Original Investigation

Appropriate Use Criteria for Coronary Revascularization and Trends in Utilization, Patient Selection, and Appropriateness of Percutaneous Coronary Intervention

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IMPORTANCE Appropriate Use Criteria for Coronary Revascularization were developed to critically evaluate and improve patient selection for percutaneous coronary intervention (PCI). National trends in the appropriateness of PCI have not been examined.

OBJECTIVE To examine trends in PCI utilization, patient selection, and procedural appropriateness following the introduction of Appropriate Use Criteria.

DESIGN, SETTING, AND PARTICIPANTS Multicenter, longitudinal, cross-sectional analysis of patients undergoing PCI between July 1, 2009, and December 31, 2014, at hospitals continuously participating in the National Cardiovascular Data Registry CathPCI registry over the study period.

MAIN OUTCOMES AND MEASURES Proportion of nonacute PCIs classified as inappropriate at the patient and hospital level using the 2012 Appropriate Use Criteria for Coronary Revascularization.

RESULTS A total of 2.7 million PCI procedures from 766 hospitals were included. Annual PCI volume of acute indications was consistent over the study period (377 540 in 2010; 374 543 in 2014), but the volume of nonacute PCIs decreased from 89 704 in 2010 to 59 375 in 2014. Among patients undergoing nonacute PCI, there were significant increases in angina severity (Canadian Cardiovascular Society grade III/IV angina, 15.8% in 2010 and 38.4% in 2014), use of antianginal medications prior to PCI (at least 2 antianginal medications, 22.3% in 2010 and 35.1% in 2014), and high-risk findings on noninvasive testing (22.2% in 2010 and 33.2% in 2014) ($P < .001$ for all), but only modest increases in multivessel coronary artery disease (43.7% in 2010 and 47.5% in 2014, $P < .001$). The proportion of nonacute PCIs classified as inappropriate decreased from 26.2% (95% CI, 25.8%-26.6%) to 13.3% (95% CI, 13.1%-13.6%), and the absolute number of inappropriate PCIs decreased from 21 781 to 7921. Hospital-level variation in the proportion of PCIs classified as inappropriate persisted over the study period (median, 12.6% [interquartile range, 5.9%-22.9%] in 2014).

CONCLUSIONS AND RELEVANCE Since the publication of the Appropriate Use Criteria for Coronary Revascularization in 2009, there have been significant reductions in the volume of nonacute PCI. The proportion of nonacute PCIs classified as inappropriate has declined, although hospital-level variation in inappropriate PCI persists.

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In 2009, the American College of Cardiology and the American Heart Association, along with other professional societies, released Appropriate Use Criteria for Coronary Revascularization to critically examine and improve patient selection for percutaneous coronary intervention (PCI) as well as address concerns about potential overuse.[1,2] Prior studies demonstrated that 1 in 6 nonacute PCIs were classified as inappropriate (new Appropriate Use Criteria documents use the term "rarely appropriate"), indicating that the benefits of the procedure were unlikely to outweigh the risks.[3,4] Furthermore, there was substantial variation in the proportion of nonacute PCIs considered inappropriate across hospitals.[3,4] These findings received considerable attention in both the academic literature and media,[5,6] prompting numerous efforts to improve the appropriateness of PCI.

In 2011, the National Cardiovascular Data Registry's CathPCI registry (NCDR CathPCI) began providing hospitals information about their performance on PCI appropriateness, which was benchmarked against other participating hospitals. Simultaneously, national quality improvement campaigns, such as the American Board of Internal Medicine's Choosing Wisely Initiative, identified PCI appropriateness as a key area for intervention,[7] insurers incorporated measures of PCI appropriateness into pay-for-performance programs,[8] and some payers declined reimbursement for certain PCIs classified as inappropriate.[9]

Despite the attention that the appropriateness of PCI has received, there has been no comprehensive, national examination of trends in the indications, patient characteristics, and appropriateness of PCI procedures after the introduction of the Appropriate Use Criteria. Similarly, the extent of hospital-level variation in the proportion of nonacute PCI considered inappropriate has not been systematically examined over time. To address these gaps in knowledge, we examined national trends in patient selection for PCI, changes in PCI appropriateness, and hospital variation in inappropriate PCI using the NCDR CathPCI Registry.

Methods

Data Source and Appropriate Use Criteria

Details of the registry have been described previously.[10,11] In brief, the NCDR CathPCI registry is the largest national registry of diagnostic cardiac catheterization and PCI, with more than 1500 participating institutions. Detailed information on clinical characteristics, cardiac testing, angiographic findings, and in-hospital management and clinical outcomes are collected by trained staff at participating hospitals using a standardized data collection form (http://cvquality.acc.org/en/NCDR-Home/Data-Collection/What-Each-Registry-Collects.aspx). All data submissions must meet specified quality standards, and randomly identified sites are monitored through annual audits. The Human Investigation Committee of the Yale University School of Medicine approved the use of a limited data set from the registry for research without requiring informed consent.

Box. An Overview of the 2012 Appropriate Use Criteria for Coronary Revascularization and Methodology for Determination of the Appropriateness of PCI

The methodology for developing the Appropriate Use Criteria for Coronary Revascularization, which are based on the modified RAND methodology and reflect a synthesis of contemporary clinical trial evidence, clinical practice guidelines, and expert opinion, has been described.[12]

Using a modified Delphi approach, a 17-member expert panel adjudicated the appropriateness of coronary revascularization, compared with medical therapy, for 198 distinct clinical indications, which were categorized by clinical indication, angiographic severity, magnitude of ischemia, severity of angina symptoms, and intensity of medical therapy.

From the individual ratings of the technical panel members, each clinical indication was classified as appropriate, uncertain, or inappropriate. An "appropriate" rating denotes that coronary revascularization, compared with medical therapy, would likely improve a patient's health status (symptoms, function, or quality of life) or survival; an "uncertain" rating implies that more research, patient information, or both is needed to further classify the indication; and an "inappropriate" rating suggests that the benefits of coronary revascularization are unlikely to outweigh the risks.

For additional details see 2012 Appropriate Use Criteria for Coronary Revascularization.[13]

The methodology used to develop the Appropriate Use Criteria for Coronary Revascularization has been described (see the **Box** for additional details).[1,13,14] The registry has developed validated algorithms mapping data collected using version 4 of the data collection form (beginning July 2009) to the Appropriate Use Criteria.[3] The Appropriate Use Criteria for Coronary Revascularization were revised in 2012 to provide greater specificity in defining nonacute indications.[13] For this analysis, we exclusively used the 2012 Appropriate Use Criteria.

Study Population and Definitions

The study cohort included all PCIs in the NCDR registry between July 1, 2009, and December 31, 2014. To accurately assess trends in appropriateness, we restricted our cohort to PCIs performed at hospitals that participated continuously in the registry during the entire study period. For patients undergoing multiple PCIs in a single visit, only the first PCI was included. We excluded hospitals that performed an average of fewer than 10 nonacute PCIs in each calendar year to provide more robust estimates of hospital performance.

Each PCI in our study cohort was initially classified as acute, nonacute, or nonmappable. Acute PCIs were defined as those performed in the setting of an acute coronary syndrome. Nonmappable PCIs were PCIs that could not be classified because of missing data elements (typically because noninvasive testing was not performed or not available). All other PCIs were considered nonacute. Each mappable PCI was then assigned a rating of procedural appropriateness (appropriate, uncertain, or inappropriate) based on the 2012 Appropriate Use Criteria for Coronary Revascularization.[13]

Statistical Analysis

All analyses were performed either at the patient level, using all PCIs to calculate an estimate, or at the hospital level, aggregating each hospitals' data to calculate a hospital-specific estimate.

PCI volume and the relative proportions of acute, nonacute, and nonmappable PCIs were examined at the patient level by year. Hospital-level variation in the proportions of PCIs for acute, nonacute, and nonmappable indications was examined across calendar year. Median hospital-level proportions with interquartile ranges were used to characterize the distribution and are displayed using box plots.

Baseline demographic and clinical characteristics as well as clinical presentation, background medical therapy, and results from noninvasive and angiographic studies were compared over time for all patients undergoing PCI and among those undergoing nonacute PCI. The proportions of appropriate, inappropriate, and uncertain PCIs at the patient level were calculated for each 6-month interval and compared over time. The proportion of nonacute PCIs considered inappropriate at the hospital level was calculated by aggregating all nonacute PCIs in the calendar year and displayed using box plots.

To identify the presence of different subgroups of hospital-level change in proportion of inappropriate PCI, we performed a latent growth curve analysis.[15,16] Latent-class growth curve analysis, using growth mixture modeling, serves to identify distinct patterns of change over time using each hospital's observed trajectory of the proportion of nonacute PCIs classified as inappropriate. Hospitals with similar patterns over time are grouped together and considered to form a latent class. The use of growth mixture modeling estimates a mean growth curve for each latent class while allowing for individual variation around the growth curve within each class. We fit 4 models: 2-group, 3-group, 4-group, and 5-group. For each model we evaluated the change in the Bayesian information criterion and calculated the approximated Bayes factor. We also plotted the observed vs the predicted values to evaluate model fit. The average posterior probabilities were used to ensure that the model adequately distinguished between identified groups. We chose the 4-group model because it performed best on these criteria. We performed this secondary analysis among hospitals in the highest quartile of proportion of inappropriate PCI between July 2009 and December 2010 to understand the trajectories of hospitals with the greatest opportunity for improvement. For each hospital, we then examined the proportion of inappropriate nonacute PCI from January 2011 to December 2014, grouping hospitals with similar patterns over time together. Last, we compared hospital characteristics across groups to identify hospital features associated with various patterns.

Statistical testing of trends was performed using the Cochran-Armitage test[17,18] for binary variables and the Jonckheere-Terpstra test[19] for categorical variables. To further assess sensitivity of hospital-level results to the aggregation of estimates within hospitals, we confirmed all test results using weighted general linear models, weighting estimates by hospital volume. Absolute changes in PCI volume and patient characteristics were calculated using 2010 and 2014 data, because the study interval began July 1, 2009. All tests for statistical significance were 2-tailed and evaluated at a significance level of .05, corrected for multiple comparisons using the Šidák correction.[20] All statistical analyses were performed using SAS version 9.3 (SAS Institute).

Results

More than 3.5 million PCIs were performed at 1561 hospitals between July 2009 and December 2014. We excluded 550 836 patients treated at 583 hospitals that did not participate continuously in the registry during the study period and an additional 273 167 cases performed at 212 facilities that performed an average of fewer than 10 nonacute PCIs in each calendar year, leaving 2 685 683 PCI procedures from 766 hospitals as the primary study cohort. Characteristics of the hospitals in the primary study cohort are shown in eTable 1 in the Supplement.

PCI Indication Over Time

Of the PCI procedures included in the analysis, 76.3% (95% CI, 76.2%-76.3%) were for acute indications, 14.8% (95% CI, 14.8%-14.9%) were for nonacute indications, and 8.9% (95% CI, 8.9%-9.0%) were nonmappable (**Table 1**). Annual PCI volume declined over the study period, from 538 076 in 2010 to 456 507 in 2014. The volume of acute PCI was relatively stable over time (377 540 in 2010; 374 543 in 2014), but there were significant declines in the volume of nonacute PCI (89 704 in 2010 and 59 375 in 2014; $P < .001$) and nonmappable PCI (70 832 in 2010 and 22 589 in 2014; $P < .001$). As a consequence, the proportion of PCIs performed for acute indications increased from 69.1% (95% CI, 68.8%-69.3%) in 2009 to 82.0% (95% CI, 81.9%-82.2%) in 2014. The proportion of PCIs for nonacute indications declined from 16.8% (95% CI, 16.7%-17.0%) to 13.0% (95% CI, 12.9%-13.1%), whereas the proportion of nonmappable PCIs declined from 14.0% (95% CI, 13.9%-14.2%) in 2009 to 4.9% (95% CI, 4.9%-5.0%) in 2014. Similar findings were noted at the hospital level (**Figure 1**).

Baseline Characteristics

Baseline demographic and clinical characteristics as well as the presence of angina symptoms, background antianginal medical therapy, results of noninvasive testing, and angiographic findings are reported in eTable 2 in the Supplement for the entire study cohort and in **Table 2** for patients undergoing nonacute PCI.

Among patients in the overall study cohort, the absolute number and relative proportion of patients undergoing PCI with Canadian Cardiovascular Society (CCS) grade I or II angina decreased over time, while the absolute number and relative proportion of patients with CCS grade IV angina increased over the study period. The numbers of patients undergoing PCI in the setting of an acute coronary syndrome (unstable angina,

Table 1. Acute, Nonacute, and Nonmappable Percutaneous Coronary Interventions From July 1, 2009–December 31, 2014

		Year					
PCI Indication/Year	Total	2009[a]	2010	2011	2012	2013	2014
Overall, No.	2 685 683	243 580	538 076	502 995	481 889	462 636	456 507
Acute							
No.	2 047 853	168 366	377 540	373 423	380 331	373 650	374 543
% (95% CI)	76.3 (76.2-76.3)	69.1 (68.9-69.3)	70.2 (70.0-70.3)	74.2 (74.1-74.4)	78.9 (78.8-79.0)	80.8 (80.7-80.9)	82.0 (81.9-82.2)
Nonacute							
No.	397 737	41 024	89 704	78 328	66 849	62 457	59 375
% (95% CI)	14.8 (14.8-14.9)	16.8 (16.7-17.0)	16.7 (16.6-16.8)	15.6 (15.5-15.7)	13.9 (13.8-14.0)	13.5 (13.4-13.6)	13.0 (12.9-13.1)
Nonmappable							
No.	240 093	34 190	70 832	51 244	34 709	26 529	22 589
% (95% CI)	8.9 (8.9-9.0)	14.0 (13.9-14.2)	13.2 (13.1-13.3)	10.2 (10.1-10.3)	7.2 (7.1-7.3)	5.7 (5.7-5.8)	4.9 (4.9-5.0)

Abbreviation: PCI, percutaneous coronary intervention.

[a] Includes July 1, 2009, to December 31, 2009.

ST-segment elevation myocardial infarction, non-ST-segment elevation myocardial infarction [NSTEMI]) were stable (367 253 in 2010 to 368 574 in 2014), with increases in the number of patients with NSTEMI (94 097 in 2010 to 107 225 in 2014) and decreases in the number of patients with unstable angina (194 008 in 2010 to 183 735 in 2014). Use of antianginal therapy increased over the study period, whereas use of noninvasive testing remained stable. The number and relative proportion of patients with unavailable or low-risk results on stress testing declined, whereas there was an increase in the number and relative proportion of patients with intermediate- and high-risk findings. The burden of coronary artery disease on angiography was similar over the study period.

Among patients undergoing nonacute PCI, the absolute number and relative proportion of patients without symptoms or with CCS grade I or II angina decreased over time. There was an increase in both the absolute number and relative proportion of patients undergoing nonacute PCI with CCS grade III angina (13 442 [15.0%] in 2010 to 20 727 [34.9%] in 2014). There was an increase in the use of antianginal therapy, with 80.6% of patients undergoing nonacute PCI in 2014 reported to be receiving at least 1 antianginal medication and 35.1% receiving 2 or more antianginal medications as compared with 69.8% and 22.3%, respectively, in 2010. Performance of noninvasive testing and fractional flow reserve testing increased over the study interval, from 64.6% and 8.1%, respectively, in 2010 to 72.5% and 30.8% in 2014. Moreover, the extent of ischemia with noninvasive testing changed over time, with 64.7% of patients having intermediate- or high-risk findings in 2010 as compared with 78.1% in 2014. The proportion of patients with multivessel coronary artery disease was 43.7% in 2010 and 47.5% in 2014.

Trends in Inappropriate PCI

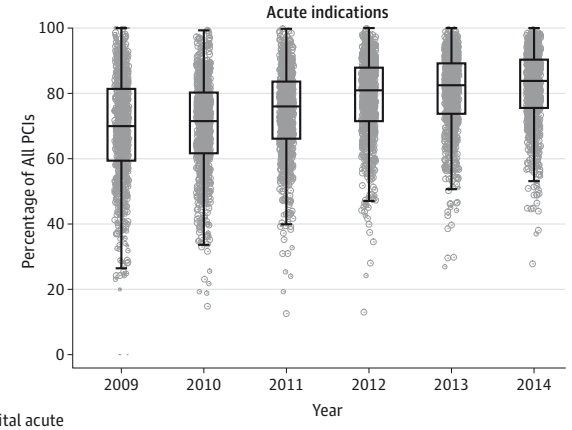
Between July 2009 and December 2014, the proportion of nonacute PCIs classified as inappropriate decreased from 26.2% (95% CI, 25.8%-26.6%) to 13.3% (95% CI, 13.1%-13.6%) ($P < .001$) (**Figure 2**A). The absolute number of inappropriate PCIs decreased from 21 781 in 2010 to 7921 in 2014. The percentage of nonacute PCIs classified as appropriate increased from 30.1% (95% CI, 29.7%-30.6%) to 53.6% (95% CI, 53.2%-54.0%), and those considered uncertain decreased from 43.7% (95% CI, 43.2%-44.2%) to 33.0% (95% CI, 32.6%-33.4%) (Figure 2A). Hospital-level trends in the proportion of inappropriate nonacute PCIs are shown in Figure 2B. The median hospital proportion of nonacute PCIs considered inappropriate decreased from 25.8% in 2009 to 12.6% in 2014. There was persistent variation in hospital-level proportion of nonacute PCIs classified as inappropriate over the study interval (interquartile range, 16.7%-37.1% in 2009 and 5.9%-22.9% in 2014).

Temporal Patterns Across Hospitals

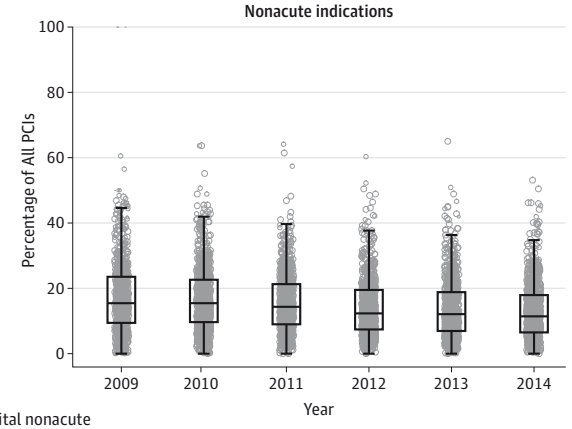
Among hospitals in the highest quartile for proportion of nonacute PCI deemed inappropriate from July 2009 to December 2010 (n = 191), we observed 4 distinct trajectories in changes in rates of inappropriate PCI from January 2011 to December 2014 (**Figure 3**). Hospitals in groups 1, 2, and 4 had similar baseline rates of inappropriate PCI; however, hospitals in group 4 (n = 108) demonstrated immediate and steady declines in rates of inappropriate PCI, from 43.9% (95% CI, 42.4%-45.3%) in 2009-2010 to 15.5% (95% CI, 14.0%-17.0%) in 2014. In contrast, hospitals in group 1 (n = 18) had minimal change in the first 2 years but demonstrated lower rates of inappropriate PCI in the last 2 years of the study period.

Hospitals in group 2 (n = 50) demonstrated steady but smaller absolute declines in rates of inappropriate PCI over the study period than groups 1 and 4, with the proportion of inappropriate nonacute PCIs decreasing from 40.9% (95% CI, 39.7%-42.1%) in 2009-2010 to 32.2% (95% CI, 30.4%-34.1%) in 2014. Last, hospitals in group 3 (n = 15) had the highest initial rates of inappropriate PCI but also the largest absolute decline over the study period, from 70.6% (95% CI, 68.5%-72.7%) in 2009-2010 to 9.4% (95% CI, 7.6%-11.1%) in 2014. There were no systematic differences in hospital characteristics, geographic location, financial status, or teaching status across hospital groups (eTable 3 in the Supplement).

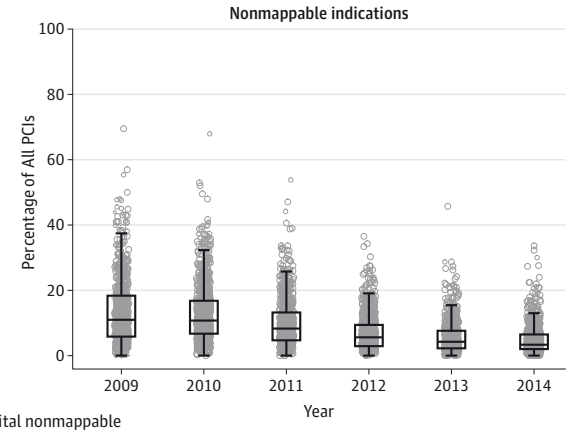
Figure 1. Proportion of PCIs for Acute, Nonacute, and Nonmappable Indications at the Hospital Level From 2009 to 2014



Hospital acute PCI volume, median No. (IQR)	2009	2010	2011	2012	2013	2014
	177 (101-289)	402 (246-629)	389 (255-614)	407 (264-627)	401 (262-620)	403 (265-620)



Hospital nonacute PCI volume, median No. (IQR)	2009	2010	2011	2012	2013	2014
	39 (20-72)	84 (46-151)	72 (39-127)	60 (34-107)	55 (29-100)	53 (27-98)



Hospital nonmappable PCI volume, median No. (IQR)	2009	2010	2011	2012	2013	2014
	30 (13-58)	61 (32-117)	44 (21-84)	28 (14-56)	22 (10-44)	18 (9-38)

All percutaneous coronary inteventions (PCIs) performed July 1, 2009, to December 31, 2014, at 766 hospitals participating continuously in the National Cardiovascular Disease Registry CathPCI Registry over study period. The horizontal line in the center of each box indicates the median; lower and upper bounds of each box, the 25th and 75th percentiles; error bars, 1.5 times the interquartile range. Each hospital is represented as a point; size of point reflects hospital volume. Results for 2009 include 6 months of data.

Discussion

Among patients undergoing PCI between July 2009 and December 2014, we found that volumes of nonacute PCIs declined significantly from 89 704 in 2010 to 59 375 in 2014, while the volume of acute PCIs remained stable, 377 540 in 2010 to 374 543 in 2014. In addition, we observed significant reductions in the proportion of nonacute PCIs classified as inappropriate, from 26.2% in 2009 to 13.3% in 2014. However, there was persistent hospital-level variation in the rate of inappropriate PCIs, with an interquartile range of 5.9% to 22.9% in 2014. Collectively, these findings suggest that the practice of interventional cardiology has evolved since the introduction of Appropriate Use Criteria in 2009.

This analysis provides details about changes in the clinical profiles of patients undergoing PCI and suggests that the observed reductions in inappropriate PCI in part reflect improvements in patient selection and clinical decision making as well as better documentation of the key elements used to determine procedural appropriateness. Trends consistent with improvements in patient selection include the reduction in nonacute PCI volume and changes in the clinical profile of patients undergoing nonacute PCI. We observed significant declines in the proportions of patients undergoing nonacute PCI who were asymptomatic or had minimal symptoms; who were not receiving or receiving only minimal antianginal therapy; and who had low- or intermediate-risk findings on noninvasive testing. We identified increased use of fractional flow reserve among patients with intermediate stenosis. These findings may indicate that clinicians are doing a better job of identifying and limiting nonacute PCI procedures to those patients most likely to benefit from revascularization.

We cannot exclude the possibility that reductions in inappropriate PCI may reflect changes in documentation or even intentional up-coding, particularly of subjective data elements such as symptom severity. Temporal trends in anginal symptom burden raise the possibility that this data element may be overestimated. Specifically, despite significant reductions in the volume of nonacute PCI, we observed increases in the numbers and proportions of patients reported to have CCS grade III and IV angina but minimal change in extent of coronary artery disease. Nevertheless, we did not see evidence that patients were being systematically shifted from nonacute to acute indications for PCI. The number of acute PCIs were stable over time, and the proportion of patients undergoing acute PCI reported to have unstable angina decreased.

The appropriateness of PCI has garnered attention from clinicians, insurers, and policy makers. It has been the subject of national quality improvement initiatives and incorporated into pay-for-performance programs. In our analysis, the observed reductions in inappropriate PCI appeared to accelerate in 2011, which coincided with the publication of a high-profile report on PCI appropriateness, the National Cardiovascular Data Registry's inclusion of procedural appropriateness in its benchmarking reports, and the launch of

Table 2. Baseline Characteristics of Patients Undergoing Nonacute Percutaneous Coronary Intervention (PCI) From July 1, 2009–December 31, 2014

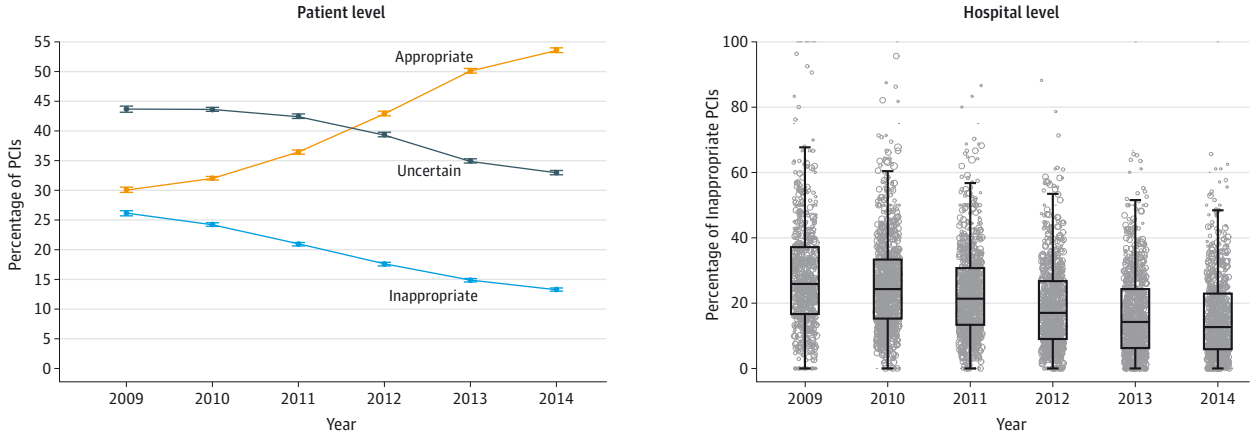
	No. (%)						
Patient Characteristics	Total	2009[a]	2010	2011	2012	2013	2014
No.	397 737 (100.0)	41 024 (10.3)	89 704 (22.6)	78 328 (19.7)	66 849 (16.8)	62 457 (15.7)	59 375 (14.9)
Age, mean (SD)	66.5 (10.9)	65.9 (11.1)	66.1 (11.0)	66.3 (10.9)	66.6 (10.8)	66.9 (10.8)	67.1 (10.8)
Male sex	275 469 (69.3)	27 574 (67.2)	60 902 (67.9)	53 801 (68.7)	46 433 (69.5)	44 457 (71.2)	42 302 (71.3)
White race	350 988 (88.3)	36 376 (88.7)	79 591 (88.7)	68 884 (87.9)	58 822 (88.0)	55 124 (88.3)	52 191 (87.9)
Insurance							
Private	278 236 (70.1)	27 640 (67.5)	61 789 (69.0)	54 489 (69.7)	47 129 (70.7)	44 514 (71.4)	42 675 (72.0)
Public only	109 827 (27.7)	12 432 (30.4)	25 723 (28.7)	21 734 (27.8)	17 909 (26.9)	16 417 (26.3)	15 612 (26.3)
Non-US citizens	266 (0.1)	33 (0.1)	57 (0.1)	46 (0.1)	37 (0.1)	40 (0.1)	53 (0.1)
None	8607 (2.2)	854 (2.1)	2004 (2.2)	1872 (2.4)	1600 (2.4)	1349 (2.7)	928 (1.6)
Clinical risk factors and comorbidities							
Current/recent smoker (<1 y)	77 355 (19.5)	8528 (21.0)	18 437 (20.6)	15 522 (19.8)	12 822 (19.2)	11 352 (18.2)	10 694 (18.0)
Hypertension	344 698 (86.7)	34 932 (85.2)	77 378 (86.3)	67 532 (86.3)	58 262 (87.2)	54 656 (87.5)	51 938 (87.5)
Dyslipidemia	341 445 (85.9)	34 755 (84.8)	77 123 (86.0)	67 145 (85.8)	57 191 (85.6)	53 981 (86.5)	51 250 (86.4)
Family history of CAD	93 873 (23.6)	10 084 (24.6)	21 969 (24.5)	18 789 (24.0)	16 194 (24.2)	14 450 (23.1)	12 387 (20.9)
Prior PCI	173 734 (43.7)	17 075 (41.6)	38 785 (43.2)	34 273 (43.8)	29 323 (43.9)	27 794 (44.5)	26 484 (44.6)
Prior CABG surgery	57 394 (14.4)	5096 (12.4)	11 615 (13.0)	10 877 (13.9)	9986 (14.9)	10 116 (16.2)	9704 (16.3)
Diabetes mellitus	156 865 (39.5)	15 505 (37.8)	34 023 (37.9)	30 794 (39.3)	26 627 (39.8)	25 467 (40.8)	24 449 (41.2)
CAD presentation							
No symptoms, no angina	91 046 (22.9)	11 899 (29.0)	23 889 (26.6)	18 367 (23.5)	13 902 (20.8)	12 301 (19.7)	10 688 (18.0)
Symptoms unlikely to be ischemic	41 247 (10.4)	4145 (10.1)	9577 (10.7)	8301 (10.6)	7179 (10.7)	6165 (9.9)	5880 (9.9)
Stable angina	265 444 (66.7)	24 980 (60.9)	56 238 (62.7)	51 660 (66.0)	45 768 (68.5)	43 991 (70.4)	42 807 (72.1)
Angina							
No symptoms	102 920 (25.9)	12 443 (30.3)	26 313 (29.3)	20 541 (26.2)	16 313 (24.4)	14 420 (23.1)	12890 (21.7)
CCS class I	44 889 (11.3)	6297 (15.4)	12 752 (14.2)	10 070 (12.9)	6484 (9.7)	4934 (7.9)	4352 (7.3)
CCS class II	148 898 (37.4)	15 824 (38.6)	34 958 (39.0)	31 366 (40.0)	25 842 (38.7)	21 571 (34.5)	19 337 (32.6)
CCS class III	89 909 (22.6)	5575 (13.6)	13 442 (15.0)	14 454 (18.5)	16 299 (24.4)	19 412 (31.1)	20 727 (34.9)
CCS class IV	11 121 (2.8)	885 (2.2)	2239 (2.5)	1897 (2.4)	1911 (2.9)	2120 (3.4)	2069 (3.5)
No. of antianginal medications							
0	102 655 (25.8)	13 811 (33.7)	27 076 (30.2)	21 306 (27.2)	15 719 (23.5)	13 222 (21.2)	11 521 (19.4)
1	187 154 (47.1)	19 272 (47.0)	42 610 (47.5)	37 427 (47.8)	31 930 (47.8)	28 884 (46.3)	27 031 (45.5)
≥2	107 885 (27.1)	7928 (19.3)	20 011 (22.3)	19 585 (25.0)	19 195 (28.7)	20 350 (32.6)	20 816 (35.1)
Stress or imaging test performed	273 237 (68.7)	26 720 (65.1)	57 942 (64.6)	53 045 (67.7)	47 420 (70.9)	45 041 (72.1)	43 069 (72.5)
Stress test results[b]							
Unavailable	40 046 (15.1)	5053 (19.6)	10 328 (18.4)	8373 (16.3)	6442 (14.0)	5142 (11.7)	4708 (11.2)
Low risk	37 316 (14.0)	4272 (16.5)	9548 (17.0)	7855 (15.2)	5953 (12.9)	5171 (11.8)	4517 (10.7)
Intermediate risk	116 078 (43.7)	10 756 (41.6)	23 920 (42.5)	22 416 (43.5)	20 319 (44.1)	19 709 (44.8)	18 958 (44.9)
High risk	72 463 (27.3)	5759 (22.3)	12 460 (22.2)	12 893 (25.0)	13 373 (29.0)	13 960 (31.7)	14 018 (33.2)
Fractional flow reserve among patients with 40%-70% lesions	14 636 (18.0)	706 (8.1)	1987 (10.2)	2285 (13.8)	2824 (21.6)	3369 (28.2)	3465 (30.8)
No. of diseased vessels (≥70% stenosis)							
0	2758 (0.7)	350 (0.9)	741 (0.8)	587 (0.8)	407 (0.6)	358 (0.6)	315 (0.5)
1	214 960 (54.1)	23 162 (56.5)	49 732 (55.4)	42 445 (54.2)	35 963 (53.8)	32 790 (52.5)	30 868 (52.0)
2	116 447 (29.3)	11 656 (28.4)	25 908 (28.9)	23 008 (29.4)	19 578 (29.3)	18 539 (29.7)	17 758 (29.9)
3	63 572 (16.0)	5856 (14.3)	13 323 (14.9)	12 288 (15.7)	10 901 (16.3)	10 770 (17.2)	10 434 (17.6)

Abbreviations: CABG, coronary artery bypass graft; CAD, coronary artery disease; CCS, Canadian Cardiovascular Society.

[a] Includes July 1, 2009, to December 31, 2009.

[b] Low risk (<1% annual mortality rate): low-risk treadmill score (≥5); normal or small myocardial perfusion defect at rest or with stress; normal stress echocardiographic wall motion or no change of limited resting wall motion abnormalities during stress. Intermediate risk (1%- 3% annual mortality rate): mild or moderate resting left ventricular dysfunction (left ventricular ejection fraction [LVEF] 35%-49%); intermediate-risk treadmill score (−11 to <5); stress-induced moderate perfusion defect without left ventricular dilation or increased lung intake (thallous chloride Tl 201); limited stress echocardiographic ischemia with wall motion abnormality only at higher doses of dobutamine involving ≤2 segments. High risk (>3% annual mortality rate): severe resting left ventricular dysfunction (LVEF <35%); high-risk treadmill score (≤−11); severe exercise left ventricular dysfunction (LVEF <35%); stress-induced large perfusion defect (particularly if anterior); stress-induced multiple perfusion defects of moderate size; large, fixed perfusion defect with left ventricular dilation or increased lung uptake (thallous chloride Tl 201); stress-induced moderate perfusion defect with left ventricular dilation or increased lung uptake (thallous chloride Tl 201); echocardiographic wall motion abnormality (>2 segments) developing at low dose of dobutamine (≤10 mg/kg/min) or at low heart rate (<120/min); stress echocardiographic evidence of extensive ischemia.

Figure 2. Proportions of Appropriate, Inappropriate, and Uncertain Percutaneous Coronary Intervention (PCI) at the Patient Level and at the Hospital Level Among Nonacute PCIs From July 1, 2009, to December 31, 2014



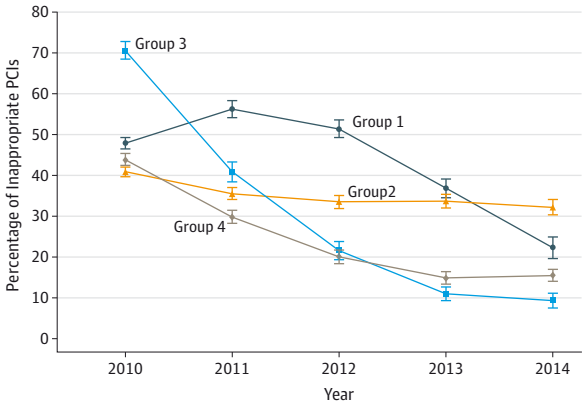
Nonacute PCI volume, No.	2009: 41024	2010: 89704	2011: 78328	2012: 66849	2013: 62457	2014: 59375
Hospital nonacute PCI volume, median No. (IQR)	39 (20-72)	84 (46-151)	72 (39-127)	60 (34-107)	55 (29-100)	53 (27-98)

Rates of at the patient and hospital level among nonacute PCIs performed July 1, 2009, to December 31, 2014, at 766 hospitals participating continuously in the National Cardiovascular Disease Registry CathPCI Registry over study period. A, Point estimates for each classification of procedural appropriateness. Error bars indicate 95% CIs. B, The horizontal line in the center of each box indicates the median; the bottom and top box boundaries indicate the 25th and 75th percentiles, respectively; error bars indicate 1.5 times the interquartile range. Each hospital is represented as a point in the box plot; the size of the point reflects the hospital volume. Results from 2009 include 6 months of data.

national performance improvement campaigns.[3,7] Our findings are consistent with an analysis of PCI appropriateness in Washington State.[21] However, because the registry was not configured to characterize PCI appropriateness until July 2009, our analyses are limited to cases performed after the release of the Appropriate Use Criteria. As such, we could not evaluate the impact of the criteria, and our findings are best considered a description of changes in patterns of care and procedural appropriateness over this period. It is likely that many factors such as the publication of the COURAGE (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation) and BARI 2D (Bypass Angioplasty Revascularization Investigation in Type 2 Diabetes) trials influenced clinical practice during this time frame.[22,23]

We observed persistent variation in hospital-level performance of inappropriate PCI. Among better-performing hospitals (lowest quartile), fewer than 6% of nonacute PCIs in 2014 were classified as inappropriate. In contrast, among worse-performing hospitals (highest quartile), more than 22% of nonacute PCIs were classified as inappropriate. These findings suggest the need for ongoing performance improvement initiatives and hospital benchmarking. Among hospitals with the highest rates of inappropriate nonacute PCI from July 2009 to December 2010, we observed distinct trajectories from January 2011 to December 2014. Although the majority of hospitals with the highest baseline rates of inappropriate PCI demonstrated large reductions in the proportion of PCIs classified as inappropriate, we identified a group of hospitals with less than 10% absolute reduction in the proportion of inappropriate PCI over the study period.

Figure 3. Trends in Inappropriate Nonacute Percutaneous Coronary Intervention at Hospitals With the Highest Initial Proportion of Inappropriate PCI (>34% From July 2009 to December 2010)



Hospital nonacute PCI volume, median (IQR)	2010	2011	2012	2013	2014
Group 1 (n = 18)	49 (25-85)	42 (17-63)	43 (19-72)	38 (24-87)	31 (16-68)
Group 2 (n = 50)	73 (36-130)	67 (41-114)	53 (29-84)	39 (26-88)	33 (21-80)
Group 3 (n = 15)	29 (11-70)	27 (20-47)	37 (27-50)	38 (25-83)	37 (24-75)
Group 4 (n = 108)	63 (35-93)	57 (36-92)	47 (33-83)	51 (28-80)	49 (28-81)

Observed rates of inappropriate nonacute percutaneous coronary intervention (PCI) for 4 groups of hospitals identified by latent growth curve analysis. Error bars indicate 95% CIs. The analysis was restricted to hospitals with the highest initial rates of inappropriate nonacute PCI performed July 2009 to December 2010 (>34%, n = 191). Results shown for 2010 include data for 2009 and 2010.

The observed differences in timing and pace of change suggest both that Appropriate Use Criteria–related quality metrics are actionable and that the specific approach adopted by a hospital affects its performance. Identifying the organizational strategies and structures most strongly associated with lower rates of inappropriate PCI remains a potentially important area for future research.

There are several limitations to our analysis. First, not all hospitals that perform PCI in the United States participate in the registry. Furthermore, we excluded hospitals that did not participate in the registry throughout the entire study period, and these hospitals may have different rates of inappropriate PCI. Regardless, our analysis included nearly 2.7 million procedures performed across 766 facilities and to our knowledge represents the most comprehensive examination of PCI appropriateness to date. In addition, only including hospitals participating in the registry over the entire study period enabled us to more rigorously investigate temporal changes in PCI utilization, clinical characteristics, and appropriateness. Second, our analysis focused mostly on trends in potential overuse (ie, inappropriate PCI). Understanding whether Appropriate Use Criteria have introduced new barriers to the performance of medically necessary procedures remains an important topic that could not be addressed in our study. Relatedly, we only have information on patients undergoing PCI, rather than the larger population of patients with coronary artery disease who might be considered for revascularization. As such, we cannot determine whether the observed changes truly reflect improved patient selection or overestimation of patient symptoms. The integration of more objective assessments of patient-reported health status into routine clinical care may provide a way to reduce the chances of misclassifying symptom burden.[24]

Conclusions

Since the publication of the Appropriate Use Criteria in 2009, there have been significant reductions in volume of nonacute PCI. The proportion of nonacute PCIs classified as inappropriate has declined, although hospital-level variation in inappropriate PCI persists.

ARTICLE INFORMATION

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