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Research

Stress testing after percutaneous coronary interventions: a population-based study

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Abstract

Background: Routine stress testing is commonly used after percutaneous coronary intervention (PCI) to detect in-stent restenosis or suboptimal procedure results; however, recent studies suggest that such testing is rarely indicated. Our main objectives were to assess temporal trends in utilization of stress testing and to determine factors associated with its use.

Methods: We conducted an observational study involving all patients who had undergone PCI in Ontario, Canada, from Apr. 1, 2004, to Mar. 31, 2012. The main outcome was stress testing within 2 years after PCI. We constructed multivariable logistic regression models to determine factors associated with the use of stress tests.

Results: Our cohort consisted of 128 380 patients who underwent PCI procedures. The 2-year rate of stress testing declined significantly, from 68.1% among patients who underwent PCI in 2004 to 60.4% in 2012 (p < 0.001). Similar reductions were observed regardless of patients' risk of restenosis and type of stent received. Patients who were older or had diabetes mellitus, prior myocardial infarction, heart failure or other comorbidities were significantly less likely to undergo stress testing. In contrast, patients with higher income and those whose PCI was performed in a nonteaching hospital were significantly more likely to undergo stress testing.

Interpretation: We observed a decrease in the use of stress testing after PCI procedures over time. However, stress tests were not performed in accordance with patients' higher baseline risk of adverse outcomes or risk of restenosis. Instead, many nonclinical factors, such as patients' socioeconomic status and hospitals' teaching status, were associated with higher use of stress tests.

During the era of bare metal stents, in-stent restenosis was considered the Achilles heel of percutaneous coronary intervention (PCI) procedures.[1] At that time, stress testing was recommended for patients who had undergone PCI to detect potential in-stent restenosis or progression of coronary atherosclerosis.[2] With the advent of drug-eluting stents more than a decade ago, rates of in-stent restenosis after PCI have declined dramatically, currently ranging from 0% to 16%.[1] Recent studies have consistently shown that routine ischemic evaluations after PCI are of low diagnostic yield.[3,4] In the latest practice guidelines, routine stress testing for asymptomatic patients after PCI procedures was designated a class III recommendation.[5] The appropriateness-of-use criteria identified that stress testing is rarely indicated within 2 years after PCI procedures.[6] The Choosing Wisely campaign (United States) has supported the latest guidelines and has also suggested that routine stress tests may lead to unnecessary invasive procedures (and potentially unnecessary radiation exposure when nuclear perfusion imaging is concomitantly performed) without any proven effect on patients' outcomes.[7]

Most of the studies investigating the use of stress testing after PCI have been conducted in the US,[8–10] which has different methods of financing health care than the Canadian health care system.[11,12] In fact, little is known about the patterns of stress testing after PCI in the Canadian setting. To address this gap in knowledge, our main objectives for this study were to assess temporal trends in utilization of stress

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testing after PCI and to determine factors associated with its use.

Methods

Data sources

PCI data were obtained from the Cardiac Registry of the Cardiac Care Network of Ontario, which collects information about all patients undergoing cardiac catheterization, PCI, cardiac surgery and electrophysiology procedures in Ontario. Nurse coordinators at each cardiac invasive care centre gather data on demographic and clinical characteristics, procedure characteristics (including stent type) and relevant comorbid conditions. Our group has used these data extensively to perform evaluative analyses.[12–15] We used the Ontario Health Insurance Plan claims database, which captures information on services provided by practising physicians, to identify physician visits and stress testing. We used the Canadian Institute for Health Information Discharge Abstract Database, which includes information about hospital admissions, to identify in-hospital stress testing and additional comorbidities. We used the Ontario Registered Persons Database, which contains vital statistics for all Ontarians, to determine rural residence and death after the index event. Finally, we used Statistics Canada census data to determine the socioeconomic status of each patient. We linked the data sets using unique encoded identifiers and performed analyses at the Institute for Clinical Evaluative Sciences (ICES).

Study population

The study population consisted of patients older than 18 years who underwent a PCI procedure from Apr. 1, 2004, to Mar. 31, 2012. We excluded patients with invalid health card numbers, those who had previous PCI or previous coronary artery bypass grafting surgery, and those who were not residents of Ontario. We excluded patients who had undergone prior cardiac revascularizations to limit the evaluation to initial care patterns after first PCI. For patients who had multiple PCI procedures during the study period, we considered the first procedure as the index event for study inclusion.

Main outcome

The main outcome was stress testing within 2 years after PCI. The 2-year timeframe was chosen because practice guidelines suggest that stress testing within this window is rarely indicated.[6] We considered stress testing as exercise or pharmacologic tests, with or without an accompanying imaging modality. Performance of these tests was identified using a combination of billing codes from the Ontario Health Insurance Plan (G112, G174, G319, G567–8, G571–2, J607–8, J807–8) and the Discharge Abstract Database, using Classification of Health Intervention code 2HZ08E.

Statistical analysis

We categorized the patient cohort by the Canadian fiscal year (Apr. 1 to Mar. 31) of the index PCI procedure. We evaluated temporal trends in the baseline characteristics of all patients who underwent PCI and the patients who received stress testing using the Cochran–Armitage trend test (for categorical variables) and linear regression (for continuous variables), with procedure year as the independent variable. We evaluated temporal trends in stress testing at 2 years for all patients, according to predicted baseline risk of repeat revascularization, stent type (bare metal or drug-eluting), and both risk and stent type. We modelled predicted risk of revascularization using logistic regression with the following variables in accordance with our prior study: age, diabetes status, stent length and stent size.[16]

We compared demographic, clinical and procedural characteristics between patients who underwent stress testing within 2 years and those who did not, using χ^2 tests for categorical variables and *t* tests for continuous variables. We developed multivariable logistic regression models to assess the association between clinical and nonclinical factors in the use of stress testing. We selected candidate variables on the basis of prior literature and clinical knowledge; these variables included demographic factors (age, sex, income, rural residence), cardiac risk factors (diabetes mellitus, hypertension, dyslipidemia, smoking), angina classification, comorbidities (myocardial infarction, heart failure, peripheral vascular disease, cerebrovascular disease, renal failure, chronic obstructive pulmonary disease), PCI characteristics (stent type, size, length) and teaching hospital status. We also performed a sensitivity analysis using a 2-level hierarchical logistic regression model, taking into account hospital clusters, to examine predictors of stress testing after PCI.

Data were analyzed with SAS version 9.3. Two-tailed p values less than 0.05 were considered significant.

Ethics approval

This study was approved by the institutional review board at Sunnybrook Health Sciences Centre, Toronto. Informed consent was not required, because Ontario law permits the use of administrative data for research purposes by prescribed entities.

Results

Study cohort

From Apr. 1, 2004, to Mar. 31, 2012, a total of 191 614 patients over the age of 18 years underwent PCI procedures in Ontario. We excluded 41 557 records because of multiple PCI procedures during the study period and 21 677 records because of prior PCI or coronary artery bypass grafting surgery. After these exclusions, our final cohort consisted of 128 380 patients. Data linkage of this cohort to the Ontario Registered Persons Database and the census data was over 99%.

Characteristics of patients who underwent PCI

The mean age of the patients who underwent PCI was 63.1 years, 71.2% were men, and the overall use of drug-eluting stents was 42.1%. Over the study period (Table 1), we observed increasing mean age, from 62.3 years in 2004/05 to 64.1 years in 2012/13, and increasing rates of diabetes (28.6%

Table 1: Trends in demographic and clinical characteristics of patients who underwent PCI from 2004/05 to 2012/13

Characteristic	2004/05 *n* = 13 733	2005/06 *n* = 14 299	2006/07 *n* = 14 462	2007/08 *n* = 13 341	2008/09 *n* = 13 778	2009/10 *n* = 14 299	2010/11 *n* = 14 862	2011/12 *n* = 14 531	2012/13 *n* = 15 075	*p* value for trend
	Fiscal year; % of patients* (*n* = 128 380)									
Demographic										
Age, yr, mean ± SD	62.3 ± 11.9	62.7 ± 12.0	62.7 ± 12.0	62.6 ± 12.1	62.9 ± 12.3	63.1 ± 12.4	63.5 ± 12.4	63.9 ± 12.5	64.1 ± 12.4	0.007
Sex, male	71.6	71.8	72.9	72.0	71.1	70.3	70.3	70.5	70.2	< 0.001
Residence, rural	15.3	14.9	14.7	15.1	14.4	14.5	15.1	15.0	14.9	0.7
Income quintile†										
1 (lowest)	19.7	20.4	20.1	20.2	19.7	19.8	20.5	19.9	19.9	0.9
2	21.1	20.6	21.1	20.2	20.3	20.3	20.4	20.0	20.7	0.07
3	19.5	20.1	18.9	19.3	20.1	20.0	19.8	20.5	20.2	0.02
4	20.2	19.6	19.8	20.4	19.8	20.4	19.6	20.1	20.2	0.6
5 (highest)	19.1	19.0	19.7	19.6	19.7	19.1	19.3	19.1	18.6	0.2
CCS angina classification†										
0	7.0	7.3	6.5	5.0	5.4	5.2	5.4	5.5	6.2	< 0.001
1	5.2	5.0	4.7	3.5	3.6	4.1	4.5	4.5	4.8	0.06
2	14.8	15.2	14.7	12.9	12.3	13.0	12.8	13.0	12.1	< 0.001
3	20.0	19.9	14.3	13.2	11.3	10.0	9.0	8.5	8.2	< 0.001
≥ 4	45.1	48.0	58.3	64.0	66.4	67.2	68.2	68.4	66.5	< 0.001
Cardiac risk factors and comorbidities										
Diabetes mellitus	28.6	29.5	30.3	29.7	30.6	30.4	31.8	31.8	33.0	< 0.001
Hypertension	68.0	69.6	74.2	73.4	74.0	73.5	74.6	74.1	74.7	< 0.001
Hyperlipidemia	53.7	54.6	68.8	67.3	66.7	65.7	65.3	63.8	63.2	< 0.001
Myocardial infarction	45.6	44.0	43.0	46.1	51.5	58.5	58.5	57.1	54.0	< 0.001
Heart failure	5.9	5.5	7.8	6.9	7.0	6.5	6.5	6.0	6.4	0.9
History of stroke	1.8	1.7	1.5	1.7	1.4	1.5	1.8	1.6	1.7	0.9
Peripheral vascular disease	5.9	6.2	6.2	6.1	5.9	5.7	5.6	5.2	5.2	< 0.001
Renal failure	2.9	2.9	2.8	2.8	2.8	3.1	3.4	3.7	3.4	< 0.001
COPD	5.9	5.6	7.2	7.4	7.1	7.1	7.1	7.1	7.0	< 0.001
Smoking history	48.8	49.3	54.8	55.7	53.8	55.3	53.4	51.5	50.1	0.02
Charlson comorbidity index, mean ± SD	0.55 ± 1.03	0.48 ± 1.01	0.50 ± 1.09	0.49 ± 1.09	0.44 ± 1.02	0.44 ± 1.05	0.44 ± 1.06	0.43 ± 1.05	0.45 ± 1.03	< 0.001
PCI characteristics‡										
Stent type										
Drug-eluting	44.8	50.5	46.3	33.6	37.1	37.3	37.9	41.9	49	< 0.001
Bare metal	62.2	55.2	59.5	69.0	62.9	61.5	61.9	57.2	50	< 0.001
No. of stented vessels										
1	53.1	50.8	51.1	53.8	53.8	55.2	56.4	57.1	56.9	< 0.001
2	25.1	26.0	26.1	25.2	25.8	25.7	25.4	25.2	25.2	0.3
≥ 3	16.7	17.4	18.0	16.5	15.0	13.3	13.2	12.6	13.0	< 0.001
Stent diameter, mm										
< 3	45.8	49.1	48.6	45.1	45.6	45.7	45.9	48.3	50.1	0.001
≥ 3	49.2	45.0	46.7	50.3	48.8	48.5	49.2	46.4	44.8	0.002
Total stent length, mm										
< 20	35.3	33.2	34.1	37.5	34.9	34.1	35.0	33.8	31.1	< 0.001
≥ 20	59.7	61.0	61.1	57.9	59.6	60.0	60.0	60.9	63.7	< 0.001

Note: CCS = Canadian Cardiovascular Society, COPD = chronic obstructive pulmonary disease, PCI = percutaneous coronary intervention, SD = standard deviation.
*Except where indicated otherwise.
†Percentages were calculated on the basis of all patients, but for each year, percentage for missing data is not reported; thus, percentages sum to slightly less than 100.
‡For stent type and stent-related variables, percentages were calculated using number of patients as the denominator. However, a patient may receive multiple stents during a PCI procedure; hence, percentages for stent type may sum to more than 100. Conversely, some vessels may not have stents placed, so the sum of percentages for stent-related variables may be less than 100.

to 33.0%), hypertension (68.0% to 74.7%) and hyperlipidemia (53.7% to 63.2%). There were also significantly higher rates of prior myocardial infarction, renal failure and chronic obstructive pulmonary disease for patients who had PCI in 2012/13 as compared with 2004/05.

The characteristics of patients who underwent stress testing within 2 years after PCI, categorized by fiscal year, are shown in Appendix 1 (available at www.cmajopen.ca/content/5/2/E417/suppl/DC1). The mean age of the patients who underwent stress testing after PCI was 60.7 years, 74.9% were men, and the overall use of drug-eluting stents was 46.2%. Temporal changes in characteristics among patients who underwent stress testing mirrored those of the overall PCI cohort, with higher rates of cardiac risk factors and comorbidities.

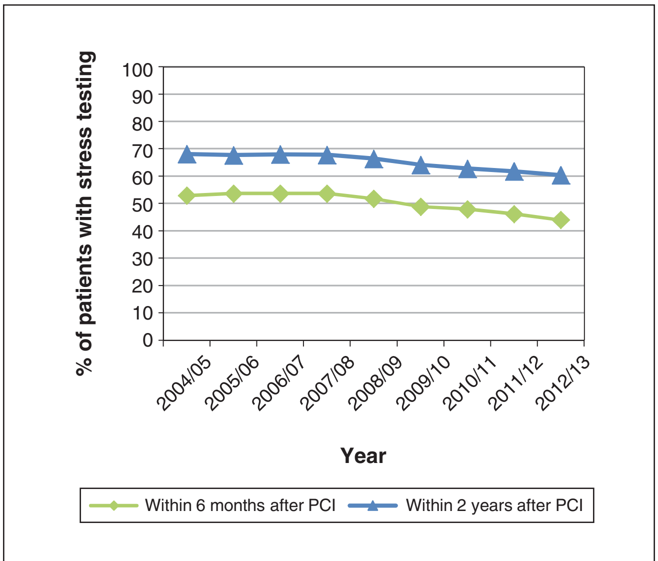

Figure 1: Trends over time (2004/05 to 2012/13) in stress test rates within 6 months and within 2 years after percutaneous coronary intervention (PCI) procedures.

Trends in the use of stress testing

Figure 1 shows the trends in use of stress testing within 6 months and within 2 years after PCI procedures. The 2-year rate of stress testing decreased significantly, from 68.1% for patients who received PCI in 2004/05 to 60.4% in 2012/13 (p < 0.001). Trends in stress testing according to predicted revascularization risk and stent type are shown in Figure 2. Patients with high, medium or low predicted risk of repeat revascularization had similar rates of testing and similar declining trends of testing. Similar declines were also seen for patients who received bare metal stents and drug-eluting stents. Higher rates of stress testing were observed consistently among patients who received drug-eluting stents over the entire study period, irrespective of their risk of predicted repeat revascularization.

Factors associated with stress testing

Comparisons between patients who underwent stress testing and those with no testing are shown in Table 2. Patients who underwent testing were significantly younger (60.7 yr v. 67.6 yr) and were more likely to be men, to fall in a higher income quintile and to have undergone PCI in a nonteaching hospital. Patients who underwent testing were also more likely to have fewer cardiac risk factors and fewer comorbidities (mean Charlson comorbidity index 0.47 v. 0.90).

A multivariable model incorporating factors to predict the use of stress testing within 2 years is shown in Table 2. We observed lower odds of stress testing according to procedure year (odds ratio [OR] 0.96, 95% confidence interval [CI] 0.96–0.97) after adjustment for clinical and nonclinical factors. Older age, cardiac risk factors and prior comorbidities

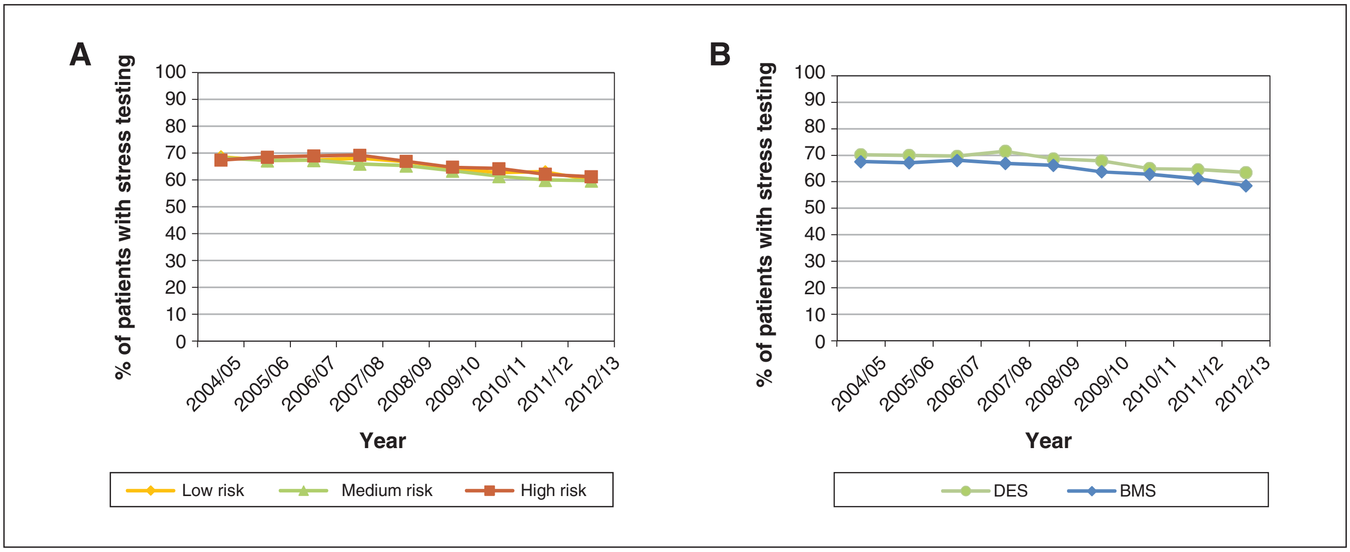

Figure 2: (A) Trends over time (2004/05 to 2012/13) in stress test rates, categorized by risk of in-stent restenosis (low, medium or high). (B) Trends over time (2004/05 to 2012/13) in stress test rates, categorized by type of stent used during percutaneous coronary intervention. BMS = bare metal stent, DES = drug-eluting stent.

Table 2: Predictors of stress tests within 2 years after PCI

Characteristic	Group; % of patients*		OR (95% CI)†
	Stress test *n* = 83 636	No stress test *n* = 44 744	
Demographic			
Age, yr, mean ± SD	60.7 ± 11.2	67.6 ± 12.7	0.958 (0.957–0.959)
Sex, male	74.9	64.3	1.22 (1.19–1.26)
Residence, rural	14.1	16.4	0.84 (0.81–0.87)
Site of PCI, teaching hospital	61.3	75.9	0.52 (0.50–0.53)
Income quintile			
1 (lowest)	18.6	22.8	1.00 (ref)
2	20.0	21.5	1.29 (1.08–1.17)
3	20.1	19.5	1.20 (1.15–1.27)
4	20.8	18.6	1.26 (1.21–1.32)
5 (highest)	20.3	17.3	1.37 (1.32–1.43)
Procedure year	NA		0.96 (0.96–0.97)
Canadian Cardiovascular Society angina classification			
0	5.6	6.5	1.00 (ref)
1	4.7	3.9	1.22 (1.12–1.32)
2	14.3	11.9	1.26 (1.19–1.35)
3	12.6	12.8	1.05 (0.98–1.11)
≥ 4	60.7	62.8	0.97 (0.92–1.02)
Cardiac risk factors and comorbidities			
Diabetes mellitus	27.7	36.3	0.83 (0.80–0.85)
Hypertension	69.6	79.0	0.95 (0.91–0.98)
Hyperlipidemia	62.8	64.0	1.15 (1.12–1.18)
Myocardial infarction	48.9	55.0	0.86 (0.83–0.88)
Heart failure	3.7	11.8	0.57 (0.54–0.60)
History of stroke	1.1	2.7	0.78 (0.71–0.86)
Peripheral vascular disease	4.1	8.9	0.75 (0.71–0.79)
Renal failure	1.8	5.5	0.79 (0.72–0.85)
Chronic obstructive pulmonary disease	4.9	10.5	0.76 (0.72–0.80)
Smoking history	53.2	51.1	0.89 (0.87–0.92)
Charlson comorbidity index, mean ± SD	0.47 ± 1.05	0.90 ± 1.58	0.94 (0.93–0.95)
PCI characteristics			
Stent type			
Drug-eluting	43.8	39.0	1.00 (ref)
Bare metal	59.7	59.9	0.87 (0.84–0.89)
No. of stented vessels			
1	46.7	48.0	1.00 (ref)
2	49.4	44.3	1.01 (0.98–1.05)
≥ 3	3.9	7.7	1.00 (0.96–1.05)
Stent diameter, mm			
< 3	46.7	48.0	1.00 (ref)
≥ 3	49.4	44.3	1.05 (1.02–1.08)
Total stent length, mm			
< 20	34.8	33.2	1.00 (ref)
≥ 20	61.2	59.1	1.00 (0.96–1.03)

Note: CI = confidence interval, NA = not applicable, OR = odds ratio, PCI = percutaneous coronary intervention, SD = standard deviation.
*Except where indicated otherwise.
†Adjusted for demographic factors (age, sex, income, rural residence), cardiac risk factors (diabetes mellitus, hypertension, dyslipidemia, smoking), angina classification, comorbidities (myocardial infarction, heart failure, peripheral vascular disease, cerebrovascular disease, renal failure, chronic obstructive pulmonary disease), PCI characteristics (stent type, size, length) and teaching hospital status.

were associated with significantly lower odds of stress testing. More specifically, each year increase in age was associated with lower odds of stress testing (OR 0.958, 95% CI 0.957–0.959). Prior myocardial infarction (OR 0.86, 95% CI 0.83–0.88), heart failure (OR 0.57, 95% CI 0.54–0.60) and bare metal stent implantation (OR 0.87, 95% CI 0.84–0.89) were associated with significantly lower odds of stress testing.

In terms of nonclinical factors, patients who underwent their PCI procedure in a teaching hospital were about half as likely to undergo stress testing after PCI (OR 0.52, 95% CI 0.50–0.53). Other nonclinical factors that were independently associated with stress testing included higher income quintile. Rural residence was also associated with reduced odds of stress testing (OR 0.84, 95% CI 0.81–0.87).

In the sensitivity analysis, based on a 2-level hierarchical logistic regression model and taking into account hospital clusters to examine predictors of stress testing after PCI, the results were similar to the original results and are shown in Appendix 2 (available at www.cmajopen.ca/content/5/2/E417/suppl/DC1).

Interpretation

This population-based study of patients who underwent PCI in Ontario had several key findings. First, we observed a declining trend in the use of stress testing over the study period, which was consistent for all patient subgroups. Despite this encouraging trend, more than 60% of patients who underwent PCI in 2012/13 received stress tests within 2 years of the procedure. Furthermore, the use of stress testing was not based on patients' risk of adverse events or their risk of restenosis. Instead, the performance of stress testing appeared discretionary, favouring patients who were younger, had higher socioeconomic status, had fewer comorbidities and underwent PCI at nonteaching facilities. These findings, together with recent reports showing the low diagnostic yield of routine stress testing after PCI, suggest that there is an opportunity to reduce routine stress testing in this population, which may potentially optimize health care resource utilization.

The US market-oriented health care system, with limited governmental control, differs from Canada's single-payer system with government reimbursement of most health care services.[11,12] In Ontario, the provincial government sets targets for procedure volumes and number of cardiac catheterization facilities according to the anticipated needs of the population. In contrast, the majority of stress tests are performed in the ambulatory setting, where the government reimburses the associated fees without a threshold. Our group has previously shown that almost twice as many cardiac invasive procedures in patients with stable coronary disease are performed in the US as in Canada.[11,12] It is therefore interesting to see that rates of stress testing after PCI, as reported here, appear to be in line with those reported from the US. For example, Shah and colleagues[8] evaluated a national health insurance claims database for the period 2004 to 2007, and found that 61% of patients 18 to 64 years of age underwent stress testing within 2 years after PCI. In the Medicare population, the rate of stress testing was estimated at 49%.[9] The rate in the Veterans Affairs population was slightly lower, at 40%.[10]

Stress testing after PCI procedures was once considered routine, because it is commonly believed that post-PCI symptoms are not reliable indicators of restenosis or progression of coronary artery disease.[2] Thus, objective evaluation of ischemia was believed to be helpful in the detection of in-stent restenosis or suboptimal interventional results.[2,17] The outcomes of PCI have improved substantially over time, and many guidelines now consider routine stress testing for asymptomatic patients who have undergone coronary revascularization to be unnecessary.[5,6] It is unlikely that the Choosing Wisely Canada campaign was responsible for the declining trend in stress testing that we observed, given that it did not have specific recommendations for post-PCI stress testing. Future efforts are required to monitor the use of stress testing and to ensure that inappropriate use of stress testing continues to decline.

Our group has previously defined the term "treatment risk paradox" as a pervasive pattern in medicine whereby treatment propensity decreases as patient risk increases.[18] In a similar manner, we observed that patients who are at highest risk of adverse cardiac outcomes or in-stent restenosis were much less likely to receive stress testing. The difference in stress testing was not due to differential use of invasive evaluation, because we found substantially lower rates of cardiac catheterization among patients who did not receive stress testing. We also do not believe it was due to refusal of stress testing, because this rarely occurs in clinical practice. In addition, nonclinical factors such as the location where the procedure was performed, the place of residence of the patient and the socioeconomic status of the patient were associated with stress test use. It has been previously shown that patients who are part of the higher income bracket are less satisfied with the Canadian health care system than patients at lower income levels.[19] In addition, it is likely that patients with higher socioeconomic status have greater access to stress testing facilities. It is possible that a proportion of the stress tests were performed for the purpose of reassuring patients at higher socioeconomic levels.

Limitations

Several limitations of our study warrant consideration. First, several studies from the US used a 90-day blanking period to exclude patients who underwent stress testing as part of cardiac rehabilitation. However, we did not apply this strategy because it would have excluded many stress tests not related to cardiac rehabilitation, because access to rehabilitation is more limited in Canada. Second, our data sets did not include any information as to whether patients undergoing stress tests were symptomatic or asymptomatic before their assessment. However, this limitation is inherent to most studies on this topic.[9] In addition, some stress testing may be performed for patients with incomplete revascularization after PCI. Accordingly, we cannot definitively conclude that stress testing after PCI was inappropriate. Nevertheless, observations from our study and others strongly suggest that additional efforts are needed to ensure appropriate use of stress tests after PCI procedures in the future.

Conclusion

Clinicians appear to have responded to recent evidence by reducing the number of stress tests after PCI. However, there remains a treatment risk paradox, whereby factors other than the risk of restenosis influence the likelihood of a patient undergoing these tests. Understanding how to manage patients' and clinicians' expectations in order to align with the latest clinical information and practice guidelines may be important in further reducing the use of routine stress testing after PCI.

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