Introduction

Percutaneous coronary intervention (PCI) represents a major advancement in the management of coronary artery disease. Among patients presenting with an acute coronary syndrome, timely PCI reduces mortality and recurrent myocardial infarction. However, the same benefits are not seen with PCI in the setting of stable ischemic heart disease. Furthermore, when PCI is used as an initial strategy for treatment of stable ischemic heart disease, the incremental relief of angina and improvement in quality of life is small, temporary, and not cost-effective. Given the limited utility of PCI in nonacute settings, a rapid expansion in the use of PCI in the past decade, and a 10-fold geographical variation in use of PCI, the appropriateness of PCI performed in the current era are in question. This is of particular importance, given that >600,000 PCIs are performed annually in the United States at a cost of $10 billion.

The American College of Cardiology, in partnership with 5 other professional organizations, developed the Appropriateness Criteria for Coronary Revascularization to serve as a national standard to quantify the appropriateness of coronary revascularization for a variety of clinical scenarios and support the effective and efficient use of PCI in optimal patient care. These criteria have been applied to determine the appropriateness of PCI captured by the American College of Cardiology – National Cardiovascular Data Registry (ACC-NCDR), with 1% of acute PCIs and 12% of nonacute PCIs being classified as inappropriate. In anticipation of applying these criteria as part of a statewide quality improvement program, we determined the prevalence of appropriate, uncertain, and inappropriate PCI stratified by acute and nonacute indications for all PCIs performed in the state of Washington. Additionally, we explored facility-level variation in PCI appropriateness.

Background

In anticipation of applying Appropriate Use Criteria for percutaneous coronary intervention (PCI) quality improvement, we determined the prevalence of appropriate, uncertain, and inappropriate PCIs stratified by indication for all PCIs performed in the state of Washington.

Methods and Results

Within the Clinical Outcomes Assessment Program, we assigned appropriateness ratings to all PCIs performed in 2010 in accordance with published Appropriate Use Criteria. Of 13,291 PCIs, we successfully mapped the clinical scenario to the Appropriate Use Criteria in 9,924 (75%) cases. Of the 3,367 PCIs not classified, common failures to map to the criteria included nonacute PCI without prior noninvasive stress results (n = 1,906; 57%) and unstable angina without high-risk features (n = 902; 27%). Of mapped PCIs, 8,010 (71%) were for acute indications, with 7,887 (98%) rated as appropriate, 39 (<1%) as uncertain, and 84 (1%) as inappropriate. Of 1,914 mapped nonacute indications, 847 (44%) were rated as appropriate, 748 (39%) as uncertain, and 319 (17%) as inappropriate. Assuming results for noninvasive stress tests when data were missing, in the best-case scenario, 319 (8%) of nonacute PCIs were classified as inappropriate compared with 1,459 (38%) in the worst-case scenario. Variation in inappropriate PCIs by facility was greatest for mapped nonacute indications (median = 14%; 25th to 75th percentiles = 9% to 24%) and nonacute indications with missing data precluding appropriateness classification (median = 54%; 25th to 75th percentiles = 35% to 66%).

Conclusions

In a complete cohort of PCIs performed in Washington state, 1% of PCIs for acute indications and 17% of PCIs for nonacute indications were classified as inappropriate. Missing data on noninvasive stress tests present a challenge in the application of the criteria for quality improvement. (Circ Cardiovasc Qual Outcomes. 2012;5:445-453.)

Key Words: appropriateness criteria • percutaneous coronary intervention • utilization • quality improvement • health services research

Circ Cardiovasc Qual Outcomes is available at http://circoutcomes.ahajournals.org

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WHAT IS KNOWN

- PCI appropriateness is an emerging quality metric that provides an assessment of anticipated procedural benefit relative to the risk of the procedure.
- Prior work from a large national PCI registry (NCDR CathPCI) suggested 1% of acute PCIs and 12% of nonacute PCIs are performed for clinical indications classified as inappropriate, with substantial hospital level variation of inappropriate PCI for nonacute procedures.

WHAT THE STUDY ADDS

- In a complete cohort of PCIs performed in Washington state that includes non-NCDR participating facilities, we found 1% of PCIs for acute indications and 17% of PCIs for nonacute indications were classified as inappropriate.
- We found similar proportions of inappropriate PCI and broad facility-level variation at NCDR and non-NCDR participating hospitals, adding to the weight of evidence suggesting at least 1 in 9 PCIs for nonacute indications are inappropriate and opportunities exist to improve patient selection for PCI.
- Our application of the Appropriate Use Criteria for Coronary Revascularization in PCI quality improvement efforts was challenged by a high proportion of nonacute PCI performed without documentation of preprocedural stress testing.

Methods

Design and Setting

The Clinical Outcomes Assessment Program (COAP) is a regional quality improvement initiative of the Foundation for Health Care Quality, a nonprofit 501(c)3 corporation, designed to produce clinical scenarios encountered for consideration of PCI in clinical practice. Although the data elements determining these clinical scenarios are limited and resulting clinical scenarios are broad, this was intentional, to ensure the scope of the associated criteria were amenable to implementation. In determining the appropriateness of revascularization for the clinical scenarios, members of the technical panel individually rated the appropriateness of each clinical scenario on a 9-point scale, with the following definition of appropriateness: *Coronary revascularization is appropriate when the expected benefits, in terms of survival or health outcomes (symptoms, functional status, and/or quality of life), exceed the expected negative consequences of the procedure.* Additional details regarding the methodology of the Appropriate Use Criteria for Coronary Revascularization are described elsewhere.11

Patient Population

Beginning in June 2009, COAP began collecting data for PCI in accordance with the NCDR CathPCI version 4.3, which includes data elements necessary for determination of appropriateness. In our analysis, we included all patients who underwent PCI in the state of Washington between January 1, 2010, and December 31, 2010. We chose our start date 6 months after the implementation of NCDR CathPCI version 4.3 to provide an opportunity for all facilities to become compliant with this data collection tool.

Main Outcome Measure

We developed an algorithm to map PCIs performed in COAP to the Appropriate Use Criteria for Coronary Revascularization and assign procedural appropriateness of appropriate, uncertain, or inappropriate (see online-only Data Supplement). This process was automated using the algorithm and data elements entered at the facility. There was no secondary chart review or manual determination of PCI appropriateness. In accordance with the Appropriate Use Criteria, severe coronary stenosis was defined as ≥50% in the left main and ≥70% in any other major epicardial coronary vessel. Maximal medical therapy was defined as ≥2 classes of antianginal medication regardless of dose.13 We conservatively assigned patients with >1 clinical scenario to the scenario with the highest appropriateness rating. We optimized our mapping algorithm to maximize the use of existing data and minimize the influence of missing data. For example, certain nonacute presentations can be assigned an appropriateness rating independent of noninvasive risk results. In these scenarios, an appropriateness classification could be provided even when noninvasive risk testing was not performed or results were not available.

Statistical Analysis

Baseline patient demographics, clinical characteristics (risk factors, prior revascularization, comorbidities), and facility characteristics (annual procedural volume, coronary artery bypass surgery program) are reported by category of appropriateness classification. Comparisons of continuous variables were completed with analysis of variance and categorical variables with chi-squared test. We report the appropriateness of PCI stratified for acute (PCI for acute myocardial infarction or unstable angina with high-risk features) or nonacute (PCI for stable angina) coronary presentation. We did not classify PCI for unstable angina without high-risk features in our primary analysis, as this clinical indication was not explicitly addressed by the Appropriate Use Criteria.14 Furthermore, in our primary analysis, we did not classify patients to a clinical scenario for patients with 1- or 2-vessel disease not involving the proximal left anterior descending (LAD) artery that allowed for classification when preprocedural stress testing was not performed and antianginal medications were not considered. We conservatively chose to consider patients who fell into this specific clinical scenario as not classified, given the broad range of potential appropriateness for the same indication when stress test data and antianginals were available. In sensitivity analysis, we considered unstable angina without high-risk features to be a nonacute indication and mapped patients to the clinical scenario that allowed for classification of 1- or 2-vessel disease not involving the proximal LAD without a stress test or antianginal medications. This sensitivity analysis was in accordance with prior work from NCDR.15 Additional details on appropriateness by type of acute indication (acute ST-segment-elevation myocardial infarction [STEMI], non-STEMI, or unstable angina with high-risk...
features, rescue PCI, etc) and clinical presentation of nonacute indication (angina severity, antianginal therapy, noninvasive risk findings, diagnostic angiographic findings, and prior bypass) are reported. Given that a large proportion of nonacute presentations were found to be missing noninvasive stress testing results necessary for determination of appropriateness classification, we performed sensitivity analyses in which we evaluated the influence of assumed results for missing noninvasive stress tests on PCI appropriateness for nonacute indications. We explored unadjusted facility-level variation in PCI appropriateness by indication and the influence of missing stress test results and assumed stress test results on PCI appropriateness for nonacute indications by facility. Given the importance of sample size and clustering issues on comparison of interfacility variability, we conducted additional analyses using a hierarchical generalized linear model in which the intercept is a random facility effect. As PCI appropriateness is a measure of the quality of patient selection, we wished to avoid inclusion of patient covariates in this model that would unduly adjust for patient selection and therefore only included age and gender as fixed effects in the primary model. We explored the impact of additional covariates that do not directly determine PCI appropriateness (hypertension, dyslipidemia, current smoker, diabetes, heart failure, prior PCI, prior valve surgery, hemodialysis, COPD) in additional modeling. From these models, predicted probabilities and confidence intervals of facility-level inappropriate PCI were determined. Analyses at the facility level were limited to hospitals that performed at least 5 nonacute PCI annually.

All statistical tests of significance were 2-sided, with values of \( P<0.05 \) considered statistically significant. All analyses were performed using IBM SPSS Statistics, version 19.0 (IBM). With the exception of hierarchical modeling of predicted facility-level rates of inappropriate PCI that was performed using STATA, version 12.0 (Statacorp LP). The authors had full access to, and take full responsibility for, the integrity of the data. All authors have read and agreed to the manuscript as written. This study was funded in part by a VA Quality Enhancement Research Initiative Rapid Response Project and approved by the Institutional Review Board at VA Puget Sound Health Care System.

Results

Between January 1, 2010, and December 31, 2010, 13,291 PCIs were performed at 31 facilities in the state of Washington. Figure 1 outlines the study cohort and the portion that could be mapped to the Appropriate Use Criteria. Two basic issues prevented us from mapping approximately 25% of all procedures; for one third of unmapped cases, the clinical scenario was not considered in the Appropriate Use Criteria, and for the remaining two thirds of the unmapped cases, missing data prevented classification. The most common clinical scenario not addressed by the criteria was unstable angina without high-risk features (\( n=902; 86\% \) of clinical scenarios not addressed by the criteria). The most commonly missing data impacting classification were noninvasive stress test results for patients undergoing PCI for nonacute indications (\( n=1906; 82\% \) of PCI not mapped due to missing data).

Baseline patient demographics, clinical characteristics, and available facility characteristics are shown in Table 1. Patients were predominantly white, male, and >60 years old. Coronary risk factors, prior history of coronary disease or revascularization, and comorbid conditions were common. Although variation in patient demographics and clinical characteristics by category of PCI appropriateness was statistically significant, in general, the size of this variation by patient and facility characteristics was small.

PCI appropriateness by indication is shown in Table 2. Of 13,291 PCIs, >70% of PCIs were performed for acute indications, with 83% being classified as appropriate. After exclusion of the 1442 (15%) PCIs for acute indications that could not be mapped to the Appropriate Use Criteria, 98% of PCIs for acute indications were classified as appropriate. Of the nearly 30% of PCIs performed for nonacute indications, 8% were classified as inappropriate, and slightly more than half could not be classified owing to missing data, predominantly for noninvasive stress testing. After exclusion of PCIs that could not be mapped to the Appropriate Use Criteria, the proportion of PCIs for nonacute indications classified as appropriate was 44%; uncertain, 39%; and inappropriate, 17%. To account for a known difference in algorithmic approach relative to prior work in NCDR, a sensitivity analysis was performed where PCIs for unstable angina without high-risk features were considered nonacute indications, and patients with 1- or 2-vessel disease that did not involve the proximal LAD without data on stress tests or antianginal medications were mapped to the criteria. In this analysis, 3519 (92%) of nonacute indications were mapped, with 1627 (46%) classified as appropriate; 1551 (44%), uncertain; and 341 (10%), inappropriate.
Table 3 summarizes appropriateness of PCI for specific acute indications. The most common acute indications were non-STEMI or unstable angina with high-risk features (n=5900; 62%) and acute STEMI (n=2144; 23%). These indications were classified as appropriate in 94% of cases, with 6% not classified. PCI in the setting of acute STEMI, non-STEMI, or high-risk unstable angina that could not be classified were most often multivessel PCI in the absence of cardiogenic shock. The criteria do not address the appropriateness of nonculprit vessel PCI in this setting. Unstable angina without high-risk features accounted for 11% of PCIs for acute indications. As described previously, PCI for unstable angina without high-risk features was not explicitly addressed by the Appropriate Use Criteria and thus not classified in our primary analysis. The overall association between type of acute condition and appropriateness category was highly statistically significant (P<0.0001).

Table 4 summarizes the appropriateness of PCI for nonacute indications by presenting characteristics. Among patients receiving PCI for nonacute indications, symptom severity was low, with 38% of patients having no symptoms or class I angina and 23% class III or IV angina. Antianginal use was low, with 35% of patients being on no antianginal medications and 20% on 2 or more classes of antianginal medication. Of patients on antianginal therapy, most were on a β-blocker (82%), and approximately 20% were on a nitrate

<table>
<thead>
<tr>
<th>Characteristic*</th>
<th>Total (n=13291)</th>
<th>Appropriate (n=8734)</th>
<th>Uncertain (n=787)</th>
<th>Inappropriate (n=403)</th>
<th>Not Classified (n=3367)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient demographics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, y (SD)</td>
<td>65±12</td>
<td>65±12</td>
<td>67±11</td>
<td>66±11</td>
<td>65±11</td>
<td>0.001</td>
</tr>
<tr>
<td>Men, %</td>
<td>72</td>
<td>71</td>
<td>77</td>
<td>72</td>
<td>73</td>
<td>0.002</td>
</tr>
<tr>
<td>White, %</td>
<td>90</td>
<td>89</td>
<td>90</td>
<td>93</td>
<td>90</td>
<td>0.013</td>
</tr>
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<td>Clinical characteristics, %</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Prior MI</td>
<td>29</td>
<td>28</td>
<td>33</td>
<td>28</td>
<td>32</td>
<td>&lt;0.0001</td>
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<td>Prior PCI</td>
<td>38</td>
<td>35</td>
<td>46</td>
<td>39</td>
<td>47</td>
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<tr>
<td>Prior CABG</td>
<td>18</td>
<td>17</td>
<td>45</td>
<td>32</td>
<td>14</td>
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<tr>
<td>HTN</td>
<td>77</td>
<td>76</td>
<td>84</td>
<td>81</td>
<td>78</td>
<td>&lt;0.0001</td>
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<tr>
<td>Dyslipidemia</td>
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<td>75</td>
<td>87</td>
<td>81</td>
<td>80</td>
<td>&lt;0.0001</td>
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<tr>
<td>Diabetes mellitus</td>
<td>32</td>
<td>31</td>
<td>36</td>
<td>34</td>
<td>34</td>
<td>0.004</td>
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<td>Current smoker</td>
<td>24</td>
<td>27</td>
<td>16</td>
<td>19</td>
<td>20</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>10</td>
<td>10</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>12</td>
<td>12</td>
<td>14</td>
<td>12</td>
<td>11</td>
<td>0.06</td>
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<tr>
<td>Heart failure</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>9</td>
<td>10</td>
<td>0.11</td>
</tr>
<tr>
<td>COPD</td>
<td>13</td>
<td>13</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>0.21</td>
</tr>
<tr>
<td>Prior valve surgery</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0.012</td>
</tr>
<tr>
<td>Hemodialysis</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0.25</td>
</tr>
<tr>
<td>Facility characteristics, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual procedural volume (SD)</td>
<td>700±336</td>
<td>686±345</td>
<td>795±286</td>
<td>748±315</td>
<td>710±323</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>&lt;100</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>100–399</td>
<td>20</td>
<td>22</td>
<td>9</td>
<td>13</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>&gt;400</td>
<td>78</td>
<td>76</td>
<td>90</td>
<td>85</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>CABG program</td>
<td>84</td>
<td>82</td>
<td>95</td>
<td>91</td>
<td>86</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Y indicates years; SD, standard deviation; MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft; HTN, hypertension; COPD, chronic obstructive pulmonary disease.

*The association between acute indication presenting characteristic and appropriateness category was statistically significant (P<0.0001).
or calcium channel blocker. The majority of PCIs (68%) were performed without documented noninvasive stress test results. We were able to classify 50% of PCIs for nonacute indications, suggesting PCIs in the absence of stress test data were reasonable in >25% of patients with missing stress test results. Of available stress test results, most were reported as intermediate-risk. Coronary stenosis was most often reported in the nonproximal left anterior descending (LAD) without other vessel involvement (41%) or with concurrent disease (18%). Stenosis involving the left main, proximal LAD, or 3-vessel disease was reported in 44% of nonacute PCIs. As expected by the Appropriate Use Criteria definitions, inappropriate PCIs for nonacute indications were more likely in patients with lower severity of symptoms, fewer antianginal medications, lower risk noninvasive stress test results, and patients with borderline severe (50% to 70%) coronary stenosis. Common clinical indications rated as inappropriate and uncertain in our primary analysis are shown in Table 5.

Sensitivity analyses, with assumed results for missing noninvasive stress tests, on PCI appropriateness demonstrated a wide potential range of PCI appropriateness for nonacute indications. In the best-case scenario, where missing noninvasive stress results were assumed high-risk, 8% of nonacute PCI were classified as inappropriate (Table 6). In the worst-case scenario, where missing noninvasive stress results were assumed low-risk, 38% of nonacute PCIs were classified as inappropriate.

There was little variation in PCI appropriateness by facility for acute indications. The proportion of inappropriate PCI for acute indications was <1% for most facilities (median=0.8%; 25th to 75th percentiles=0.3% to 1.1%; range=0% to 2.2%). The larger degree of facility-level variation in PCI appropriateness for nonacute indications that could be mapped to the criteria is summarized in Figure 2A (median=14%; 25th to 75th percentiles=9% to 24%; range=0% to 35%). An even greater degree of facility-level variation was observed in the proportion of PCI for nonacute indications that could not be classified (median=54%; 25th to 75th percentiles=35% to 66%; range=25% to 100%). Facilities with 100% not classified PCI for nonacute indications were low-volume elective centers (<10 nonacute PCI). We explored the influence of assumed stress test results for missing data on facility-level PCI appropriateness for nonacute indications as shown in Figure 2B. The extent of facility-level variation in PCI appropriateness for nonacute indications was greater when missing stress test results were assumed low-risk (median=40%; 25th to 75th percentiles=29% to 53%; range=18% to 78%) than when missing stress test results were assumed high-risk (median=6%; 25th to 75th percentiles=3% to 9%; range=0% to 11%). Additionally, comparisons between facility-level PCI appropriateness for nonacute indications were influenced by the assumed stress test results. Results of unadjusted analyses of facility-level variation were confirmed in hierarchical regression modeling (see online-only Data Supplement). These findings highlight the challenge created by missing stress test data in the application of Appropriate Use Criteria for quality improvement in site-to-site or site-to-state comparisons.

Finally, to explore the generalizability of PCI appropriateness in NCDR hospitals to non-NCDR participating facilities, we stratified our analysis by hospital participation in NCDR in addition to COAP. Of the 31 COAP hospitals, 24 (77%) contribute data to NCDR. For nonacute indications, 16% were inappropriate at NCDR participating hospitals (n=23) compared with 23% inappropriate at non-NCDR participating hospitals (n=8) (P=0.10). Among NCDR participating facilities, the median proportion of inappropriate cases was 15% (25th to 75th percentiles=7% to 23%), and, for other centers, the median was 27% (25th to 75th percentiles=15% to 34%).

**Discussion**

In our evaluation of the appropriateness of PCI performed at 31 facilities in Washington state, >70% of PCIs were for acute indications where the procedure was nearly uniformly rated as appropriate. Of nonacute PCI mapped to the Appropriate Use Criteria, 44% were rated as appropriate, 39% as uncertain, and 17% as inappropriate. Our ability to ascertain the appropriateness of PCI in nonacute indications was challenged by a high proportion of missing noninvasive stress testing results. In the best-case scenario, where missing noninvasive stress results were assumed high-risk, 8% of nonacute PCIs were classified as inappropriate. There was evidence of facility-level variation in the appropriateness of PCI, ranging from 0% to 35% as inappropriate for mapped nonacute indications. Comparisons between facility-level PCI appropriateness

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Table 3. Appropriateness of PCI for Acute Indications by Presenting Characteristics*

<table>
<thead>
<tr>
<th>PCI Indication, %</th>
<th>Total (n=9452)</th>
<th>Appropriate (n=7887)</th>
<th>Uncertain (n=39)</th>
<th>Inappropriate (n=84)</th>
<th>Not Classified (n=1442)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute STEMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>StemI &gt;12 h from symptom onset</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstable</td>
<td>&lt;1</td>
<td>61</td>
<td>0</td>
<td>0</td>
<td>39</td>
</tr>
<tr>
<td>Stable</td>
<td>&lt;1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>STEMI with PCI after lytics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successful lytics</td>
<td>&lt;1</td>
<td>0</td>
<td>58</td>
<td>13</td>
<td>28</td>
</tr>
<tr>
<td>Failed lytics (rescue PCI)</td>
<td>&lt;1</td>
<td>90</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Non-STEMI or high-risk UA</td>
<td>65</td>
<td>92</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Nonhigh risk UA</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

PCI indicates percutaneous coronary intervention; STEMI, ST-segment-elevation myocardial infarction; UA, unstable angina.

*The association between acute indication presenting characteristic and appropriateness category was statistically significant (P<0.0001).
were influenced by missing noninvasive stress test data that ranged from 25% to 100% at the facility level. Previous work evaluating the appropriateness of PCI captured in the ACC-NCDR found similar proportions of PCI rated as inappropriate for acute and nonacute indications as reported in the present study. The algorithm for classification of appropriateness in the present study was developed independent of the ACC-NCDR analysis. Additionally, nearly a quarter of facilities in COAP do not participate in NCDR. The independent finding of similar rates of inappropriate PCI for all procedures performed in Washington state among both NCDR and non-NCDR participating hospitals adds to the generalizability of PCI appropriateness from NCDR hospitals to non-NCDR participating facilities, and the weight of evidence suggesting at least 1 in 9 PCIs for nonacute indications are inappropriate. As in prior studies, patients with lower severity of symptoms, fewer antianginal medications, and lower-risk noninvasive stress findings comprised the majority of inappropriate PCI for nonacute indications across studies. These findings suggest an opportunity for greater application of the evidence base on which the Appropriate Use Criteria for Coronary Revascularization are built.4

The assessment of procedural appropriateness represents a new era for programs intent on improving the quality of care for patients receiving PCI. Previously, quality improvement programs for PCI focused on processes of care and procedural outcomes of PCI.16,17 For example, the COAP program provides risk-adjusted mortality and door-to-balloon time as the 2 main publically reported quality measures for PCI.15 Opportunities remain to improve patient outcomes through promotion of procedural access sites and antithrombotic strategies associated with lower bleeding rates.18–20 Although these efforts are critical to ensuring the best outcomes after PCI, the creation of a quality measure to ascertain whether a stent was appropriate before placement allows for the entirely new and standardized measurement of anticipated procedural benefit relative to the risk of procedural harm. Reducing truly inappropriate PCI would likely improve quality of care by

### Table 4. Appropriateness of PCI for Nonacute Indications by Presenting Characteristics

<table>
<thead>
<tr>
<th>PCI Indication, %</th>
<th>Total (n = 3839)</th>
<th>Appropriate (n = 847)</th>
<th>Uncertain (n = 748)</th>
<th>Inappropriate (n = 319)</th>
<th>Not Classified (n = 1925)</th>
<th>P Value</th>
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<tbody>
<tr>
<td>Angina severity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>No symptoms</td>
<td>29</td>
<td>7</td>
<td>16</td>
<td>17</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Class I</td>
<td>9</td>
<td>16</td>
<td>21</td>
<td>8</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Class II</td>
<td>39</td>
<td>19</td>
<td>25</td>
<td>6</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Class III</td>
<td>18</td>
<td>51</td>
<td>14</td>
<td>1</td>
<td>34</td>
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</tr>
<tr>
<td>Class IV</td>
<td>5</td>
<td>44</td>
<td>12</td>
<td>&lt;1</td>
<td>44</td>
<td></td>
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<tr>
<td>No. of antianginal medications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>0</td>
<td>35</td>
<td>16</td>
<td>20</td>
<td>10</td>
<td>54</td>
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</tr>
<tr>
<td>1</td>
<td>45</td>
<td>17</td>
<td>20</td>
<td>10</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>&gt;2</td>
<td>20</td>
<td>44</td>
<td>17</td>
<td>2</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Antianginal medications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>β-blockers</td>
<td>82</td>
<td>26</td>
<td>19</td>
<td>7</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Nitrates</td>
<td>23</td>
<td>41</td>
<td>20</td>
<td>3</td>
<td>36</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CCB</td>
<td>19</td>
<td>33</td>
<td>18</td>
<td>6</td>
<td>42</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>60</td>
<td>14</td>
<td>2</td>
<td>25</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Noninvasive risk assessment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Low-risk</td>
<td>8</td>
<td>16</td>
<td>40</td>
<td>42</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Intermediate-risk</td>
<td>14</td>
<td>20</td>
<td>62</td>
<td>16</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>High-risk</td>
<td>11</td>
<td>72</td>
<td>24</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>68</td>
<td>15</td>
<td>8</td>
<td>4</td>
<td>73</td>
<td></td>
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<tr>
<td>Coronary disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>1 or 2 borderline</td>
<td>3</td>
<td>7</td>
<td>36</td>
<td>53</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1 nonproximal LAD</td>
<td>41</td>
<td>10</td>
<td>15</td>
<td>9</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>1 proximal LAD</td>
<td>9</td>
<td>37</td>
<td>19</td>
<td>1</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>2 nonproximal LAD</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>7</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>2 proximal LAD</td>
<td>8</td>
<td>34</td>
<td>16</td>
<td>9</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>3 vessel disease</td>
<td>20</td>
<td>40</td>
<td>31</td>
<td>9</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Left main</td>
<td>7</td>
<td>43</td>
<td>34</td>
<td>9</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>CTO</td>
<td>7</td>
<td>11</td>
<td>15</td>
<td>8</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Prior bypass</td>
<td>22</td>
<td>25</td>
<td>41</td>
<td>14</td>
<td>20</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

PCI indicates percutaneous coronary intervention; CCB, calcium channel blockers; LAD, left anterior descending; CTO, chronic total occlusion.
eliminating procedural risks associated with PCI when the procedure is unlikely to benefit the patient. Risks of PCI include relatively common outcomes of major bleeding in 2% of patients, vascular complications in 1% of patients, and rarer outcomes such as the need for transfusion or emergent coronary artery bypass grafting. The secondary gains of decreasing inappropriate procedures accrue for the healthcare system in greatly lowered costs, including the procedure costs, complication costs, and the costs of drug and antiplatelet therapy.

The intent of measuring and reducing inappropriate use of PCI is to provide more consistent use of PCI across practice settings in the provision of high-quality care; not to eliminate inappropriate use for the individual patient. In the development of clinical scenarios for the Appropriate Use Criteria, the writing group estimated >4000 clinical scenarios would be required to account for all potential permutations of clinical variables that influence PCI appropriateness. Given the intentional limitation to ~180 clinical scenarios to ensure applicability of the criteria, there will always be clinical scenarios for which the appropriateness of PCI for an individual patient is not fully captured by the criteria; however, the considerable facility-level variation in PCI for nonacute indications highlights the potential to improve patient care by reducing practice level variation of inappropriate PCI.

Despite this potential, we encountered significant challenges in the application of the Appropriate Use Criteria as part of a quality improvement program. Foremost was the lack of noninvasive stress test data for half of patients receiving PCI for nonacute indications, with broad facility-level variation in missing data that makes challenging site-to-site and site-to-state comparisons of PCI appropriateness. We are unable to determine if this resulted from a failure to perform, or a failure to document, preprocedural noninvasive stress tests; however, from a quality improvement perspective, failure to perform or document noninvasive stress testing results that are critical to justify the clinical indication for PCI speaks to a failure in high-quality care. As a result, the COAP quality improvement program anticipates employing several strategies to improve the ascertainment of noninvasive risk assessment before nonacute PCI. First, in addition to reporting procedural appropriateness by facility, we anticipate reporting the proportion of PCI that could not be rated owing to missing data. Additionally, as in other quality improvement data sets, missing data might be interpreted as normal or low-risk. We are hopeful these strategies will improve rates of preprocedural risk stratification and documentation necessary to ascertain PCI appropriateness and support high-quality care.

Relative to shortcomings in the data used to ascertain PCI appropriateness, the shortcomings of the criteria themselves were minimal. The ability to rate PCI appropriateness for the vast majority of clinical scenarios was remarkable, with >90% of PCI mapped to the criteria in the present study when necessary data were available. Further, unstable angina without high-risk features represented nearly 90% of clinical scenarios that were not addressed by the criteria in the present study. We conservatively chose to consider unstable angina without high-risk features as not explicitly addressed by the Appropriate Use Criteria and did not map to a scenario for 1- or 2-vessel proximal LAD disease when stress test and antianginal medication data were missing. In this manner, we hoped to avoid contentions about our approach to rating appropriateness in a publically reported quality improvement program in favor of emphasizing clear opportunities to improve the use of PCI to maximize patient benefit. Given the

Table 5. Common Percutaneous Coronary Interventions for Nonacute Clinical Scenarios Classified as Inappropriate and Uncertain by the Appropriate Use Criteria

<table>
<thead>
<tr>
<th>Appropriate Use Criteria Scenario No.</th>
<th>Coronary Anatomy</th>
<th>Prior Bypass</th>
<th>Symptoms (CCSC)</th>
<th>Stress Test Risk Assessment</th>
<th>Antianginal Therapy</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12B</td>
<td>1- or 2-vessel CAD, no proximal LAD involvement</td>
<td>No</td>
<td>I or II</td>
<td>Low</td>
<td>None/Minimal</td>
<td>63 (19)</td>
</tr>
<tr>
<td>54B</td>
<td>&gt;1 stenoses in non-CABG territory, all bypass grafts patent</td>
<td>Yes</td>
<td>I or II</td>
<td>Low</td>
<td>None/Minimal</td>
<td>51 (16)</td>
</tr>
<tr>
<td>14A</td>
<td>1- or 2-vessel CAD, no proximal LAD involvement</td>
<td>No</td>
<td>Asymptomatic</td>
<td>Medium</td>
<td>None/Minimal</td>
<td>49 (15)</td>
</tr>
<tr>
<td>48A</td>
<td>&gt;1 stenoses in saphenous vein graft(s)</td>
<td>Yes</td>
<td>Asymptomatic</td>
<td>Low</td>
<td>None/Minimal</td>
<td>36 (11)</td>
</tr>
<tr>
<td>12A</td>
<td>1- or 2-vessel CAD, no proximal LAD involvement</td>
<td>No</td>
<td>Asymptomatic</td>
<td>Low</td>
<td>None/Minimal</td>
<td>32 (10)</td>
</tr>
<tr>
<td>Uncertain PCI</td>
<td>12B</td>
<td>No</td>
<td>I or II</td>
<td>Intermediate</td>
<td>None/Minimal</td>
<td>144 (19)</td>
</tr>
<tr>
<td>48A</td>
<td>&gt;1 stenoses in saphenous vein graft(s)</td>
<td>Yes</td>
<td>I or II</td>
<td>Low</td>
<td>None/Minimal</td>
<td>91 (12)</td>
</tr>
<tr>
<td>12C</td>
<td>1- or 2-vessel CAD, no proximal LAD involvement</td>
<td>No</td>
<td>Asymptomatic</td>
<td>High</td>
<td>None/Minimal</td>
<td>41 (5)</td>
</tr>
<tr>
<td>48B</td>
<td>&gt;1 stenoses in saphenous vein graft(s)</td>
<td>Yes</td>
<td>III or IV</td>
<td>Low</td>
<td>None/Minimal</td>
<td>41 (5)</td>
</tr>
</tbody>
</table>

CCSC indicates Canadian Cardiovascular Society Classification; PCI, percutaneous coronary intervention; CAD, coronary artery disease; LAD, left anterior descending.

Table 6. Assumed Noninvasive Risk Results for Missing Data and PCI Appropriateness for Nonacute Indications

<table>
<thead>
<tr>
<th>Assumption for Missing Stress Test</th>
<th>Appropriate</th>
<th>Uncertain</th>
<th>Inappropriate</th>
<th>Not Classified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-risk</td>
<td>748 (19%)</td>
<td>1582 (41%)</td>
<td>1471 (38%)</td>
<td>38 (1%)</td>
</tr>
<tr>
<td>Intermediate-risk</td>
<td>1075 (28%)</td>
<td>1958 (51%)</td>
<td>768 (20%)</td>
<td>38 (1%)</td>
</tr>
<tr>
<td>High-risk</td>
<td>2254 (58%)</td>
<td>1228 (32%)</td>
<td>319 (8%)</td>
<td>38 (1%)</td>
</tr>
</tbody>
</table>

PCI indicates percutaneous coronary intervention.
benefit of PCI for unstable angina is most definitive for high-risk clinical scenarios, an alternative would be to consider unstable angina without high-risk features equivalent to stable angina, as was done in the assessment of PCI appropriateness from ACC-NCDR.\textsuperscript{12,22,23} In our sensitivity analyses where this approach was undertaken, as well as mapping to the clinical scenario for 1- or 2-vessel nonproximal LAD disease with missing data, \( > 90\% \) of PCI could be mapped to the Appropriate Use Criteria and the proportions of appropriate, uncertain, and inappropriate PCI were very similar to those previously reported from NCDR.

Although the limitations of the Appropriate Use Criteria were minimal, their application in ongoing quality improvement may face challenges beyond capture of noninvasive stress testing results. First, the determination of PCI appropriateness for nonacute indications is dependent on antianginal medications at the time of the procedure and physician assessment of symptom severity.\textsuperscript{11} As providers become increasingly aware of the clinical determinants of PCI appropriateness and pressure to reduce inappropriate use of PCI mounts, physicians may be motivated to initiate antianginal medications immediately before PCI, without adequate interval to assess for response or upcode patient-reported symptoms to influence apparent appropriateness. Emphasizing patient-centered measures of symptom severity, through incorporation of tools such as the Seattle Angina Questionnaire, may serve to improve the accuracy of the Appropriate Use Criteria in improving patient care.\textsuperscript{24}

Second, the criteria currently assess the appropriateness of PCI for a clinical scenario, not the appropriateness of PCI for a specific coronary vessel within the clinical scenario. For example, PCI may be rated as appropriate for a clinical scenario even when the territory of ischemia and the treated coronary vessel are not correlated. To measure and influence PCI use for coronaries that are not linked to territories of ischemia by noninvasive or invasive measures, greater specificity in the Appropriate Use Criteria and detailed data collection on ischemic territory would be required.

In conclusion, within a complete cohort of PCIs performed in Washington state, 75\% were successfully mapped to the Appropriate Use Criteria for Coronary Revascularization, with 1\% of PCIs for acute indications and 17\% of PCIs for nonacute indications classified as inappropriate. PCI appropriateness and facility-level variation were similar in NCDR and non-NCDR participating facilities across Washington state. Considerable facility-level variation in appropriateness for nonacute PCI suggests an opportunity to improve patient selection, to maximize anticipated benefit from PCI and optimal patient care; however, the extent of facility-level variation in missing stress tests for nonacute PCI introduces significant challenges in the implementation of the Appropriate Use Criteria for quality improvement in site-to-site or site-to-state comparisons. Further emphasis on preprocedural risk stratification and documentation will be necessary to improve the relevance of the appropriateness ratings in practice.
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Disclosures
All authors had full access to all of the data in the study and take full responsibility for the integrity of the data and the accuracy of the data analysis. The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs or the United States government.

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References
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Steven M. Bradley, Charles Maynard and Chris L. Bryson

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SUPPLEMENTAL MATERIAL

Supplemental Methods

Appropriateness Mapping Algorithm

Legend. Numbers reflect data elements by NCDR code.

- Cardiogenic shock = Cardiogenic shock within 24 hours (NCDR #5060) or at the time of procedure (#7030) OR cardiac arrest within 24 hours (#5065) OR use of an Intraaortic balloon pump (#5330) OR use of other mechanical ventricular support (#5340)
- Three Vessel CAD = $\geq 50\%$ in #6110 AND $\geq 70\%$ in #6150; OR $\geq 70\%$ in #6120, #6140, AND #6150; OR $\geq 70\%$ in #6130, #6140, AND #6150; OR $\geq 70\%$ in #6140, #6150, AND #6160; OR $\geq 70\%$ in #6120, #6150, AND #6160; OR $\geq 70\%$ in #6130, #6150, AND #6160
- NSTEMI/UA High-risk Features for Short-term Risk of Death or Non-fatal MI = #7035 PCI for High-risk NSTEMI/UA or #7035 other AND Cardiogenic Shock as defined above or #7035 other AND Patient Age $> 75$ (Procedure Date #5300 – Patient Birth Date #2050)
- CTO without other stenoses = #7120 "Yes" AND (100% in #6120 AND $<70\%$ in 6140, 6150, 6160; OR 100% in #6130 AND $<70\%$ in 6140, 6150, 6160; OR 100% in #6140 AND $<70\%$ in 6120, 6130, 6150, 6160; OR 100% in 6150 AND $<70\%$ in 6120, 6130, 6140, 6150; OR 100% in #6160 AND $<70\%$ in 6120, 6130, 6140, 6150)
- One or Two Vessel Borderline Stenosis CAD = $>50\%$ and $<70\%$ in up to two of #6120, #6130, #6140, #6150, or #6160.
- Noninvasive Stress Results (If More Than One Type of Stress Test Performed, Grade as the Higher Risk Finding) = Stress Testing Performed (#5100); Exercise Stress Test and Results (#5200, 5201, 5202); Stress Echocardiogram and Results (#5210, 5211, 5212); Stress MPI and Results (#5220, 5221, 5222); Stress CMR and Results (#5230, 5231, 5232)
- Bypass Grafts Patent = $<70\%$ in #6170, 6180, 6190, 6200, AND 6210
- Lesion in Native without Grafts = $>50\%$ in #6110 AND no entry for BOTH #6170 OR #6180 AND #6190; OR $>70\%$ in #6120 OR #6130 AND no entry for #6170 OR #6180; OR $>70\%$ in #6140 AND no entry for #6190; OR $>70\%$ in #6150 AND no entry for #6200; OR $>70\%$ in #6160 AND no entry for #6210
- Anginal Symptoms = #5020
- Maximal Antianginals = At least two of the following – Beta blockers (#5026), Calcium Channel Blockers (#5027), Long Acting Nitrates (#5028), Ranolazine (#5029), or Other Anti-Anginal Agent (#5030)
- If Both FFR and IVUS performed, Grade as the More Significant Stenosis
Figure 1. Base Algorithm for All PCI

PCI Indication (#7035)

Immediate PCI for STEMI
#7035
Figure 2

PCI for STEMI
(Stable, >12 hrs from Sx onset)
#7035
Figure 3

Rescue PCI for STEMI
(after failed full-dose lytics)
Figure 2

PCI for high risk
Non-STEMI or unstable angina
Figure 4

Staged PCI or Other

Unstable Angina #5000 and Patient Age >75
Figure 4

Unstable Angina #5000 and Patient Age <75
Figure 5

Prior CABG
Figure 6

Cardiogenic Shock (see legend)
No Cardiogenic Shock
Not determined

AND Symptoms Onset <24 Hours
(Procedure Date/Time #5300/#5301 - Symptom Onset Date/Time #5005/#5006)

A9

No Prior CABG
Figure 5

A9
Figure 2. STEMI Immediate PCI or Rescue PCI

Vessels PCI #7100

PCI of Single Culprit Artery
(#7100 = 1; #7110 = Yes)

PCI of Multiple Vessels
(#7100 > 1)

Evidence of Cardiogenic Shock (see legend)
Figure 3. STEMI Stable Post-Lytics

PCI for STEMI (Stable after successful full-dose thrombolysis) #7035

LV Systolic Dysfunction or Cardiomyopathy

Yes (#5050 = Yes or #7025 EF < 50%)

Three Vessel CAD (see legend)
Elective/semi-elective (urgent) PCI (#7020)

No (#5050 = No or #7025 EF ≥ 50%)

PCI of Presumed Culprit (#7100 = 1; #7110 = Yes)

PCI of Non-Culprit Artery (#7100>1 OR #7110 = No)
Figure 4. High Risk NSTEMI-UA

PCI for high risk Non-STEMI or unstable angina (#7035)

PCI of Single Culprit Vessel (#7100 = 1; #7110 = Yes)  
A_	ext{a}

Culprit Artery Uncertain AND Revascularization of Multiple Vessels (#7100 >1; #7110 = Unknown)  
A_	ext{a}

PCI of Multiple Vessels with Culprit Identified (#7100 >1; #7110 = Yes)

Cardiogenic Shock (see legend)  
A_	ext{a}
Figure 5. Base Algorithm for Non-ACS without Prior CABG

Cardiac Catheterization

Left Main Disease (#6110 > 50%)

- Yes (Fig. 7)
  - LV Systolic Dysfunction or Cardiomyopathy
    - Yes (#5050 = Yes or #7025 EF < 50%) (Fig. 8)
    - No (#5050 = No AND #7025 EF ≥ 50%) (Fig. 9)

- No
  - 3 Vessel Disease (see legend)
    - Yes
      - No

CTO of one major epicardial coronary without other stenoses (see legend)

- No
  - Disease Involving Proximal LAD (#6120 ≥ 70%)
    - Yes
      - 1 or 2 Vessel Disease not Involving Proximal LAD (#6130, 6140, 6150, or #6160 > 70%) (Fig. 13)
    - No

- 1 or 2 Vessel Borderline Stenosis (see legend)

Noninvasive Results

- Not performed or equivocal (Fig. 14)
Figure 6. Base Algorithm for Non-ACS with Prior CABG

Grafts Patent (see legend)

Yes

One or More Lesions in Native Vessels Without Grafts (see legend) (Fig. I)

No

One or More Stenoses in Saphenous Vein Grafts (#7175=Vein) (Fig. J)
Sub-Algorithms

Figure 7. Left Main Disease

Isolated LM disease

Anginal Symptoms

Asymptomatic

CCSC I or II

CCSC III or IV

A (9)

A (9)

A (9)
Figure 8. Three Vessel Disease (No Left Main) with Abnormal LV Function

Asymptomatic
A (8)

CCSC I or II
A (9)Q

CCSC III or IV
A (9)
Figure 9. Three Vessel Disease (No Left Main) with Normal LV Function

Antianginal Therapy

No or Minimal Antianginals
- Asymptomatic
  - Non-invasive Risk: Low U (5)
  - Intermediate A (7)
  - High A (7)
- CCSC I or II
  - Non-invasive Risk: Low U (6)
  - Intermediate A (7)
  - High A (8)
- CCSC III or IV
  - Non-invasive Risk: Low A (7)
  - Intermediate A (8)
  - High A (9)

Maximal Antianginals
- Asymptomatic
  - Non-invasive Risk: Low U (5)
  - Intermediate A (7)
  - High A (8)
- CCSC I or II
  - Non-invasive Risk: Low A (7)
  - Intermediate A (8)
  - High A (9)
- CCSC III or IV
  - Non-invasive Risk: Low A (8)
  - Intermediate A (9)
  - High A (9)
Figure 10. Chronic Total Occlusion of One Major Epicardial Coronary without Other Stenoses

- Antianginal Therapy
  - No or Minimal Antianginals
    - Asymptomatic
      - Non-invasive Risk: Low I (1) Intermediate I (3) High U (4)
    - CCSC I or II
      - Non-invasive Risk: Low I (2) Intermediate U (4) High U (5)
    - CCSC III or IV
      - Non-invasive Risk: Low I (3) Intermediate U (6) High A (7)
  - Maximal Antianginals
    - Asymptomatic
      - Non-invasive Risk: Low I (1) Intermediate U (4) High A (7)
    - CCSC I or II
      - Non-invasive Risk: Low U (4) Intermediate U (5) High A (7)
    - CCSC III or IV
      - Non-invasive Risk: Low U (6) Intermediate A (7) High A (8)
Figure 11. One Vessel Disease Involving the Proximal LAD

- Antianginal Therapy
  - No or Minimal Antianginals
    - Asymptomatic
      - Non-invasive Risk: Low U (4) Intermediate U (4) High A (7)
    - CCSC I or II
      - Non-invasive Risk: Low U (5) Intermediate U (6) High A (8)
    - CCSC III or IV
      - Non-invasive Risk: Low A (7) Intermediate A (7) High A (9)
  - Maximal Antianginals
    - Asymptomatic
      - Non-invasive Risk: Low U (4) Intermediate U (5) High A (7)
    - CCSC I or II
      - Non-invasive Risk: Low A (7) Intermediate A (8) High A (9)
    - CCSC III or IV
      - Non-invasive Risk: Low A (8) Intermediate A (9) High A (9)
Figure 12. Two Vessel Disease Involving the Proximal LAD

Antianginal Therapy

No or Minimal Antianginals

Asymptomatic

- Non-invasive Risk: Low U (4)
- Intermediate U (5)
- High A (7)

CCSC I or II

- Non-invasive Risk: Low U (6)
- Intermediate A (7)
- High A (8)

CCSC III or IV

- Non-invasive Risk: Low A (7)
- Intermediate A (8)
- High A (9)

Maximal Antianginals

Asymptomatic

- Non-invasive Risk: Low U (5)
- Intermediate U (6)
- High A (7)

CCSC I or II

- Non-invasive Risk: Low A (7)
- Intermediate A (7)
- High A (8)

CCSC III or IV

- Non-invasive Risk: Low A (8)
- Intermediate A (9)
- High A (9)
Figure 13. One or Two Vessel Disease Not Involving the Proximal LAD

- **Antianginal Therapy**
  - **No or Minimal Antianginals**
    - Asymptomatic
      - Non-invasive Risk: Low I (1)
        - Intermediate I (3)
        - High U (6)
      - Non-invasive Risk: Low U (5)
        - Intermediate U (6)
        - High A (8)
    - CCSC I or II
  - CCSC III or IV
  - **Maximal Antianginals**
    - Asymptomatic
      - Non-invasive Risk: Low I (2)
        - Intermediate U (4)
        - High A (7)
    - CCSC I or II
    - CCSC III or IV

Non-invasive Risk:
- Low I (2)
- Intermediate U (5)
- High A (7)
- Low U (5)
- Intermediate U (6)
- High A (8)
- Low A (7)
- Intermediate A (8)
- High A (9)
Figure 14. One or Two Vessel Borderline Stenoses without Noninvasive Testing or Equivocal Results

- FFR or IVUS Results
  - Not Performed
    - Asymptomatic
      - CCSC I or II
        - I (2)
      - CCSC III or IV
        - I (3)
    - FFR > 0.75 (#7135) or nonsignificant IVUS (#7125 = No)
      - Asymptomatic
        - CCSC I or II
          - I (1)
      - CCSC III or IV
        - I (2)
    - FFR < 0.75 (#7135) or significant IVUS (#7125 = Yes)
      - Asymptomatic
        - CCSC I or II
          - I (3)
      - CCSC III or IV
        - U (6)
      - CCSC III or IV
        - A (7)
Figure 15. Patent Bypass Graft(s) With One or More Lesions in Native Vessels Without Bypass Grafts – EF <50% = non-low risk

- Antianginal Therapy
  - No or Minimal Antianginals
    - Asymptomatic
      - Non-invasive Risk: Low including normal EF (EF > 50%) *1*
        - Intermediate I (3)
        - High U (6)
    - CCSC I or II
      - Non-invasive Risk: Low including normal EF (EF > 50%) I (3)
        - Intermediate U (5)
        - High A (7)
      - CCSC III or IV
        - Non-invasive Risk: Low including normal EF (EF > 50%) U (6)
          - Intermediate A (7)
          - High A (8)
  - Maximal Antianginals
    - Asymptomatic
      - Non-invasive Risk: Low including normal EF (EF > 50%) I (3)
        - Intermediate U (4)
        - High U (5)
      - CCSC I or II
        - Non-invasive Risk: Low including normal EF (EF > 50%) U (5)
          - Intermediate U (6)
          - High A (8)
        - CCSC III or IV
          - Non-invasive Risk: Low including normal EF (EF > 50%) A (7)
            - Intermediate A (8)
            - High A (9)
Figure 16. One or More Stenoses in Saphenous Vein Graft(s) – EF <50% = non-low risk

- **Antianginal Therapy**
  - **No or Minimal Antianginals**
    - **Asymptomatic**
      - Non-invasive Risk: Low including normal EF ( #7025 EF ≥ 50%) I (3) Intermediate U (4) High A (7)
    - CCSC I or II
      - Non-invasive Risk: Low including normal EF ( #7025 EF ≥ 50%) U (4) Intermediate U (6) High A (7)
    - CCSC III or IV
      - Non-invasive Risk: Low including normal EF ( #7025 EF ≥ 50%) U (6) Intermediate A (7) High A (7)
  - **Maximal Antianginals**
    - **Asymptomatic**
      - Non-invasive Risk: Low including normal EF ( #7025 EF ≥ 50%) U (4) Intermediate A (7) High A (9)
    - CCSC I or II
      - Non-invasive Risk: Low including normal EF ( #7025 EF ≥ 50%) U (6) Intermediate A (7) High A (8)
    - CCSC III or IV
      - Non-invasive Risk: Low including normal EF ( #7025 EF ≥ 50%) A (7) Intermediate A (8) High A (9)
Supplemental Results

The following figures represent facility-level predicted probabilities and confidence intervals from hierarchical generalized linear modeling in which the intercept is a random facility effect. As PCI appropriateness is a measure of the quality of patient selection, we wished to avoid inclusion of patient covariates in this model that would unduly adjust for patient selection and therefore only included age and gender as fixed effects in the primary model. We explored the impact of additional covariates that do not directly determine PCI appropriateness (hypertension, dyslipidemia, current smoker, diabetes, heart failure, prior PCI, prior valve surgery, hemodialysis, COPD) in an expanded model. Evaluation of the impact of assumed stress test results were limited to the primary model as results were not meaningfully changed by the expanded model. For consistency to the manuscript figures, facilities are identified by non-acute procedural volume with “NA#” used to specify facilities that did not perform non-acute procedures for acute indications figure.
Figure 17. PCI Appropriateness by Facility for Acute Indications Mapped to the AUC

A. Primary Hierarchical Model

B. Expanded Hierarchical Model
Figure 18. PCI Appropriateness by Facility for Non-Acute Indications Mapped to AUC

A. Primary Hierarchical Model

B. Expanded Hierarchical Model
Figure 19. Inappropriate PCI for Non-Acute Indications After Assumed Non-Invasive Stress Results for Missing Data – Primary Hierarchical Model

A. Assumed Missing Stress Tests Low Risk

B. Assumed Missing Stress Tests Intermediate Risk
C. Assumed Missing Stress Tests High Risk

![Graph showing percent inappropriate vs facility identified by non-acute procedural volume. The x-axis represents facility identified by non-acute procedural volume with values ranging from 107 to 182, and the y-axis represents percent inappropriate with values ranging from 0% to 12%. The graph includes a horizontal line at the 8% threshold.](image)