Appropriateness of Percutaneous Coronary Intervention

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Context Despite the widespread use of percutaneous coronary intervention (PCI), the appropriateness of these procedures in contemporary practice is unknown.

Objective To assess the appropriateness of PCI in the United States.

Design, Setting, and Patients Multicenter, prospective study of patients within the National Cardiovascular Data Registry undergoing PCI between July 1, 2009, and September 30, 2010, at 1091 US hospitals. The appropriateness of PCI was adjudicated using the appropriate use criteria for coronary revascularization. Results were stratified by whether the procedure was performed for an acute (ST-segment elevation myocardial infarction, non–ST-segment elevation myocardial infarction, or unstable angina with high-risk features) or nonacute indication.

Main Outcome Measures Proportion of acute and nonacute PCIs classified as appropriate, uncertain, or inappropriate; extent of hospital-level variation in inappropriate procedures.

Results Of 500 154 PCIs, 355 417 (71.1%) were for acute indications (ST-segment elevation myocardial infarction, 103 245 [20.6%]; non–ST-segment elevation myocardial infarction, 105 708 [21.1%]; high-risk unstable angina, 146 464 [29.3%]), and 144 737 (28.9%) for nonacute indications. For acute indications, 350 469 PCIs (98.6%) were classified as appropriate, 1055 (0.3%) as uncertain, and 3893 (1.1%) as inappropriate. For nonacute indications, 72 911 PCIs (50.4%) were classified as appropriate, 54 988 (38.0%) as uncertain, and 16 838 (11.6%) as inappropriate. The majority of inappropriate PCIs for nonacute indications were performed in patients with no angina (53.8%), low-risk ischemia on noninvasive stress testing (71.6%), or suboptimal (≤1 medication) antianginal therapy (95.8%). Furthermore, although variation in the proportion of inappropriate PCI across hospitals was minimal for acute procedures, there was substantial hospital variation for nonacute procedures (median hospital rate for inappropriate PCI, 10.8%; interquartile range, 6.0%-16.7%).

Conclusions In this large contemporary US cohort, nearly all acute PCIs were classified as appropriate. For nonacute indications, however, 12% were classified as inappropriate, with substantial variation across hospitals.

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Approximately 600 000 percutaneous coronary interventions (PCIs) are performed in the United States each year,[1] at a cost that exceeds $12 billion.[2] Patients who undergo PCI are exposed to risks of periprocedural complications and longer-term bleeding and stent thrombosis. Moreover, recent trials in stable patients without acute coronary syndromes have shown that PCI, compared with medical therapy, may provide only a modest population-average improvement in symptom relief.[3] Given the cost and invasiveness of PCI, determining the extent to which PCI procedures are performed for appropriate and inappropriate indications could identify procedural overuse and areas for quality improvement and cost savings. However, a lack of national standards for defining appropriate PCI use has hampered previous efforts to identify opportunities for improved patient selection. Furthermore, the few existing studies[4-6] were conducted before many of the current advances in PCI and more contemporary clinical trials on coronary revascularization.[3]

Recently, appropriate use criteria for coronary revascularization were jointly developed by 6 professional organizations to support the rational and judicious use of PCI.[7] The inclusion of the appropriate use criteria in the most recent update to the prospective National Cardiovascular Data Registry (NCDR) CathPCI Registry data collection forms provides a unique opportunity to evaluate the

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appropriateness of PCI in contemporary practice throughout the United States. Accordingly, we analyzed data from the CathPCI registry to (1) quantify the proportion of PCIs classified as appropriate, of uncertain appropriateness, and as inappropriate for acute as well as nonacute indications; (2) identify factors and clinical scenarios associated with PCIs classified as inappropriate; and (3) assess the extent of hospital-level variation in the proportion of inappropriate PCIs classified.

METHODS

Data Sources and Appropriate Use Criteria

The design of the NCDR CathPCI Registry, sponsored by the American College of Cardiology and the Society for Cardiovascular Angiography and Interventions, has been previously described.[8,9] Briefly, the NCDR CathPCI registry is a national registry of diagnostic cardiac catheterization and PCI data collected from more than 1000 US sites. Detailed information on patient and hospital characteristics, coronary angiographic findings and PCIs, and in-hospital outcomes is collected by trained staff at participating hospitals using standardized data elements (available from the CathPCI Registry Web site [https://www.ncdr.com/webncdr/DefaultCathPCI.aspx]). All data submissions must meet specified quality standards.[8] Patient race was self-identified and was abstracted from the medical records by dedicated staff at each hospital.

The methodology for the appropriate use criteria for coronary revascularization has been previously described.[7] Using a modified Delphi approach, a 17-member expert panel adjudicated the appropriateness of coronary revascularization for 198 distinct and mutually exclusive clinical indications. These indications were developed to represent a diverse range of clinical situations encountered in routine practice and involved different combinations of (1) clinical presentation (acute coronary syndrome, stable coronary artery disease, prior coronary artery bypass graft surgery); (2) symptom severity (Canadian Cardiovascular Society angina class); (3) ischemia severity (low, intermediate, high) on noninvasive functional testing; (4) high-risk clinical features (eg, left ventricular dysfunction, ventricular arrhythmia); (5) intensity of antiischemic medical therapy; and (6) extent of coronary anatomical findings on angiography (significant 1-, 2-, or 3-vessel coronary artery disease with or without disease of the proximal left anterior descending artery, left main artery, or bypass graft). Significant obstructive coronary artery disease was defined as 50% or greater stenosis of the left main coronary artery or 70% or greater stenosis of a major epicardial or branch vessel 2.0 mm or greater in diameter.[7]

For each clinical indication, technical panel members of the appropriate use criteria independently assessed the expected gains in survival or health status (symptoms, function, or quality of life) relative to the risks of the procedure[7] based on clinical practice guidelines, published literature, and their expert opinion. They then assigned ratings from 1 (least appropriate) to 9 (most appropriate). From the median of the individual ratings of the 17 technical panel members, each clinical indication was classified as appropriate (median, 7-9), uncertain (median, 4-6), or inappropriate (median, 1-3). In the published appropriate use criteria, an "appropriate" rating denoted that coronary revascularization would likely improve a patient's health status (symptoms, function, or quality of life) or survival; an "uncertain" rating implied that more research, more patient information, or both was needed to further classify the indication; and an "inappropriate" rating denoted that coronary revascularization was unlikely to improve the patient's health status or survival.[7]

Study Population

In anticipation of the publication of the appropriate use criteria for coronary revascularization, the NCDR CathPCI Registry revised its data collection form to ensure that the requisite data elements to assess procedural appropriateness could be prospectively collected. These data then allowed for each PCI to be assigned to an appropriate use criteria indication, and the appropriateness rating for that indication determined the appropriateness of a PCI. In the rare circumstance in which a patient could be assigned to more than 1 indication, the indication with the highest appropriateness rating was used. The accuracy of the algorithms to match PCIs to appropriate use criteria indications was ascertained by manual mapping of 200 randomly generated nonacute procedures by an investigator (P.S.C.) blinded to the algorithm results, in which we found 100% concordance in appropriateness assignments between the algorithms and the manual match. In addition, the NCDR conducted separate manual mapping of 127 inappropriate PCIs at 11 sites and also found 100% concordance in appropriateness assignments. Details of the mapping algorithm are available from the American College of Cardiology NCDR program.

For this study, we evaluated the appropriateness of 602 781 PCIs submitted to the NCDR between July 1, 2009, and September 30, 2010, following the implementation of this new version (4.0) of the NCDR CathPCI data collection form. Acute indications for PCI were defined as those performed in the setting of an acute coronary syndrome, including all myocardial infarctions (ST-segment elevation and non–ST-segment elevation myocardial infarction), as well as unstable angina with high-risk features. High-risk unstable angina was defined by the appropriate use criteria as accelerating tempo of ischemic symptoms or prolonged ongoing rest pain with additional high-risk clinical features, such as new or worsening pulmonary edema, transient ST-segment changes, new bundle-branch block, sustained ventricular tachycardia, or hypotension.

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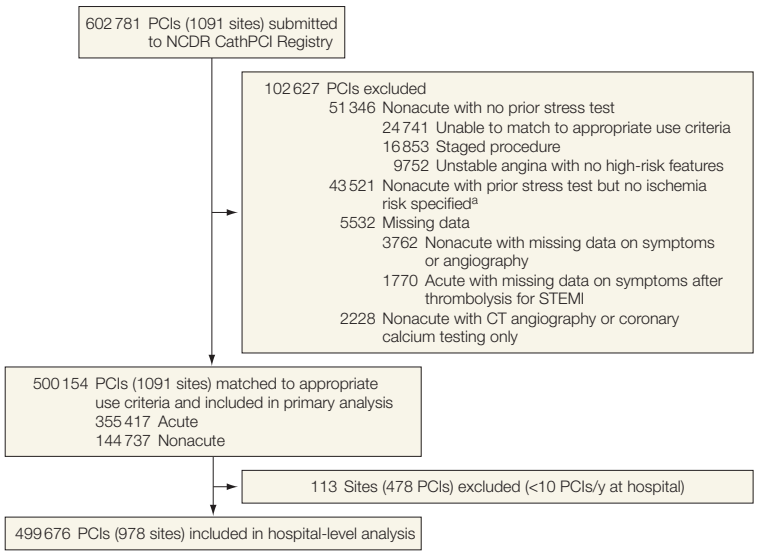
All other PCIs were considered as having been performed for nonacute indications.

The institutional review board at Saint Luke's Mid America Heart and Vascular Institute granted a waiver of written informed consent and provided authorization for this study.

We were able to classify 500 154 PCIs (83.0%) from 1091 hospitals to an appropriate use criteria indication, and these procedures constituted the study cohort (FIGURE 1). Excluded procedures were those in which the requisite data for mapping patients were not available, primarily because of the absence of noninvasive stress test results for nonacute procedures. Specifically, these included 16 853 staged PCI procedures (2.8%), 9752 patients (1.6%) presenting with unstable angina without high-risk features who proceeded directly to coronary angiography, and 24 741 patients (4.1%) without any prior noninvasive testing. Also excluded were 43 521 nonacute PCIs (7.2%) in which a preprocedural stress test was performed but the results were unknown. These latter patients were included in our sensitivity analyses. The remaining exclusions comprised 2228 nonacute procedures (0.4%) with coronary calcium or computed tomography angiographic testing but without an ischemia assessment, 3762 nonacute procedures (0.6%) with missing information on symptoms or angiographic data, and 1770 acute procedures (0.3%) in which patients with an ST-segment elevation myocardial infarction were successfully treated with fibrinolytic therapy but had missing data on symptoms after fibrinolysis but before PCI.

Figure 1. PCI Appropriateness Study Cohort



CT indicates computed tomography; NCDR, National Cardiovascular Data Registry; PCI, percutaneous coronary intervention; STEMI, ST-segment elevation myocardial infarction.
[a] Included as part of sensitivity analyses.

Statistical Analysis

The proportion of PCIs classified as appropriate, uncertain, or inappropriate was determined, stratified by acute vs nonacute indication. Baseline demographic characteristics and clinical variables (risk factors and comorbid conditions, symptoms, anti-ischemic therapy, and results from noninvasive and angiographic studies) of patients undergoing PCI were then compared by appropriateness category. Continuous variables were evaluated using analysis of variance and categorical variables with the χ^2 test. Because patients undergoing nonacute PCIs with incomplete information on ischemia risk were excluded, we conducted a sensitivity analysis in which these procedures were included and assigned a value for noninvasive testing of either high-risk or low-risk ischemia, which provides a best-case and worst-case estimate for the range of appropriateness ratings.

To examine the extent of hospital-level variation for inappropriate procedures, we included only those hospitals with at least 10 nonacute procedures per year (478 procedures [0.3%] from 113 hospitals excluded). Procedures were aggregated by appropriateness category within each hospital, and the distribution in rates of inappropriate PCIs across hospitals was examined separately for acute and nonacute indications. We then examined the extent to which variations in rates of inappropriate PCIs were explained at the hospital level by determining the median rate ratio (RR),[10-12] derived using multivariable hierarchical regression with only patient-level factors included. The median RR can be interpreted as the likelihood that 2 patients with identical clinical features presenting to separate, randomly chosen hospitals would receive a PCI for an inappropriate indication at one of the hospitals as compared with the other. A median RR of 1 suggests no variation between hospitals. To ensure the robustness of the hospital-level variation findings we repeated the above analyses, including only those hospitals with at least 200 nonacute procedures annually.

In addition, for hospitals with at least 10 nonacute PCIs annually, we examined the relationship between the annual nonacute PCI volume at a hospital and the hospital's rate of inappropriate PCIs for nonacute indications using Spearman correlations. The variance in inappropriate PCIs accounted for by a hospital's case volume was assessed by determining the R^2 statistic. Lastly, the relationship between hospital status (private vs public) and the hospital rate of inappropriate PCIs in nonacute settings was displayed using box plots and evaluated using hierarchical linear regression models.

All tests for statistical significance were 2-tailed and evaluated at a signifi-

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cance level of $P < .05$. All statistical analyses were performed using SAS version 9.2 (SAS Institute Inc, Cary, North Carolina) or R version 2.10.0 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Overall Cohort

Of 500 154 procedures classified, 103 245 (20.6%) were for ST-segment elevation myocardial infarction, 105 708 (21.1%) for non–ST-segment elevation myocardial infarction, 146 464 (29.3%) for high-risk unstable angina, and 144 737 (28.9%) for nonacute elective indications. Based on the appropriate use criteria definition for acute procedures, 355 417 PCIs (71.1%) were for acute indications and 144 737 (28.9%) were for nonacute indications.

Acute Procedures

TABLE 1 summarizes procedural indications and clinical characteristics of patients undergoing acute PCI. The mean age was 63.9 (SD, 12.6) years, and 67.0% were men. Myocardial infarction comprised 58.8% of all acute procedures, while high-risk unstable angina comprised 41.2%. Approximately 44% of patients had 1-vessel coronary artery disease as the culprit stenosis on coronary angiography, while 56% had 2- or 3-vessel coronary artery disease. One in 10 patients had left ventricular systolic dysfunction, and 3% presented in cardiogenic shock.

The vast majority (350 469 [98.6%; 95% confidence interval {CI}, 98.6%-98.6%]) of acute PCIs were classified as appropriate, with 1055 (0.3%; 95% CI, 0.3%-0.3%) classified as uncertain and 3893 (1.1%; 95% CI, 1.1%-1.1%) as inappropriate. All inappropriate procedures involved an asymptomatic, stable patient with PCI performed more than 12 hours from symptom onset following an ST-segment elevation myocardial infarction and without hemodynamic or electrical instability. Lastly, there was minimal hospital variation in rates of inappropriate PCI for acute indications (median hospital rate, 0.7%; interquartile range, 0.0%-1.5%; range, 0.0%-6.2%).

Nonacute Procedures

TABLE 2 summarizes clinical characteristics of patients undergoing nonacute PCI. The mean age was 65.3 (SD, 11.3) years, 66.8% were men, and two-thirds had private health insurance. The prevalence of hypertension and dyslipidemia was 86%

Table 1. Patient Characteristics for Acute Percutaneous Coronary Interventions (PCIs), Stratified by Appropriateness

	No. (%)			
		Procedural Appropriateness		
Characteristic	Total (N = 355 417)	Appropriate (n = 350 469)	Uncertain (n = 1055)	Inappropriate (n = 3893)
Demographics				
Age, mean (SD), y	63.9 (12.6)	63.9 (12.6)	59.1 (11.6)	62.7 (13.4)
Men	238 295 (67.0)	234 912 (67.0)	759 (71.9)	2624 (67.4)
White race	314 055 (88.4)	309 782 (88.4)	942 (89.3)	3331 (85.6)
PCI indication				
STEMI				
Immediate PCI	88 806 (25.0)	88 806 (25.3)	0	0
PCI >12 h from symptoms				
Patient unstable	5288 (1.5)	5288 (1.5)	0	0
Patient stable	4403 (1.2)	671 (0.2)	0	3732 (95.9)
PCI after thrombolysis				
Successful lysis, patient stable	1446 (0.4)	230 (0.1)	1055 (100)	161 (4.1)
Failed lysis, rescue PCI	3302 (0.9)	3302 (0.9)	0	0
NSTEMI	105 708 (29.7)	105 708 (30.2)	0	0
High-risk unstable angina	146 464 (41.2)	146 464 (41.8)	0	0
Clinical factors				
Prior MI	101 268 (28.5)	100 341 (28.6)	161 (15.3)	766 (19.7)
Prior PCI	124 686 (35.1)	123 760 (35.3)	172 (16.3)	754 (19.4)
Prior CABG	61 100 (17.2)	60 770 (17.3)	55 (5.2)	275 (7.1)
LVEF <40%	34 861 (9.8)	34 451 (9.8)	35 (3.3)	375 (9.6)
Cardiogenic shock	10 785 (3.0)	10 721 (3.1)	13 (1.2)	51 (1.3)
Coronary artery stenoses				
1	156 642 (44.1)	154 262 (44.0)	668 (63.3)	1712 (44.0)
2	119 101 (33.5)	117 415 (33.5)	289 (27.4)	1397 (35.9)
3	79 674 (22.4)	78 792 (22.5)	98 (9.3)	784 (20.1)
Presence of proximal LAD stenosis	116 000 (32.6)	114 518 (32.7)	156 (14.8)	1326 (34.1)

Abbreviations: CABG, coronary artery bypass graft surgery; LAD, left anterior descending artery; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NSTEMI, non–ST-segment elevation myocardial infarction; STEMI, ST-segment elevation myocardial infarction.

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for each, and 38% of patients had diabetes mellitus. More than half had undergone either prior PCI or coronary artery bypass graft surgery, and 30% had experienced a prior myocardial infarction.

Overall, half (72 911 [50.4%; 95% CI, 50.1%-50.7%]) of nonacute PCIs were classified as appropriate, while 54 988 (38.0%; 95% CI, 37.8%-38.3%) were for uncertain indications and 16 838 (11.6%; 95% CI, 11.4%-11.8%) were for inappropriate indications. In general, compared with procedures classified as appropriate and uncertain, inappropriate PCIs were more likely to occur in patients with no angina (inappropriate, 53.8%; uncertain, 13.2%; appropriate, 5.9%; $P<.001$) and low-risk noninvasive stress testing results (inappropriate, 71.6%; uncertain, 35.6%; appropriate, 14.0%; $P<.001$) (Table 3). Inappropriate PCIs also were performed more frequently for patients not taking antianginal therapy or with angiographic findings of either single-vessel coronary artery disease or noninvolvement of the proximal left anterior descending artery. The most frequent clinical indications for an uncertain or inappropriate PCI in the nonacute setting are outlined in Table 4. Notably, more than 82% of all inappropriate procedures were confined to 5 clinical scenarios in the appropriate use criteria.

There was substantial hospital-level variation in the proportion of inappropriate procedures for nonacute indications. Hospitals in the lowest quartile had rates of inappropriate PCI of 6% or lower, while the rate of inappropriate PCI was greater than 16% among hospitals in the highest quartile (median hospital rate, 10.8%; interquartile range, 6.0%-16.7%; range, 0%-55.0%) (Figure 2A). The median RR was 1.80 (95% CI, 1.74-1.86; $P<.001$), suggesting an 80% greater likelihood of patients with identical clinical characteristics receiving an inappropriate PCI at one randomly selected hospital as compared with another.

Despite significant hospital variation, the relationship between a hospital's annual nonacute PCI volume and its rate of inappropriate PCI was weak (Spearman correlation, 0.06), accounting for less than 0.4% of the variance in rates of inappropriate PCIs (Figure 2B). Moreover, the median hospital rate of inappropriate PCIs was similar between private hospitals (n=457 [47%]) and public hospitals (n=521 [53%]) (eFigure, available at http://www.jama.com), and private hospitals were not more likely

Table 2. Patient Characteristics for Nonacute Percutaneous Coronary Interventions (PCIs), Stratified by Appropriateness

	No. (%)			
		Procedural Appropriateness		
Characteristic	Total (N = 144 737)	Appropriate (n = 72 911)	Uncertain (n = 54 988)	Inappropriate (n = 16 838)
Demographics				
Age, mean (SD), y	65.3 (11.3)	65.3 (11.5)	65.1 (11.1)	65.5 (10.7)
Men	96 622 (66.8)	48 632 (66.7)	36 430 (66.3)	11 560 (68.7)
White race	128 757 (89.0)	64 552 (88.5)	49 022 (89.2)	15 183 (90.2)
Insurance				
Private	96 078 (66.3)	47 370 (65.0)	36 792 (66.9)	11 916 (70.8)
Public only	44 186 (30.5)	22 916 (31.4)	16 632 (30.1)	4638 (27.5)
Non-US[a]	93 (0.1)	57 (0.1)	31 (0.1)	5 (0.0)
None	4380 (3.0)	2568 (3.5)	1533 (2.8)	279 (1.7)
Clinical factors				
Use of tobacco	32 629 (22.5)	16 718 (22.9)	12 368 (22.5)	3543 (21.0)
Hypertension	124 138 (85.8)	63 110 (86.6)	46 841 (85.2)	14 187 (84.3)
Dyslipidemia	123 688 (85.5)	62 344 (85.5)	47 039 (85.5)	14 305 (85.0)
Family history of CAD	36 352 (25.1)	18 350 (25.2)	14 133 (25.7)	3869 (23.0)
Prior MI	42 761 (29.5)	23 044 (31.6)	15 803 (28.7)	3914 (23.2)
Heart failure	15 848 (0.9)	9172 (12.6)	5301 (9.6)	1375 (8.2)
Prior valve surgery	1870 (1.3)	880 (1.2)	756 (1.4)	234 (1.4)
Prior PCI	66 396 (45.9)	34 445 (47.2)	25 482 (46.3)	6469 (38.4)
Prior CABG	19 056 (13.2)	10 260 (14.1)	6902 (12.6)	1894 (11.2)
Hemodialysis	3080 (2.1)	1701 (2.3)	1024 (1.9)	355 (2.1)
Cerebrovascular disease	17 639 (12.2)	9485 (13.0)	6226 (11.3)	1928 (11.5)
Peripheral arterial disease	18 990 (13.1)	9968 (13.7)	6899 (12.5)	2123 (12.6)
Chronic lung disease	21 303 (14.7)	11 350 (15.6)	7812 (14.2)	2141 (12.7)
Diabetes mellitus	54 404 (37.6)	28 368 (38.9)	20 040 (36.4)	5996 (35.6)

Abbreviations: CABG, coronary artery bypass graft surgery; CAD, coronary artery disease; MI, myocardial infarction.
[a] Payer does not originate in the United States.

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to perform inappropriate PCIs in nonacute settings than public hospitals (risk difference, 0.05%; $P = .93$).

Sensitivity Analysis

When we assigned nonacute procedures with missing information on ischemia risk a value of high-risk ischemia on stress testing, 57.5% of nonacute PCIs were classified as appropriate, 33.6% as uncertain, and 8.9% as inappropriate. Conversely, when these procedures were assigned a value of low-risk ischemia on stress testing, 38.5% were classified as appropriate, 40.2% as uncertain, and 21.3% as inappropriate. Lastly, when we restricted the hospital variation analyses to only those hospitals with at least 200 nonacute PCIs annually (total of 223 hospitals), there remained substantial hospital variation in rates of inappropriate PCIs for nonacute indications (median hospital rate, 10.3%; interquartile range, 6.4%-15.4%; range, 0.5%-44.0% [median RR, 1.79; 95% CI, 1.72-1.85]).

COMMENT

In this large, contemporary national registry of patients undergoing PCI in the United States, we found that the vast majority of PCIs performed in acute settings were classified as appropriate using standardized appropriate use criteria. In the nonacute setting, however, only 50% of procedures were classified as appropriate, 38% as uncertain, and 12% as inappropriate. Moreover, there was substantial variation in the hospital proportion of inappropriate PCIs in nonacute settings, ranging from 0% to 55%. Collectively, these findings suggest an important opportunity to examine and improve the selection of patients undergoing PCI in the nonacute setting.

Until recently, efforts to adjudicate the appropriateness of PCI have been limited by the lack of standardized criteria. With the development of appropriate use criteria and the presence of national registries such as the NCDR CathPCI Registry, this study extends the observations of prior studies[4] by explicitly and prospectively collecting detailed clinical information about the indications for PCI at more than 1000 US hospitals. Importantly, because our assessments of PCI appropriateness were conducted before the NCDR CathPCI Registry had presented the data to participating centers, we believe that our findings reflect contemporary practice and provide important benchmarks for future assessments of procedural appropriateness at the national and hospital level.

Most of the nonacute procedures classified as inappropriate were performed in settings in which the benefit of PCI has not been demonstrated. For instance, 98.5% of patients undergoing an inappropriate PCI in the nonacute setting were

Table 3. Key Variables in Classifying Appropriateness for Nonacute Percuntaneous Coronary Interventions

	No. (%)				
		Procedural Appropriateness			
Variable	Total (N = 144 737)	Appropriate (n = 72 911)	Uncertain (n = 54 988)	Inappropriate (n = 16 838)	*P* Value
Angina					
No symptoms	20 607 (14.2)	4305 (5.9)	7239 (13.2)	9063 (53.8)	
CCS class					
I	17 709 (12.2)	4407 (6.0)	11 136 (20.3)	2166 (12.9)	<.001
II	48 853 (33.8)	13 606 (18.7)	29 890 (54.4)	5357 (31.8)	
III	45 486 (31.4)	39 636 (54.4)	5675 (10.3)	175 (1.0)	
IV	12 082 (8.3)	10 957 (15.0)	1048 (1.9)	77 (0.5)	
Noninvasive ischemia evaluation					
Low risk	29 665 (30.1)	7312 (14.0)	10 779 (35.6)	11 574 (71.6)	<.001
Intermediate risk	39 049 (39.6)	17 757 (34.0)	16 691 (55.1)	4601 (28.4)	
High risk	29 971 (30.4)	27 158 (52.0)	2813 (9.3)	0	
None performed[a]	46 052	20 684	24 705	663	
No. of antianginal medications					
0	40 549 (28.0)	15 726 (21.6)	17 697 (32.2)	7126 (42.3)	<.001
1	65 906 (45.5)	28 695 (39.4)	28 196 (51.3)	9015 (53.5)	
2	31 547 (21.8)	23 311 (32.0)	7629 (13.9)	607 (3.6)	
>2	6735 (4.7)	5179 (7.1)	1466 (2.7)	90 (0.5)	
Coronary artery stenoses					
1	72 219 (49.9)	29 851 (40.9)	31 849 (57.9)	10 519 (62.5)	<.001
2	47 792 (33.0)	24 469 (33.6)	18 030 (32.8)	5293 (31.4)	
3	24 726 (17.1)	18 591 (25.5)	5109 (9.3)	1026 (6.1)	
Presence of proximal LAD stenosis	38 564 (26.6)	28 168 (38.6)	9379 (17.1)	1017 (6.0)	<.001

Abbreviations: CCS, Canadian Cardiovascular Society; LAD, left anterior descending artery.
[a] These percutaneous coronary interventions were matched to indications in the appropriate use criteria (18-21 or 46-47) that did not require prior noninvasive stress evaluation.

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either asymptomatic or only mildly symptomatic (Canadian Cardiovascular Society angina class I or II), 72% had low-risk ischemia on noninvasive stress testing prior to PCI, and 94% did not have high-risk coronary anatomical findings. Moreover, 96% of patients undergoing an inappropriate PCI were treated with suboptimal antianginal therapy—a finding highlighted in a recent analysis of medical therapy after publication of the COURAGE (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation) trial.[13] In Table 4, we have outlined the 5 most common appropriate use criteria indications for an inappropriate nonacute PCI.

Although some of the inappropriate procedures may be explained by extenuating circumstances (eg, high-risk coronary anatomical findings not captured in the appropriate use criteria), these factors are expected to be uncommon and should not account for the majority of procedures classified as inappropriate. It is also possible that patient preferences may influence physician decisions about coronary revascularization.[14] However, recent studies have found that patients often overestimate the benefits of PCI,[15] and most PCIs are performed ad hoc (immediately following diagnostic angiography), which limits the opportunity for informed discussions with patients about the relative benefits and risks of PCI.[16,17] Rather, it is likely that clinician factors are responsible for many of these procedures. Our previous finding of substantial variation in rates of agreement in appropriateness assignments (range, 5%-76%) between individual cardiologists and the technical panel of the appropriate use criteria[18] further supports this hypothesis. This suggests a need for further education of physicians about procedural appropriateness to improve patient selection in the nonacute setting.

A major finding of this study was that rates of inappropriate PCI varied markedly at the hospital level. Although some degree of inappropriate PCI use may be attributable to limitations in the appropriate use criteria methodology (eg, high-risk coronary anatomical findings or clinical features not captured in the appropriate use criteria),[7] it is unlikely that the proportion of such exceptional cases would vary substantially across hospitals. The best-performing hospitals had 6% or fewer of their nonacute PCIs classified as inappropriate, suggesting that a low hospital rate for inappropriate PCIs is achievable. However, 25% of hospitals had at least 1 in 6 of their nonacute procedures classified as inappropriate, which suggests overuse of PCI in these hospitals and an important opportunity for improvement in patient selection. One strategy for improvement might be the development of additional decision tools that can provide physicians performing the diagnostic coronary angiogram with real-time guidance about the appropriateness of proceeding to PCI.

Our findings also point toward new challenges and directions required for assessing the overall appropriateness of PCI. For instance, a substantial number of procedures were performed in nonacute settings in which proce-

Table 4. Most Common Clinical Scenarios for Nonacute Percutaneous Coronary Interventions (PCIs) Classified as Inappropriate and Uncertain by the Appropriate Use Criteria[a]

Appropriate Use Criteria Scenario No.[b]	Indication					No. (%)
	Anatomy	Prior CABG	Symptoms	Cardiac Risk (Stress Test)	Anti-ischemic Therapy	
Inappropriate PCI						
12B	1- or 2-vessel CAD, no proximal LAD involvement	No	CCS class I or II	Low	None/minimal	6662 (39.6)
14A	1- or 2-vessel CAD, no proximal LAD involvement	No	Asymptomatic	Intermediate	None/minimal	4127 (24.5)
12A	1- or 2-vessel CAD, no proximal LAD involvement	No	Asymptomatic	Low	None/minimal	3083 (18.3)
54B	≥1 Stenoses in non-CABG territory, all bypass grafts patent	Yes	CCS class I or II	Low	None/minimal	568 (3.4)
56A	≥1 Stenoses in non-CABG territory, all bypass grafts patent	Yes	Asymptomatic	Intermediate	None/minimal	493 (2.9)
Uncertain PCI						
18B	1- or 2-vessel CAD, no proximal LAD involvement	No	CCS class I or II	NA[c]	NA[d]	24 657 (44.8)
14B	1- or 2-vessel CAD, no proximal LAD involvement	No	CCS class I or II	Intermediate	None/minimal	7231 (13.2)
12C	1- or 2-vessel CAD, no proximal LAD involvement	No	CCS class III or IV	Low	None/minimal	3052 (5.6)
14C	1- or 2-vessel CAD, no proximal LAD involvement	No	CCS class III or IV	Intermediate	None/minimal	2896 (5.3)
16A	1- or 2-vessel CAD, no proximal LAD involvement	No	Asymptomatic	High	None/minimal	1964 (3.6)
13B	1- or 2-vessel CAD, no proximal LAD involvement	No	CCS class I or II	Low	Maximal	1517 (2.8)

Abbreviations: CABG, coronary artery bypass graft surgery; CAD, coronary artery disease; CCS, Canadian Cardiovascular Society; LAD, left anterior descending artery; NA, not available.
[a] These reasons comprised 88.7% of all inappropriate PCIs and 75.3% of all uncertain PCIs in nonacute settings.
[b] Ordered by decreasing number of procedures. Scenario numbers from Patel et al.[7]
[c] Stress test not performed.
[d] Medical therapy not specified for this scenario.

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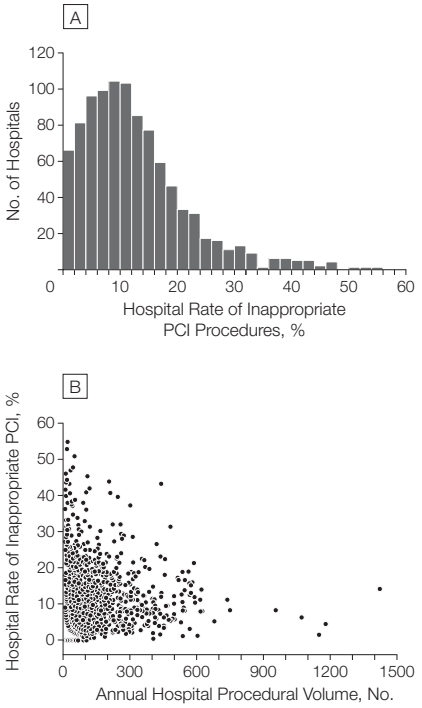
Figure 2. Variation in Hospital Rates of Inappropriate Percutaneous Coronary Interventions for Nonacute Indications



A, Distribution of hospital rates of inappropriate percutaneous coronary interventions (PCIs) for nonacute indications. Only hospitals with at least 10 nonacute PCIs annually were included (499 676 PCIs, 978 sites); 478 PCIs from 113 low-volume hospitals were excluded. The distribution of hospital rates was similar when analyses were restricted to hospitals with a minimum of 200 nonacute PCIs annually (see "Methods"). B, Relationship between a hospital's nonacute PCI volume and its rate of inappropriate PCI in the nonacute setting.

dural appropriateness was uncertain. Although 64% of these patients had intermediate or high-risk ischemia on noninvasive testing, only 12% had severe (class III or IV) angina (Table 3). The rating of uncertain appropriateness therefore suggests that there were insufficient data for the technical panel of the appropriate use criteria to conclude that the benefits of PCI, compared with medications alone, would justify the risk and cost of PCI for these indications.

Indications with uncertain appropriateness represent gaps in knowledge and underscore the need for future outcomes-based studies to clarify the benefits of PCI. In addition, although our analyses were conducted prior to hospitals' knowledge about their rates of procedural appropriateness, future studies of procedural appropriateness will need to account for potential "gaming" of key variables used in appropriateness assessments, such as symptom severity. The use of objective and validated patient-centered health status questionnaires to assess angina and routine data audits would help to facilitate the integrity of future appropriateness assessments.

Our study should be interpreted in the context of the following limitations. First, not all hospitals that perform PCI in the United States participate in the NCDR CathPCI Registry. Our analyses, however, were conducted in a patient sample from more than 1000 hospitals, and our results are currently the most complete assessment of practice patterns throughout the United States. Second, while we examined potential overuse of PCI (ie, inappropriate PCI) within the appropriate use criteria, we were unable to evaluate underuse of PCI—another important component of procedural appropriateness.

Third, we excluded nonacute procedures because of unavailable ischemia risk assessment results, which precluded an assignment of procedural appropriateness. Our sensitivity analyses showed that the rate of appropriate PCIs in the nonacute setting would increase only modestly, from 50% to 58%, even if we ascribed high-risk ischemia results to patients with incomplete information on ischemia risk. Conversely, the rate of inappropriate PCIs in the nonacute setting increased to 21% when we ascribed low-risk ischemia to each of these patients. Fourth, it is possible that hospitals may have inflated their rates of appropriate PCI by reporting more severe symptoms and stress test results; however, this is unlikely, because the period of analysis in this study preceded feedback reports to hospitals about their rates of inappropriate procedures.

Fifth, we were able to categorize PCIs in which assessments of fractional flow reserve were used in the evaluation of coronary artery stenoses between 50% and 60%. However, the use of fractional flow reserve in coronary artery stenoses of greater than 60% were not adjudicated in the appropriate use criteria, which may account for some of the procedures excluded because of no ischemia assessment. Lastly, the appropriate use criteria reflect a synthesis of contemporary clinical trial evidence, clinical practice guidelines, and expert opinion. Some PCIs classified as uncertain or inappropriate may be appropriate when considering unique clinical and patient factors (eg, coronary anatomy not covered by the indications); likewise, some procedures classified as appropriate may be inappropriate in a particular clinical situation (eg, patient with limited life expectancy or end-stage renal disease). Although it is possible that certain factors may lead to a reclassification of procedural appropriateness, this is likely to be uncommon and would not explain the substantial variation in rates of inappropriate procedures across hospitals.

In conclusion, in this large national registry, nearly all PCIs performed for acute indications were appropriate. However, for nonacute indications, the rate of inappropriate procedures was 12%, with the majority of these procedures performed in patients with little to no angina or with low-risk ischemia on stress testing. Moreover, there was substantial hospital variation in the rate of inappropriate PCI for nonacute indications. Better understanding of the clinical settings in which inappropriate PCIs occur and reduction in their variation across hospitals should be targets for quality improvement.

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Analysis and interpretation of data: Chan, Patel, Klein, Krone, Dehmer, Kennedy, Nallamothu, Weaver, Masoudi, Rumsfeld, Brindis, Spertus.
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