR (95% CI)	p Value	OR (95% CI)	p Value	OR (95% CI)	p Value
Demographic and clinical characteristics at time of index PCI						
Age, per 10 yrs	1.20 (1.14–1.27)	<0.001	2.12 (2.06–2.19)	<0.001	0.99 (0.93–1.05)	0.64
BMI, per unit, kg/m^2	1.01 (1.01–1.02)	<0.001	1.05 (1.05–1.06)	<0.001	1.00 (0.99–1.00)	0.30
White race vs. other	0.88 (0.80–0.98)	0.01	0.92 (0.88–0.98)	0.005	1.12 (1.01–1.23)	0.03
Male vs. female	1.04 (0.97–1.12)	0.23	0.56 (0.54–0.58)	<0.001	0.95 (0.89–1.02)	0.15
PVD	0.99 (0.89–1.11)	0.89	1.52 (1.44–1.60)	<0.001	0.97 (0.87–1.08)	0.58
History of heart failure	1.16 (1.01–1.33)	0.03	1.58 (1.48–1.69)	<0.001	0.83 (0.72–0.97)	0.02
Diabetes mellitus	1.15 (1.07–1.24)	<0.001	1.44 (1.39–1.50)	<0.001	0.99 (0.92–1.07)	0.87
Hypertension	0.97 (0.90–1.05)	0.39	1.20 (1.15–1.26)	<0.001	0.93 (0.86–1.00)	0.06
Statin use	1.04 (0.96–1.12)	0.36	0.90 (0.87–0.94)	<0.001	0.93 (0.87–1.00)	0.06
Current smoker	0.94 (0.84–1.05)	0.26	1.50 (1.42–1.59)	<0.001	1.03 (0.93–1.14)	0.57
Family history of CAD before age 55	0.96 (0.86–1.06)	0.40	1.29 (1.23–1.36)	<0.001	1.08 (0.98–1.20)	0.13
Previous MI (>7 days from PCI)	1.01 (0.94–1.10)	0.74	0.95 (0.91–0.99)	0.009	0.95 (0.88–1.03)	0.19
GFR <30 ml/min/1.73m^2 or dialysis dependent, vs. GFR ≥60	1.04 (0.97–1.12)	0.23	1.19 (1.15–1.23)	<0.001	1.04 (0.97–1.11)	0.28
Previous PCI	0.87 (0.80–0.95)	<0.001	1.14 (1.09–1.19)	<0.001	1.01 (0.94–1.09)	0.78
Previous CABG	1.04 (0.95–1.14)	0.42	1.23 (1.17–1.29)	<0.001	0.98 (0.89–1.08)	0.68
Cardiac status at time of PCI admission presentation, vs. stable angina						
No symptoms	0.98 (0.87–1.10)	0.69	1.10 (1.04–1.16)	0.002	0.94 (0.85–1.05)	0.27
Atypical chest pain	1.05 (0.91–1.20)	0.52	1.06 (0.99–1.14)	0.10	0.82 (0.72–0.93)	0.003
Unstable angina	0.99 (0.89–1.08)	0.75	1.02 (0.97–1.07)	0.56	1.00 (0.91–1.10)	0.98
NSTEMI	1.21 (1.07–1.36)	0.002	1.04 (0.97–1.11)	0.26	0.92 (0.82–1.03)	0.16
STEMI	1.25 (1.07–1.47)	0.006	0.85 (0.77–0.93)	<0.001	0.88 (0.75–1.03)	0.12
Multivessel disease	1.01 (0.94–1.07)	0.89	1.11 (1.07–1.15)	<0.001	0.86 (0.80–0.91)	<0.001
PCI procedure and facility characteristics						
PCI status vs. elective						
Urgent	0.95 (0.38–2.34)	0.91	0.99 (0.95–1.03)	0.49	1.14 (1.06–1.23)	<0.001
Emergency	1.05 (0.91–1.21)	0.49	1.07 (0.99–1.17)	0.10	1.12 (0.97–1.29)	0.13
Salvage	0.95 (0.38–2.34)	0.91	1.36 (0.82–2.28)	0.24	0.85 (0.32–2.29)	0.75
Drug-eluting vs. bare metal stents	1.11 (1.03–1.20)	0.007	0.86 (0.83–0.90)	<0.001	0.93 (0.87–1.01)	0.08
Census division vs. South Atlantic						
New England	1.99 (1.75–2.27)	<0.001	0.60 (0.55–0.66)	<0.001	1.13 (0.96–1.33)	0.14
Middle Atlantic	0.76 (0.65–0.89)	<0.001	1.08 (1.00–1.16)	0.05	1.20 (1.02–1.40)	0.02
East North Central	1.30 (1.18–1.43)	<0.001	1.10 (1.04–1.16)	<0.001	1.76 (1.58–1.96)	<0.001
West North Central	0.56 (0.48–0.66)	<0.001	1.12 (1.05–1.19)	<0.001	2.18 (1.92–2.47)	<0.001
East South Central	2.43 (2.16–2.73)	<0.001	1.05 (0.98–1.13)	0.19	1.51 (1.29–1.76)	<0.001
West South Central	1.30 (1.13–1.49)	<0.001	1.38 (1.28–1.48)	<0.001	2.14 (1.86–2.45)	<0.001
Mountain	1.73 (1.50–1.99)	<0.001	1.14 (1.05–1.24)	0.002	4.26 (3.71–4.88)	<0.001
Pacific	1.30 (1.15–1.47)	<0.001	1.00 (0.93–1.07)	0.92	5.08 (4.53–5.70)	<0.001
PCI hospital vs. university						
Government	0.63 (0.46–0.85)	0.002	1.32 (1.15–1.52)	<0.001	0.20 (0.14–0.28)	<0.001
Private and nonteaching	1.04 (0.92–1.18)	0.49	1.28 (1.19–1.38)	<0.001	0.54 (0.48–0.60)	<0.001
Private and teaching	0.89 (0.80–1.00)	0.06	1.13 (1.06–1.22)	<0.001	0.56 (0.50–0.63)	<0.001
Average annual PCI volume, per 100 increase	0.99 (0.99–1.00)	<0.001	1.00 (0.99–1.00)	0.001	0.99 (0.98–0.99)	<0.001
No. of CMS-certified beds, per 100 increase	1.08 (1.06–1.09)	<0.001	1.01 (1.01–1.02)	<0.001	1.01 (1.00–1.03)	0.12
Calendar quarter of stress test	1.02 (1.01–1.03)	<0.001	1.00 (1.00–1.01)	0.24	0.99 (0.98–1.00)	0.04
Time from PCI to stress test, per 30 days	0.80 (0.79–0.81)	<0.001	1.04 (1.03–1.04)	<0.001	0.96 (0.95–0.97)	<0.001

CI = confidence interval; OR = odds ratio; other abbreviations as in Table 1.

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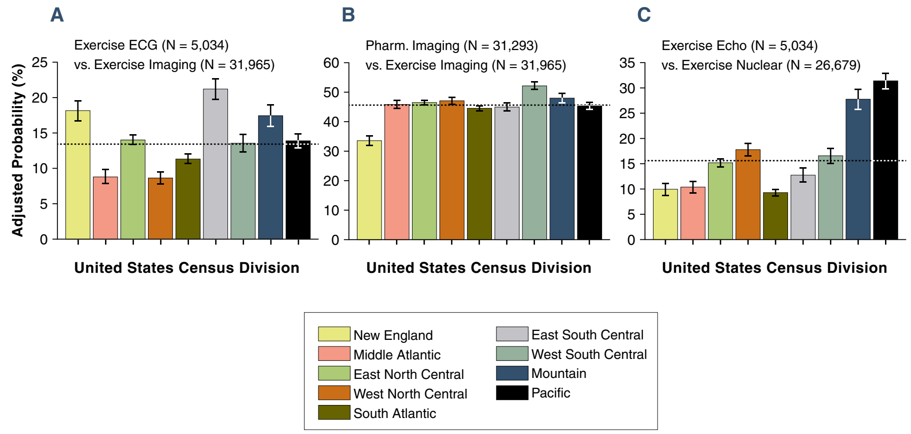

Figure 5. Geographic Variation in Stress Testing Modalities

Adjusted probability of receiving **(A)** exercise electrocardiography (ECG) versus exercise imaging, **(B)** pharmacological stress versus exercise stress with imaging, and **(C)** exercise nuclear versus exercise echocardiography (Echo), based on United States Census Division. The **dotted line** indicates cohort mean. Pharm. = pharmacological stress testing.

ing, may be reasonable. This strategy was supported by a recent trial comparing ECG-only versus nuclear stress testing for initial diagnosis of coronary artery disease among women, which showed that despite greater need for additional testing, the "exercise ECG first" strategy was cost saving (20).

Compared with nuclear testing, exercise echocardiography resulted in more subsequent stress testing, potentially due to the more challenging interpretation of echocardiography studies or less physician confidence in results (21). The rate of catheterization was also slightly lower, suggesting that downstream processes of care may differ as a result. Patients receiving pharmacological stress testing experienced a lower rate of additional stress testing and had a similar rate of proceeding to catheterization, but had a slightly lower revascularization rate after catheterization. It is unclear whether the lower revascularization rate after catheterization among pharmacological stress patients is the result of lower stress test specificity due to the absence of exercise tolerance data, or if physicians are more reluctant to revascularize pharmacological stress recipients, who are on average older and with a higher burden of comorbidities.

Certain factors should be considered in the interpretation of these results. The use of combined CathPCI Registry and Medicare data allowed for analysis of a large, well-described population of patients. Nevertheless, data are limited to FFS Medicare patients ages 65 years and older, and findings may not generalize outside this population. Findings may also not generalize to patients treated at facilities not participating in the CathPCI Registry, or to patients whose CathPCI Registry record could not be merged with Medicare claims data; however, recent work suggests that the linked dataset is generalizable in this respect (13). The CathPCI Registry data provide a clinical description of the time of PCI, but data on symptoms, ECG parameters, and ability to exercise at the time of testing are unavailable, limiting our ability to fully adjust regression models and preventing iden-

Table 3. Short-Term (90-Day) Cumulative Incidence of Additional Testing and Revascularization After Initial Post-PCI Stress Testing

	Cumulative Incidence (%)						p Values, Comparing		
	Total	Exercise ECG	Exercise Imaging (Nuclear or Echo)	Exercise Nuclear	Exercise Echo	Pharm Imaging	Exercise ECG vs. Exercise Imaging	Pharm. Imaging vs. Exercise Imaging	Exercise Echo vs. Exercise Nuclear
Additional stress testing	3.3	13.7	2.9	2.3	5.8	2.1	<0.001	<0.001	<0.001
Catheterization	14.4	7.4	14.1	14.5	12.4	15.8	<0.001	<0.001	<0.001
Revascularization	7.1	3.8	7.2	7.4	6.4	7.6	<0.001	0.13	0.02
Revascularization rate after catheterization*	49.5	51.1	51.2	51.0	51.5	47.8	0.99	0.002	0.82

*Defined as the incidence of any revascularization within 90 days of the date of catheterization, among patients who received catheterization.
Abbreviations as in Table 1.

tification of the concordance of testing patterns with current AUC.

CONCLUSIONS

This analysis uses a post-PCI population to evaluate processes of care related to stress testing and provides several important implications for practice and future investigations. Declining test utilization in the post-PCI population suggests that multi-pronged efforts are having a measurable effect. Additional research is needed to ensure that unintended consequences do not result, such as limiting access for patients with legitimate testing needs. Patients receiving imaging stress had more downstream procedures than patients receiving ECG-only testing. Taken together with the large geographic variations in use of stress testing modalities, these findings suggest there would be value in determining more precisely the optimal use of stress test modalities after PCI in individual patients. This effort will likely require the collection of prospectively collected data so that clinical status and indications for testing are captured. Finally, associations between modality and downstream procedures observed in this analysis also indicate that attempts to define the costs and benefits of stress test modalities should consider their effects not only on testing cost, but on the entire episode of care. As efforts continue to identify the optimal use of stress testing after PCI while controlling cost, carefully constructed, holistic evaluations will provide important guidance.

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