Population-Based Study on Patterns of Cardiac Stress Testing After Percutaneous Coronary Intervention

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Background—The appropriate use criteria considers cardiac stress testing within 2 years after percutaneous coronary intervention (PCI) to be rarely appropriate, unless prompted by symptoms or change in clinical status. Little is known about the patterns of cardiac stress testing after PCI in the single-payer Canadian healthcare system, where mechanisms for reimbursement are different from the United States.

Methods and Results—Frequency and timing of cardiac stress testing within 2 years of PCI performed between April 2004 and March 2013 in Ontario, Canada, was determined from linked provincial databases. Subsequent rates of coronary angiography and revascularization after stress testing were ascertained. Of the 112 691 patients with PCI, 67 442 (59.8%) underwent at least 1 stress test, with 38 267 (34.0%) undergoing repeat stress testing (ie, >1 stress test) within 2 years. Patients who underwent stress testing were younger, had less medical comorbidities, were more likely to reside in urban areas, and had higher incomes. Spikes in incidence of repeat stress testing were observed at 3 to 4 months, 6 to 7 months, and 12 to 13 months after the prior stress test. Of those tested, only 5.9% underwent subsequent coronary angiography, and only 3.1% underwent repeat revascularization within 60 days of stress testing.

Conclusions—More than half of all patients undergo cardiac stress testing within 2 years of PCI, with one third undergoing repeat stress tests. Only 1 of 30 tested patients underwent repeat revascularization. These findings reinforce the appropriate use criteria recommendations against routine stress testing after PCI. Further work is needed to aid with the selection of patients most likely to benefit from stress testing after PCI. **(*Circ Cardiovasc Qual Outcomes*. 2017;10:e003660. DOI: 10.1161/CIRCOUTCOMES.117.003660.)**

Key Words: atherosclerosis ■ exercise test

Increased use of cardiac stress testing after percutaneous coronary intervention (PCI) has occurred in the absence of evidence establishing the impact of routine stress testing after revascularization on clinical outcomes.[1–3] Recent analysis from the national cardiovascular data registry shows that in the United States, ≈50% of patients undergo stress testing within a median of 2 years after PCI, with patients with higher risk features at baseline less likely to undergo post-PCI stress testing.[2] Rate of subsequent revascularization after stress testing was low, with only 9% of patients undergoing revascularization within 90 days. To assist clinical decision making and address the concerns on expansion in use, the American College of Cardiology Foundation developed appropriate use criteria (AUC) for stress testing.[4,5] The AUC considers cardiac stress testing to be rarely appropriate within 2 years after PCI, unless prompted by symptoms or other changes in clinical status.[6] The current American College of Cardiology Foundation/American Heart Association/Society for Cardiovascular Angiography and Intervention practice guidelines also recommend against routine stress testing for asymptomatic patients after PCI procedures (class III).[7]

Most of the data on the use of cardiac stress testing after PCI has originated from the United States, which has different methods of financing health care when compared with the single-payer Canadian healthcare system. Prior cross-country

Received February 14, 2017; accepted September 7, 2017.

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The opinions, results, and conclusions reported in this paper are those of the authors and are independent from the funding sources. No endorsement by the Institute for Clinical Evaluative Sciences or the Ministry of Health and Long-Term Care is intended or should be inferred. Parts of this material are based on data and information compiled and provided by the Canadian Institute for Health Information (CIHI). However, the analyses, conclusions, opinions, and statements expressed herein are those of the authors and not necessarily of CIHI.

The Data Supplement is available at http://circoutcomes.ahajournals.org/lookup/suppl/doi:10.1161/CIRCOUTCOMES.117.003660/-/DC1.

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WHAT IS KNOWN

- The appropriate use criteria considers cardiac stress testing within 2 years after percutaneous coronary intervention (PCI) to be rarely appropriate, unless prompted by symptoms or change in clinical status.
- Data from the national cardiovascular data registry shows that in the United States, ≈60% of elderly Medicare patients undergo cardiac stress testing between 60 days and 2 years after PCI, with patients with higher risk features at baseline less likely to undergo post-PCI stress testing. Rate of subsequent revascularization after stress testing was low, with only 9% of patients undergoing revascularization within 90 days.

WHAT THE STUDY ADDS

- Cardiac stress testing after PCI is also common in a single-payer fee-for-service system in Ontario, Canada, with more than one half of all patients undergoing at least 1 cardiac stress test between 60 days and 2 years after PCI; observed rates in Ontario, Canada, are lower than fee-for-service community practice but higher than integrated healthcare systems in the United States.
- One third of patients underwent multiple stress tests within 2 years, with spikes in frequency of stress testing, including stress nuclear imaging, at time intervals potentially corresponding to times of routine follow-up.
- Of the patients tested, <6% went on to subsequent coronary angiography, and only 1 in 30 underwent repeat revascularization, with similar rates of revascularization post-stress testing irrespective of timing of stress testing relative to PCI.

comparison studies between the United States and Canada have highlighted differences in the use of cardiac procedures because of methods of incentivizing health care,[8,9] resulting in twice as many cardiac catheterizations per capita in New York State as Ontario, Canada.[10] Little is known about the practice of stress testing post-PCI in the Canadian system. To address this gap, in this population-based study, we sought to determine patterns of cardiac stress testing after PCI in Ontario, Canada, where the fee for these tests is reimbursed solely by the provincial government. Given the increasing focus on how best to use limited healthcare resources, it is important to understand differences in procedural use and their associated implications. We specifically aimed to ascertain the frequency and timing of stress testing within 2 years of PCI, as well as downstream coronary angiography and revascularization that resulted from stress testing, and determine how these rates compare with those reported in the United States.

Methods

Data Sources

The study population was identified from the cardiac care network of Ontario cardiac registry, which collects information on all patients in the province undergoing cardiac catheterization, PCI, cardiac surgery, and electrophysiology procedures. Data coordinators at each invasive cardiac center regularly submit data on patient demographics including comorbid conditions, clinical, and procedure characteristics. The Ontario health insurance plan claims database captures information on services provided by practicing physicians and was used to identify outpatient cardiac stress testing. The Canadian institute of health information discharge abstract database, which includes information on hospitalizations, was used to identify in-hospital stress testing procedures and additional comorbidities. The Ontario registered persons database, which contains vital statistics for all Ontarians, was used to determine rural residency and mortality. Statistics Canada census data were used to determine the socioeconomic status of each patient. These datasets were linked using unique encoded identifiers and analyzed at the Institute for Clinical Evaluative Sciences. These data have been used extensively to perform evaluative analyses by our group.[11–14]

Study Population

The study population consisted of patients between 18 and 105 years of age who had a PCI procedure in Ontario, Canada, between April 1, 2004, and March 31, 2013 (n=184 024). Ontario is Canada's largest province, with a population of ≈13.6 million, all of whom are provided universal medical coverage, through a publicly funded single third party payer, the Ministry of Health and Long-Term Care. Patients unable to be linked with administrative data and those with recorded death date before the PCI procedure were excluded. We excluded patients with prior PCI or coronary artery bypass grafting (CABG) to evaluate the initial care patterns after the first PCI. In addition, patients with limited life expectancy (cancer, dementia, liver or end stage renal disease requiring dialysis) were excluded (n=11 481). Finally, we excluded patients who died on the day of the index PCI (n=469). For patients who had multiple PCI procedures during the study period, the first procedure was considered as the index PCI for study inclusion.

Study Outcomes

Cardiac stress testing within 2 years after PCI was determined. A 2-year timeframe was chosen because practice guidelines suggest that stress testing within this time window is rarely indicated.[6] Both exercise and pharmacological stress tests were included, with or without an accompanying imaging modality. Performance of these tests was identified using a combination of billing codes from Ontario health insurance plan (G319: treadmill stress ECG; G112: dipyridamole thallium stress test; G174: dobutamine stress test; G571/572/567/568: transthoracic echocardiography; G583/584: stress echocardiography; and J607/608/807/808: myocardial perfusion scintigraphy).

We determined rates of subsequent coronary angiography and revascularization, both PCI and CABG, within 60 days of stress testing. Coronary angiography, PCI, and CABG procedures were identified using billing codes from Ontario health insurance plan (coronary angiography: Z442, G297; PCI: Z434, G298; and CABG: R742, R743) and Canadian Classification of Health Interventions codes (coronary angiography: 3IP10; PCI: 1IJ26, 1IJ50, 1IJ55, 1IJ57; and CABG: 1IJ76, 1IJ80). Patients were censored at the earliest occurrence of the following: index PCI date+730 days, repeat PCI procedure occurring post–index PCI, CABG procedure occurring post–index PCI, or death.

Statistical Analysis

We compared demographic, clinical, and procedural characteristics among patients who received at least 1 stress test within 2 years after PCI versus those who did not, using χ^2 test for categorical or binary variables and 1-way ANOVA or Kruskal–Wallis test for continuous variables. In addition to examining overall stress testing incidence, stress nuclear imaging was analyzed as a subgroup. The timing of first stress test after index PCI was examined. Similarly, we examined the timing of second stress test after first stress test among patients who underwent >1 stress test and the timing of third stress test after

second stress test among patients who underwent >2 stress tests. For patients undergoing at least 1 stress test within 2 years of index PCI, we analyzed rates of coronary angiography within 60 days of the stress test, as well as rates of coronary revascularization, both PCI and CABG. The 60-day window was chosen to capture sequential procedures most likely to result from stress testing. Two-tailed *P* values <0.05 were considered significant.

Data were analyzed with SAS, version 9.3 (SAS Institute, Inc, Cary, NC). The study was approved by the Institutional Review Board at Sunnybrook Health Sciences Center, Toronto, Canada. Informed consent was not required in accordance with Ontario law, which permits the use of administrative data for research purposes by prescribed entities.

Results

Characteristics of the Study Cohort

A flow chart summarizing the creation of the cohort is presented in Figure 1. The final study cohort comprised of 112 691 PCI-treated patients. The mean age of the study cohort was 62.3 years, 71.6% were men, and 85.1% resided in urban areas; 29.1% had diabetes mellitus, 39.1% had myocardial infarction including the event for which index PCI was performed, 1.8% had renal impairment, and 6.4% had peripheral vascular disease. Drug eluting stents were used in 42.1% of the index PCI procedures, with 56.4% of the patients receiving a single stent.

Frequency and Timing of Cardiac Stress Testing After PCI

Within 2 years of index PCI, 67 442 (59.8%) patients underwent at least 1 cardiac stress test, 29 175 (25.9%) had 1 stress test, 22 307 (19.8%) had 2 stress tests, 10 797 (9.6%) had 3 stress tests, and 5163 (4.6%) had ≥4 stress tests. To avoid inclusion of stress tests that may relate to cardiac rehabilitation or assessment of residual ischemia, thereby excluding stress tests performed within the first 60 days after PCI, 57 800 (51.3%) patients underwent at least 1 cardiac stress test between day 61 and 2 years after PCI. Compared with patients who did not undergo a stress test, those who underwent cardiac stress testing were younger, more likely to be men, resided in an urban area, and had higher income. These patients were less likely to have medical comorbidities, including diabetes mellitus, hypertension, myocardial infarction, heart failure, stroke, chronic obstructive lung disease, renal impairment, and peripheral vascular disease (Table 1). Although such patients were less likely to have received >1 stent at the time of the index PCI and had smaller total stent length, drug eluting stents were used more frequently among these patients.

The first stress test was performed at a median (interquartile range) of 67 (38–150) days after index PCI; 61.1% (or 36.6% of the overall PCI patient population) underwent first stress test within 90 days, 17.4% within 90 to 180 days, 11.1% within 180 to 365 days, and 10.4% within 365 to 730 days. Patients undergoing stress testing early within 90 days of index PCI were younger, had higher income, were more likely to reside in an urban area, and received index PCI in the setting of a myocardial infarction but had fewer comorbidities, including diabetes mellitus, hypertension, stroke, renal failure, and peripheral vascular disease (Table 2). In addition to a large early spike in incidence of first stress test around 1 to 3 months, an additional spike was observed at 12 to 13 months post-PCI (Figure 2). Among patients undergoing >1 stress test, spikes in frequency of repeat stress testing were observed at 3 to 4 months, 6 to 7 months, and 12 to 13 months after prior stress test (Figure 3).

Coronary Angiography and Revascularization After Stress Testing

Of patients undergoing cardiac stress testing within 2 years of the index PCI, 3947 (5.9%) had a subsequent coronary angiogram within 60 days of stress testing (Table 3). Of those patients undergoing stress testing followed by coronary angiography, only 2060 (52.2%) or 3.1% of all patients undergoing stress testing underwent repeat revascularization. Frequency of coronary angiography was lower among patients undergoing stress testing within the first 90 days of index PCI (5.1%) versus those with stress testing after 90 days of index

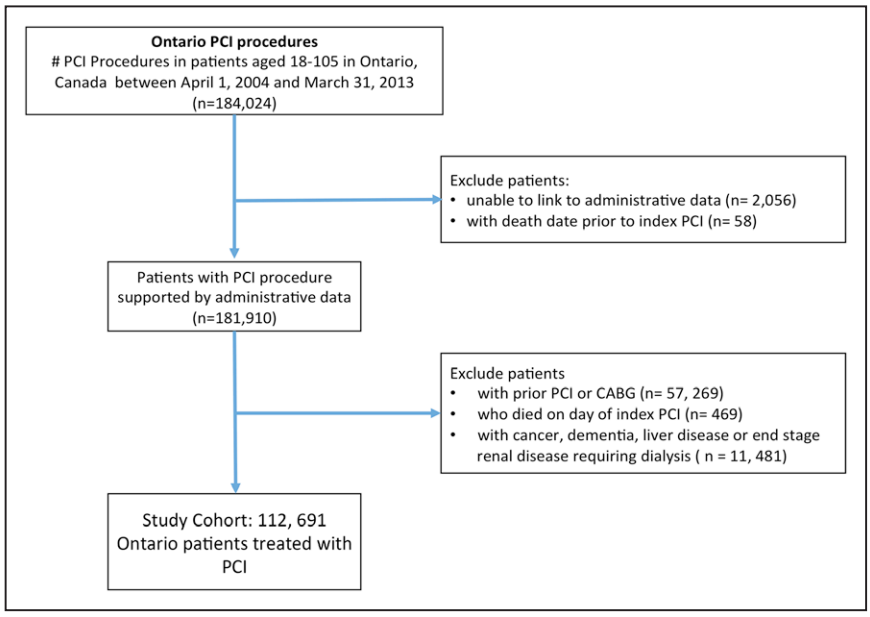

Figure 1. Description of study cohort. CABG indicates coronary artery bypass grafting; and PCI, percutaneous coronary intervention.

Table 1. Characteristics of Patients With and Without Cardiac Stress Testing Within 2 Years After Index PCI

Characteristics	At Least 1 Cardiac Stress Test (n=67 442)	No Cardiac Stress Test (n=45 249)	*P* Value
Demographic and presentation characteristics			
Age, y, mean±SD	60.0±11.2	65.6±12.8	<0.001
Male sex, n (%)	50 447 (74.8)	30 216 (66.8)	<0.001
Rural area, n (%)	9520 (14.1)	7249 (16.0)	<0.001
Income quintile, n (%)			<0.001
1	12 518 (18.6)	9931 (21.9)	
2	13 485 (20.0)	9663 (21.4)	
3	13 497 (20.0)	8888 (19.6)	
4	14 054 (20.8)	8517 (18.8)	
5	13 677 (20.3)	8044 (17.8)	
Missing	211 (0.3)	206 (0.5)	
Smoking history, n (%)	29 661 (44.0)	18 736 (41.4)	<0.001
Diabetes mellitus, n (%)	17 812 (26.4)	14 994 (33.1)	<0.001
Hypertension, n (%)	43 581 (64.6)	32 745 (72.4)	<0.001
Hyperlipidemia, n (%)	38 366 (56.9)	25 723 (56.8)	0.90
Myocardial infarction, n (%)	25 348 (37.6)	18 759 (41.5)	<0.001
Heart failure, n (%)	4173 (6.2)	7133 (15.8)	<0.001
Stroke, n (%)	384 (0.6)	649 (1.4)	<0.001
COPD, n (%)	10 778 (16.0)	10 443 (23.1)	<0.001
Renal failure, n (%)	683 (1.0)	1350 (3.0)	<0.001
Peripheral vascular disease, n (%)	3267 (4.8)	3928 (8.7)	<0.001
Charlson comorbidity index, mean±SD	0.33±0.79	0.57±1.14	<0.001
Admission for MI or angina 1 wk before PCI, n (%)	25 091 (37.2)	14 002 (30.9)	<0.001
Procedural characteristics			
Drug eluting stent, n (%)	29 306 (43.5)	18 091 (40.0)	<0.001
No. of stents, n (%)			<0.001
1	40 117 (59.5)	23 421 (51.8)	
2	17 430 (25.8)	11 533 (25.5)	
≥3	8001 (11.9)	6625 (14.6)	
Missing	1894 (2.8)	3670 (8.1)	
Smallest stent diameter, mm, n (%)			<0.001
<3	31 110 (46.1)	21 595 (47.7)	
≥3	34 405 (51.0)	19 947 (44.1)	
Missing	1927 (2.9)	3707 (8.2)	
Total stent length, mm, n (%)			<0.001
<20	25 223 (37.4)	14 706 (32.5)	
≥20	40 283 (59.7)	26 836 (59.3)	
Missing	1936 (2.9)	3707 (8.2)	

COPD indicates chronic obstructive pulmonary disease; MI, myocardial infarction; and PCI, percutaneous coronary intervention.

PCI (7.0%), *P*<0.001. Revascularization rates were also lower among patients undergoing stress testing within the first 90 days of index PCI (2.7%) versus those with stress testing after 90 days of index PCI (3.5%), *P*<0.001. Coronary angiography was performed directly without a preceding stress test in an additional 11 592 (10.3%) patients within 2 years.

Frequency and Timing of Stress Nuclear Imaging

In the subgroup analyses of patients undergoing stress nuclear imaging, we found similar results. Stress nuclear imaging was performed in 31 020 (27.5%) patients within 2 years after index PCI; 24 957 (22.2%) underwent 1 test, 5361 (4.8%) underwent 2 tests, 649 (0.6%) underwent 3 tests, and 53 (0.04%) underwent ≥4 tests. Compared with patients not undergoing stress nuclear imaging, patients undergoing at least 1 stress nuclear imaging test were younger, more likely to reside in an urban area, have diabetes mellitus and dyslipidemia, but less likely to have heart failure, stroke, renal impairment, peripheral vascular disease, or receive index PCI in the setting of a myocardial infarction (Table I in the Data Supplement). Drug eluting stent use was greater among these patients, despite fewer overall stent use and shorter total length.

Similar to overall stress testing, initial spike in incidence of stress nuclear imaging tests was observed at 1 to 3 months after PCI (Figure 2). Among patients undergoing >1 stress nuclear imaging test, spikes in testing frequency were observed at 12 to 14 months after the prior stress nuclear imaging test (Figure 3). Of patients undergoing stress nuclear imaging testing within 2 years, 2956 (9.5%) had a subsequent coronary angiogram within 60 days of testing. Of those patients undergoing stress nuclear imaging testing followed by coronary angiography, only 1530 (51.8%), or 4.9% of all patients undergoing stress nuclear imaging testing underwent repeat revascularization.

Discussion

In this population-based study of 112 691 PCI-treated patients in Ontario, Canada, several important observations on practice of cardiac stress testing after PCI emerge. Cardiac stress testing after PCI is common with more than one half of patients undergoing at least 1 cardiac stress test within 2 years of PCI and approximately one third undergoing stress nuclear imaging. Patients with greater comorbidities, that is, higher risk, were less likely to undergo stress testing. One third underwent multiple stress tests within 2 years, with spikes in frequency of stress testing, including stress nuclear imaging, at time intervals potentially corresponding to times of routine follow-up. Of the patients tested, <6% went on to subsequent coronary angiography, and only 1 in 30 underwent repeat revascularization, with similar rates of revascularization post-stress testing irrespective of timing of stress testing relative to PCI.

Our finding that 51.3% of PCI-treated patients undergo cardiac stress testing between 60 days and 2 years after PCI in Ontario, Canada, is in between rates observed in fee-for-service community practice and integrated healthcare systems in the United States. Shah et al[1] found that 61% of privately insured patients aged <65 years in the United States underwent stress testing between 90 days and 2 years after PCI. Similarly, high stress testing rates were observed among elderly Medicare

Table 2. Characteristics of Patients Stratified by Time of First Stress Test After Index PCI

Characteristics	0–90 d (n=41 239)	90–180 d (n=11 744)	180–365 d (n=7463)	365–730 d (n=6996)
Demographics and presentation characteristics				
Age, y, mean±SD	59.1±10.9	61.0±11.2	61.8±11.5	61.9±11.5
Male sex, n (%)	31 808 (77.1)	8412 (71.6)	5254 (70.4)	4973 (71.1)
Rural area, n (%)	5649 (13.7)	1950 (16.6)	1008 (13.5)	913 (13.1)
Income quintile, n (%)				
1	7082 (17.2)	2367 (20.2)	1622 (21.7)	1447 (20.7)
2	7976 (19.3)	2462 (21.0)	1561 (20.9)	1486 (21.2)
3	8300 (20.1)	2278 (19.4)	1500 (20.1)	1419 (20.3)
4	8852 (21.5)	2394 (20.4)	1447 (19.4)	1361 (19.5)
5	8905 (21.6)	2208 (18.8)	1310 (17.6)	1254 (17.9)
Missing	124 (0.3)	35 (0.3)	23 (0.3)	29 (0.4)
Smoking history, n (%)	18 307 (44.4)	5203 (44.3)	3179 (42.6)	2972 (42.5)
Diabetes mellitus, n (%)	9988 (24.2)	3251 (27.7)	2297 (30.8)	2276 (32.5)
Hypertension, n (%)	25 562 (62.0)	7900 (67.3)	5187 (69.5)	4932 (70.5)
Hyperlipidemia, n (%)	22 819 (55.3)	6659 (56.7)	4550 (61.0)	4338 (62.0)
Myocardial infarction, n (%)	16 011 (38.8)	4431 (37.7)	2613 (35.0)	2293 (32.8)
Heart failure, n (%)	2024 (4.9)	851 (7.2)	688 (9.2)	610 (8.7)
Stroke, n (%)	176 (0.4)	88 (0.7)	58 (0.8)	62 (0.9)
COPD, n (%)	5914 (14.3)	2114 (18.0)	1419 (19.0)	1331 (19.0)
Renal failure, n (%)	295 (0.7)	115 (1.0)	154 (2.1)	119 (1.7)
Peripheral vascular disease, n (%)	1664 (4.0)	655 (5.6)	483 (6.5)	465 (6.6)
Charlson comorbidity index, mean±SD	0.28±0.71	0.37±0.83	0.44±0.97	0.42±0.92
Admission for MI or angina 1 wk before PCI, n (%)	16 177 (39.2)	4262 (36.3)	2470 (33.1)	2182 (31.2)
Procedural characteristics	834 (2.0)	417 (3.6)	396 (5.3)	456 (6.5%)
Drug eluting stent, n (%)	17 393 (42.2)	5373 (45.8)	3362 (45.0)	3178 (45.4)
No. of stents, n (%)				
1	24 720 (59.9)	6891 (58.7)	4375 (58.6)	4131 (59.0)
2	10 594 (25.7)	3078 (26.2)	1981 (26.5)	1777 (25.4)
≥3	4821 (11.7)	1466 (12.5)	889 (11.9)	825 (11.8)
Missing	1104 (2.7)	309 (2.6)	218 (2.9)	263 (3.8)
Smallest stent diameter, n (%)				
<3 mm	18 609 (45.1)	5537 (47.1)	3606 (48.3)	3358 (48.0)
≥3 mm	21 503 (52.1)	5891 (50.2)	3636 (48.7)	3375 (48.2)
Missing	1127 (2.7)	316 (2.7)	221 (3.0)	263 (3.8)
Total stent length, n (%)				
<20 mm	15 316 (37.1)	4435 (37.8)	2843 (38.1)	2629 (37.6)
≥20 mm	24 791 (60.1)	6991 (59.5)	4397 (58.9)	4104 (58.7)
Missing	1132 (2.7)	318 (2.7)	223 (3.0)	263 (3.8)

COPD indicates chronic obstructive pulmonary disease; MI, myocardial infarction; and PCI, percutaneous coronary intervention.

patients, where 59% underwent stress testing between 60 days and a median of 24 months after PCI.[2] These rates are higher than the 38% 2-year stress testing rate after PCI observed in an integrated healthcare system of >10 000 patients undergoing PCI at 55 Veterans Affairs hospitals between 2007 and 2010.[15] Although, unlike the United States, the volume of hospital-based invasive cardiac procedures are regulated by the provincial government, the single payer in Canada, the volume of

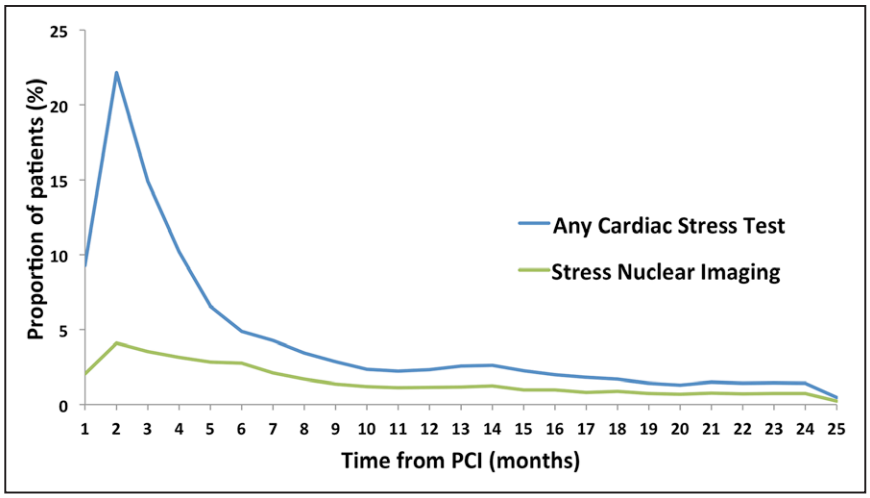

Figure 2. Time to first stress test after percutaneous coronary intervention (PCI). Spikes in incidence of first stress test at 1 to 3 mo and 12 to 13 mo after PCI.

noninvasive cardiac stress testing, performed mainly outside of the hospitals is not regulated or capped. Physician payment for the most part remains fee-for-service in Canada, creating incentives for overtesting.

It is, therefore, not surprising that rates of cardiac stress testing after PCI remain high, despite introduction of the AUC standards[4,5] and Choosing Wisely campaigns. In all studies, the rates of stress testing far exceed the 15% to 18% 1-year rates of angina symptoms reported previously in PCI-treated patients,[16,17] suggesting a considerable proportion of stress testing being performed in asymptomatic patients. Our findings that elderly patients and those with a greater burden of comorbidities were less likely to receive stress testing, similar to observations in US populations,[2,18] highlight a paradoxical practice in testing after PCI, where stress testing is preferentially being performed in lower risk patients. Shah et al[19] found that nuclear and echocardiographic stress testing after revascularization were more frequent among patients treated by physicians who billed for technical fees, professional fees, or both compared with those treated by physicians who did not bill for these services. Although such findings are of particular relevance to practice governed by fee-for-service payment, large facility-level differences in use of stress testing that persist after risk standardization have been observed even within integrated healthcare delivery system of the US Veterans Affairs[15] and capitated healthcare delivery setting of Medicare advantage.[20] These findings suggest factors other than patient characteristics, reimbursement structure, and care delivery integration influence practice variation in the use of stress testing.

The finding that only 5.9% of patients with stress testing undergo coronary angiography regardless of symptomatic status suggests that testing in this population identified a small proportion of patients who either had positive stress test results or other indications for further invasive investigations. It has been previously suggested that highest-risk patients may be referred directly for coronary angiography. Consistent with observations in an elderly Medicare population, where 10% underwent coronary angiography first within 60 days and a median of 24 months after PCI,[2] we also found that 10.3% of patients in our Ontario study cohort underwent cardiac catheterization directly without an intervening cardiac stress test. In patients who proceeded to coronary angiography after stress testing, approximately one half underwent revascularization. As a result, the overall rate of repeat revascularization after stress testing was extremely low (3.1%). Rate of repeat revascularization after stress nuclear imaging, performed in one third of patients within 2 years post-PCI, was not substantially greater (4.9%). Although some stress tests, particularly early after PCI, may be performed for purposes of cardiac rehabilitation or assessment of functional capacity, revascularization rates post-stress testing performed 90 days after index PCI were not substantially higher.

Prior administrative database studies from the United States have also found low rate of repeat revascularization after stress testing post-PCI. Shah et al[1] reviewed the use of stress testing after revascularization (PCI or CABG) from administrative billing records and found that the yield of stress testing for subsequent revascularization was 5%.

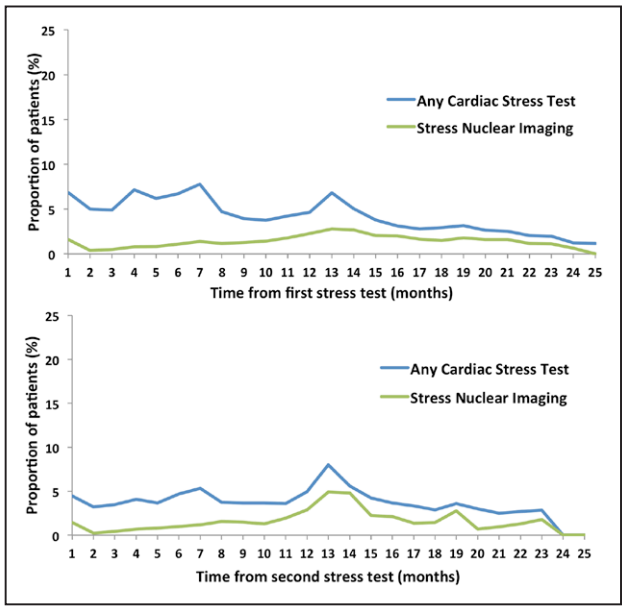

Figure 3. A, Time to second stress test after first stress test. Spikes in incidence of second stress test at 3 to 4 mo, 6 to 7 mo, and 12 to 13 mo after first stress test. **B**, Time to third stress test after second stress test. Spikes in incidence of third stress test at 6 to 7 mo, 12 to 13 mo, and 18 to 19 mo after second stress test.

Table 3. Stress Testing Yield Stratified by Time of Stress Test After PCI

Outcome Within 60 d	0–90 d	90–180 d	180–365 d	365–730 d	Total
Any cardiac stress test	41 239	11 744	7463	6996	67 442
Coronary angiography, n (%)	2112 (5.1)	800 (6.8)	579 (7.8)	456 (6.5)	3947 (5.9)
PCI, n (%)	1018 (2.5)	405 (3.5)	257 (3.4)	166 (2.4)	1846 (2.7)
CABG, n (%)	116 (0.28)	56 (0.48)	27 (0.36)	17 (0.24)	216 (0.3)
PCI or CABG, n (%)	1132 (2.7)	461 (3.9)	284 (3.8)	183 (2.6)	2060 (3.1)
Nuclear stress test	9712	7555	6741	7012	31 020
Coronary angiography, n (%)	937 (9.6)	758 (10.0)	684 (10.2)	577 (8.2)	2956 (9.5)
PCI, n (%)	465 (4.8)	379 (5.0)	306 (4.5)	208 (3.0)	1358 (4.4)
CABG, n (%)	33 (0.3)	25 (0.3)	12 (0.2)	8 (0.1)	78 (0.3)
PCI or CABG, n (%)	519 (5.3)	439 (5.8)	336 (5.0)	236 (3.4)	1530 (4.9)

CABG indicates coronary artery bypass grafting; and PCI, percutaneous coronary intervention.

Mudrick et al[2] reported a revascularization rate of 9% post-stress testing in a Medicare population who had undergone PCI. Similar to our study, these studies did not have information about patient symptoms at the time of stress testing. In a cohort of asymptomatic patients after PCI, the yield of stress imaging was even lower, resulting in further revascularization in <1% of patients.[18] In this study, a low rate of abnormal stress tests was accompanied by low referral to angiography; these findings are consistent with other studies demonstrating modest rates of referral to angiography among patients with abnormal stress test results.[21,22] Although abnormal results at stress echocardiography or radionuclide myocardial perfusion imaging in patients with previous revascularization have repeatedly been shown to be predictive of subsequent events, clinical benefit of further revascularization, particularly in asymptomatic patients has not been established.[3,23,24] This is particularly important because the detection of clinically silent coronary disease progression may expose the patients to the risks and expense of further revascularization without prognostic benefit.

One third of patients underwent multiple stress tests within 2 years of index PCI. Sequential stress testing was performed without intervening coronary revascularization. The role of serial stress testing, even among patients with an abnormal first test is not established, raising questions on factors driving this practice pattern. Spikes in frequency of repeat stress testing at 3 to 4 months, 6 to 7 months, and 12 to 13 months potentially relate to times of routine follow-up visits. Spikes in frequency of repeat stress nuclear imaging were also observed around times of routine follow-up. Although it is possible that patients do not report symptoms until scheduled visits, at which time symptom-driven testing may be ordered, these findings may reflect a pattern of routine surveillance testing contrary to practice guidelines[7] and AUC.[6] Routine testing, particularly stress nuclear imaging, not only has enormous cost implications but also exposes patients to unnecessary radiation, false-positive results with risks of additional invasive investigations and treatments, negatively affecting the overall quality of care.

Given the large population of patients with PCI, further work is required to evaluate the clinical impact and cost effectiveness of routine stress testing after PCI. Applied to our province-wide cohort, plan-do-study-act cycles may generate valuable insights into the contemporary practice patterns and factors driving the use of stress testing and be useful to evaluate informatics-based novel approaches including computerized physician order entry, as well as clinical decision supports incorporated into electronic medical records, shown previously to reduce the redundancy of test ordering and improve resource utilization.[25] Furthermore, shared decision making with patients may also improve application of evidence-based and AUC for selection of patients most likely to benefit from testing after PCI. Finally, linking quality of care received with payment by incorporating performance-based financial reimbursement may be additional strategies to incentivize appropriate use of stress testing in this publically funded single-payer system.

Limitations

Our observations are derived from an administrative data set, limiting the granularity of clinical data. We did not have information on symptomatic status and clinical presentation at that time of stress testing and thus, are unable to evaluate the appropriateness of stress testing. Some stress tests, particularly early after PCI performed for purposes of cardiac rehabilitation, or exercise prescriptions may be appropriate. In addition, rates of coronary revascularization post-stress testing alone do not fully represent the usefulness of the cardiac stress test because a rule out negative test in a symptomatic patient is considered useful. Although some but not all prior US studies have used a 60- or 90-day blanking period to exclude stress testing performed as part of cardiac rehabilitation or for evaluation of residual ischemia, we did not use this strategy because this would exclude many tests not related to rehabilitation. Cardiac stress testing within 90 days of PCI was performed in 36.6% of the study population, with this rate substantially >5.8% for cardiopulmonary assessment within 90 days of PCI estimated from a regional cardiac rehabilitation registry. Beyond clinical indications and physician practice patterns, how the use of stress testing may have been influenced by patient preferences and expectations cannot be determined in this data set. In addition, results of the stress

tests and whether they altered medical management or clinical outcomes are not available. Data are limited to fee-for-service Ontario health insurance plan patients undergoing index PCI and may not be generalizable to other populations.

Conclusions

Stress testing after PCI is frequently performed in Ontario, Canada, with patterns suggesting multiple and routine surveillance testing contrary to practice guidelines and AUC. Regardless of symptomatic status, rate of repeat revascularization after such stress testing is low, with approximately only 1 of 30 tested patients undergoing further revascularization. Given the lack of current evidence that routine testing after revascularization improves clinical outcomes, these findings highlight opportunities for improvement in patient selection for stress testing after PCI.

Acknowledgments

We acknowledge that the clinical registry data used in this publication is from participating hospitals through the Cardiac Care Network of Ontario, which serves as an advisory body to the Minister of Health and Long-Term Care (MOHLTC), is funded by the MOHLTC, and is dedicated to improving the quality, efficiency, access, and equity in the delivery of the continuum of adult cardiac services in Ontario, Canada.

Sources of Funding

This research is supported by the Heart and Stroke Foundation/University of Toronto Polo Chair in Cardiology Young Investigator Award. Dr Goodman is supported by the Heart and Stroke Foundation/University of Toronto Polo Chair. Dr Ko is supported by a Mid-Career Award from the Heart and Stroke Foundation, Ontario Provincial Office. This study was supported by the Institute for Clinical Evaluative Sciences, which is funded by an annual grant from the Ministry of Health and Long-Term Care.

Disclosures

None.

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Population-Based Study on Patterns of Cardiac Stress Testing After Percutaneous Coronary Intervention

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Circ Cardiovasc Qual Outcomes. 2017;10:
doi: 10.1161/CIRCOUTCOMES.117.003660
Circulation: Cardiovascular Quality and Outcomes is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

Print ISSN: 1941-7705. Online ISSN: 1941-7713

SUPPLEMENTAL MATERIAL

Supplemental Table 1: Characteristics of Patients With and Without Stress Nuclear Imaging Within 2 years After Index PCI

Characteristics	At least one Nuclear Stress Imaging Test (n=31,020)	No Stress Nuclear Imaging (n=81,671)	P-value
Demographics and presentation characteristics			
Age in years, Mean± SD	60.9 ± 11.4	62.8 ± 12.4	<0.001
Male sex, n (%)	22,239 (71.7%)	58,424 (71.5%)	0.60
Rural area, n (%)	3,129 (10.1%)	13,640 (16.7%)	<0.001
Income quintile, n (%)			<0.001
1	6,106 (19.7%)	16,343 (20.0%)	
2	6,310 (20.3%)	16,838 (20.6%)	
3	6,200 (20.0%)	16,185 (19.8%)	
4	6,323 (20.4%)	16,248 (19.9%)	
5	6,003 (19.4%)	15,718 (19.2%)	
Missing	78 (0.3%)	339 (0.4%)	
History smoking, n (%)	13,408 (43.2%)	34,989 (42.8%)	0.25
Diabetes, n (%)	9,294 (30.0%)	23,512 (28.8%)	<0.001
Hypertension, n (%)	21,098 (68.0%)	55,228 (67.6%)	0.21
Hyperlipidemia, n (%)	18,716 (60.3%)	45,373 (55.6%)	<0.001
Myocardial infarction, n (%)	11,119 (35.8%)	32,988 (40.4%)	<0.001
Heart Failure, n (%)	2,347 (7.6%)	8,959 (11.0%)	<0.001
Stroke, n (%)	223 (0.7%)	810 (1.0%)	<0.001
COPD, n (%)	5,295 (17.1%)	15,926 (19.5%)	<0.001
Renal failure, n (%)	426 (1.4%)	1,607 (2.0%)	<0.001
Peripheral vascular disease, n (%)	1,810 (5.8%)	5,385 (6.6%)	<0.001
Charlson Comorbidity Index, Mean ± SD	0.38 ± 0.87	0.44 ± 0.99	<0.001
Admission for MI or angina 1 week prior to PCI, n (%)	11,228 (36.2%)	27,865 (34.1%)	<0.001
Procedural characteristics			
Drug eluting stent, n (%)	13,896 (44.8%)	33,501 (41.0%)	<0.001
Number of stents, n (%)			<0.001
1	17,935 (57.8%)	45,603 (55.8%)	
2	8,250 (26.6%)	20,713 (25.4%)	
≥3	4,016 (12.9%)	10,610 (13.0%)	
Missing	819 (2.6%)	4,745 (5.8%)	
Smallest stent diameter, n (%)			<0.001
< 3mm	15,049 (48.5%)	37,656 (46.1%)	
≥3 mm	15,130 (48.8%)	39,222 (48.0%)	
Missing	841 (2.7%)	4,793 (5.9%)	
Total stent length, n (%)			<0.001
<20 mm	11,242 (36.2%)	28,687 (35.1%)	
≥ 20 mm	18,936 (61.0%)	48,183 (59.0%)	

Missing	842 (2.7%)	4,801 (5.9%)